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Use of satellite telemetry to delineate bald eagle activity centers for hazard mitigation and land planning within the upper Chesapeake Bay. Final Report

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USE OF SATELLITE TELEMETRY TO DELINEATE BALD EAGLE ACTIVITY CENTERS FOR HAZARD MITIGATION AND LAND PLANNING WITHIN THE UPPER CHESAPEAKE BAY

CENTER FOR CONSERVATION BIOLOGY
COLLEGE OF WILLIAM AND MARY
VIRGINIA COMMONWEALTH UNIVERSITY

USE OF SATELLITE TELEMETRY TO DELINEATE BALD EAGLE ACTIVITY CENTERS FOR HAZARD MITIGATION AND LAND PLANNING WITHIN THE UPPER CHESAPEAKE BAY

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Cover photo by Ted Ellis. Bald eagle (transmitter 74415) with shad photographed at Conowingo Dam, MD in October 2009.

The Center for Conservation Biology is an organization dedicated to discovering innovative solutions to environmental problems that are both scientifically sound and practical within today's social context. Our philosophy has been to use a general systems approach to locate critical information needs and to plot a deliberate course of action to reach what we believe are essential information endpoints

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EXECUTIVE SUMMARY

Sustaining the duel military and environmental stewardship missions on Aberdeen Proving Ground (APG) has become increasingly challenging as the number of eagles using the installation has grown dramatically. Military testing and training activities conducted on APG are vital to national security. APG likely holds the greatest conservation value for bald eagles of any federal property along the Atlantic Coast. The property supports a complex mixture of eagles including a growing breeding population that is rapidly approaching saturation, a large population of non-breeding residents, and migrant populations from the northeast and southeast. Major activity centers such as active nests, communal roosts and foraging areas are protected under the disturb and sheltering provision of the federal Bald and Golden Eagle Protection Act. The level of site-specific information on eagles required to tightly integrate their needs into the space requirements of a diverse and dynamic military operation has not been available.

The focus of this project has been to collect and provide eagle information that will enable the incorporation of effective environmental planning into the military mission. Between 2007 and 2009 satellite transmitters were deployed on a large (n = 65) cohort of eagles that represent the cross section of populations that use APG. Between 2007 and 2011 transmitters collected nearly 700,000 GPS locations from within every state and Canadian province along the Atlantic Coast confirming APG's role as a hub of eagle activity within eastern North America. Locations (n > 320,000) within the upper Chesapeake Bay were used in spatial models to develop probability surfaces that identify high-use activity centers by season within APG. Midnight locations (n > 10,300) were used in separate spatial models to delineate communal roosts.

Results of this study provide site-specific information designed to inform future management decisions. Maps reveal the locations of significant communal roosts, foraging areas, loafing areas and movement corridors used by eagles on APG. Levels of use are quantified by location to facilitate prioritization of sites for management consideration. Seasonal and time-of-day patterns are provided to inform the scheduling of activities. The intersection of activity centers with the electrical infrastructure is examined to identify locations with the highest mortality risk. Lines intersecting with high-use activity centers have produced mortality rates that are 42 times higher than lines intersecting with low-use areas. Site-specific information is provided to allow for the phasing of hazard mitigation.

This report concludes the largest investigation of space use by bald eagles ever conducted. The project has clarified several aspects of eagle ecology within the upper Chesapeake Bay and has moved the science of eagle management forward in a way that will inform management throughout the species range. The still ongoing tracking database holds a great deal of promise for new ecological discoveries and management solutions.

1. BACKGROUND

The Chesapeake Bay now supports the largest breeding population of bald eagles in eastern North America and is a convergence area for migrant populations from along the entire Atlantic Coast (Watts et al. 2007, 2008). The largest estuary in the United States, the Bay contains more than 19,000 km of tidal shoreline. The Bay's wide salinity gradient, shallow water and climate have made it one of the most productive aquatic ecosystems in North America. Bald eagles breed throughout the estuary from the Atlantic Ocean to the fall line. However, low salinity portions of the Bay support the highest breeding densities, produce the largest number of young (Watts et al. 2006) and host the majority of migrants during both summer and winter (Watts et al. 2007). These tidal-fresh reaches of the Bay have some of the highest conservation value to bald eagles of anywhere throughout the species range.

The Chesapeake Bay was the site of the first successful European settlement in North America and the natural landscape has been altered by European culture for more than four centuries. The human population within counties adjacent to the tidal reach of the Bay has increased from 1.63 million people in 1900 to 3.81 million people in 1950 to 8.06 million people in 2000 (http://www.census.gov). The Chesapeake Bay landscape lies within the second largest mega-region (BoWash) in the world accounting for 2.2 trillion dollars in economic activity or 20% of the gross domestic product of the United States (Florida et al. 2008). This economic engine is spilling out across the landscape and consuming natural habitats at rates well beyond historical levels. Consumption of open land to fuel residential and industrial development across the Bay landscape has increased dramatically in recent decades (Gray et al. 1988) and is expected to reach 110 km^2/yr over the next 30 years (Goetz et al. 2004) resulting in a 60% increase in urban sprawl (Boesch and Greer 2003). Such development and associated human activity is threatening the natural landscape and the species that depend on it. Moving forward government and dedicated conservation lands will play an increasingly vital role in the future of these resources.

Aberdeen Proving Ground (APG) is a 350-km^2 United States Department of Defense military installation that lies along the northwestern shore of the upper Chesapeake Bay in southern Harford and eastern Baltimore Counties, Maryland. The site is situated within a tidal-fresh reach of the Upper Chesapeake Bay Bald Eagle Concentration Area and is likely the single most significant federal property for eagle conservation within eastern North America. APG supports a breeding population of bald eagles that has grown from 1 pair in 1977 to 58 pairs in 2011 and hosts a complex mixture of nonbreeding, resident eagles and migrant eagles from northern and southern populations. The installation maintains a long history as a major U.S. Army testing facility for artillery and other ordnance, military vehicles, and a variety of other military equipment. It also serves as a training area for the Navy, Air Force, and Marines. Since APG's establishment in 1917, the Aberdeen Area has been the site of intense research and development; large-scale testing of munitions, weapons, and materiel; and a training school for ordnance officers and enlisted specialists. Ongoing missions on APG are critical to national security.

Sustaining APG's duel military and environmental stewardship missions is challenging and for the past 30 years has been a collaborative effort between the United States Department of Defense and the United States Fish and Wildlife Service (USFWS). Consultation between these two federal agencies was initiated shortly after the discovery of the first bald eagle nesting pair of the recovery era and continues to the present time. As all of the eagle populations that use APG have recovered, growing use of the installation by eagles has been coupled with an increase in documented mortalities that exceeded 15 birds/yr by 2005, leading to formal consultation with the USFWS under the Endangered Species Act, Section 7(c)(1). A Biological Assessment was prepared to evaluate the potential effects of activities at APG on the rising mortality rate. A Biological Opinion (BO) (USFWS 2006) and subsequent revision of the bald eagle management plan for APG (Paul 2009) outlined a set of information needs designed to inform future management decisions. This study was funded and conducted to satisfy a portion of these information needs.

1.1 Objectives

One of the greatest challenges in environmental planning for a species of conservation concern is to achieve an understanding of the spatial and temporal aspects of activity that is adequate to be used in plans designed to minimize disturbance or other impacts. It is not possible to effectively avoid impacts without this understanding. The primary objective of this project was to track a large cohort of eagles throughout APG and the surrounding upper Chesapeake Bay in order to map and delineate major activity centers to support the planning of mitigation, testing, and training operations. Such information is the foundation of effective planning.

1.2 Acknowledgements

This study would not have been possible without F. Smith, C. Koppie, S. Voss, and J. Baylor who contributed countless hours trapping eagles. C. Koppie assisted with climbs to access nestlings and advised on the project. The field component of this project went smoothly in part because we had strong support from the Marine, Wildlife and Environmental Division of the Directorate of Emergency Services. B. Roberts, C. Volz, L. Merrill, W. Armstrong, M. Stewart, and R. Plummer assisted with baiting sites and rocket-net trapping. Officers Roberts and Volz also assisted searching for carcasses and transmitters. J. Paul, A. Burgess, and J. Ondek gave logistical support to access nests and trapping sites. J. Neubauer, B. McLaughlin, C. Corbett, E. Lawler, and M. Roberts provided contract support.

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2 STUDY AREA

2.1 Upper Chesapeake Bay

The study area (5,415 km^2) included the northern portion of the Chesapeake Bay from the Bay Bridge at Annapolis, MD to just above the Conowingo Dam on the Susquehanna River (Figure 2.1). Several major tributaries including the Chester, Sassafras, Elk, Bush and Gunpowder Rivers and many smaller creeks enter the main stem of the Bay within this area resulting in an extensive shoreline. The western portion of the study area contains sprawling residential development including the urban areas of Baltimore and Annapolis. The eastern portion of the study area is primarily rural with forest lands interspersed with agriculture. The northern part of the study area contains the Susquehanna Flats, a historically important site for wintering waterfowl (Lynch 2001).

The study area includes the Upper Chesapeake Bay Bald Eagle Concentration Area, one of several areas within the Chesapeake Bay where bald eagles from along the Atlantic Coast converge (Watts et al. 2007). Throughout the Bay such concentration areas have formed within low salinity, tidal-fresh waters where prey availability is high (Watts et al. 2006). For the resident breeding population, brood provisioning and chick growth tend to be high in these areas (Markham and Watts 2008) leading to both high breeding success and productivity (Watts et al. 2006). The study area supports a significant number of eagles during the fall and winter months (Steenhof et al. 2008). These birds are a mix of Chesapeake Bay residents and migrants from northern populations. Historically, northern migrant eagles have moved south to the Bay in November when open water within their breeding range began to freeze (Buehler et al. 1991). These birds appear to feed on waterfowl and mammals when fish move into deeper waters and many waterbirds migrate into the Bay (DeLong et al. 1989, Mersmann 1989).

2.2 Aberdeen Proving Ground

Aberdeen Proving Ground (APG) is a 350-km^2 United States Department of Defense military installation that lies along the northwestern shore of the upper Chesapeake Bay in southern Harford and eastern Baltimore Counties, Maryland. The installation maintains a long history as a major U.S. Army testing facility for artillery and other ordnance, military vehicles, and a variety of other military equipment. It also serves as a training area for the Navy, Air Force, and Marines. Since APG's establishment in 1917, the Aberdeen Area has been the site of intense research and development; large-scale testing of munitions, weapons, and materiel; and a training school for ordnance officers and enlisted specialists. The site is located within the Upper Chesapeake Bay study area and supports a large breeding population of eagles and a significant population of non-breeding eagles comprised of nonbreeding birds from the Chesapeake Bay population and migrant populations from both northeastern and southeastern North America. Due to its mission, the installation supports extensive undeveloped forest lands and undisturbed shorelines that represent ideal habitat for bald eagles.

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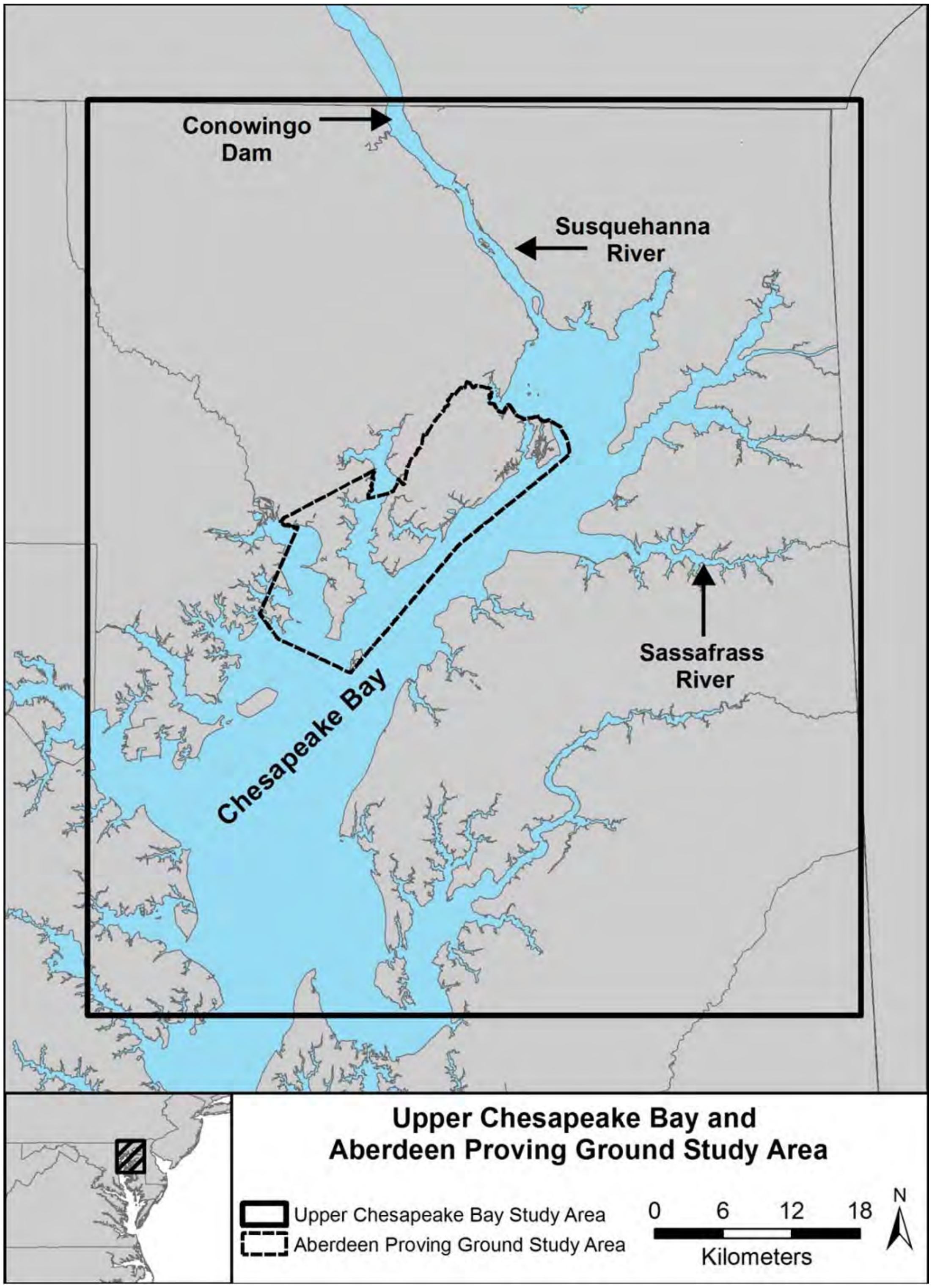

Figure 2.1. Upper Chesapeake Bay and Aberdeen Proving Ground study areas.

3 METHODS

3.1 Field Techniques

3.1.1 Trapping Techniques

We trapped bald eagles *(n* = 63) and golden eagles *(n* = 2) on APG between August 2007 and February 2011. We chose specific techniques to target both resident Chesapeake Bay eagles and migrant eagle populations. Southern migrants and resident eagles were trapped in summer and fall by boat. Northern migrants and resident eagles were trapped in winter on land.

We also targeted eagles from the resident population by climbing nests *(n* = 17) and capturing nestlings during the pre-fledging period. Nests were accessed using standard arborist equipment when the chicks were between 45 and 65 days old. We ascended the nest tree and lowered the nestlings to the ground to complete banding and transmittering activities.

We selected trap locations based on observations of foraging birds, conditions conducive to successfully trapping (low human disturbance, wind protection, topographic features, etc.) and our ability to access ranges. We trapped at sites along the shorelines of the Gunpowder River, Bush River, Romney Creek, Mosquito Creek, Spesutie Narrows, and the Chesapeake Bay (Figure 3.1).

We used a variety of trap types to capture free-flying eagles (Table 3.1, Figure 3.2). These included monofilament nooses deployed on floating fish (Cain and Hodges 1989, Jackman et al. 1993), rocket net baited with a deer carcass (Grubb 1988), noose carpet, and leg-hold traps baited with fish (King et al. 1998). Traps were set in the pre-dawn hours and monitored until dusk. We immediately removed eagles from traps once they were caught.

Table 3.1. Summary of trapping effort by trap type. Each trap required at least two people to monitor.

Trap Type	Total Hours	No. Eagles Caught
Floating fish	294	15
Leg-hold	119	10
Noose carpet	4	0
Rocket net	382	52

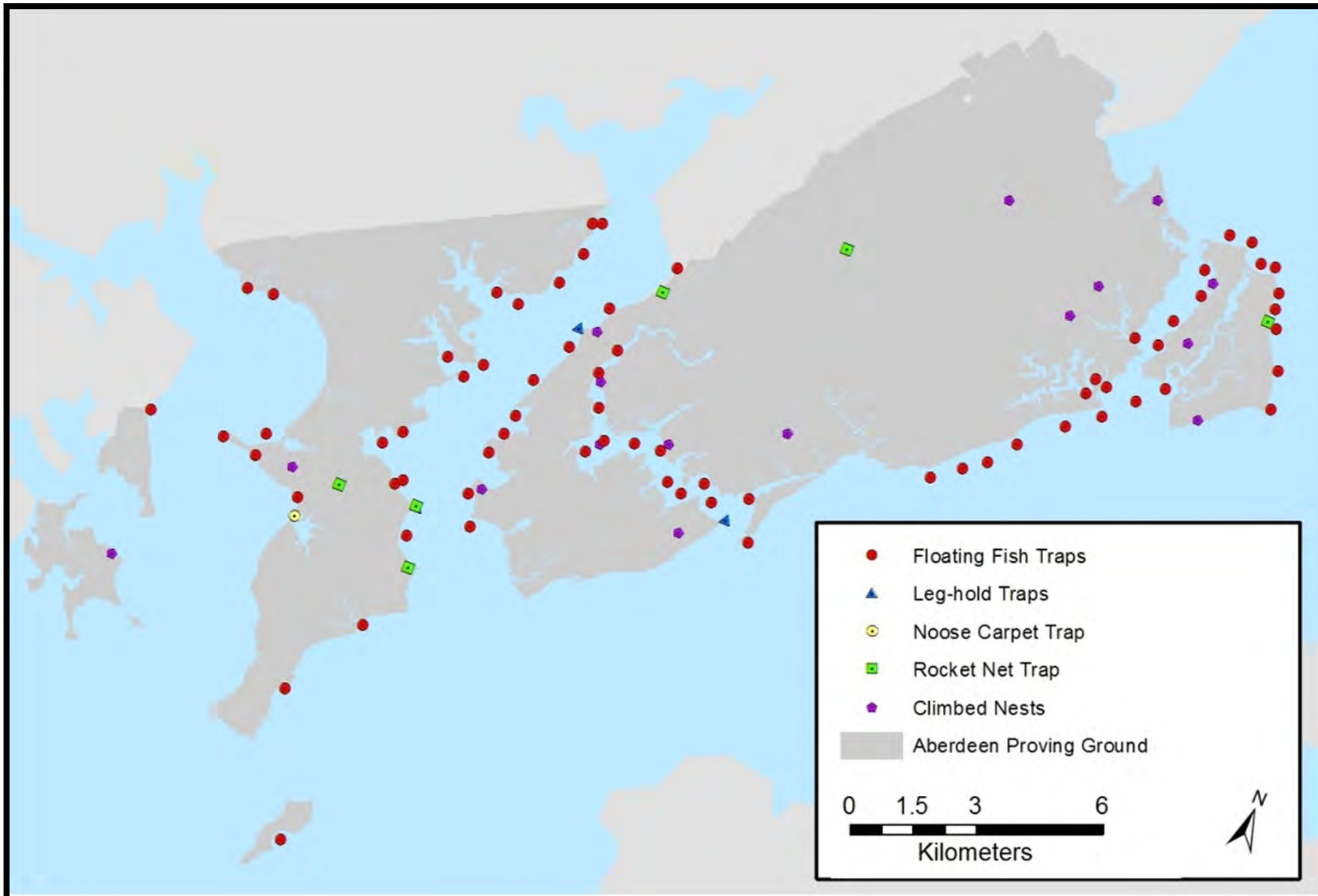

Figure 3.1. Trapping locations for eagles on Aberdeen Proving Ground.

Figure 3.2. Clockwise from top left: Craig Koppie (USFWS) climbs Towner Cove nest tree, subadult eagles and turkey vulture at rocket net bait site on M-field, baited rocket net equipment on H-field, Bryan Watts (CCB) sets a leg hold trap on Coopers Creek, subadult eagle captured with a floating fish trap, floating fish trap set on Mosquito Creek.

3.1.2 Banding Techniques

All eagles were banded, measured, and sampled for genetic material. The following morphometric measurements were taken on all eagles when possible: weight, wing length, tail length, culmen length, culmen depth, and hallux length. Wing and tail length were measured with a ruler (± 1 mm) and culmen length, culmen depth, hallux length, and tarsus length were measured with dial calipers (± 0.1 mm). Eagles were weighed on a digital scale (± 1 g). Two feathers were pulled from the breast area and stored in a paper envelope. All data and samples were labeled with the eagle's band number and banding location.

Eagles were marked with silver numeric federal leg bands (USGS Bird Banding Lab, Laurel, MD) on the right tarsus and purple alpha-numeric color bands (ACRAFT Sign and Nameplate, Edmonton, Alberta) on the left tarsus (Figure 3.3). Purple is the color authorized by the Bird Banding Lab and identifies bald eagles banded in Maryland and Virginia.

One chick from every climbed nest was selected for additional tissue collection during the 2008 breeding season. Blood samples were collected from the brachial vein in the wing using 23 gauge butterfly needles and 4cc heparinized BD Vacutainers©. A maximum of 6cc of blood was collected from each eagle. Blood samples were immediately packed on ice and frozen within 4 hours of collection. Two feathers were pulled from the breast area and stored in a paper envelope. All samples were labeled with the eagle's band number and banding location. Addled eggs were washed with tap water and allowed to air dry, then wrapped in aluminum foil and frozen. Eggs were later freeze dried by the lab in preparation for contaminants analysis.

Methodology for animal handling and tissue collection was in compliance with protocols approved by the Institutional Animal Care and Use Committee at the College of William and Mary. Banding, transmitter attachment, trapping, and tissue collection were in accordance with state and federal permits.

Figure 3.3. Clockwise from top left: Craig Koppie (USFWS) and John Paul (APG) band nestling at Range 18 nest; federal and color leg bands; Libby Mojica (CCB) , Sam Voss (EA), and Craig Koppie banding at Plum Point nest; nestlings in Chilbury nest.

3.1.3 Tracking Techniques

We fit eagles with 70g solar-powered GPS-PTT satellite transmitters (Microwave Telemetry Inc, Columbia, MD). The transmitters were attached using a backpack harness constructed with 0.63 cm Teflon ribbon (Bally Ribbon Mills, Bally, PA). Transmitters were deployed on a stratified subset of captured eagles based on their source population.

Transmitters recorded an eagle's location based on global positioning system (GPS) satellites. Transmitters were programmed to record a fix every hour during daylight and an additional hour at midnight. Every three days the transmitter uploaded the GPS data to weather satellites with Argos system receivers. We downloaded the data and parsed it to extract GPS locations, weather satellite locations, and engineering data on transmitter voltage and temperature. Parsed data was downloaded and cataloged in a Microsoft Access database and archived online with the Satellite Tracking and Analysis Tool (Coyne and Godley 2005).

In February 2011, we deployed prototype GPS-GSM transmitters (Global System for Mobile Communications) on two bald eagles. The transmitters record one GPS fix each hour for 24 hours then transmit the data through the cell phone network. These units were excluded from all analyses because they had a different data collection rate and were also not part of the original sample of 65 eagles.

3.1.4 Feather Collection

We collected molted feathers within occupied breeding territories and communal roosts from 2007-2010. We only sampled territories and roosts that were safely accessible on foot. Breeding territories were sampled in two or more consecutive years. Feathers determined to belong to an adult bird by wear, color and texture, were collected from the ground within 50 m of the nest. Chesapeake Bay bald eagles are territorial and resident year-round, and during or after nesting, adults frequently shed molted feathers while roosting or feeding on their nest tree or neighboring trees. It was not known whether collected feathers were from the male or female, but sampled feathers had been shed within a few weeks of collection based on condition and location. Because eagles in this population defend nest sites year-round, it is extremely unlikely that birds other than the parents would shed a feather near a nest tree. Feathers were stored at room temperature in a paper envelope until analysis for mercury concentration.

The ground within communal roosts was systematically searched within the boundaries of each roost. We collected feathers monthly at Sod Run roost and Romney Creek roost from January 2008 through February 2009. Feathers were stored in paper envelopes and labeled with a collection date and location.

Figure 3.4. Molted feathers, white wash and pellets found on the ground in the Sod Run roost.

3.1.5 Mortality Monitoring

We monitored eagle movements remotely for mortality events using an activity sensor on the transmitter which recorded horizontal movement. A ground search was conducted to search for transmitters or dead eagles if a transmitter stopped moving after 3 days or stopped transmitting completely. We only searched areas on APG or within the Chesapeake Bay that could be safely accessed. Volunteers searched for one unit in Florida but were unsuccessful. Eagles were classified with an unknown status if a transmitter or carcass was not recovered.

3.1.6 Nest monitoring

Nest surveys were conducted 4-6 times a year between mid-January and late-May by Army personnel or contractors. Surveys documented eagle nest locations, breeding activity, and productivity. Nests were observed from a helicopter which hovered 800' above each nest. Additional ground observations were made at select nests to confirm aerial observations. Eagle activity and breeding status were recorded and nests were coded using national conventions (U.S. Fish and Wildlife Service 2010).

A breeding territory was defined as occupied if a pair of eagles was observed in association with the nest and there was evidence of recent nest maintenance (e.g., well-formed cup, fresh lining, or structural maintenance). Nests were considered active if a bird was observed in an incubating posture or if eggs or young were observed in the nest. The number of young was recorded for each nest.

3.2 ANALYTICAL TECHNIQUES

3.2.1 Delineation of Communal Roosts

We used midnight locations to delineate communal roosts. Locations from breeding adults roosting near nests were excluded. Locations from nestlings were not included until after they began roosting away from the natal site. Minimum convex polygons (MCP) of roost boundaries were delineated using a nearest neighbor clustering script in Crimestat III (Levine 2004). Cluster parameters were set to search a fixed distance of 100 m for a minimum of five midnight locations (i.e., roost-nights). At least two individual eagles had to visit a roost during the study period for it to qualify as a communal roost. Roosts used by single eagles were manually removed from the dataset. Landscape features of each roost were evaluated using digital raster graphics in ArcMap 9.3 (Environmental Systems Research Institute, Inc.© 1999-2009, Redlands, California, U.S.A.). Roosts within the same forest patch and within 200 m of one another were merged into a single MCP. Once established, roost boundaries were overlaid on roost locations to evaluate seasonality and relative magnitude (i.e. number of roost-nights, number of individuals) of use.

3.2.2 Brownian Bridge Movement Modeling

We used Brownian bridge movement models (BBMM; Horne et al 2007) to develop utilization distributions (UD) for bald eagles within the study area using locations (n = 320,304) collected between August 2007 and June 2011. UD allows for the mapping of the intensity of use within a defined area. Conventional estimation of UD requires only a sample of independent locations. BBMM improves on traditional UD approaches by incorporating the temporal structure of tracking data allowing for the explicit modeling of movement paths. This approach allows for the identification not only of areas with high activity but also the movement corridors that connect them. BBMM incorporates fixed positions (x and y), time stamps (t), telemetry error (δ^2), and the variance of Brownian motion (δ^2_m) to estimate spatial patterns of movement probability. The model approximates the movement path between successive locations by applying a conditional random walk. Thus, deviation from a straight-line path between locations depends on the magnitude of Brownian motion variance (BMV). Low BMV values produce pathways where the probability of deviating from a straight-line path is low. BBMM estimates BMV using cross-validation and maximum likelihood techniques.

We produced BBMM-derived UD surfaces across a grid system of 1-ha cells (n = 541,476) overlaid on the study area. In order to reduce "edge effects" for movement probabilities we created an 80-km buffer around the study area and included positions within the buffer in modeling. Independent surfaces were produced for all non-breeding eagles with transmitters (*n* = 60; remaining birds were determined to hold breeding territories and were excluded). Data from birds marked as nestlings were excluded until the birds dispersed from the natal area. We combined UD surface maps produced for individual birds to create a population-wide UD. BBMM produces a relative probability surface that reflects spatial variation in estimated utilization. Because sample sizes varied between individuals, surfaces were weighted according to the number of locations per individual, combined, and standardized.

3.2.3 Home Range Analysis

We calculated fixed kernel home range utilization distributions using Animal Movement Extension in ArcView 3.3 (Hooge and Eichenlaub 2000). We batch processed data for bald eagles *(n* = 62) and golden eagles *(n* = 2) using a minimized smoothing parameter (H) of 10,000. We produced a shapefile with polygons for 25%, 50%, 75% and 95% probability distributions.

3.2.4 Contaminants

3.2.4.1 Mercury

Mercury analysis took place in the Cristol Lab at the Department of Biology, College of William and Mary. Total mercury values of whole blood, breast feathers, and freeze-dried egg were analyzed using a Milestone® DMA 80 (direct mercury analyzer) using cold vapor atomic absorption spectroscopy. Two replicates from each sample were analyzed to validate homogeneity of Hg in samples. A blank was run every 20 samples to standardize equipment. Methyl mercury (MeHg), the form most available for uptake by birds, was assumed to compose 95% of the total Hg present in samples and was not analyzed separately. Feather mercury levels represent total body burden from the time of the last molt, which in nestlings was 2-3 weeks prior to sampling. Blood mercury represents recent dietary uptake. All Hg data are reported as wet or fresh weight values.

3.2.4.2 Persistent organic pollutants

Persistent organic pollutants were analyzed at the Hale Lab at the Virginia Institute of Marine Science, College of William and Mary. Whole blood and egg samples were freeze-dried for 48 hours before compound extraction. Extracts were analyzed using gas chromatography and mass spectrometry. Blood and egg samples were analyzed the following pesticides: *trans*-chlordane, MC5, *cis*-chlordane, *trans*-nonachlor, *cis*-nonachlor, DDMU, p,p'-DDE, p,p'-DDD, p,p'-DDT. Egg samples were additionally tested for heptachlore epoxide isomer B, oxychlordane, MC6, MC8, and MC3. Samples were also tested for polychlorinated biphenyls (PCBs) including: PCB-28/31, PCB-33/20, PCB-22, PCB-52, PCB-49, PCB-47/48/75, PCB-44, PCB-42/59, PCB-71, PCB-103, PCB-100, PCB-63, PCB-74, PCB-70/95/66, PCB-91, PCB-56/60, PCB-92, PCB-84, PCB-101/90, PCB-99, PCB-119, PCB-83, PCB-97, PCB-117, PCB-87/115, PCB-85, PCB-136, PCB-110, PCB-77, PCB-151, PCB-135, PCB-144, PCB-147, PCB-107/123, PCB-149, PCB-118, PCB-134, PCB-114, PCB-165, PCB-146, PCB-153/132, PCB-105, PCB-179, PCB-141, PCB-137, PCB-176, PCB-130, PCB-164/163, PCB-138/158, PCB-178, PCB-175, PCB-187, PCB-183, PCB-128, PCB-167, PCB-185, PCB-174, PCB-177, PCB-202, PCB-171, PCB-156, PCB-201, PCB-172, PCB-197, PCB-180/193, PCB-191, PCB-200, PCB-170/190, PCB-199, PCB-203/196, PCB-189, PCB-208, PCB-195, PCB-207, PCB-194, PCB-205, PCB-206, and PCB-209.

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4 **RESULTS**

4.1 Tracked Population

4.1.1 Descriptive Statistics on Eagles Processed on APG

APG and the upper Chesapeake Bay support three geographically distinct bald eagle populations (northeast, southeast, and Chesapeake Bay). Because of this convergence, actions taken on APG have the potential to impact distant eagle populations. In examining space use by eagles within the installation it was important that these populations be represented within the sample of birds tracked. By design, we specifically targeted birds during different seasons to include them in the sample pool. This section gives an overview of the eagles captured on APG and the cohort of eagles included in the tracking study. The section also gives a detailed summary of GPS locations collected by bird and geographic area. This information is the basis of most analyses included within this report.

4.1.2 Cohort of Eagles

A total of 108 eagles were processed on APG between 31, May 2007 and 7 February, 2011 including 107 bald eagles and 2 golden eagles. Band numbers, transmitter deployments, date of encounter and morphometrics for all birds processed are provided in Appendix 1. At the time of capture the cohort included 30 nestlings, 13 fledged first-year birds, 22 second-year birds, 13 third-year birds, 13 fourth-year birds, and 16 adults. The 2 golden eagles were in their second and third year when captured. Initially, bald eagles tracked with transmitters had a similar age distribution but over time the age distribution shifted to older age classes (Table 4.1.1). For bald eagles 43 were classified as males, 60 classified as females and gender was unknown for 2 individuals. Both golden eagles were females.

Table 4.1.1. Age structure of bald eagles tracked with satellite transmitters (2007-2012)

Year	Hatch year	Second year	Third year	Fourth year	Adult
2007	8	3	1	1	3
2008	12	15	10	4	14
2009	5	12	15	12	15
2010	2	4	10	14	23
2011		2	4	7	29
2012			2	3	29

As of June of 2012, a reasonable portion of the birds tracked by satellite transmitter are alive and still being tracked by the project (Table 4.1.2). Another large group of birds is not being tracked but their status is unknown. For this group we do not know if the transmitter was lost or failed but the bird is fine or if the bird has died. For 8 birds the transmitter was removed by the eagle and recovered through a ground search. These birds successfully removed the transmitter by biting through the Teflon harness. A total of 7 birds were known to be dead but the cause of death could be determined for only 3 of these. One bird was electrocuted on J-field APG in July of 2010 after being tracked for 18 months. A second bird was electrocuted on APG after being tracked for 6 months. The third bird was hit by a car in New York after being tracked for 30 months. Details of information available as of June 2012 on each bird are provided in Appendix 2. All but one of the nestlings that were fitted with a transmitter fledged and dispersed successfully (Appendix 3). Estimated mean fledging age for remaining birds was 76.5 d ± 2.05 (S.E.).

Table 4.1.2. Status of Bald and Golden Eagles tracked with satellite transmitters as of June 2012.

Eagle Status	**Total**
Alive	27[a]
Assumed alive - harness severed by eagle	8
Dead – vehicle collision	1
Dead - electrocution	2
Dead - unknown	4
Unknown status	25

[a] Includes 2 golden eagles and 2 bald eagles with GPS-GSM units

4.1.3 Tracking Data

The cohort of tracked birds generated nearly 700,000 GPS locations between May of 2007 and June of 2011. The number of locations for individual birds varied between 1,119 and more than 19,000 (Appendix 4). The length of time birds were tracked varied between 73 and 1,753 days. The longest tracked bird is still transmitting. Birds with active transmitters have been tracked for a mean length of time of 1,484±35.7 days or just over 4 years. All of these birds have been transmitting for more than 3 years and 18 have been transmitting for more than 4 years. On average, birds that removed their transmitter took more than 2 years to do so and mean tracking time was 738±135.6 days.

4.1.4 Bird Distribution

By design, transmitters were deployed on a mix of age classes from resident and migrant populations. Based on tracking patterns and size the cohort included residents, northern migrants and southern migrants (Table 4.1.3). However, birds traveled widely spending time in every eastern state and Canadian province (Table 4.1.4). Outside the tidal reach of the Chesapeake Bay, large amounts of time were spent in several jurisdictions throughout the east including Quebec and Newfoundland in the Northeast, Pennsylvania, New York and Delaware in the mid-Atlantic, and Florida in the Southeast.

Table 4.1.3. Source population for eagles processed on APG (2007-2011).

Eagle Population	**No. banded**	**No. Transmittered**
Local	87	47
Northern Migrant	16[b]	14[b]
Southern Migrant	4	4
	107	65

[a] Includes 2 golden eagles

Table 4.1.4. Number of eagles and GPS locations collected by state or province (2001-2011).

Country	State or Province	No. Locations	No. Eagles
United States	Connecticut	360	6
	Delaware	20,546	47
	District of Columbia	2	2
	Florida	17,658	5
	Georgia	419	4
	Maine	7,361	8
	Maryland	443,081	62
	Massachusetts	320	9
	New Hampshire	420	9
	New Jersey	9,318	26
	New York	27,611	27
	North Carolina	5,941	9
	Pennsylvania	31,606	48
	Rhode Island	25	5
	South Carolina	2,937	5
	Vermont	3,593	11
	Virginia	39,548	30
	West Virginia	1,388	5
Canada	New Brunswick	12,831	7
	Newfoundland & Labrador	21,032	9
	Ontario	1,216	6
	Quebec	49,035	15

Birds captured on APG exhibited a tremendous range of geographic associations (Appendix 5). Even birds from the Chesapeake Bay population wandered widely throughout the mid-Atlantic region. These patterns suggest that the upper Chesapeake Bay is a geographic hub for eagles hosting birds from throughout all eastern regions for varying periods of time. For some individuals APG represents the center of their life cycle. Others may only visit the site for brief periods of time (Appendix 4). Nearly half of birds tracked spent less than 10% of their time on APG (Figure 4.1.1). Migrants in particular spent less time on APG compared to Chesapeake Bay residents. A home range map of all eagle tracking data centers on the upper Chesapeake Bay with the 95% contour extending down to Blackwater National Wildlife Refuge and Caledon State Park (Figure 4.1.2).

4.1.5 Molted Feathers

We visited 39 bald eagle breeding territories on APG and collected 637 adult feathers (Appendix 6). Feathers are stored in paper envelopes and are available for genetic analysis. We made several collecting trips to 9 communal roosts on APG and collected 2,933 feathers (Appendix 7). Feathers are cataloged and stored in paper envelopes and available for genetic or contaminants analysis.

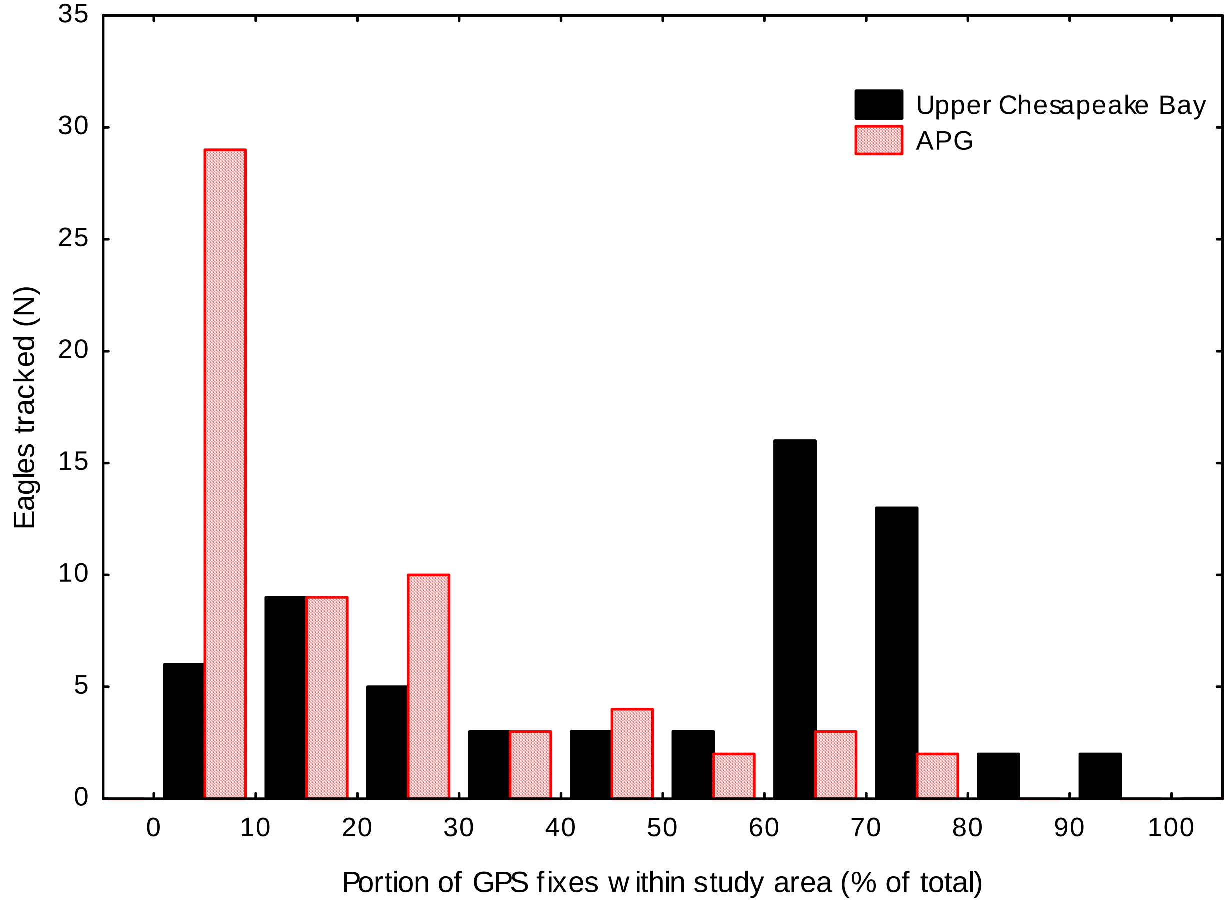

Figure 4.1.1. Portion of tracked data within the Chesapeake Bay and Aberdeen Proving Ground study areas.

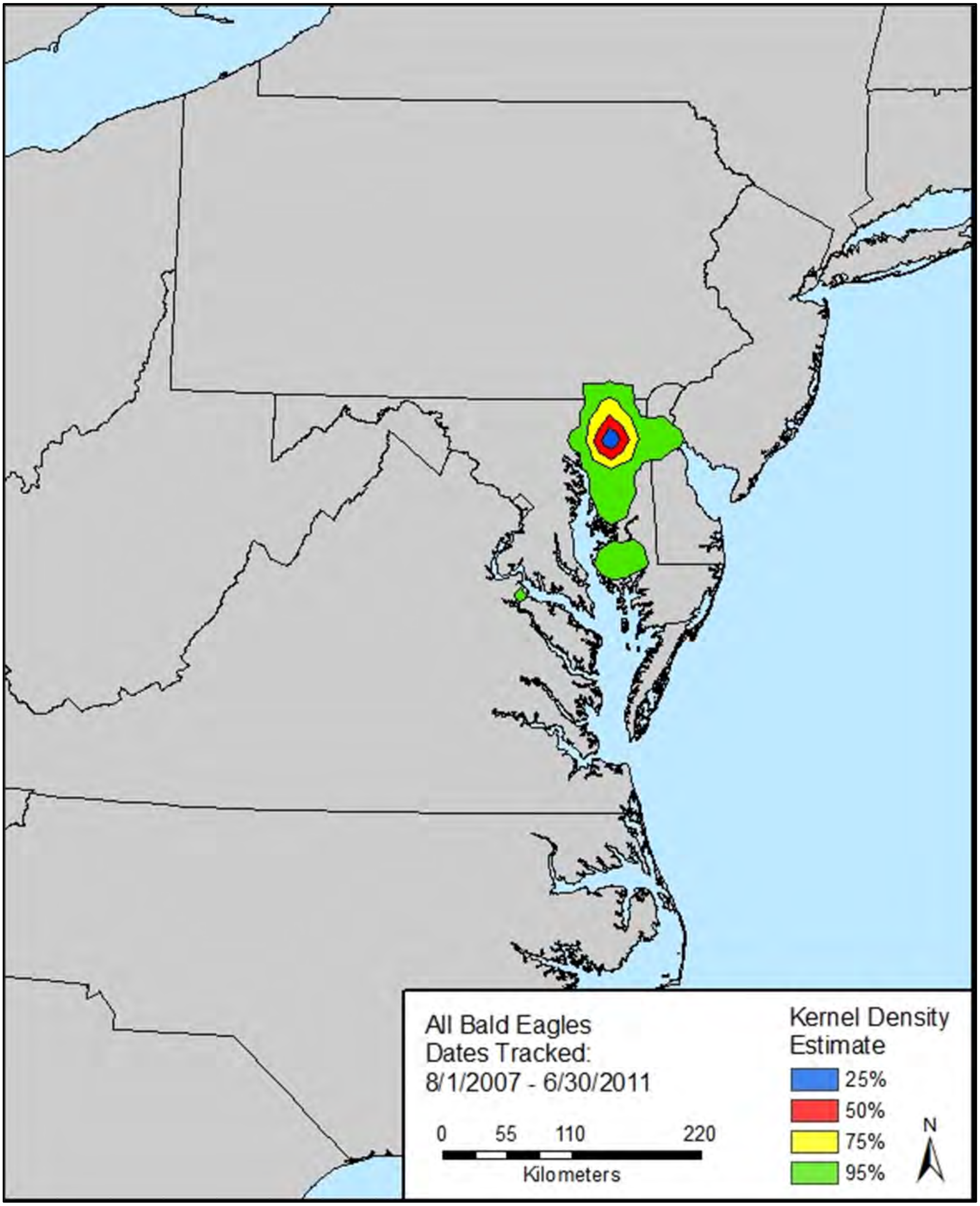

Figure 4.1.2. Fixed kernel home range utilization distribution for all bald eagles (n= 62) throughout their range during August 2007 – June 2011.

4.2 Communal Eagle Roosts

4.2.1 Chapter Background

Non-breeding Bald Eagles within concentration areas are typically very gregarious. Rather than roosting individually, birds often form communal roosts where several to several hundred individuals roost together within a relatively confined space. The distribution of communal roosts is believed to reflect a dynamic balance between the cost of travel to and from feeding areas, the relative profitability of feeding areas, and the energy savings achieved from roosting within protected microclimates. Loss of communal roosts may negatively impact energy budgets or cause the abandonment of important feeding sites. Because communal roosts play an important role in the life cycle of Bald Eagles, they are protected under the "disturb and sheltering" provisions of the federal Bald and Golden Eagle Protection Act. Several communal roosts were identified on APG during the early to mid-1980s. Four of these sites including Mosquito Creek, AA-5, Romney Creek, and Woodrest Creek have been monitored intensively since the early 1990s and their management is one element of the current bald eagle management plan for APG.

Work Presented

We used more than 10,000 midnight GPS locations to delineate and map a network of communal roosts within the upper Chesapeake Bay and APG study areas. This is the largest investigation of bald eagle communal roosts conducted to date and results provide insights to the broader management community. Results of this analysis are detailed in a manuscript included here that was published in the Journal of Raptor Research with the following citation –

Watts, B.D. and E.K. Mojica 2012. Use of Satellite Transmitters to Delineate Bald Eagle Communal Roosts within the Upper Chesapeake Bay. Journal of Raptor Research 46:121-128.

A reprint of this publication is provided in Appendix 8.

All communal roosts delineated on APG were evaluated in detail to provide site-specific management information. Summary information for the entire installation roost network was compiled in a report provided here with the following citation:

Watts, B.D. and E.K. Mojica. 2009. Bald Eagle Communal Roosts within Aberdeen Proving Ground. Center for Conservation Biology Technical Report Series, CCBTR-09-08. College of William and Mary & Virginia Commonwealth University, Williamsburg, VA. 20 pp.

A detailed map of each roost boundary is provided (Appendix 9) with descriptive statics including seasonal use, daytime use, number of individual eagles using the roost and total number of roost nights.

4.2.2 Use of Satellite Transmitters to Delineate Bald Eagle Communal Roosts within the Upper Chesapeake Bay

Abstract.- Although Bald Eagle (*Haliaeetus leucocephalus*) roosts are protected under the federal Bald and Golden Eagle Protection Act, we have little systematic information on the distribution and abundance of roosts, and a policy framework that governs day-to-day management decisions has not been developed. We used satellite transmitters *(n* = 63) deployed on Bald Eagles that represented a cross section of age classes and populations present within the study area. The units were programmed to record nocturnal roost locations *(n* = 10,321) to assess roosting behavior and to delineate the boundaries of communal roosts within the upper Chesapeake Bay. More than 27% *,* 2800) of roost locations were not associated with communal roosts and were assumed to reflect solitary roosting. The remaining 72% *(n* = 7,475) of roost locations were clustered within 170 communal roosts that varied in area (0.04 – 20.13 ha), relative use (5 - 755 roost-nights), and number of transmittered birds present (2 - 35). The number of communal roosts within the study area has grown 10-fold over the past 20 years, presumably reflecting the growth of source populations and eagle use of the area.

KEY WORDS: *Bald Eagle*; Haliaeetus leucocephalus; *Chesapeake Bay*; *communal roost*; *satellite transmitter*.

Congregations of nonbreeding Bald Eagles (*Haliaeetus leucocephalus*) form around rich food resources (McClelland et al. 1982, Isaacs and Anthony 1987, Hunt et al. 1992), and associated communal roosts typically are clustered around profitable feeding patches (Keister et al. 1987, Wilson and Gessaman 2003). Feeding and roosting are exclusive activities, require different habitats, and are often separated by considerable distances (Swisher 1964, Edwards 1969, Keister and Anthony 1983). The distribution of communal roosts is believed to reflect a dynamic balance between the cost of travel to and from feeding areas, the relative profitability of feeding areas, and the energy savings achieved from roosting within protected microclimates (Stalmaster and Gessaman 1984, Keister et al. 1985). For this reason, loss of communal roosts may negatively impact energy budgets or cause the abandonment of important feeding sites. Because communal roosts play an important role in the life cycle of Bald Eagles, they are protected under the "disturb and sheltering" provisions of the federal Bald and Golden Eagle Protection Act (Eagle Act) of 1940 (16 U.S.C. 668-668c) and their management is incorporated into the National Bald Eagle Management Guidelines (U.S. Fish and Wildlife Service 2007a). These guidelines define communal roost sites as areas where Bald Eagles congregate to perch overnight in forested areas protected from inclement weather and close to foraging areas (U.S. Fish and Wildlife Service 2007a).

Bald Eagles throughout the conterminous United States have increased from an estimated low in 1963 of 417 pairs (Sprunt 1963) to 5748 pairs by 1998 (Millar 1999) and 9789 pairs by 2007 (U.S. Fish and Wildlife Service 2007b). Presumably, the subadult population has increased at a comparable rate, and by 2007 likely exceeded 40 000 (based on expected age distribution for a population at equilibrium). Increases in breeding populations are reflected during the nonbreeding period when migrant adults and subadults congregate together within overwintering (Steenhof et al. 2002) and oversummering locations (Chester et al. 1990, Watts and Byrd 1999) and during the breeding season when local subadults congregate within breeding areas (Curnutt 1992). For this reason, population increases likely have resulted in a proliferation of communal roosts throughout the species' range, particularly within regions supporting large numbers of nonbreeders.

The Chesapeake Bay is a convergence area for Bald Eagle populations along the Atlantic Coast. In addition to a resident breeding population that has recovered to historic levels (Watts et al. 2008), the Chesapeake Bay supports populations of northern and southern migrants (Watts et al. 2007). In late spring and early summer, eagles migrate north from Florida and other southeastern states to spend the summer months in the bay (Broley 1947, Wood 1992, Millsap et al. 2004, Mojica et al. 2008). In the late autumn, eagles migrate south from New England and the maritime provinces of Canada to spend the winter on the bay (McCollough 1986, Buehler et al. 1991a). Nonbreeders from all three populations congregate in several concentration areas distributed within low-salinity reaches (Watts et al. 2007). Within these areas, communal roosts have been identified that support several to well over 100 birds during different periods of the year (e.g., Wallin and Byrd 1984, Haines 1988, Buehler et al. 1991b).

Despite similar protections afforded under the Eagle Act for roosts and nests, most management activities have focused on nest sites. Furthermore, throughout most of the species' range, we have comparatively little systematic information on the abundance and distribution of Bald Eagle roosts (Isaacs et al. 1996). We here report on our use of satellite transmitters to delineate a network of communal Bald Eagle roosts within the upper Chesapeake Bay.

4.2.2.1 Methods

Our study area included the northern part of the Chesapeake Bay from the Bay Bridge at Annapolis, MD to just above the Conowingo Dam on the Susquehanna River (Fig. 1). This area (2,729 km^2) includes the Upper Chesapeake Bay Bald Eagle Concentration Area (Watts et al. 2007) and is very similar in distribution and extent to that described by Buehler et al. (1991a). The eastern portion of the study area is primarily rural, with forest lands interspersed with agriculture. The western portion contains the urban areas of Baltimore and Annapolis but also includes Aberdeen Proving Ground (APG), a 350-km^2 military installation that is primarily forested with extensive shorelines. The northern part of the study area contains the Susquehanna Flats, a historically important site for wintering waterfowl (Lynch 2001). This area, along with the nearby Conowingo Dam, supports a significant number of eagles during the fall and winter months (Steenhof et al. 2008). Eagles within the area feed primarily on fish during the summer months, but switch to waterfowl and mammals during the autumn and winter when fish move to deeper waters and many waterbirds migrate into the bay (DeLong et al. 1989, Mersmann 1989).

We captured resident and migrant Bald Eagles (n = 63) on APG, banded, and fitted them with satellite transmitters between August 2007 and May 2009. Free-flying eagles were trapped on three sandy beaches (n = 10) using padded leg-hold traps (King et al. 1998), in three open fields (n = 26) using rocket nets baited with deer carcasses (Grubb 1988) and on open waters (n = 10) using floating fish traps (Frenzel and Anthony 1982, Cain and Hodges 1989, Jackman et al. 1993). We climbed nest trees throughout APG to access broods (8-10 wk of age) and deployed a transmitter on one nestling per brood (n = 17). We conducted floating fish and leg-hold trapping during the summer months to target resident and southern migrants. We conducted rocket-net trapping in the winter months to target resident and northern migrants. Eagle capture and handling methods were in compliance with IACUC protocols at the College of William and Mary (IACUC-20051121-3).

We used solar-powered, 70-g, GPS-PTT satellite transmitters (Microwave Telemetry, Inc. Columbia, Maryland, U.S.A.) to track eagle movements. Transmitters were attached using a backpack-style harness constructed of 0.64-cm Teflon® ribbon (Bally Ribbon Mills, Bally, Pennsylvania, U.S.A.). Transmitters were programmed to collect GPS locations (±18 m) every daylight hour and one additional location at midnight. GPS locations were processed by Argos satellites (CLS America, Largo, Maryland, U.S.A.) and stored online by Satellite Tracking and Analysis Tool (Coyne and Godley 2005).

We used midnight locations (n = 10,321) to delineate communal roosts occupied from August 2007 to August 2009. Locations from breeding adults roosting near nests were excluded. Locations from nestlings were not included until after they began roosting away from the natal site. Minimum convex polygons (MCP) of roost boundaries were delineated using a nearest neighbor clustering script in Crimestat III (Levine 2004). Cluster parameters were set to search a fixed distance of 100 m for a minimum of five midnight locations (i.e., roost-nights). At least two individual eagles had to visit a roost during the study period for it to qualify as a communal roost. Roosts used by single eagles were manually removed from the dataset. Landscape features of each roost were evaluated using digital raster graphics in ArcMap 9.3 (Environmental Systems Research Institute, Inc.© 1999-2009, Redlands, California, U.S.A.). Roosts within the same forest patch and within 200 m of one another were merged into a single MCP. Once established, roost boundaries were overlaid on roost locations to evaluate seasonality and relative magnitude (i.e. number of roost-nights, number of individuals) of use.

4.2.2.2 Results

All of the eagles tracked in this study had nonbreeding home ranges within the study area at the time of capture. We deployed transmitters on 17 local nestlings. Based on the review of positions in the months following transmitter deployment on free-flying birds we deployed transmitters on an additional 29 residents, 13 northern migrants and 4 southern migrants.

We delineated 170 communal roosts within the study area (Fig. 4.2.11). Eagles roosted widely throughout the upper Bay and 7475 (72%) midnight locations fell within the definition of a communal roost used in our analysis. Remaining locations (2846) were not associated with other transmittered eagles and were assumed to be locations resulting from solitary roosting. Communal roosts were skewed to more rural parts of the study area and included the Eastern Shore, the lower Susquehanna River and APG. APG alone accounted for 40% of delineated roosts. In contrast, the metropolitan areas within the southwestern portion of the study area supported very little roosting.

Relative use of communal roosts varied dramatically such that a small number of roosts accounted for a large portion of overall roosting activity. Overall, the number of roost-nights per roost varied from 755 to the established minimum of 5 (44 ± 6.1, mean ± SE), the number of calendar nights from 455 to 5 d (37 ± 4.3 d) and the number of different transmittered birds supported from 35 to 2 (7 ± 0.47). These three parameters were inter-correlated (correlation coefficients Pearson's $r > 0.72$, $P < 0.05$), suggesting that the roosts receiving the highest use were also the most consistently used roosts and accommodated the largest number of individuals. The result of variation in relative use is a "decelerating utility function" such that 10%, 30% and 50% of roosts support 52%, 78%, and 89% of roost nights respectively (Fig. 4.2.2).

The total area encompassed by all roost sites was 322.1 ha, or 0.1% of the study area. Area of communal roosts varied from 0.04 to 20.13 ha (mean = 1.9 ± 0.21 ha) and the density of use ranged from 5.3 to 427.5 roost-nights/ha for the study period. A significant portion (48%) of this area was owned by the government or conservation organizations, including roosts on lands controlled by the military (33%), nongovernmental organizations (7.8%), state and local governments (5.8%), other federal agencies (1.6%). The remaining roosts were on privately owned land (52%). A plot of the minimum area trajectory indicated that 10% and 20% of the roost area supported more than 30% and 50% of the roosting activity, respectively (Fig. 4.2.3).

4.2.2.3 Discussion

The number of communal roosts within the upper Chesapeake Bay appears to have increased dramatically over the past 20 years. Buehler et al. (1991b) used conventional VHF transmitters (n =73) to locate communal roosts within the same study area (1988-1989). They followed individuals to nocturnal roost sites twice weekly for 12 months to reveal the roost network and monitored delineated roosts from the ground. They classified roosts as communal based on visual observations of additional eagles using the roosts. Of the 17 communal roosts described, 13 were still active during our study. In the intervening years, the number of active roosts has proliferated with an average doubling time of just over 6 yr, representing a 10-fold increase in 20 yr. Over this same period, the breeding population has exhibited a comparable increase within the portion of the study area that has been surveyed annually (J. Pottie and J. Paul unpubl. data). The distribution of roosts described here was similar to that described by Buehler et al. (1991b), with most roosts occurring along the Eastern Shore, on the lower Susquehanna River, or on APG lands and very little roosting activity in the urbanized landscape including the cities of Baltimore and Annapolis.

Throughout the network of communal roosts, the use of individual sites varied dramatically such that 10% of the roosts accounted for more than 50% of the total roost activity. Variation in the relative significance of roosts has been noted in other study areas. Keister and Anthony (1983) collected pellets under six communal roosts in the Klamath Basin and found that nearly 49% of the total pellets were from a single roost and that more than 80% were from the two largest roosts. Although the range of use was narrower, Isaacs et al. (1996) found that eagles wintering along the Upper John Day River in Oregon typically used small roosts that were an order of magnitude smaller than the largest roosts. Within the current study site, monthly surveys of four communal roosts (1996-2003) indicated that use varied more than an order of magnitude between sites (General Physics 2004). Here, the use of roosts varied by more than two orders of magnitude. Together, these studies illustrated that roost sites vary considerably in terms of their relative use and presumed value to eagle populations.

More than 2800 (27%) roost-nights were not associated with areas delineated as communal roosts and were assumed to represent solitary roosting events. Solitary roosting has been reported elsewhere (e.g. Southern 1964, Stalmaster 1976, Grubb et al. 1989) and results presented here were comparable to those in other studies that have systematically evaluated roosting behavior. An intensive investigation of roosts and roosting behavior in Oregon classified more than 30% of roosting events as solitary roosts (Isaacs et al. 1996). Within the upper Chesapeake, solitary roosters accounted for 41% of documented (n = 81) roost-nights in the 1980s (Buehler et al. 1991b). Because of the large portion of roost-nights attributed to solitary roosters and their wide distribution, they greatly expand the overall portion of the study area used by roosting eagles.

Variation in the area of communal roost sites was comparable to that documented in other investigations where roost boundaries were mapped. Other studies have shown roosts that vary from a single tree (Isaacs et al. 1993) to a 254-ha forest patch (Keister and Anthony 1983), including roosts in North Carolina (1.3 – 5.0 ha; Chester et al. 1990), Maryland (0.39 – 1.0 ha; Buehler et al. 1991b), Florida (20 ha; Curnutt 1992), South Dakota (5 ha; Steenhof et al. 1980), Montana (42 ha; Crenshaw and McClelland 1989), and Oregon (2.4 – 28.3 ha; Isaacs and Anthony 1987).

Unlike nests that, from a regulatory perspective, are homogeneous in terms of their benefit to populations, the importance of roost sites may vary considerably. Bald eagles employ a wide range of roosting strategies. Here we have demonstrated roosting scenarios that vary from a large number of locations where individuals appear to roost alone to relatively few communal roosts that are used by many individuals throughout the year. Solitary roosts are numerous and cover nearly the entire study area. Small communal ephemeral roosts used on average less than 1 d / mo are widespread and common. Large roosts used throughout the year by individuals from populations along the entire Atlantic Coast, are much less common. The most significant roost detected was at the Conowingo Dam, and was used by 28 birds with transmitters, covered 9.8 ha, and accounted for >10% of all communal roosting activity. Ten percent of the roosts accounted for 50% of the roosting activity, but only 30% of the total area of all roosts.

The question of how or whether to manage the continuum of roost sites is central to the formulation of effective policy. Protections afforded to roost sites under the Eagle Act are nonspecific. The act does not define what constitutes a roost. Roosts have been defined as $\geq$1 eagle for $\geq$1 night (Grubb et al. 1989, Buehler et al. 1991b), and $\geq$3 eagles for $\geq$2 nights (Anderson et al. 1985). Although these definitions clearly describe biological events, they may not be viable from a regulatory perspective. Solitary roosts were numerous and widespread. Placing management buffers around these consumes all of the land within the study area. These sites also are the most likely to be ephemeral such that managing them provides an uncertain benefit to the population. Although less pronounced, small communal roosts are also widespread and account for a relatively small portion of roosting activity, suggesting that the benefit accrued to eagles for their protection relative to the burden to landowners is small. Within the current roost network, applying a management threshold of 0.5% (i.e., roosts accounting for >0.5% of roosting activity receive protection) would reduce the burden to managers and landowners by more than 75% with only minimal presumed impact to eagles.

4.2.2.4 Acknowledgments

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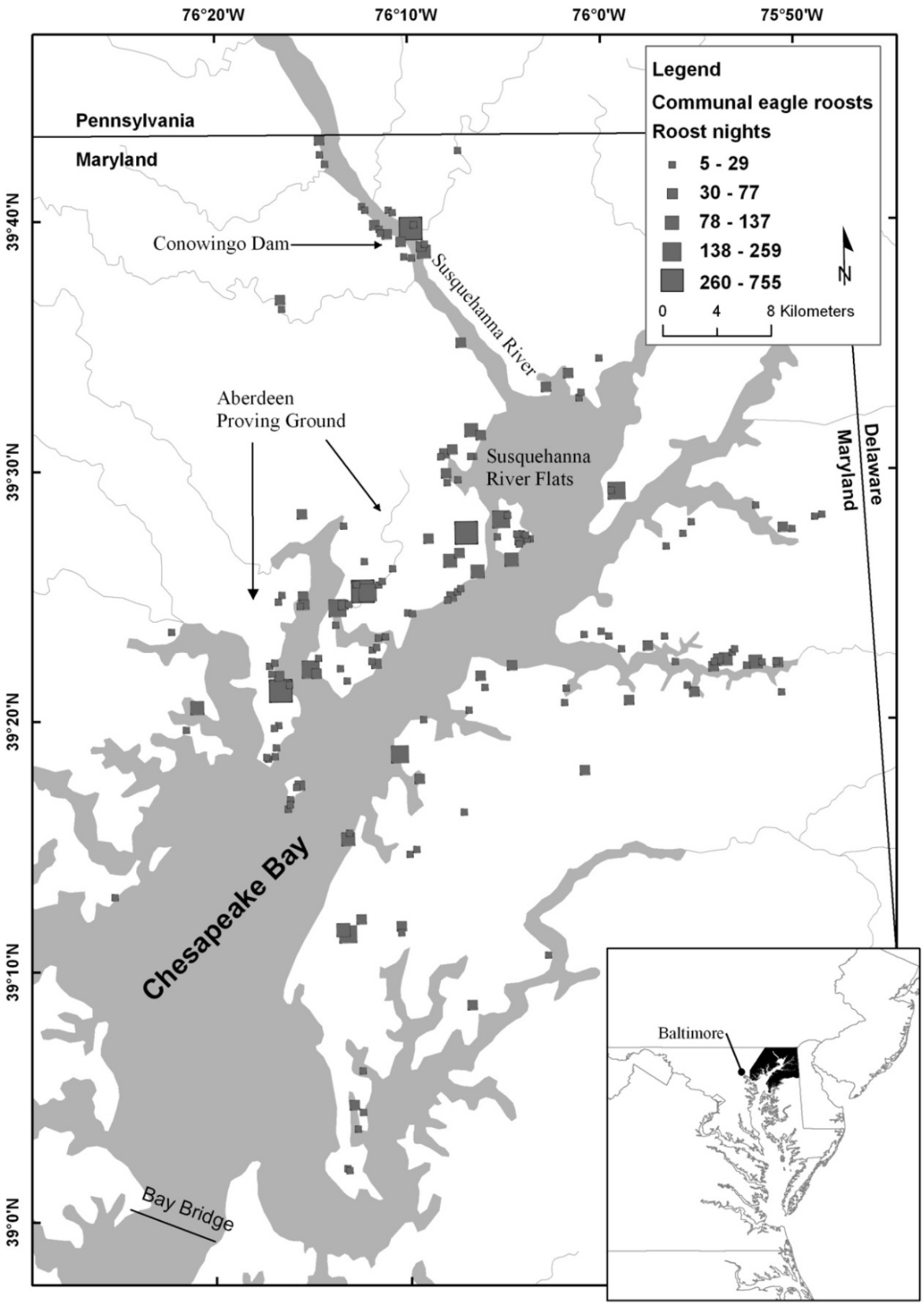

Figure 4.2.1. Upper Chesapeake Bay including communal roosts within the study area. This portion of the tidal reach of the bay includes the Upper Chesapeake Bay Bald Eagle Concentration Area.

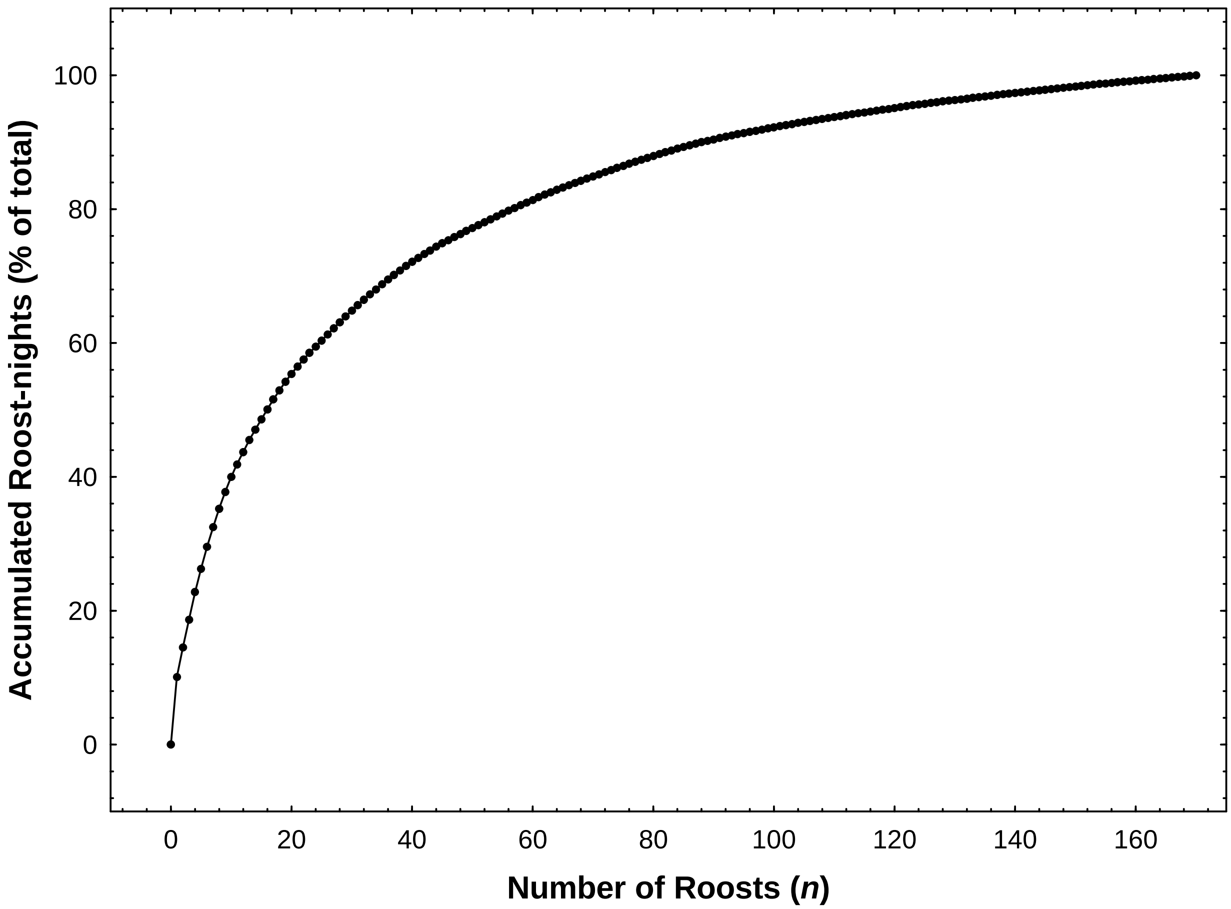

Figure 4.2.2. Relationship between the number of roosts and the cumulative proportion of roosting nights supported. The graph reflects the minimum number of roosts to support the highest portion of roost nights. Roosts were ordinated from high to low according to the number of roost nights supported. An accumulation curve was then generated by sequentially adding each roost to the total and expressing the result as a portion of the total roost nights against the number of roosts included.

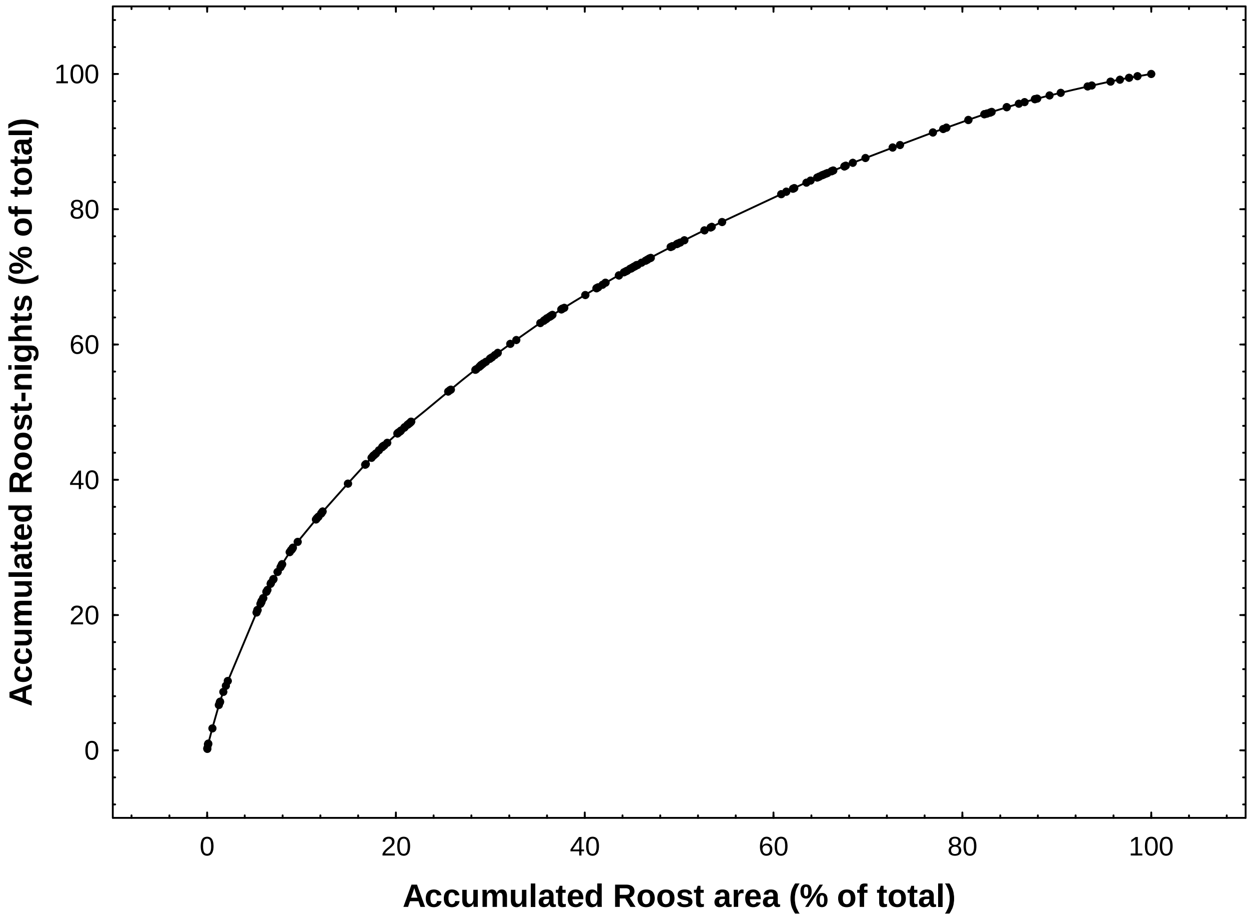

Figure 4.2.3. Relationship between the amount of land and the cumulative proportion of roosting nights supported. The graph reflects the minimum area to support the highest portion of roost nights. Roosts were ordinated from high to low according to roost density (accumulated roost-nights/roost area). An accumulation curve was then generated by sequentially adding each roost to the total and expressing the result as a portion of the total roost nights against the sum of roost area included.

4.2.3 Aberdeen Proving Ground Study Area

Published report: Watts, B.D. and E.K. Mojica. 2009. Bald Eagle Communal Roosts within Aberdeen Proving Ground. Center for Conservation Biology Technical Report Series, CCBTR-09-08. College of William and Mary & Virginia Commonwealth University, Williamsburg, VA. 20 pp.

4.2.3.1 Background

The Chesapeake Bay is an area of convergence for post-nesting and sub-adult Bald Eagles from breeding populations along the entire Atlantic Coast. The Bay supports a resident population that has been growing exponentially with an average doubling time of 8.2 years (Watts et al. 2008). This population currently includes more than 2,000 breeding adults, as many as, 1,000 non-breeding adults, and more than 4,000 subadult birds. In addition to the resident population, the Chesapeake Bay also supports migrant birds during different seasons (Watts et al. 2007). In late spring and early summer, approximately 2,000 eagles migrate north from Florida and other southeastern states to spend the summer months in the Bay. In the late fall, approximately 1,000 eagles migrate south from eastern Canada and New England to spend the winter months on the tributaries of the Bay. The convergence of three geographically distinct populations (northeast, southeast, and Chesapeake Bay) suggests that the Bay plays a particularly important role in the recovery of Bald Eagles in eastern North America.

Southern Migrants

The northward migration of Bald Eagles from Florida to the Chesapeake Bay was first documented during a review of band returns from the 1940s by Broley (1947). Broley showed that young birds banded in Florida as nestlings migrated north along the coast to the mid-Atlantic (or in a few instances further north). Definitive confirmation of these early findings has been obtained in recent years by Millsap *et al.* (2002) who used satellite telemetry to track 57 young eagles from Florida to their summer territories. Nearly 50% of these birds spent the summer in the Chesapeake Bay or coastal North Carolina. The birds returned to Florida for the winter months and established winter territories. What proportions of the southeastern populations migrate to the Bay for the summer is currently unknown. Observations of birds within several of these concentration areas (Watts pers. obs.) implies that the migrants utilize the Bay not just as foraging areas but as a molting ground suggesting that the Bay plays an important role in their annual cycle.

Based on band returns and direct observations, Broley (1947) estimated that birds begin to leave Florida in April. This estimate was consistent with telemetry data obtained by Mojica et al 2008. Migrant eagles appear to move into the Bay in early to mid-May. Use of concentration areas begins to rise during this period and reaches a peak between mid-June and mid-July (Watts and Byrd, *unpublished data*). In most years, numbers decline within concentration areas from mid-July through the end of September (Watts and Byrd, *unpublished data*). The timing of movements out of the Bay is consistent with Broley's (1947) estimate from band recoveries of when birds return to Florida. Adults and subadults exhibit different schedules of migration and appear to have different residency periods within the Bay. Birds that move into the Bay in May are predominantly sub-adults. These birds are followed by adults such that the ratio of adults to sub-adults increases through the early summer and eventually reaches an approximate 1:1 ratio by the peak period. Age ratio shifts back toward a sub-adult bias through the early fall. Taken together, these patterns suggest that adults enter the Bay later and stay for a shorter period of time compared to sub-adults.

Northern Migrants

Bald Eagles from northeastern Canada and the United States migrate southward into the Chesapeake Bay during the late fall and early winter period (Stewart and Robbins 1958, McCollough 1986, Byrd *et al.* 1990). These birds apparently move south in advance of large water bodies freezing over in northern latitudes and their appearance in the Bay coincides with the movement of waterfowl into the area. Historically, numbers have increased through November and December typically reaching a peak in January. In recent years, movements into the Bay appear to be later, possibly due to later freeze up to the north. The change in the distribution of ice cover may be shifting the winter range of the species northward. Most northern birds are believed to have moved northward out of the Bay by late March.

Bald Eagle Concentration Areas

Bald Eagle "concentration areas" are locations where eagles congregate in numbers much higher than what may be accounted for by local breeding pairs and their offspring, and that support one to several communal roosts. Due to the status of the Chesapeake Bay as both a summer and winter destination for migrants, concentration areas may support a complex mix of individuals of different ages and from different populations. For example, during the summer months, concentration areas may support adults, sub-adults and young-of-the-year from the Chesapeake Bay population (some of which may vacate their territories after breeding to move into concentration areas) and from the Southeast. Similarly, winter concentration areas may support non-breeding birds from the Chesapeake Bay and both reproductive and non-breeding birds from the Northeast.

Summer Concentration Areas

Migrant eagles are not distributed evenly throughout the Chesapeake Bay during the summer months (Watts et al. 2007). Since the early 1980s, six summer "concentration areas" have been identified and delineated that consistently support birds year after year. These include the upper James River (Scott 1971, Clark 1992, Watts and Factor 1994, Watts and Whelan, 1997, Watts and Byrd 1999), the upper Rappahannock River (Portlock 1994, Watts 1998), the upper Potomac River (including several sub-sites) (Wallin and Byrd 1984, *Caledon State Natural Area unpublished data*, *Mason Neck NWR unpublished data*), the Pocomoke River (Watts *unpublished data*), the Nanticoke River (Watts *unpublished data*), and the upper Bay including Aberdeen Proving Ground (Millsap *et al.* 1983, SWCA, Inc. 1995). In addition to these somewhat stable concentration areas, it should be noted that eagles are very responsive to the distribution of prey, and through the years ephemeral concentration areas have been documented that develop and disband in response to short-term food resources (Watts, *personal observation*).

In general, use of summer concentration areas has not been monitored as intensively as the breeding population. Peak counts of birds using the upper James River concentration area increased by a factor of 5 between 1982 and 1991 (Watts and Byrd 1999). This level of increase is generally consistent with the growth in the populations believed to utilize the Bay during summer. Collectively, summer concentration areas within the Chesapeake Bay support a minimum of 1,500 birds (Watts et al. 2007). This composite number is based on peak Bald Eagle estimates within concentration areas during the mid-1990s from shoreline surveys. Peak counts include: James River (450), upper Rappahannock River (320), Upper Potomac River (500+), Pocomoke River (30), Nanticoke River (150), and the upper Chesapeake Bay including Aberdeen Proving Ground (100). How many total birds may pass through these areas during the summer months or what proportion of birds is from distant populations is unknown.

Winter Concentration Areas

As during the summer months, wintering eagles are not distributed evenly throughout the Chesapeake Bay. Several concentration areas have been described including the upper Chesapeake Bay (APG and lower Susquehanna River), Blackwater NWR, Fishing Bay WMA, Pocomoke River, upper Potomac River (Mason Neck NWR to Caledon Natural Area), upper Rappahannock River, upper James River, and the northwest corner of the Great Dismal Swamp NWR (Byrd *et al.* 1990, Fraser *et al.* 1991, Watts et al. 2007, Schwab, *personal communication*). In addition to these somewhat stable concentration areas, it should be noted that eagles are very responsive to the distribution of prey and through the years ephemeral concentration areas have been documented that develop and disband in response to short-term food resources (Watts, *personal observation*).

As with summer concentration areas, winter concentration areas within the Chesapeake Bay have not been monitored with the same intensity as the breeding population. However, mid-winter surveys have been conducted in both Virginia and Maryland within selected concentration areas since the early 1980s. Between 1986 and 2000 the number of birds within Maryland sampling areas increased at an annual rate of 5.4% (Steenhof *et al.* 2002). This increase is similar to that reported for Virginia of 4.5% between 1997 and 2000 (Steenhof *et al.* 2002). Both of these rates are considerably below those reported for the New England breeding population that is the origin for a portion of birds identified in the Chesapeake mid-winter surveys. The trends reported by Steenhof *et al.* (2002) were developed using a complex form of route regression that reports annualized population changes. The Maryland figure represents an analysis of 40 surveys of 3 routes conducted between 1986 and 2000. The Virginia figure represents an analysis of 8 surveys of 2 routes conducted between 1997 and 2000.

However, some specific sites have shown considerably higher increases in use than the overall state averages (*e.g.* Portlock 1994 and Maryland Department of Natural Resources (DNR)). Maryland DNR data have shown considerably greater population increases than the bay wide averages. Maryland DNR recorded data in the upper bay inclusive of Aberdeen Proving Ground, Susquehanna River, and Blackwater National Wildlife Reserve in Dorchester County, Maryland, as sampled during mid-winter surveys, have had an annual average increase of 14% between 1986 and 2000.

4.2.3.2 Communal Roosts

Non-breeding Bald Eagles within concentration areas are typically very gregarious. Rather than roosting individually, birds often form communal roosts where several to several hundred individuals roost together within a relatively confined space. Within the Chesapeake Bay, communal roosts have been identified that support several to well over 100 birds during different periods of the year *(e.g.* Wallin and Byrd 1984, Haines 1988, Buehler *et al.* 1991, Watts, *unpubl. data*).

Although communal roosts have been identified within different situations throughout the Chesapeake Bay, most roost sites share some physical characteristics. Most sites discovered are 1) positioned close to major foraging areas, 2) isolated from human disturbance, 3) contain suitable substrate for roosting, and 4) when applicable are positioned in areas protected from harsh weather. Another characteristic that seems to be common among roost sites is a clear movement corridor between the roost and primary foraging areas. Substrates include both pines and/or hardwoods. Actual roost trees tend to be large with good crown access for entry and exit. This typically means that they are super canopy trees or are along some type of habitat discontinuity (*e.g.*; tree edge along a field, waterway, or marsh). Roosts have also been known to form within stands of snags over flooded marshes or beaver ponds.

The use of communal roost sites depends on several factors such that sites may form, and be used for variable lengths of time. Bald eagles are very opportunistic foragers and concentrated food patches that are ephemeral may lead to the formation of communal roosts sites that may only be used for a couple of days. In contrast, sites that are strategically located within stable concentration areas may be used for many years. Concentration areas that depend on seasonal prey bases have communal roosts that are seasonal in use. Because the location of roost sites depends not only on the characteristics of the site itself but also on the distribution of prey, changes in site characteristics, the surrounding landscape, or the distribution of foraging areas may all influence site use. The distribution of communal roosts in the lower Chesapeake Bay has been documented to shift rapidly in response to changes in the distribution of both prey and super canopy trees (Watts unpublished data). Chronic disturbance within primary foraging areas has also been shown to change roost use (Watts, *unpublished data*).

4.2.3.3 Legal Responsibilities

Communal roosts are protected under the Bald and Golden Eagle Protection Act (Eagle Act) (16 U.S.C. 668-668d) under the working definition of the "disturb" clause. In anticipation of the formal removal of the Bald Eagle from the federal Endangered Species Act (ESA) (16 U.S.C. 1531 et seq.), the U.S. Fish and Wildlife Service published a regulatory definition of the term "disturb" on 16 February, 2006 (71 FR 8265). Following a period of public comment, they later revised the definition on 5 June, 2007 (72 FR 31131). Their final definition is as follows: "Disturb means to agitate or bother a bald or golden eagle to a degree that causes, or is likely to cause, based on the best scientific information available, (1) injury to an eagle, (2) a decrease in its productivity, by substantially interfering with normal breeding, feeding, or sheltering behavior, or (3) nest abandonment, by substantially interfering with normal breeding, feeding, or sheltering behavior." Further clarification of the definition within the final rule as it pertains to productivity clearly indicates that actions impacting sheltering behavior that, based on the best available scientific understanding, are deemed to impact biological fitness are included in the definition and as such are prohibited. Alternatives should be sought for actions that may either alter the physical structure of roost sites or cause disturbances that may impact the ability of individuals to use them.

4.2.3.4 Aberdeen Proving Ground

Aberdeen Proving Ground is strategically positioned within the upper Chesapeake Bay Bald Eagle Concentration Area. This area receives a great deal of use by resident breeding eagles, as well as, non-breeding eagles from the Chesapeake Bay and migrant populations. APG supports more eagles annually than any other federal property along the Atlantic Coast.

Summer Concentration Area

Since at least the late 1970s, APG and surrounding areas has been known to support elevated numbers of eagles during the summer months (Millsap *et al.* 1983). Buehler *et al.* (1987) conducted aerial shoreline surveys throughout the northern Chesapeake Bay between 1984 and 1985 and show that APG supported the highest density of birds within the study area. Average linear density of eagles along the shoreline of APG was significantly higher than other areas within the northern Chesapeake during the summer months. SWCA, Inc. (1996) also conducted aerial shoreline surveys of APG between 1993 and 1995. Both Buehler *et al.* (1987) and SWCA, Inc. (1996) documented a summer peak in eagle use consistent with other concentrations areas throughout the Chesapeake Bay suggesting that the local population is augmented by southern migrants. The latter study recorded peak summer counts of approximately 80 birds on APG. In the 10-year period between the two studies, summer shoreline use appears to have increased by 4-fold. This is generally consistent with observations elsewhere in the Bay during a similar period and may reflect population increases in source populations.

Winter Concentration Area

Bald Eagles within the northern Chesapeake Bay winter concentration area appear to be focused on the lower Susquehanna River near the Conowingo Dam and on

APG (Buehler *et al.* 1987). As during the summer months, Buehler *et al.* (1987) conducted aerial shoreline surveys between 1984 and 1985 and show that APG supported the highest density of birds within the northern Chesapeake Bay during the winter months. Birds using APG exhibit a peak in numbers during the December-February time period (SWCA, Inc. 1996). This pattern is consistent with other locations in the Chesapeake Bay that support winter migrants. A mid-winter survey conducted each year between 1983 and 2001 shows an increase in birds of approximately 5-fold (Pottie 2001). On average the winter population has been growing at a rate 21% per year (General Physics 2004). This is considerably higher than the rate of 5.4% reported for the later years in Maryland (Steenhof *et al.* 2002). Data from the Maryland DNR for the years 2000-2004, continue to support the earlier Buehler data.

Communal Roosts

In the 1970s, Ondek reported there were no known roost sites at APG and that concentration areas were confined to the Bush River and on the Bay shoreline (Ondek, personal observations). Radio telemetry and bird behavior were used during the 1980s to locate communal roosts within APG. Several communal roosts were identified during this time period (Millsap *et al.* 1983, Buehler *et al.* 1987). Four of these sites including Mosquito Creek, AA-5, Romney Creek, and Woodrest Creek have been monitored intensively between 1993 and 1995 by SWCA, Inc. (1996), from 1996-2005 by General Physics, and from 2006 to present by EA Engineering. Collectively, use of these roost sites has exhibited a seasonal pattern with summer and winter peaks that correspond to the influx of migrants from southern and northern populations respectively (SWCA, Inc. 1996).

There has also been considerable year-to-year variation in use. Collective use appears to be relatively stable between 1997 and 2000 but shows a sharp increase in 2001. After 2001 there has been a decline. It is possible that some of the year-to-year variation may reflect use of unknown roost areas on APG or surrounding lands. Since the 1980s there has been no systematic attempt to survey for new communal roosts though some have been located incidentally.

Use of individual sites within a network of communal roosts is often dynamic. Short-term shifts of individual birds between sites are common and may reflect, among other factors, short-term changes in the spatial distribution of prey, disturbances within particular foraging areas, or disturbances within roost sites. Using radio transmitters to track birds, Buehler *et al*. (1987) documented numerous individuals moving between different roost sites on successive nights within APG. Seasonal shifts in the relative importance of particular roost sites may reflect the distribution of prey that are used in different seasons. Population-level shifts between roost sites that persist over time typically reflect more fundamental changes in the roost itself or within prominent foraging areas. For example, loss of super canopy trees within communal roosts to mortality or because they were overtaken by rapidly growing pines has led to the permanent loss of sites as communal roosts in the lower Chesapeake Bay (Watts *et al.*, *unpublished data*). Similarly, a change in the pattern of human disturbance along the shoreline has been shown to cause a shift in shoreline use by Bald Eagles and a subsequent change in the use of communal roosts (Watts and Factor 1994).

4.2.3.5 Management of Communal Roosts

Throughout the Chesapeake Bay region, establishment of human activity buffers around communal roost sites is a stated objective (Byrd *et al.* 1990). In Virginia communal roosts are given similar consideration as active nests (Watts 2005) with management buffers including a primary management zone (229 m or 750 ft radius around the delineated roost area) and a secondary management zone (from the outer edge of the primary buffer to 400 m or 1320 ft radius around the roost). Time-of-year restrictions on winter roosts are 1 November through 28 February and for summer roosts are 1 May through 30 September. Activities that fall under these restrictions are determined on a case-by-case basis.

Communal Roost Sites on APG are currently managed using a combination of buffer zones and activity restrictions. This general approach is consistent with that recommended for this species throughout its range (*e.g.* Stalmaster and Newman 1978, Steenhof 1978, Cline 1990) and is mandated by the USFWS biological opinion. Currently, the recommended management protocol for APG calls for a buffer zone of 500 m around known roost sites with activity restrictions. In order to protect habitat, land clearing, timber harvesting, and construction activities are generally restricted within the buffer zone. In order to protect eagles from disturbance, human activity is reduced within the buffer zone. Restrictions are currently year-round for all known roosts.

4.2.3.6 PATTERNS AND IMPLICATIONS FROM SATELLITE TRACKING

Approach to Delineating Communal Roosts

Communal roosts were delineated using GPS locational data recorded from transmittered eagles tagged at APG. Sixty-three GPS/Argos solar-powered satellite transmitters (Microwave Telemetry Inc, Columbia, MD) were deployed on nestling, sub-adult, and adult Bald Eagles on APG from August 2007-May 2009. Based on body measurements and migration data, eagles were categorized into resident (n = 46), northern (n = 15), or southern (n = 4) populations. GPS fixes (accuracy $\pm$ 18m) were recorded by transmitters every hour during daylight and one additional location at midnight. Midnight GPS fixes were selected as the location an individual eagle roosted each night. Midnight locations for all eagles were combined in a nearest neighbor clustering analysis using Crimestat 3.0 (Levine 2004). Minimum convex polygons were generated for each roost where at least 20 midnight locations were within a 600 foot distance of one other. Roosts boundaries were mapped using ArcGIS 9.3 (ESRI, Redlands, CA) and named using nearby landscape features. Two or more roosts were clustered if located in close proximity to another roost. All roosts were used by at least two transmittered eagles during the study period August 2007-August 2009.

Distribution of Documented Communal Roosts

Roosts were distributed throughout all sections of APG though most were located on the Aberdeen portion of the post. Roosts were delineated on Aberdeen (*n* = 31), Carroll Island (*n* = 1), Edgewood (*n* = 14), Graces Quarter (*n* = 1), Pooles Island (*n* = 4), Spesutie Island (*n* = 8; Figure 4.2.4; Appendix 9).

Roosts averaged 13.8 acres in size (min 0.7, max = 44.9, SD = 10.8, Table 4.2.1). Total acreage of communal roosts on APG was 815 acres and 500 m buffers around roost totaled 14,295 acres. Forest edges along creeks, rivers, bogs, and the Chesapeake Bay were the predominant location for eagle roosts on APG. Roosts habitat consisted of mature mixed hardwoods with open understory.

Fourteen of the roosts occurred surrounding active or inactive eagle nests (Abbey Point, Bear Point, C-tower, Cooper's Creek, Graces Quarters, Fairview Pt, Mosquito Creek, Pooles Island North, Pooles Island Pothole, Sandy Point, Towner Cove, Woodrest Creek). The fact that these interactions occur during the nesting cycle opens many questions about potential impacts of migrant eagles on the nesting activities and reproductive performance of the resident population of eagles. This study is the first to document large numbers of Bald Eagle pairs nesting within the boundaries of occupied communal roosts. These breeding pairs challenge our long-held assumptions about territoriality in this species. A relaxation of behaviors related to territorial defense may reflect the relationship between social context and energetic benefits. At this time, substrate for nests or communal roosts does not appear to be limiting on APG. The fact that new nests have been built within existing roosts and that roosts have developed around existing nests suggests that social facilitation may play a role in these associations.

Seasonality of Communal Roosts

The number of transmittered eagles roosting on APG fluctuated throughout the year as migrant populations entered and left the Bay (Figure 2). Resident eagles were present year-round but were the dominant users of APG during April-July and October-December. Migrants from northern eagle populations arrived on APG in December and left in late March. Southern migrants arrive in the Bay in May and left August-November.

Roosts use on APG varied by season and location on the landscape (Table 4.2.2). Eagles used roosts close to shorelines in summer months and inland roosts in winter months (Figure 3). This seasonal pattern may reflect a shift in prey distribution or need for additional shelter during low winter temperatures. Year-round roosts were typically found inland while those used only in summer months were < 500m from a shoreline.

Roost Use and Time of Day

Eagles primarily entered roosts near dusk and exited before dawn. Ground observations confirmed a majority of eagles began exiting the roost 30 minutes before dawn and continued until 15 minutes after dawn. Transmitter data and ground observation found eagles continued to enter and exit roosts throughout the day (Figure 4).

Management of Communal Roosts

We modeled three different management scenarios for communal roosts based on buffer size and seasonal variation. Roost buffers were overlaid with range and training area boundaries determined from 1 m aerial Digital Orthophoto Quarter Quads (Maryland DNR 1995). Area names were labeled based on the 1997 APG installation map. Names for several areas were unknown including ranges on Spesutie (named ranges a-m).

Scenario 1. Year-Round 500m Roost Buffers

Application of 500 meter buffers restricted approximately 4,063 of the 17,440 acres (23%) of ranges and training areas on APG (Table 4.2.3).

Scenario 2. Seasonal 500m Roost Buffers

Roost buffers were applied to ranges and training areas based on roost occupancy for each quarter of the calendar year (Table 4.2.4). This scenario allowed the greatest flexibility in managing the roosts for range and training activities.

Scenario 3. Half-Mile Roost Buffers

Application of the ½ mile roost buffer recommended in the National Bald Eagle Management Guidelines restricted 7,606 of the 17,440 acres (44%) of ranges and training areas on APG (Table 4.2.5).

Regardless of which roost buffer scenario is implemented into the eagle management program at APG, the effects of eagle restrictions on range and training activities will substantially increase. The National Eagle Management Plan's ½ mile buffer restricts up to 44% of the range and training areas. The current 500 m roost buffer used on APG will impact 23% of range and training areas. A modification of the 500 m buffer based on seasonal occupancy of a roost would vary that impact from 18% to 23%.

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Table. 4.2.1. Roost size and number of transmittered eagles using communal eagle roosts on Aberdeen Proving Ground.

Roost Name	Area	Acres	Hectares	No. Transmittered Eagles
Abbey Point	Aberdeen	9.3	3.7	8
Back Creek	Spesutie Island	0.7	0.3	12
Bear Point -A	Spesutie Island	18.2	7.3	18
Bear Point -B	Spesutie Island	4.3	1.8	11
Black Point	Aberdeen	17.5	7.1	26
Briery Point	Edgewood	17.9	7.3	20
Carroll Island	Carroll Island	9.3	3.8	9
Cherry Tree Pt-A	Aberdeen	9.5	3.8	24
Cherry Tree Pt-B	Aberdeen	1.7	0.7	15
Cherry Tree Pt-C	Aberdeen	9.4	3.8	16
Cherry Tree Pt-D	Aberdeen	11.3	4.6	20
Cod Creek Rd - A	Aberdeen	9.7	3.9	8
Cod Creek Rd - B	Aberdeen	4.5	1.8	7
Cod Creek Rd - C	Aberdeen	9.4	3.8	4
Coopers Creek	Edgewood	44.9	18.2	32
Doves Cove	Edgewood	2.7	1.1	13
Doves Cove Cliff	Edgewood	30.7	12.4	28
Dynomometer	Aberdeen	14.4	5.8	13
Elm Tree Point	Aberdeen	16.3	6.6	19
Fairview Point -A	Edgewood	10.3	4.2	12
Fairview Point -B	Edgewood	4.5	1.8	12
Fairview Point -C	Edgewood	10.3	4.2	9
Fords Point - A	Edgewood	6.3	2.6	17
Fords Point - B	Edgewood	5.1	2.1	12
Graces Quarters	Graces Quarters	32.4	13.1	16
H-field	Edgewood	11.9	4.8	19
J-field	Edgewood	5.0	2.0	9
Lauderick Creek - A	Edgewood	8.6	3.5	9
Lauderick Creek - B	Edgewood	6.1	2.5	9
Little Romney Creek - A	Aberdeen	13.2	5.4	17
Little Romney Creek - B	Aberdeen	8.5	3.4	12
Locust Point - A	Aberdeen	13.5	5.5	22
Locust Point - B	Aberdeen	28.1	11.4	26
Locust Point - C	Aberdeen	16.7	6.8	13
Mosquito Creek - A	Aberdeen	37.7	15.3	29
Mosquito Creek - B	Aberdeen	10.9	4.4	15
Palmer House	Aberdeen	8.1	3.3	12
Pooles Island North	Pooles Island	34.3	13.9	20
Pooles Island Peach Orchard	Pooles Island	11.6	4.7	11

Roost Name	Area	Acres	Hectares	No. Transmittered Eagles
Pooles Island Pothole	Pooles Island	10.9	4.4	12
Pooles Island South	Pooles Island	7.8	3.1	13
Poverty Island	Aberdeen	13.9	5.6	14
Range 7a -A	Spesutie Island	7.1	2.9	7
Range 7a -B	Spesutie Island	4.1	1.7	5
Range 7a -C	Spesutie Island	2.0	0.8	10
Range 8	Spesutie Island	10.8	4.4	15
Romney Creek - A	Aberdeen	12.2	4.9	27
Romney Creek - B	Aberdeen	5.2	2.1	12
Romney Creek - C	Aberdeen	17.5	7.1	39
Romney Creek - Upper	Aberdeen	26.3	10.6	18
Sandy Point	Spesutie Island	18.8	7.6	15
Sod Run - A	Aberdeen	31.3	12.6	39
Sod Run - B	Aberdeen	39.5	16.0	44
Swan Creek -A	Aberdeen	8.9	3.6	14
Swan Creek -B	Aberdeen	4.2	1.7	11
Towner Cove	Aberdeen	13.4	5.4	8
Water Treatment Plant	Aberdeen	4.7	1.9	7
Wilson Point	Edgewood	8.4	3.4	10
Woodrest Creek	Aberdeen	42.8	17.3	33

Table 4.2.2. Seasonal occupancy of eagle communal roosts on APG.

	Quarter			
Roost Name	1	2	3	4
Abbey Point	x		x	
Back Creek			x	
Bear Point	x	x	x	x
Black Point	x	x	x	x
Briery Point	x	x	x	
Carroll Island	x	x	x	
Cherry Tree Point		x	x	
Cod Creek Road	x	x	x	x
Coopers Creek	x	x	x	x
Doves Cove		x	x	x
Doves Cove Cliff	x	x	x	x
Dynomometer	x	x	x	x
Elm Tree Point	x	x	x	x
Fairview Point	x	x	x	x
Fords Point	x		x	x
Graces Quarters	x	x	x	x
H-field	x	x	x	x
J-field		x	x	x
Lauderick Creek	x	x	x	x
Little Romney Creek	x	x	x	x
Locust Point	x	x	x	x
Mosquito Creek	x	x	x	x
Palmer House		x	x	x
Pooles Island Peach Orchard			x	x
Pooles Island North	x	x	x	x
Pooles Island Pothole	x	x	x	x
Pooles Island South	x	x	x	
Poverty Island	x	x	x	x
Range 7a		x	x	
Range 8		x	x	
Romney Creek	x	x	x	x
Romney Creek - Sod Run	x	x	x	x
Romney Creek - upper	x	x	x	
Sandy Point	x	x	x	
Sod Run	x	x	x	x
Swan Creek	x	x	x	x
Towner Cove (at nest)	x	x	x	x
Water Treatment Plant		x	x	
Wilson Point		x	x	
Woodrest Creek	x	x	x	x

Table 4.2.3. Size of ranges and training areas on APG affected by 500 m roost buffers.

Range or Training Area	Acres	Hectares
9600 YD impact Area	86.5	35.0
Abbey Point Impact Area	28.8	11.6
Abbey Point Impact Buffer	721.0	291.8
C-field	70.3	28.5
D-field	56.0	22.7
H-field	110.8	44.9
Hi Velocity Range	57.9	23.4
I-field	53.7	21.7
J-field	306.4	124.0
Lauderick Creek field	63.7	25.8
L-field	22.8	9.2
Main Front Buffer Area	1,628.7	659.1
M-field	21.7	8.8
Munson Test Area	0.6	0.2
NBF Impact Area	123.5	50.0
N-field	18.7	7.6
Old Bombing Field	1.0	0.4
Perryman Test Area	123.7	50.1
Poverty Island	8.1	3.3
Romney Creek (Below	262.9	106.4
Romney Creek Ranges	9.8	3.9
Spesutie Fuze Range	14.9	6.0
Spesutie Narrows Waterway	70.2	28.4
Spesutie Range a	3.0	1.2
Spesutie Range b	21.6	8.7
Spesutie Range c	20.8	8.4
Spesutie Range d	28.3	11.5
Spesutie Range e	0.5	0.2
Spesutie Range f	13.7	5.5
Spesutie Range i	32.2	13.0
Spesutie Range j	5.8	2.3
Spesutie Range k	6.8	2.8
Spesutie Range m	19.1	7.7
Unknown Range	2.4	1.0
Unknown Romney Range	18.2	7.4
Unknown Training Area a	10.4	4.2
Vibration Facility	18.6	7.5
Grand Total	**4,063**	**1,644**

Table 4.2.4. Acres of range and training areas affected by eagle roost buffers during the calendar year.

	Quarter			
Range or Training Area	**1**	**2**	**3**	**4**
9600 YD impact Area	86.5	86.5	86.5	86.5
Abbey Point Impact Area	28.8	-----	28.8	-----
Abbey Point Impact Buffer	721.0	474.1	721.0	474.1
C-field	-----	70.3	70.3	0.8
D-field	56.0	56.0	56.0	8.4
H-field	110.8	110.8	110.8	110.8
Hi Velocity Range	57.9	57.9	57.9	57.9
I-field	53.7	20.7	53.7	53.7
J-field	206.8	210.3	306.4	306.4
Lauderick Creek field	63.7	63.7	63.7	63.7
L-field	20.9	22.8	22.8	22.8
Main Front Buffer Area	1,297.4	1,628.7	1,628.7	1,297.4
M-field	21.7	21.7	21.7	21.7
Munson Test Area	0.6	0.6	0.6	0.6
NBF Impact Area	123.5	123.5	123.5	123.5
N-field	18.7	18.7	18.7	18.7
Old Bombing Field	1.0	1.0	1.0	1.0
Perryman Test Area	-----	123.7	123.7	123.7
Poverty Island	8.1	8.1	8.1	8.1
Romney Creek (Below	262.9	262.9	262.9	262.9
Romney Creek Ranges	9.8	9.8	9.8	3.5
Spesutie Fuze Range	14.9	14.9	14.9	14.9
Spesutie Narrows Waterway	-----	70.1	70.2	-----
Spesutie Range a	-----	3.0	3.0	-----
Spesutie Range b	-----	21.6	21.6	-----
Spesutie Range c	20.8	20.8	20.8	-----
Spesutie Range d	28.3	28.3	28.3	-----
Spesutie Range e	-----	0.5	0.5	-----
Spesutie Range f	0.0	13.7	13.7	-----
Spesutie Range i	-----	32.2	32.2	-----
Spesutie Range j	4.1	5.8	5.8	-----
Spesutie Range k	-----	6.8	6.8	-----
Spesutie Range m	-----	10.5	19.1	-----
Unknown Range	2.4	2.4	2.4	2.4
Unknown Romney Range	18.2	18.2	18.2	-----
Unknown Training Area a	10.4	10.4	10.4	-----
Vibration Facility	18.6	18.6	18.6	18.6
Grand Total	**3,267**	**3,650**	**4,063**	**3,082**

Table 4.2.5. Size of ranges and training areas on APG affected by ½ mile roost buffers.

Range or Training Area	Acres	Hectares
9600 YD impact Area	157.3	63.6
Abbey Point Impact Area	68.1	27.6
Abbey Point Impact Buffer	1,122.2	454.1
Ballistic Range	0.4	0.2
Briar Point Pond	0.3	0.1
C-field	95.2	38.5
D-field	87.1	35.3
Fords Farm	5.8	2.4
Graces Quarters Tower	24.8	10.0
H-field	278.3	112.6
Hi Velocity Range	60.7	24.6
I-field	174.5	70.6
J-field	414.9	167.9
Lauderick Creek field	95.5	38.7
L-field	25.1	10.2
Main Front Buffer Area	3,214.1	1,300.7
M-field	91.5	37.0
Michaelsville Firing Position	2.0	0.8
Munson Test Area	46.3	18.7
NBF Impact Area	148.4	60.1
N-field	22.5	9.1
Old Bombing Field	78.7	31.8
Perryman Test Area	241.1	97.6
Plate Range	26.1	10.6
Poverty Island	74.8	30.3
Romney Creek (Below Monocacy)	392.9	159.0
Romney Creek Ranges	17.4	7.0
Spesutie Fuze Range	14.9	6.0
Spesutie Narrows Waterway	148.9	60.2
Spesutie Range a	18.0	7.3
Spesutie Range b	57.5	23.3
Spesutie Range c	20.8	8.4
Spesutie Range d	32.7	13.2
Spesutie Range e	4.4	1.8
Spesutie Range f	39.5	16.0
Spesutie Range i	54.1	21.9
Spesutie Range j	5.8	2.3
Spesutie Range k	6.8	2.8
Spesutie Range l	37.3	15.1
Spesutie Range m	59.5	24.1

Range or Training Area	Acres	Hectares
Undek Pond	15.8	6.4
Unknown Building	14.8	6.0
Unknown Range	13.7	5.5
Unknown Romney Range	19.2	7.8
Unknown Training Area a	57.8	23.4
Vibration Facility	18.6	7.5
Wirsing Training Area	1.1	0.5
Grand Total	**7,607**	**3,079**

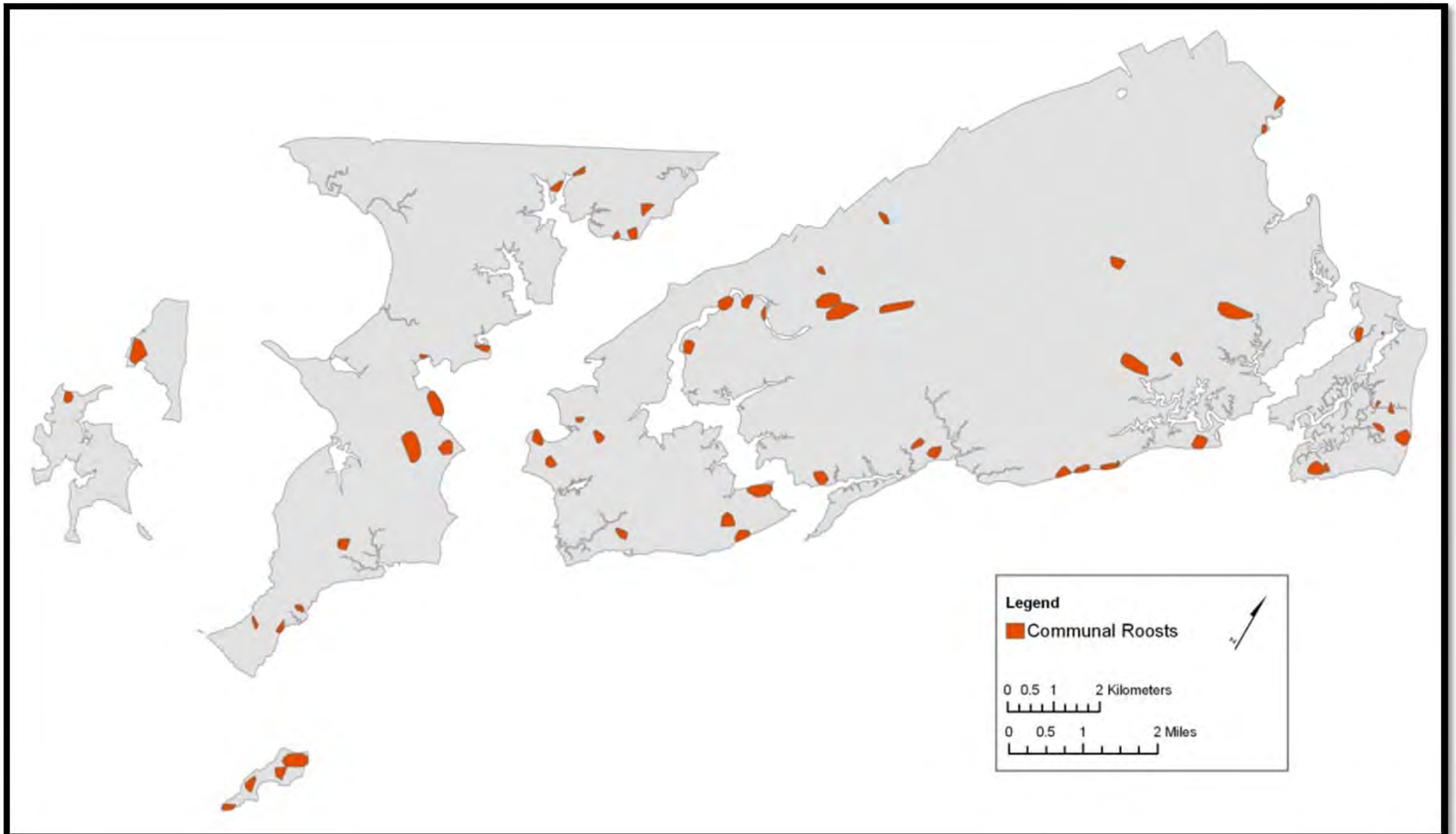

Figure 4.2.4. Communal eagle roosts on Aberdeen Proving Ground delineated using satellite telemetry.

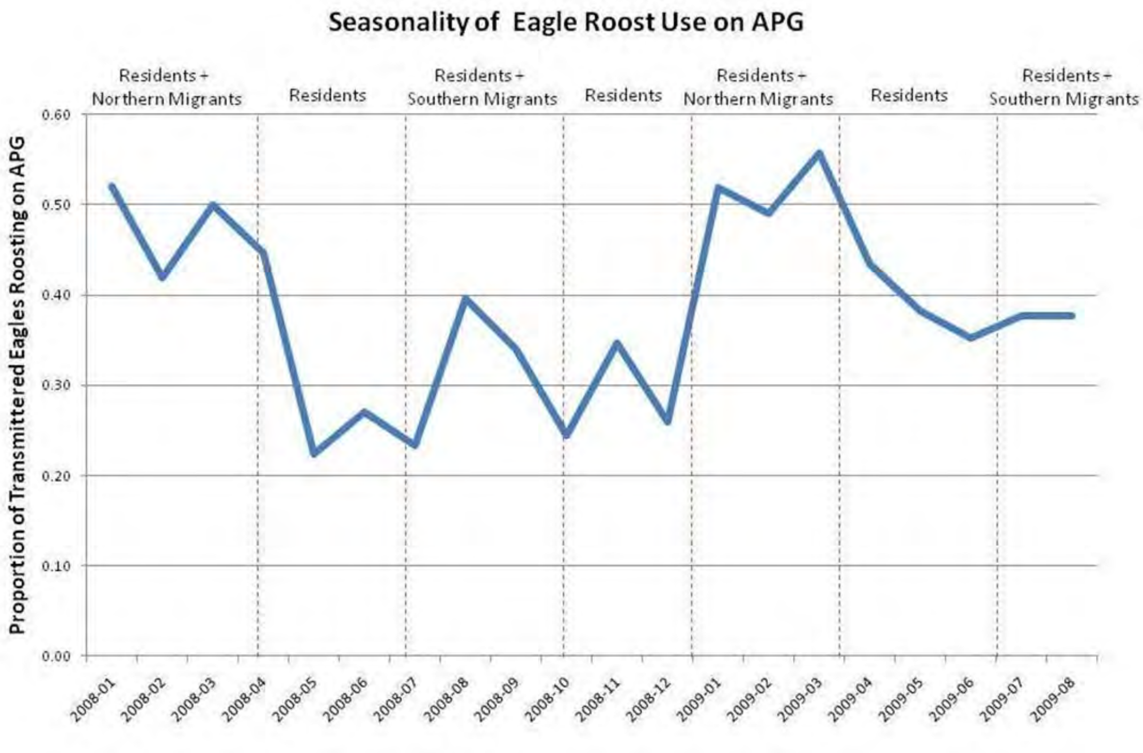

Figure 4.2.5. Use of eagle roosts on APG fluctuated with presence of migrant eagle populations.

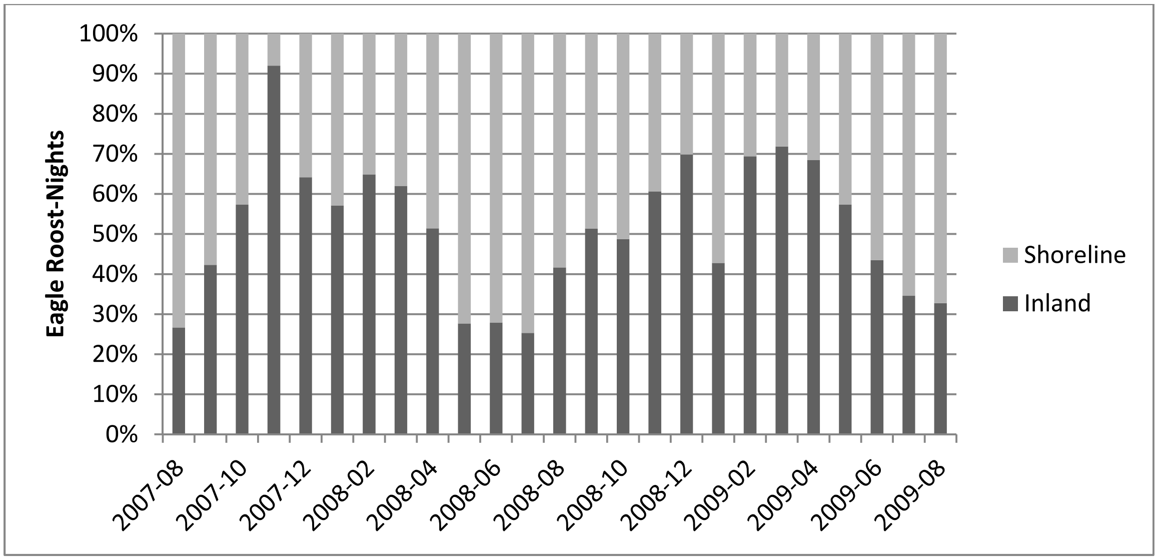

Figure 4.2.6. Seasonal distribution of communally roosting eagles at shoreline and inland roosts on Aberdeen Proving Ground.

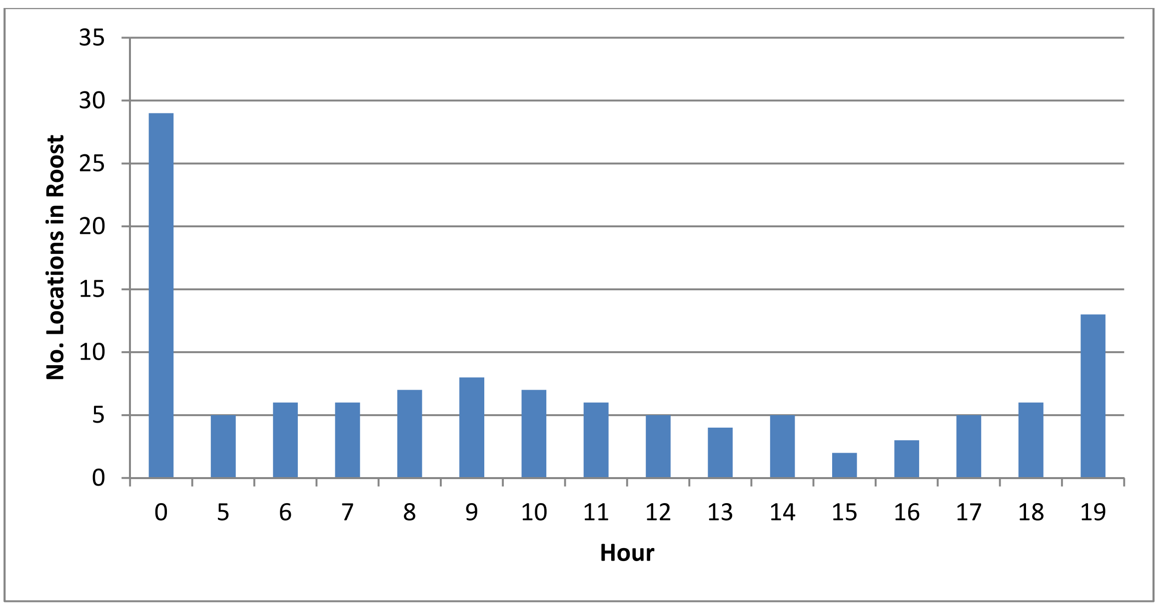

Figure 4.2.7. Hourly roost usage at Mosquito Creek during June 2009. Eagles primarily entered the roost at dusk and exited at dawn, however eagles continued to use the roost throughout the day.

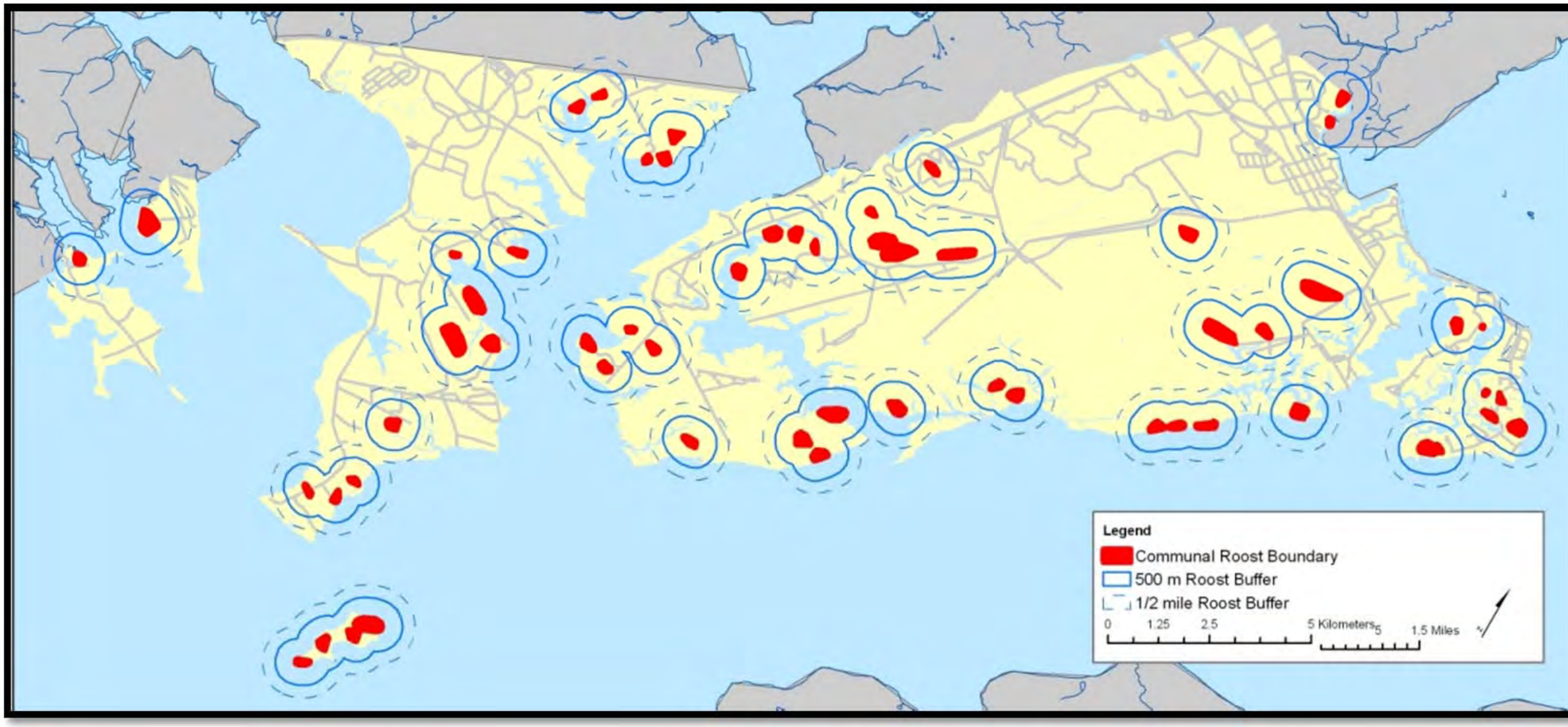

Figure 4.2.8. Two buffer scenarios surrounding communal eagle roosts on Aberdeen Proving Ground.

4.3 Bald Eagle Activity Centers and Electrical Infrastructure

4.3.1 Chapter Background

Overhead electrical lines represent a hazard to birds on a global scale and have been the subject of several international symposia focused on mitigation techniques. Birds are killed by perching on poles and completing an electrical circuit by touching two electrical elements or flying into wires and succumbing to trauma or electrocution when their wings come in contact with two wires simultaneously. Two general strategies have been pursued to mitigate the impact of electrical lines on birds including 1) making poles and lines “safer” for birds and 2) reducing the overlap between birds and the hazard by placing lines away from the primary activity centers of vulnerable species. Although the second strategy is most effective it requires a considerable amount of information on activity centers and movement corridors. APG environmental staff began documenting bald eagle mortalities associated with the electrical infrastructure in the 1980s and the number of incidences increased along with the rise in eagle use of the installation. An adaptive management approach that has included perch excluders, flight diverters, and more recently, line burial has been used to reduce mortalities.

Work Presented

We used more than 320,000 GPS locations along with Brownian bridge movement modeling to delineate and map bald eagle activity centers within the upper Chesapeake Bay and APG study areas. The electrical infrastructure and documented eagle mortalities were overlaid on the map of eagle utilization to examine the intersection between eagle use and line hazards and to assess the correspondence between mortalities and projected risks. Results of this analysis are detailed in a manuscript included here that will be submitted for publication with the following citation –

Watts, B. D., E. K. Mojica, and B. J. Paxton. 2012. Use of Brownian bridges to assess potential interactions between bald eagles and electrical hazards in the upper Chesapeake Bay.

Mortality rates were calculated for all areas on APG that were classified as high-use by bald eagles as a measure to prioritize for mitigation. Detailed descriptions of all sites with management recommendations are provided.

4.3.2 Using Brownian bridges to assess potential interactions between bald eagles and electrical hazards within the upper Chesapeake Bay

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Abstract: One of the most effective strategies to minimize mortalities of large raptors due to collisions with hazards is to site hazards away from major activity centers. Delineation of such activity centers on the landscape has been a significant impediment to progress in proactive infrastructure planning. We used Brownian bridge movement modeling to develop a population-wide, utilization probability surface for bald eagles (*Haliaeetus leucocephalus*) within the upper Chesapeake Bay. We used locations (n = 320,304) for individuals (n = 63) tracked with GPS satellite transmitters between 2007 and 2011 in the analysis. We overlaid the electrical network on the probability surface within Aberdeen Proving Ground, a 350-km^2 military installation in order to identify intersections between power lines and eagle activity centers. We overlaid line-attributed mortalities (n = 67) documented on the installation to assess the relationship between mortality rates and utilization probabilities. Areas of high bald eagle use were relatively rare on the landscape with only 0.1% and 5% of the area accounting for 10% and 30% of estimated activity respectively. Most electric lines were distributed away from eagle activity centers with only 0.3% of lines located within areas with the highest estimated use. Eagle mortalities were highly skewed to lines that overlapped with eagle activity centers. Eagle mortality rates were 42 times higher along lines associated with the highest eagle use compared to lines associated with the lowest use suggesting that estimated utilization may be an effective proxy for mortality risk associated with electric line hazards. The majority (71.9%) of high-use bald eagle areas delineated within the study area have no existing electric lines. Utilization probabilities may be a potential tool for site-specific infrastructure planning.

Key Words: Bald Eagle, *Haliaeetus leucocephalus*, Chesapeake Bay, Brownian bridge movement modeling, power lines, mortality, utilization.

As the infrastructure associated with modern society expands across the globe, man-made hazards represent a growing source of mortality for many bird species (Banks 1979, Erickson et al. 2005). Fishing gear (Brothers et al. 1999, Belda and Sanchez 2001, Davoren 2007), roadways (Erritzoe et al. 2003, Kociolek et al. 2011), buildings (Erickson et al. 2005, Klem 2009), oil spills (Hunt 1987, Carter 2003), wind turbines (Percival 2001, Drewitt and Langston 2006) and many other structures represent passive hazards within the landscape that contribute to annual mortality rates. For a growing number of species, mortality attributed to man-made hazards has been shown to be unsustainable and is contributing to documented declines (e.g. Hunt et al. 1999, Lewison and Crowder 2003). How to mitigate the demographic impacts of such hazards has become an important theme in conservation biology (e.g. Niel and Lebreton 2004, Bright et al. 2008, Dillingham and Fletcher 2008).

Overhead electrical lines represent a hazard to flying birds (Janss and Ferrer 1999, Manville 2005) and have been the topic of numerous symposia and management plans focused on understanding and mitigating their impacts (e.g. Avian Power Line Interaction Committee [APLIC] 1994, 1996, 2006). The specific causes of mortality are well known. Birds perched on poles or lines may be electrocuted when they touch two electrical elements and complete a circuit. Flying birds may be killed by striking wires and succumbing to trauma or electrocution if their wings come in contact with two wires simultaneously and complete an electrical circuit. Vulnerability to line mortality varies dramatically between species (Bevanger 1998, Janss 2000) and impacts have been documented to reach the population level in some species (e.g. Crivelli et al. 1988, Bevanger 1995). Several factors have been demonstrated to influence the risk of line collision including line and pole configuration, weather, visibility, wingspan, and bird experience (APLIC 2006, Lehman et al. 2007).

Two general strategies have been pursued to mitigate the impact of electrical lines on birds including 1) making poles and lines “safer” for birds and 2) reducing the overlap between birds and the hazard by placing lines away from the primary activity centers of vulnerable species. “Avian-safe” standards (APLIC 2006) have been developed for line engineering that includes specifications for wire spacing to reduce mortality for species with long wingspans and guidelines for grounding and insulating transformers to prevent pole electrocutions. Strategies to reduce line collisions include making the lines more visible to flying birds with marker balls, bird diverters, and paint or elevating the flight line of birds above lines by maintaining tall vegetation. Use of these techniques for both installation of new lines or retrofitting of existing lines has been successful in reducing mortality in some locations. Although arguably the preferred strategy, much less progress has been made in reducing the interaction between birds and lines by avoiding avian activity centers when installing new lines or the removal of existing lines within such locations. Identification and delineation of major activity centers for vulnerable species has been one of the major impediments to progress.

Due to their large size, style of flight, and perching behavior, bald eagles (*Haliaeetus leucocephalus*) are particularly vulnerable to electrical networks throughout their range (e.g. Harmata et al. 1999, Harness and Wilson 2001). Trauma and electrocution are listed as the first and third causes of mortality within the United States representing 23 and 12% of documented deaths respectively (n > 4,300) between the early 1960s and mid-1990s (Franson et al. 1995). Acknowledging this source of mortality, the National Bald Eagle Management Guidelines (United States Fish and Wildlife Service [USFWS] 2007) recommend siting new electric lines away from areas of high eagle activity and burying existing lines within such locations.

Our objectives here were to delineate areas of high bald eagle activity within the upper Chesapeake Bay, to examine the intersection of electric lines with activity centers for a portion of the upper Bay, and to evaluate the correspondence between these intersections and documented eagle mortalities. The utilization surface created has relevance for the placement of future electric lines and where mitigation of existing lines would be most beneficial.

4.3.2.1 Study Area

Our study areas included the northern part of the Chesapeake Bay from the Bay Bridge at Annapolis, MD to just above the Conowingo Dam on the Susquehanna River (movement analysis) and Aberdeen Proving Ground (hazard and mortality analysis) (Figure 4.3.1). The broader study area (5,415 km^2) includes the Upper Chesapeake Bay Bald Eagle Concentration Area (Watts et al. 2007). The western portion contains extensive residential development including the urban areas of Baltimore and Annapolis. The eastern portion of the study area is primarily rural, with forest lands interspersed with agriculture. The northern part of the study area contains the Susquehanna Flats, a historically important site for wintering waterfowl (Lynch 2001). This area, along with the nearby Conowingo Dam, supports a significant number of eagles during the fall and winter months (Steenhof et al. 2008). Positioned along the western shoreline is Aberdeen Proving Ground (APG), is a 350-km^2 United States Department of Defense military installation that is primarily forested with extensive shorelines. The installation contains a network of three-phase, above-ground electrical distribution lines (<40 kv). Poles are an early design that is not “avian safe” (APLIC 2006) and the wingspan of eagles is sufficient to touch multiple conductors simultaneously (General Physics 2004). APG supports one of the largest concentrations of bald eagles on the East Coast of North America (Watts et al. 2007). Growing use of the installation by eagles has been coupled with an increase in documented mortalities that exceeded 15 birds/yr by 2005, leading to formal consultation with the United States Fish and Wildlife Service under Section 7 of the Endangered Species Act, the production of a formal Biological Assessment (General Physics 2004) and a subsequent Biological Opinion

(USFWS 2006). Recommendations including the removal of overhead lines within high-use areas have been integrated into the current bald eagle management plan (Paul 2009).

4.3.2.2 Methods

Transmitters

We captured resident and migrant Bald Eagles (*n* = 63) on APG, banded, and fitted them with satellite transmitters between August 2007 and May 2009. Free-flying eagles were trapped on three sandy beaches (*n* = 10) using padded leg-hold traps (King et al. 1998), in three open fields (*n* = 26) using rocket nets baited with deer carcasses (Grubb 1988) and on open waters (*n* = 10) using floating fish traps (Frenzel and Anthony 1982, Cain and Hodges 1989, Jackman et al. 1993). We climbed nest trees throughout APG to access broods (8-10 wk of age) and deployed a transmitter on one nestling per brood (*n* = 17). We conducted floating fish and leg-hold trapping during the summer months to target resident and southern migrants. We conducted rocket-net trapping in the winter months to target resident and northern migrants. Eagle capture and handling methods were in compliance with IACUC protocols at the College of William and Mary (IACUC-20051121-3).

We used solar-powered, 70-g, GPS-PTT satellite transmitters (Microwave Telemetry, Inc. Columbia, Maryland, U.S.A.) to track eagle movements. Transmitters were attached using a backpack-style harness constructed of 0.64-cm Teflon® ribbon (Bally Ribbon Mills, Bally, Pennsylvania, U.S.A.). Transmitters were programmed to collect GPS locations (±18 m) every daylight hour and one additional location at midnight. GPS locations were processed by Argos satellites (CLS America, Largo, Maryland, U.S.A.) and stored online by Satellite Tracking and Analysis Tool (Coyne and Godley 2005).

Movement Modeling

We used Brownian bridge movement models (BBMM) (Horne et al. 2007) to develop utilization distributions (UD; Worton 1989) for bald eagles within the study area. UD allows for the mapping of the intensity of use within a defined area. Conventional estimation of UD requires only a sample of independent locations. BBMM improves on traditional UD approaches by incorporating the temporal structure of tracking data allowing for the explicit modeling of movement paths. This approach allows for the identification not only of areas with high activity but also the movement corridors that connect them. BBMM incorporates fixed positions (x and y), time stamps (t), telemetry error (δ^2), and the variance of Brownian motion (δ^2_m) to estimate spatial patterns of movement probability. The model approximates the movement path between successive locations by applying a conditional random walk. Thus, deviation from a straight-line path between locations depends on the magnitude of Brownian motion variance (BMV). Low BMV values produce pathways where the probability of deviating from a straight-line path is low. BBMM estimates BMV using cross-validation and maximum likelihood techniques.

We produced BBMM-derived UD surfaces across a grid system of 1-ha cells (*n* = 541,476) overlaid on the study area. In order to reduce “edge effects” for movement probabilities we created an 80-km buffer around the study area and included positions within the buffer in modeling. Independent surfaces were produced for all non-breeding eagles with transmitters (*n* = 59; three birds were determined to hold breeding territories and one nestling died at fledging and were excluded). Data from birds marked as nestlings were excluded until the birds dispersed from the natal area. We combined UD surface maps produced for individual birds to create a population-wide UD. BBMM produces a relative probability surface that reflects spatial variation in estimated utilization. Because sample sizes varied between individuals, surfaces were weighted according to the number of locations per individual, combined, and standardized.

We evaluated the intersection between the electrical infrastructure and eagle utilization within the APG study area only due to limitations on the availability of digital line coverage throughout the remaining landscape. We assumed that the likelihood that eagles cross a segment of electrical line reflects the utilization probability within that location (Lewis et al. 2011) as represented in the population-wide UD. We evaluated spatial variation in crossing probability by superimposing the network of electrical lines on the UD. This approach allowed for the stratification of the electrical network according to the estimated level of eagle activity.

Mortality Information

We examined the spatial correspondence between eagle activity, electrical infrastructure, and eagle mortality using records (*n* = 113) of eagle mortality maintained on APG (1985-2011). As part of the installation's bald eagle management plan (Pottie 2001, Paul 2009), the location and circumstances of eagle mortalities are investigated and documented. Age class of recovered birds was recorded as subadult or adult according to plumage characteristics (McCollough 1989). Dead or injured eagles are typically discovered during routine maintenance activities. No systematic surveys for dead eagles have been conducted. We included mortality events (*n* = 67) within this study if the cause of death was identified as electrocution through necropsy or examination or if there was strong circumstantial evidence that the death was related to the electrical infrastructure (e.g. carcass found under lines, burn marks on carcass). We excluded injuries or mortalities unrelated to electrical lines (e.g. infections, conspecific fights). We assumed that carcass detection rates around electric lines were equal across the study area. We feel that this is a reasonable assumption since all lines were subject to regular maintenance and the majority of electrical lines parallel well-traveled roads with mowed grass beneath the lines. Mortality events were drawn from a long time span compared to telemetry data. Although anecdotal observations and previous tracking studies (Buehler et al. 1991) suggest that eagles have used the APG landscape in a similar way over time we do not have comparable datasets to test this assumption. For this reason, possible correspondence between eagle activity, electrical lines, and mortality should be considered conservative.

Analysis

We used an arbitrary schema to stratify the UD surface for analytical and presentation purposes. The population-wide UD was estimated over a large study area with a relatively high level (1 ha) of spatial resolution resulting in a large number of probability values. To facilitate presentation, we ordinated cell values from highest to lowest and grouped cells within categories that represented 10% of the total eagle utilization such that the first category was comprised of the cells with the highest utilization. This approach allows for an examination of the relationship between the level of utilization and area (i.e. the first category reflects the minimum area to achieve 10% of the total utilization, the second category reflects the minimum area to achieve the next 10% of the total utilization, etc.).

The relationship between eagle utilization and mortality was evaluated using frequency statistics. Line length within each utilization category was used to calculate the expected mortality. Mortality events were stratified according to the lines where they occurred and summed by utilization category to generate an observed distribution. Average, annual mortality rates were calculated by summing the mortality events, dividing by the line lengths by utilization category and dividing by the number of years (1985-2011) carcasses were collected.

4.3.2.3 Results

Tracking birds (*n* = 59) within the study area resulted in 320,304 transmitter locations. Based on the review of positions in the months following transmitter deployment, the cohort was a mixture of Chesapeake Bay residents (42), migrants from the Southeast (4), and migrants from the Northeast (13). Because of the various geographic affiliations, residency time within the study area and associated locational data varied considerably among individuals. Locations per bird ranged from 35 to 13,136 with a mean of 5,166 ± 490.2 (SE).

Although bald eagles are widespread and may be seen virtually anywhere throughout the upper Chesapeake Bay, areas with high levels of activity are relatively rare. This result is illustrated by the relationship between accumulated utilization and area (Figure 4.3.2). For example, less than 0.1% (5.4 km^2), 1% (37.7 km^2), 5% (254.8 km^2) and 15% (823.8 km^2) of the study area supported 10%, 30%, 70% and 90% of the estimated eagle activity respectively. The remaining 10% of the eagle activity was distributed widely across 85% (4,591.2 km^2) of the area. Areas with high estimated eagle utilization included communal roosts, major foraging areas, and movement corridors between these activity centers. While a portion of these activity centers have been well-documented and monitored over a long period of time, others were completely unknown to the management community reflecting the anecdotal nature of previously known use. With few exceptions (e.g. area of high use near Conowingo Dam on Susquehanna River), major foraging areas were located on prominent points of land along the primary shoreline of the Chesapeake Bay and major tributaries that front expanses of open water (Figure 4.3.3). Although not discernible within the current treatment, major communal roosts tend to be further inland in more protected positions. Movement corridors connect activity centers and are often positioned along tributaries, along primary shorelines, or between inland roosts and major foraging areas.

APG includes a network of 839 km of above-ground lines (Figure 4.3.4). Lines were not evenly distributed throughout the installation with respect to eagle activity areas. The majority of lines were located within the residential or business areas of the installation, locations that eagles appear to avoid. Only 0.3% of all lines were located within areas with the highest estimated eagle use. Forty percent of the eagle activity overlapped with only 10% of the lines while more than 65% of the lines were located in the lowest eagle use areas.

Eagle mortalities were distributed widely throughout APG (Figure 4.3.4). Of the birds (*n* = 62) where age class was recorded, 20 (32%) were adult-plumaged birds and 42 (68%) were subadults. Mortalities were highly skewed to lines that were in areas with high eagle use compared to areas with low use (Figure 4.3.5). Average mortality rates for lines associated with the highest eagle use areas (1.1 deaths/100 km/year) were 42 times higher than those for lines associated with the lowest use areas (0.026 deaths/100 km/year). Of the 24 discreet areas on APG delineated as high-use (polygons representing 40% of utilization) 8 had no electric lines. Mortality rates within the remaining sites varied from 0 to 13.5 deaths/100 km/year. Examination of high-use polygons within the upper Chesapeake Bay study area outside of APG revealed that 23 (71.9%) of 32 areas had no electric lines.

4.3.2.4 Discussion

Overlap between centers of bald eagle activity and electric lines resulted in elevated mortality rates. This finding is consistent with studies of other species that have documented high mortality where electric lines intersect with movement corridors (e.g. Thompson 1978, Faanes 1987, Podolsky et al. 1998, Schomburg 2003). From a management perspective, this finding supports National Bald Eagle Management Guidelines (USFWS 2007) that recommend siting new lines away from or burying lines near activity centers. Proactively siting hazards away from activity centers for species of conservation concern may be the most effective option for reducing impacts. However, this approach requires an understanding of animal movements that is typically beyond what is available for most species. Results presented here support the use of utilization probabilities for both prioritizing existing hazards for mitigation and when assessing potential mortality risk for planning purposes. The majority of high-use activity centers delineated within the upper Chesapeake Bay study area have no existing overhead lines. These areas should be avoided in infrastructure planning when possible.

The relationship between mortality rates and utilization probabilities presumably reflects an increase in mortality risk with the number of line crossings. However, other factors contribute to variation in the risk of line strikes including the altitude of flight paths relative to lines. Altitude of flights may vary systematically across the landscape depending on topography, vegetation, location of foraging areas, etc. Proximity to shoreline foraging areas and the presence of screening vegetation have been shown to contribute to variation in eagle mortality caused by above-ground lines (Mojica et al. 2009). It is possible that such factors contributed to the variation in mortality rates associated with high-use areas on APG. Because no systematic searches for eagle carcasses were performed, it is also possible that the likelihood of carcass discovery was not evenly distributed. Either or both of these factors could contribute to observed variation in mortality rates among sites with both high use and existing lines.

The use of BBMM to develop UD surfaces takes advantage of auto correlated data to delineate activity centers and the corridors that connect them. Activity centers for bald eagles within the upper Chesapeake Bay study area include communal roosts (also used as daytime loafing areas) and major foraging areas. Well-used movement corridors connect communal roosts to foraging areas, communal roosts to communal roosts, and foraging areas to other foraging areas. Prominent flight corridors may be seen connecting activity centers (Figures 4.3.4 and 4.3.5) with UD probabilities reflecting relative use. BBMM models the movement between two fixed positions as a conditional random walk (Horne et al. 2007). The uncertainty of the path that connects the two positions is influenced by the distance and time interval between the locations. Because many more points are located within activity centers rather than along the pathways that connect them, the UD probabilities for movement corridors tend to be lower. However, several mortality events occurred where these movement corridors crossed line hazards (Figure 4). The location of these movement corridors should be considered in mitigation planning.

The Upper Chesapeake Bay Bald Eagle Concentration Area is a relatively small area where three geographically distinct populations of bald eagles converge (Watts et al. 2007). The area supports a complex mixture of age classes from the resident Chesapeake Bay population. In late spring and early summer, eagles migrate north from Florida and other southeastern states to spend the summer months (Broley 1947, Wood *et al*. 1990, Millsap *et al*. 2004). In the late fall, eagles migrate south from New England populations to spend the winter months (McCollough 1989). Because the site supports populations from along the entire Atlantic Coast, land-use decisions made within the area may have far-reaching consequences.

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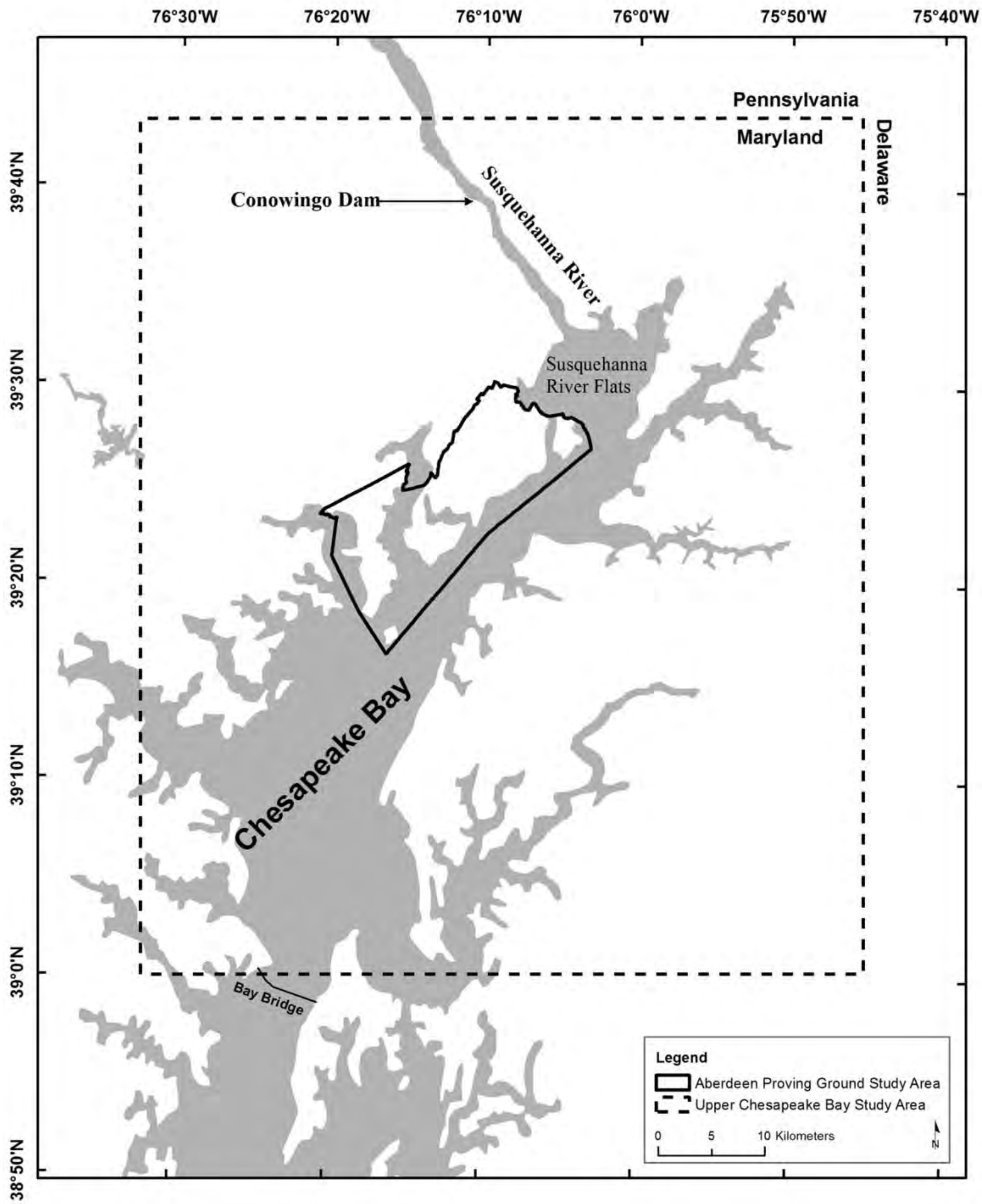

Figure 4.3.1. Map of upper Chesapeake Bay study area and Aberdeen Proving Ground study area (enclosed in dark boundary) within the Chesapeake Bay of Maryland.

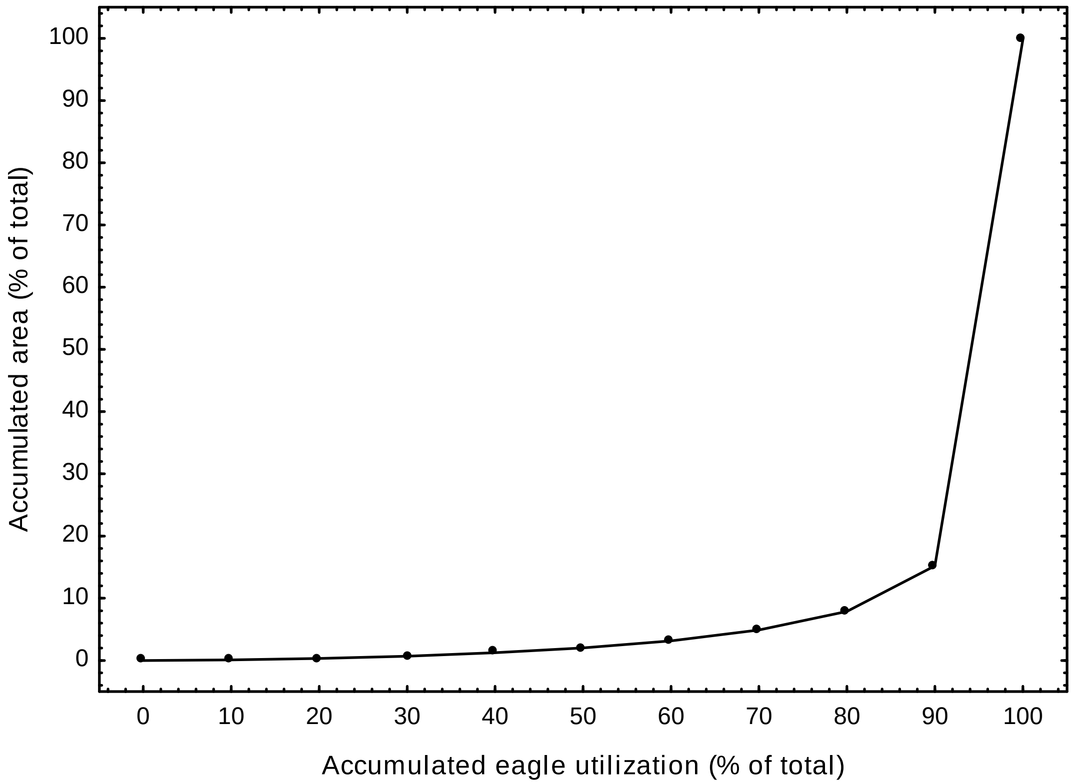

Figure 4.3.2. Relationship between accumulated bald eagle utilization (expressed as a % of total utilization) and accumulated area (expressed as a % of total area). Total area refers to the upper Chesapeake Bay study area with a surface area of 5,415 km^2.

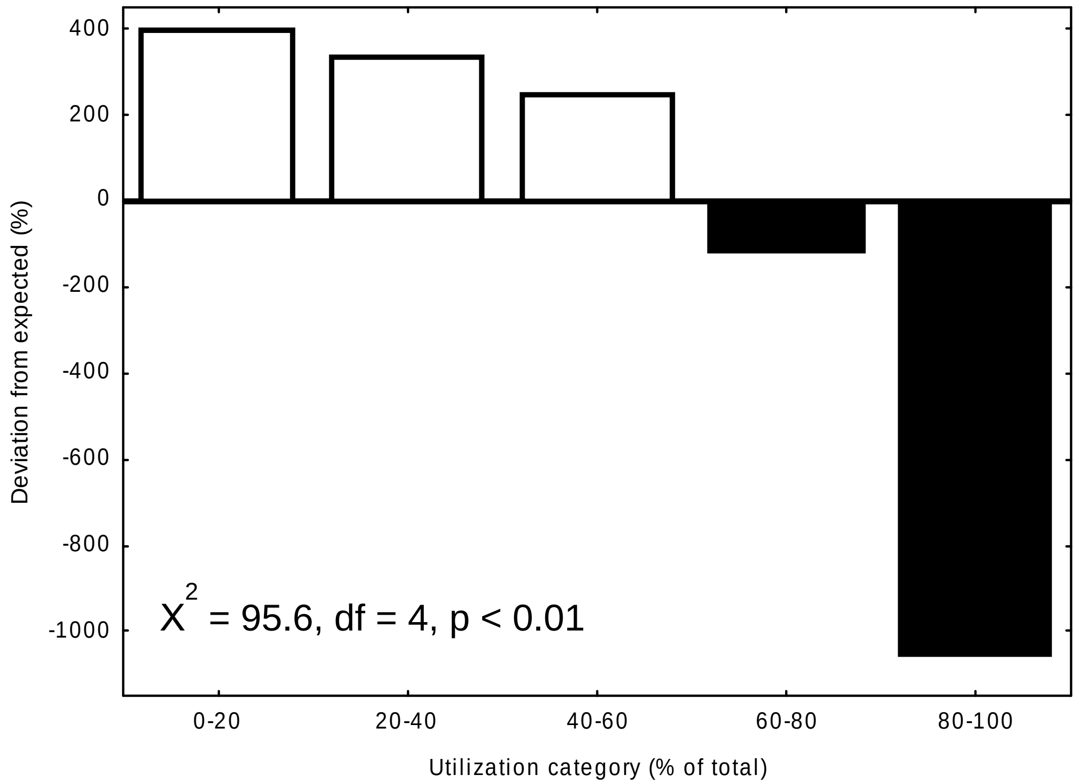

Figure 4.3.3. Deviation from expected mortality by bald eagle utilization category. Expected mortality was calculated based on the length of electric lines within each category assuming that mortalities were randomly distributed among lines. Positive deviation implies that observed mortalities were greater than expected by chance. Negative deviation implies that observed mortalities were lower than expected by change.

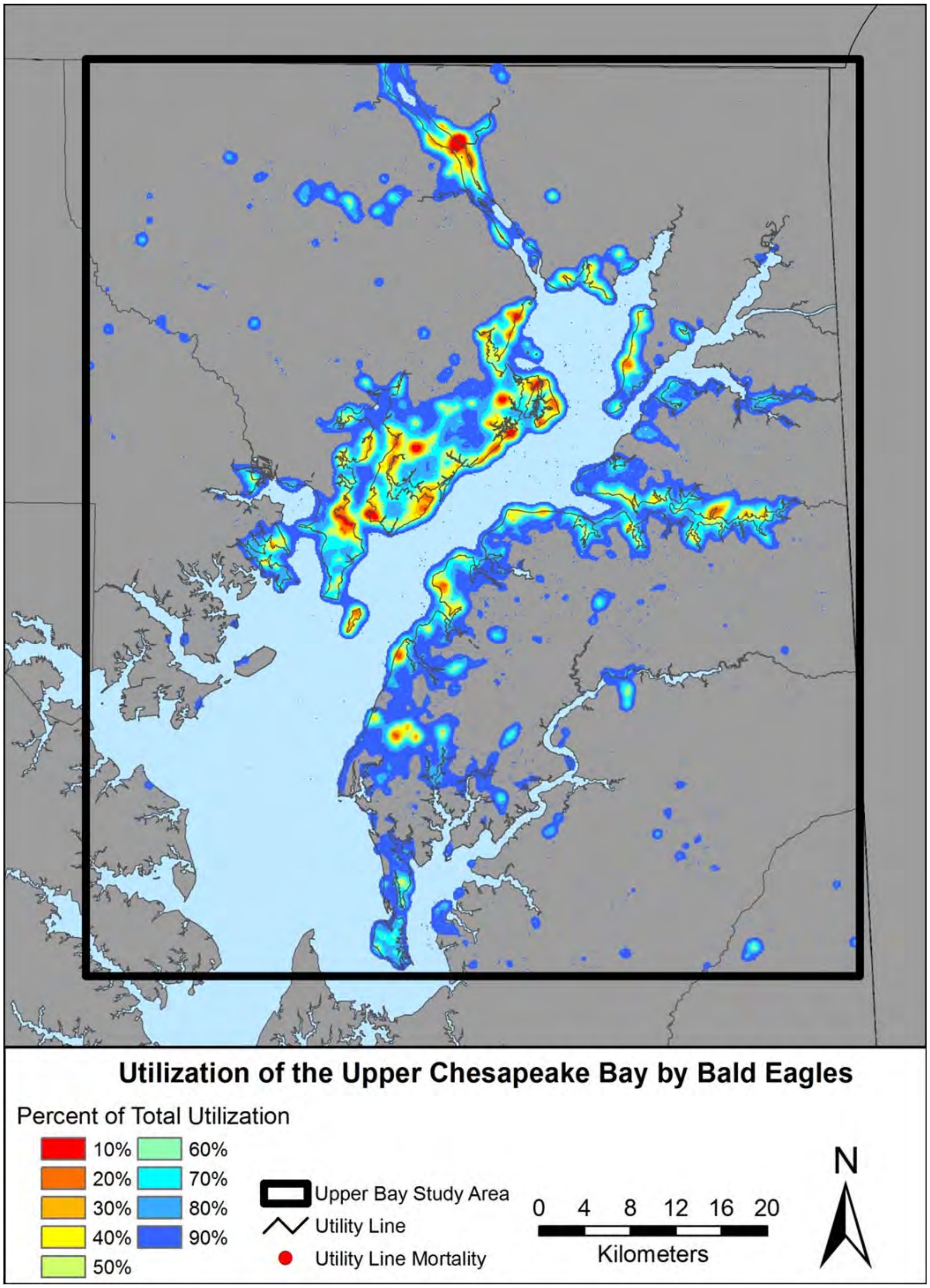

Figure 4.3.4. Results of Brownian bridge movement modeling showing utilization distribution for bald eagles tracked within the upper Chesapeake Bay study area. Warmer colors reflect areas with higher utilization density.

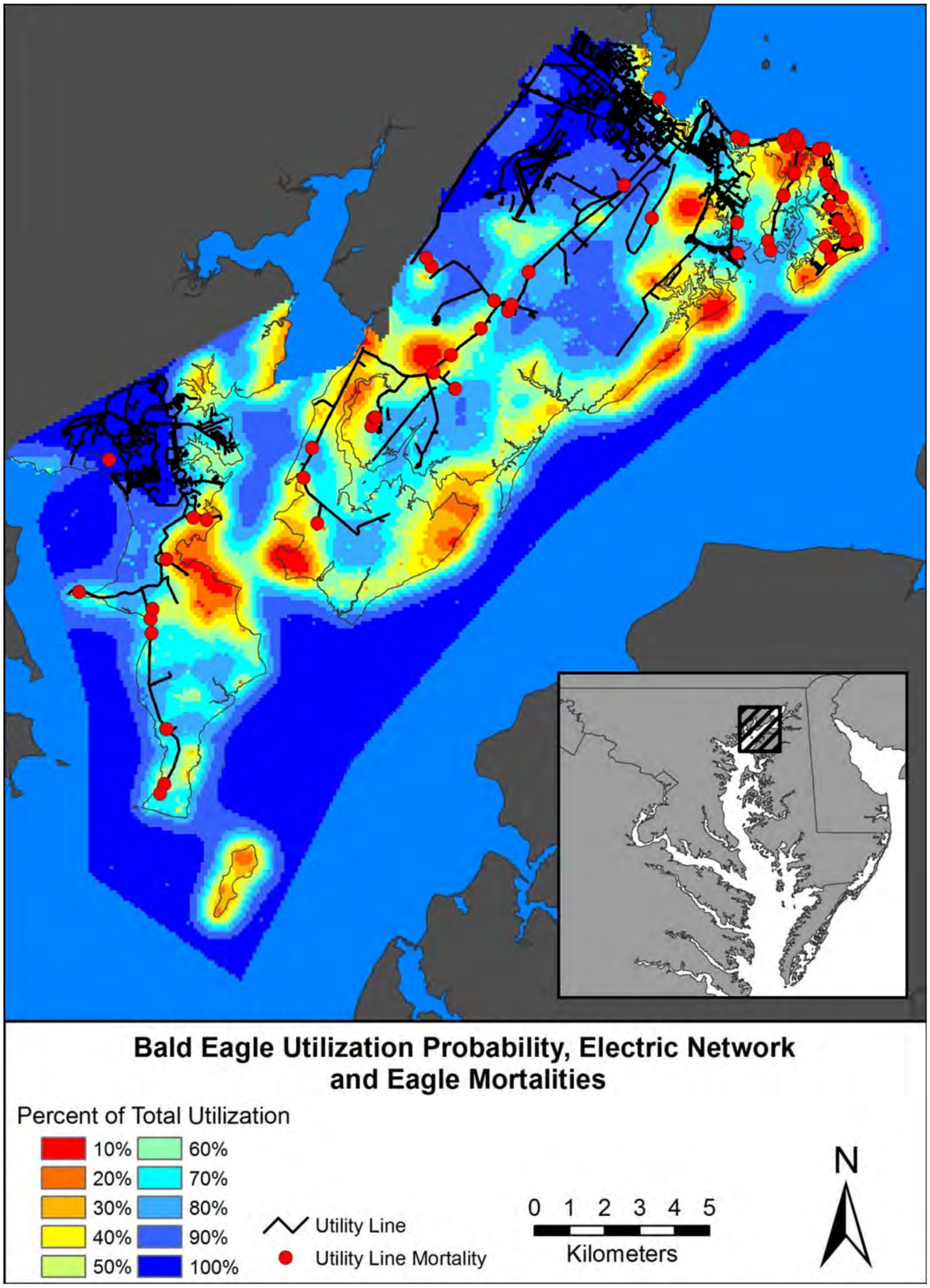

Figure 4.3.5. Bald eagle utilization distribution, electrical network, and documented line mortalities of bald eagles within the Aberdeen Proving Ground study area. Heavy black lines show the electrical network. Lighter lines show the Chesapeake Bay shoreline and tributaries. Red dots show the location of mortality events.

4.3.3 Aberdeen Proving Ground Study Area

4.3.3.1 Background

APG supports one of the largest concentrations of bald eagles on the East Coast of North America. Growing use of the installation by eagles has been coupled with an increase in documented mortalities that exceeded 15 birds/yr by 2005, leading to formal consultation with the United States Fish and Wildlife Service under Section 7 of the Endangered Species Act, the production of a formal Biological Assessment and a subsequent Biological Opinion . Recommendations including the removal of overhead lines within high-use areas have been integrated into the current bald eagle management plan (Paul 2009). Overhead line removal began on Spesutie Island in 2008 as mitigation for the high number eagle mortalities on the north and east shorelines in the early 2000s.

The electrical infrastructure on Aberdeen Proving Ground is composed of three-phase distribution lines (<40 kv) with three phases on a 6' cross arm and one neutral line located 5' below the energized wires. This pole configuration is not classified as ''avian-safe'' and the 6' wing- span of eagles is sufficient to simultaneously touch multiple conductors and lines(General Physics 2004). Since 1985, 67 eagles have been documented injured or dead as a result of electrical line strikes or electrocutions on APG. APG has approximately 839 km of overhead lines on APG. There are 146 km of electrical line along shoreline areas which are important foraging habitat for resident and migrant eagles (Buehler et al. 1991, General Physics 2004).

Our objectives were to delineate areas of high bald eagle activity within APG, , to examine the intersection of electric lines with activity centers for APG, to evaluate the correspondence between these intersections and documented eagle mortalities, and to make management recommendations on mitigation of existing lines and placement of future lines.

We used Brownian bridge movement models to develop utilization distributions (UD; Worton 1989) for bald eagles tagged on APG. We then examined the spatial correspondence between eagle activity, electrical infrastructure, and eagle mortality using records (*n* = 113) of eagle mortality maintained on APG (1985-2011) (Appendix 10). Mortalities related to the electrical infrastructure (n = 67) were overlaid on polygons representing 40% utilization of eagle movements plus a 250 m buffer. These polygons highlight dense use by eagles and an increased risk of line strike or electrocution (Figure 4.3.6).

The highest rate of mortalities per length of electrical line occurred at the mouth of Watson Creek, the road to J-field, and shorelines around C-field and L-field (Table 4.3.1). Future eagle management should prioritize mitigation measures to reduce of mortalities in these areas.

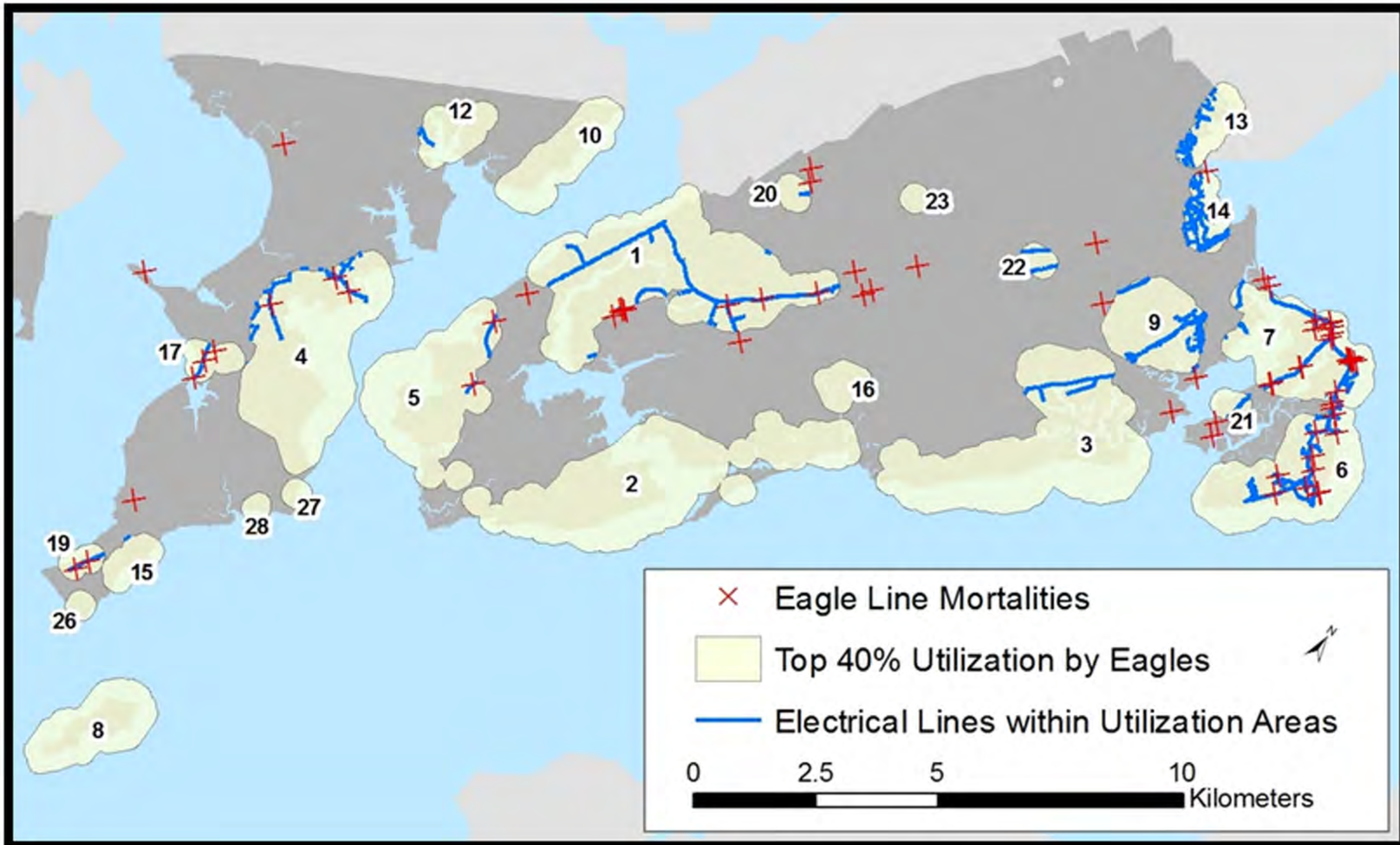

Figure 4.3.6. Spatial correspondence between eagle activity, electrical infrastructure, and eagle mortality on APG.

Table 4.3.1. Rates of electrical line mortalities within 250m of 40% utilization polygons on APG.

Polygon number	Line Length	Mortalities	Mortalities per 100	Mortality rate (100 km per	Polygon size
1	43.4	5	11.5	0.4	1,146
2	0.0	0	0.0	0.0	1,117
3	3.0	0	0.0	0.0	1,060
4	5.7	3	53.1	2.0	852
5	5.0	2	39.9	1.5	640
6	29.6	11	37.2	1.4	560
7	41.0	18	43.9	1.6	508
8	0.0	0	0.0	0.0	320
9	29.0	0	0.0	0.0	316
10	0.0	0	0.0	0.0	288
12	1.0	0	0.0	0.0	162
13	7.9	0	0.0	0.0	132
14	24.0	1	4.2	0.2	119
15	0.1	0	0.0	0.0	95
16	0.0	0	0.0	0.0	89
17	0.8	3	364.3	13.5	82
19	0.8	2	240.5	8.9	51
20	0.9	0	0.0	0.0	45
21	2.8	0	0.0	0.0	44
22	2.4	0	0.0	0.0	43
23	0.0	0	0.0	0.0	31
26	0.0	0	0.0	0.0	31
27	0.0	0	0.0	0.0	31
28	0.0	0	0.0	0.0	30

4.3.3.2 Utilization Area Descriptions and Management Recommendations

Polygon 1

This area is the largest utilization polygon and centers around Romney Creek. There are 8 breeding territories and 8 communal roosts within the polygon. The electrical lines in this area are along Old Baltimore Road and smaller feeder roads to Chilbury Point, Poverty Island, AA-5, and Fords Farm. This area is the densest area on post for eagle breeding, foraging, and roosting activities. Management recommendations: monitor electrical lines for mortalities and remove sections of line with repeat mortality incidents.

Polygon 2

This area is the second largest utilization polygon and centers around the mouth of Romney and Little Romney Creeks. There are 5 breeding territories and 7 communal roosts within the polygon. There are no known electrical lines in this area. Management recommendation: avoid the addition of future electrical infrastructure.

Polygon 3

This area has no known mortalities. The area centers on Mosquito Creek, Black Point, and Cherry Tree Point. There are 2 breeding territories and 7 communal roosts within the polygon. The electrical lines in this area are along the Hi Velocity range road. Management recommendations: monitor electrical lines for mortalities and remove sections of line with repeat mortality incidents.

Polygon 4

The area centers around Doves Cove on the Bush River. There are 2 breeding territories and 5 communal roosts within the polygon. This area has the third highest mortality rate on post. The mortalities have occurred on lines on C-field and L-field. Management recommendations: monitor electrical lines for mortalities and remove sections of line with repeat mortality incidents.

Polygon 5

The area centers around Doves Cove on the Bush River. There is 1 breeding territory and 4 communal roosts within the polygon. A single mortality has occurred on Code Creek Road. Management recommendations: monitor electrical lines for mortalities and remove sections of line with repeat mortality incidents.

Polygon 6

The area centers around Doves Cove on the Bush River. There are 4 breeding territories and 6 communal roosts within the polygon. Numerous mortalities have occurred along Spesutie Island Road and feeder roads to the ranges. Management recommendations: continue burying the electrical infrastructure underground to avoid future mortalities.

Polygon 7

This area has the highest mortality on APG. The area centers on Spesutie Narrows, Back Creek, and the North shoreline of Spesutie Island . There is 1 breeding territory and 2 communal roosts within the polygon. Numerous mortalities have occurred along Morgan and Spesutie Island Roads. This area is currently undergoing a line burial process to place the electrical infrastructure underground. Management recommendations: continue burying the electrical infrastructure underground to avoid future mortalities.

Polygon 8

Pooles Island has no known mortalities or electrical infrastructure. There are 4 breeding territories and 4 communal roosts within the polygon. Management recommendation: avoid the addition of future electrical infrastructure.

Polygon 9

The area centers on Woodrest Creek. There is 1 breeding territory and 1 communal roost within the polygon. No known mortalities have occurred related to the electrical infrastructure around the Vibration Facility and surrounding ranges. Management recommendations: monitor electrical lines for mortalities and remove sections of line with repeat mortality incidents.

Polygon 10
The area centers on Monks Creek. There are 2 breeding territories and 3 communal roosts within the polygon. There is currently no electrical infrastructure in the area and no known mortalities. Management recommendation: avoid the addition of future electrical infrastructure.

Polygon 12
The area centers on Lauderick Creek. There are 2 communal roosts within the polygon. There are no known mortalities related to electrical infrastructure in this area. Management recommendations: monitor electrical lines for mortalities and remove sections of line with repeat mortality incidents.

Polygon 13
The area centers on Swan Creek. There are 2 communal roosts within the polygon. The electrical infrastructure in this area is mainly supporting family housing units. Eagle movements are concentrated along Swan Creek and are likely away from the lines. Management recommendations: monitor electrical lines for mortalities and remove sections of line with repeat mortality incidents.

Polygon 14
This area centers on the mouth of Swan Creek. There are no breeding territories or communal roosts within the polygon. The electrical infrastructure supports a mixture of military/commercial and residential buildings. Management recommendations: monitor electrical lines for mortalities and remove sections of line with repeat mortality incidents.

Polygon 15
This area centers on the mouth of Fords Point on the Bush River. There are 2 communal roosts within the polygon. There is a single electrical line running alongside Rickett Point Rd. No known mortalities have occurred in this area. Management recommendations: monitor electrical lines for mortalities and remove sections of line with repeat mortality incidents.

Polygon 16
This area includes the upper reaches of Delph Creek and Bomb Proof Road. There are no breeding territories or communal roosts within the polygon. There are no known electrical lines or mortalities in this area. Management recommendation: avoid the addition of future electrical infrastructure.

Polygon 17
This area encompasses the mouth of Watson Creek and adjacent M-field. There are no breeding territories or communal roosts within the polygon. This area has the highest mortality rate per km of electrical line on post. Eagles fly over Watson Creek to reach the Gunpowder River crossing the electrical lines at the mouth of the creek. The creek is surrounded by Phragmites vegetation which could make viewing carcasses difficult at this site. M-field is a loafing area for eagles during the day and they perch on the electrical poles along Watson Creek Road, concrete walls and backstop on M-field, and on the prototype building. Management recommendations: monitor electrical lines for mortalities and remove sections of line with repeat mortality incidents.

Polygon 19
This area includes the Gunpowder River shoreline adjacent to J-field. There is one communal roost within the polygon. There have been two mortalities from the electrical line alongside Rickett Point road. This area has the second highest mortality rate per length of line on post. Management recommendations: monitor electrical lines for mortalities and remove sections of line with repeat mortality incidents.

Polygon 20
This area is located at the Palmer House on Aberdeen. There is one communal roost within the polygon. An electrical line bisects the roost. There are no known mortalities in this area. Management recommendations: monitor electrical lines for mortalities and remove sections of line with repeat mortality incidents.

Polygon 21
This area is located on the West Leg of Spesutie Island. There is one breeding territory within the polygon. An electrical line runs along Morgan Road. There are no known mortalities in this area but dense *Phragmites* vegetation could hinder finding carcasses. Management recommendations: monitor electrical lines for mortalities and remove sections of line with repeat mortality incidents.

Polygon 22
This area is located on the near the Dynomometer facility on Aberdeen. There is one breeding territory and one communal roost within the polygon. Electrical lines runs along Michaelsville Road and Trench Warfare Range Road. There are no known mortalities in this area. Management recommendations: monitor electrical lines for mortalities and remove sections of line with repeat mortality incidents.

Polygon 23
This area is located on the Wirsing Area where eagles forage at the pond. There is one breeding territory within the polygon. There are no known electrical lines or mortalities in this area. Management recommendation: avoid the addition of future electrical infrastructure.

Polygon 26
This area is located at the tip of the Edgewood peninsula. There is one breeding territory within the polygon. There are no known electrical lines or mortalities in this area. Management recommendation: avoid the addition of future electrical infrastructure.

Polygons 27 & 28
Both of these areas are on the Bush River shoreline adjacent to H-field. There are no breeding territories or communal roosts within the polygons. There are no known electrical lines or mortalities in this area. Eagles forage on the shorelines and loaf on the open grassland on H-field. Management recommendation: avoid the addition of future electrical infrastructure.

4.4 Bald Eagle Activity Centers and Shoreline Planning

4.4.1 Chapter Background

Bald eagles require access to food resources for self-maintenance and reproduction and important foraging areas are protected under the disturb and sheltering provisions of the federal Bald and Golden Eagle Protection Act. Foraging eagles are sensitive to human disturbance and chronic disturbance may render foraging areas unsuitable. Considerable research has been conducted to determine the causes and patterns of disturbance and disturbance buffers have been recommended throughout the species range as a technique to reduce impacts. However, significant foraging areas must be located before protective measures may be implemented. APG and the broader upper Chesapeake Bay study areas have extensive shorelines that are used by a large number of eagles throughout the year. Identifying high-use foraging areas is a first step toward considering bald eagles when planning military training exercises and recreational activity.

Work presented

We used more than 320,000 GPS locations along with Brownian bridge movement modeling to delineate and map bald eagle activity centers during both summer and winter seasons within the upper Chesapeake Bay and APG study areas. Seasonal use maps were produced for each bird (Appendix 11) and then compiled to produce population-wide maps. The shoreline was overlaid on the eagle utilization map to delineate shoreline segments that receive high use by foraging eagles. Summer and winter maps were compared to identify segments that were exclusive to season and those that were used throughout the year. Results of this analysis are detailed in a manuscript included here that will be submitted for publication with the following citation –

Watts, B. D., E. K. Mojica, and B. J. Paxton. 2012. Estimating seasonal patterns of shoreline use within the upper Chesapeake Bay using Brownian bridges.

All high-use shoreline areas within APG were delineated by season and information, insight and recommendations were provided for individual sites in Appendix 12.

4.4.2 Estimating seasonal patterns of shoreline use by bald eagles within the upper Chesapeake Bay using Brownian bridges

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Abstract: Access to food resources is essential to self-maintenance and reproduction and for species of conservation concern foraging areas are considered critical habitat. Human disturbance is an important factor restricting access to prey resources in bald eagles and guidelines have been developed to mitigate its impact. However, our ability to implement such guidelines has been limited by information on important foraging areas. We used Brownian bridge movement modeling to develop a population-wide, utilization probability surface for bald eagles (*Haliaeetus leucocephalus*) along shorelines within the upper Chesapeake Bay. We used locations (*n* = 320,304) for individuals (*n* = 63) tracked with GPS satellite transmitters between 2007 and 2011 in the analysis. We examined seasonal variation by developing utilization surfaces for summer and winter. Although shoreline use was widespread, segments receiving high levels of activity were relatively rare. Shorelines classified as having the highest category of use and accounting for 10% of the total utilization accounted for 0.41% and 0.55% of the total shoreline for winter and summer respectively. From a management perspective, there is a clear pattern of diminishing returns in conservation value for including sequentially lower-use shorelines in land-use plans. Shoreline use shifted dramatically in both location and extent between seasons. During the summer months, utilization was highly concentrated on shorelines along the main stem of the Bay or along major (> 1 km wide) tributaries. During the winter months utilization shifted away from the main stem of the Bay and was more focused on minor (< 100 m wide) tributaries and inland ponds. Seasonal shifts in shoreline utilization argue for season-based management objectives.

Key Words: Bald Eagle, *Haliaeetus leucocephalus*, Chesapeake Bay, Brownian bridge movement modeling, foraging, shoreline use, land planning

An animal's ability to acquire food is essential for self-maintenance and reproduction. Because bald eagles (*Haliaeetus leucocephalus*) are sensitive to human disturbance (Fraser 1985), chronic human activity within potential foraging habitat will effectively render those areas unsuitable and prevent eagles from accessing prey populations. Over time, this loss in access to resources will serve to reduce the capacity of the area to support eagles and the population would be expected to decline to a new equilibrium with the remaining landscape. This relationship is the basis for protection of important foraging areas under the disturb and sheltering provisions of the federal Bald and Golden Eagle Protection Act (Eagle Act) of 1940 (16 U.S.C. 668-668c) and why their management is considered within the National Bald Eagle Management Guidelines (US Fish and Wildlife Service [USFWS] 2007).

Considerable research has been conducted over the past 30 years to determine what conditions disturb eagles within foraging areas (e.g. Stalmaster and Newman 1978, Knight and Knight 1984, McGarigal et al. 1991, Brown and Stevens 1997). The frequent human activity associated with shoreline development has led to the avoidance of shorelines by foraging birds or presumptive habitat loss (Buehler et al. 1991a, Chandler et al. 1995, Clark 1992). Management recommendations designed to protect important foraging areas include setbacks of residential and industrial development from the shoreline (Buehler et al. 1991a). Episodic human activities from the water (Knight and Knight 1984, McGarigal et al. 1991, Brown and Stevens 1997), air (Stalmaster and Kaiser 1997) or land (Stalmaster and Kaiser 1988, Grubb and King 1991) flush eagles from the shoreline and disrupt hunting behavior. Because the impacts of these activities decline with distance (Smith 1988, McGarigal et al. 1991, Watts and Whalen 1997), management recommendations include the establishment of protective buffers around important foraging areas (Howard and Postovit 1987, Knight and Skagen 1987, Rodgers and Schwikert 2003, USFWS 2007).

Although we understand how human activities influence foraging behavior and have developed approaches to mitigate such impacts a major obstacle preventing the implementation of recommendations is the identification and delineation of the foraging areas themselves. We are unable to protect foraging areas until we determine their location. Our objectives here were to identify high-use shoreline segments within the upper Chesapeake Bay and examine seasonal (summer vs. winter) variation in shoreline use.

4.4.2.1 Study Area

Our study area (5,415 km^2) included the northern portion of the Chesapeake Bay from the Bay Bridge at Annapolis, MD to just above the Conowingo Dam on the Susquehanna River (Figure 4.4.1). The eastern portion of the study area is primarily rural with forest lands interspersed with agriculture. The western portion contains the urban areas of Baltimore and Annapolis but also includes Aberdeen Proving Ground (APG), a 350 km^2 military installation that is primarily forested with extensive shorelines. The northern portion of the study area contains the Susquehanna Flats, a historically important site for wintering waterfowl (Lynch 2001).

The study area includes the Upper Chesapeake Bay Bald Eagle Concentration Area, a relatively small area where three geographically distinct populations of bald eagles converge (Watts et al. 2007). The area supports a complex mixture of age classes from the resident Chesapeake Bay population. In late spring and early summer, eagles migrate north from Florida and other southeastern states to spend the summer months (Broley 1947, Wood *et al*. 1990, Mojica et al. 2008). In the late fall, eagles migrate south from New England populations to spend the winter months (McCollough 1989). Eagles within the study area feed primarily on fish during the summer months but switch over to waterfowl and mammals during the fall and winter when fish move to deeper water and waterbirds migrate into the Bay (DeLong et al. 1989, Mersmann 1989). Because the site supports populations from along the entire Atlantic Coast, land-use decisions made within the area may have far-reaching consequences.

4.4.2.2 Methods

Transmitters

We captured resident and migrant Bald Eagles (*n* = 63) on APG, banded, and fitted them with satellite transmitters between July 2007 and May 2009. Free-flying eagles were trapped on three sandy beaches (*n* = 10) using padded leg-hold traps (King et al. 1998), in three open fields (*n* = 26) using rocket nets baited with deer carcasses (Grubb 1988) and on open waters (*n* = 10) using floating fish traps (Frenzel and Anthony 1982, Cain and Hodges 1989, Jackman et al. 1993). We climbed nest trees throughout APG to access broods (8-10 wk of age) and deployed a transmitter on one nestling per brood (*n* = 17). We conducted floating fish and leg-hold trapping during the summer months to target resident and southern migrants. We conducted rocket-net trapping in the winter months to target resident and northern migrants. Eagle capture and handling methods were in compliance with IACUC protocols at the College of William and Mary (IACUC-20051121-3).

We used solar-powered, 70-g, GPS-PTT satellite transmitters (Microwave Telemetry, Inc. Columbia, Maryland, U.S.A.) to track eagle movements. Transmitters were attached using a backpack-style harness constructed of 0.64-cm Teflon® ribbon (Bally Ribbon Mills, Bally, Pennsylvania, U.S.A.). Transmitters were programmed to collect GPS locations (±18 m) every daylight hour and one additional location at midnight. GPS locations were processed by Argos equipped weather satellites (CLS America, Largo, Maryland, U.S.A.) and stored online by Satellite Tracking and Analysis Tool (Coyne and Godley 2005).

Movement Modeling

We used Brownian bridge movement models (BBMM) (Horne et al. 2007) to develop utilization distributions (UD; Worton 1989) for bald eagles within the study area using locations (*n* = 320,304) collected between August 2007 and June 2011. UD allows for the mapping of the intensity of use within a defined area. Conventional estimation of UD requires only a sample of independent locations. BBMM improves on traditional UD approaches by incorporating the temporal structure of tracking data allowing for the explicit modeling of movement paths. This approach allows for the identification not only of areas with high activity but also the movement corridors that connect them. BBMM incorporates fixed positions (x and y), time stamps (t), telemetry error (δ^2), and the variance of Brownian motion (δ^2_m) to estimate spatial patterns of movement probability. The model approximates the movement path between successive locations by applying a conditional random walk. Thus, deviation from a straight-line path between locations depends on the magnitude of Brownian motion variance (BMV). Low BMV values produce pathways where the probability of deviating from a straight-line path is low. BBMM estimates BMV using cross-validation and maximum likelihood techniques.

We produced BBMM-derived UD surfaces across a grid system of 1-ha cells (*n* = 541,476) overlaid on the study area. In order to reduce "edge effects" for movement probabilities we created an 80-km buffer around the study area and included positions within the buffer in modeling. Independent surfaces were produced for all non-breeding eagles with transmitters (*n* = 59; three birds were determined to hold breeding territories and one nestling died at fledging and were excluded). Two maps including summer (May through August) and winter (November through Marsh) were produced to reflect the migration seasons and possible variation in shoreline use. Data from birds marked as nestlings were excluded until the birds dispersed from the natal area. We combined UD surface maps produced for individual birds to create a population-wide UD for both winter and summer seasons. BBMM produces a relative probability surface that reflects spatial variation in estimated utilization. Because sample sizes varied between individuals, surfaces were weighted according to the number of locations per individual, combined, and standardized.

Analysis

We used an arbitrary schema to stratify the UD surface for analytical and presentation purposes. The population-wide UD was estimated over a large study area with a relatively high level (1 ha) of spatial resolution resulting in a large number of probability values. To facilitate presentation, we ordinated cell values from highest to lowest and grouped cells within categories that represented 10% of the total eagle utilization such that the first category was comprised of the cells with the highest utilization. This approach allows for an examination of the relationship between the level of utilization and area (i.e. the first category reflects the minimum area to achieve 10% of the total utilization, the second category reflects the minimum area to achieve the next 10% of the total utilization, etc.). Because this treatment is focused on shoreline use, we overlaid the shoreline on the utilization surface and assigned use classes to the shoreline according to the underlying surface. This allowed for mapping utilization intensity and distribution.

4.4.2.3 Results

Bald eagles tracked with satellite transmitters moved widely throughout the study area and used most of the available shoreline (Figures 4.4.2 and 4.4.3). A total of 2,236 km of shoreline was delineated throughout the study area and 29% (648.9 km) of this length was classified as used to some level during either the summer or winter seasons or both. Areas with very little use include the southwestern corner of the study area around Baltimore where the landscape is dominated by urban development and the communities of Havre de Grace and Perryville at the mouth of the Susquehanna River. Although shoreline use was widespread, segments receiving high levels of activity were relatively rare. Shorelines classified as having the highest category of use and accounting for 10% of the total utilization accounted for 0.41% and 0.55% of the total shoreline for winter and summer respectively. Even shorelines accounting for 40% of use collectively accounted for only 5.64% and 5.58% of the total shoreline for the two seasons suggesting that shoreline use is highly aggregated in relatively few locations.

Shoreline use shifted dramatically in both location and extent between seasons (Figures 4.4.2 and 4.4.3). During the summer months, utilization was highly concentrated on shorelines along the main stem of the Bay or along major (> 1 km wide) tributaries. An exception to this is the large concentration of birds below the Conowingo Dam where eagles congregate to feed on stunned fish around the outflow. During the winter months utilization shifted away from the main stem of the Bay and was more focused on minor (< 100 m wide) tributaries and inland ponds. Dramatic examples of this pattern were the seasonal shifts apparent on Aberdeen Proving Ground and the Sassafras River. Use of Aberdeen Proving Ground in summer was concentrated on the outer shoreline whereas in winter birds shifted inland and used smaller tributaries and ponds. Use of the Sassafras River in summer was focused on shorelines around the mouth with little activity along the upper reaches. Utilization was reversed in the winter with most of the activity recorded along the upper section.

Eagles were more dispersed along the shoreline during winter when compared to summer. This is illustrated by examining the length of shoreline required to account for percentages of total utilization (Figure 4.4.3). Interestingly, although there were shifts in location, high-use areas occurred along similar lengths of shorelines between the two seasons. Low-use areas were dramatically different such that it requires more shoreline to account for the same utilization in winter. It requires more than twice as much shoreline to account for 80% of the eagle utilization in winter (270 km) compared to summer (115 km).

The concentration of birds within relatively few high-use shoreline segments during both seasons has management implications. The density of actual transmitter fixes along the shoreline for the study period varied from 1,746 and 1,540 locations/km for the highest-use category (10% utilization) during summer and winter respectively to 1.4 and 0.9 locations/km for the lowest-use category (90% utilization). From a management perspective, there is a clear pattern of diminishing returns in conservation value for including sequentially lower-use shorelines in land-use plans (Figure 4). More than 60% of locations were concentrated along the highest-use shorelines (equating to 40% utilization from BBMM) that represent 5.6% or 126 km of the shoreline for both seasons.

Seasonal shifts in shoreline utilization argue for season-based management objectives. Although high-use (40% utilization) shorelines were similar in total length between summer and winter 68% of the collective segments were exclusive to each season (Figure 4.4.5). Remaining 32% or 39.6 km of shoreline received high eagle use throughout the year. Permanent restrictions on the use of these shorelines and seasonal restrictions on remaining shorelines would effectively reduce disturbance for a large portion of the bald eagle community within the study area.

4.4.2.4 Discussion

Although eagles were widely distributed throughout the study area, consistent, high-use shoreline segments were relatively rare. This finding is consistent with studies within other locations (e.g. Keister et al. 1987, Garrett et al. 1993, Brown and Stevens 1997) that have documented the occurrence of eagle foraging areas where specific elements including rich food resources, quality perches, and low human activity come together on the landscape. BBMM with tracking locations was effective in documenting spatial variation in shoreline use. Such information is useful not only for delineating shorelines receiving high use but also in characterizing the full range of utilization that may be useful in evaluating cost-benefit tradeoffs in management planning. Within the current treatment, protecting shorelines during winter with the highest 10% of utilization would require focused management along 9 km of shoreline whereas protecting shorelines with the lowest 10% of utilization would require focused management on more than 1,000 km of shoreline.

Use of the upper Chesapeake Bay landscape shifted dramatically with season with birds during summer concentrated along the widest (1-10 km) water within the study area and during the winter focused on narrower (<100 m) tributaries and inland areas. This pattern is consistent with previous studies that have documented seasonal shifts and suggested that birds are moving to avoid weather exposure. Steenhoff et al. (1980) working along the Missouri River in South Dakota showed that birds moved to protected perches and into communal roosts during periods of high wind and extreme wind chill. Stalmaster and Gessaman (1984) working along the Nooksak River in Washington show that eagles in winter conserve energy by selecting beneficial microclimates and shifting behavior depending on weather. However, Buehler et al. (1991b) modeled energy costs for travel and thermoregulation for shoreline and inland roosts within the upper Chesapeake Bay and found no energy savings for using inland roosts despite the fact that eagles shifted to inland roosts between seasons and inland roosts were more protected from prevailing winds (Buehler et al. 1991c).

Bald eagles within the Chesapeake Bay do exhibit a seasonal shift in diet. Breeding adults with dependent broods (Markham and Watts 2008) and summer migrants (Watts and Whalen 1997) feed almost exclusively on fish. A large portion of these fish appear to be captured live from or near the surface of the water but dead fish are frequently scavenged from the surface or along the shoreline. Winter migrants and residents rely more heavily on waterfowl and mammals (Haines 1988, Mersmann 1989). Live fish move into deeper water during the winter months and are less accessible to surface or near surface predators. DeLong et al. (1989) assessed prey availability with gillnet sampling and found that fish numbers in the upper Bay declined seasonally November through March while waterfowl abundances peaked in the winter months until April. An exception to this is below the outfall of the Conowingo Dam where eagles congregate and fish are available all year. Shifts in prey dominance within the diet and related distribution may explain changes in roost use as well.

Regardless of the underlying ecological factors, shifts in shoreline use have management implications. Approximately two thirds of high-use shorelines were exclusive to season and the remaining segments were used all year. Management priority should be given to shoreline segments that are used during both seasons since these sites meet eagle requirements throughout the year and have the greatest conservation value. Flushing probabilities with distance have been examined widely throughout the species range (e.g. Knight and Knight 1984, Buehler et al. 1991, McGarigal et al. 1991, Watts and Whalen 1997, Rodgers and Schwikert 2003) with mean flushing distances ranging from 150 to 250 m. Flushing responses have led to recommendations of disturbance buffers for foraging birds in the range of 300-400 m. Consideration of these buffers around high-use shorelines in the summer months when planning discretionary activities would be beneficial to foraging birds. During the winter months when eagles move into narrow tributaries most birds would be flushed by any boat traffic because flushing distances are greater than channel width. Effective protection of foraging eagles during this time of year would require waterway closures.

4.4.2.5 Acknowledgments

The U.S. Army and The Center for Conservation Biology provided financial support for the telemetry study and analysis. This study would not have been possible without F. Smith, C. Koppie, S. Voss, and J. Baylor who contributed countless hours trapping eagles. C. Koppie assisted with climbs to access nestlings. B. Roberts, C. Volz, L. Merrill, W. Armstrong, M. Stewart, and R. Plummer assisted with baiting sites and rocket-net trapping. J. Paul, A. Burgess, and J. Ondek gave logistical support to access nests and trapping sites. J. Neubauer, C. Corbett, E. Lawler, and M. Roberts provided contract support.

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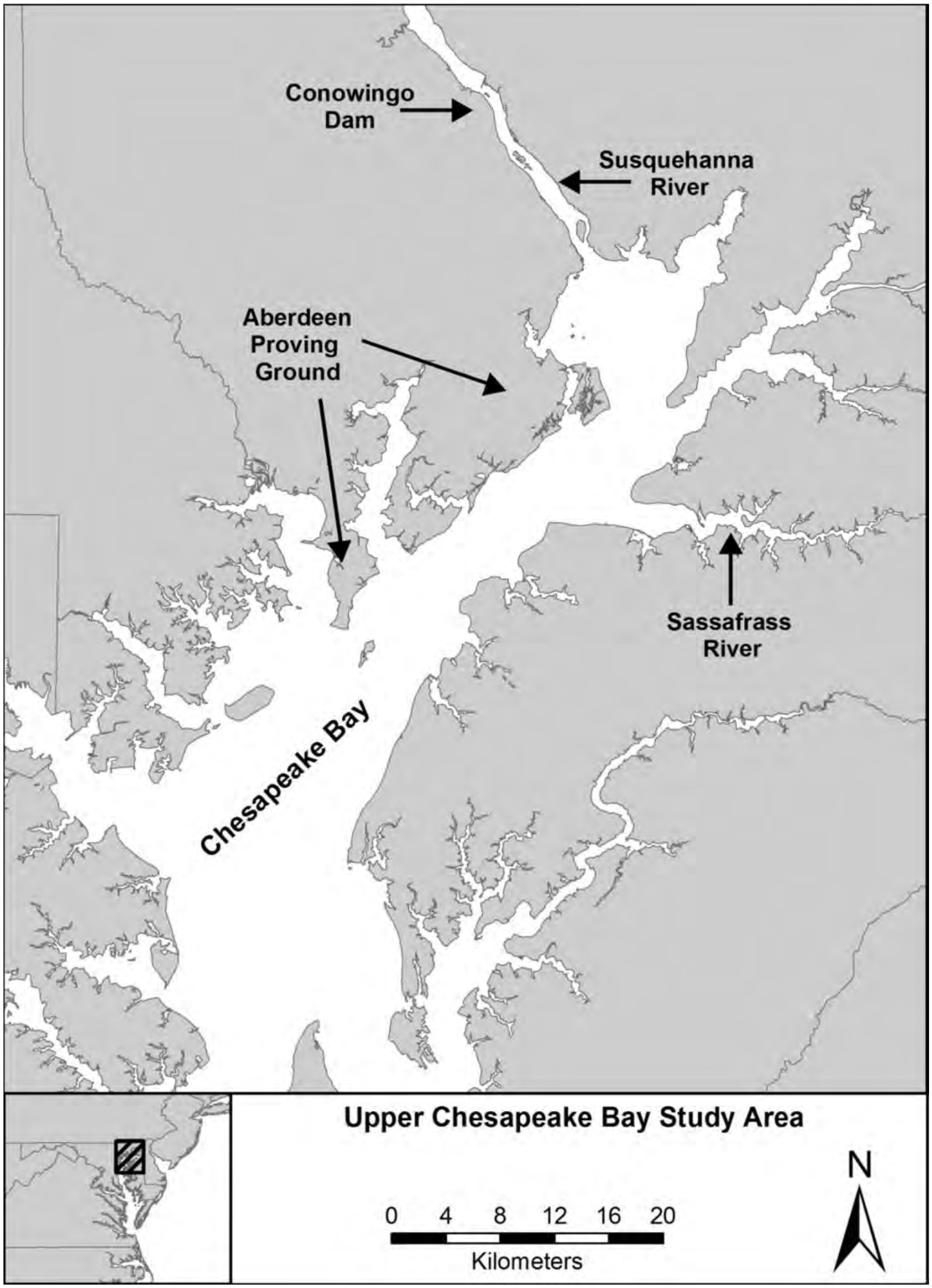

Figure 4.4.1. Map of upper Chesapeake Bay including the study area. This portion of the tidal reach of the Bay includes the Upper Chesapeake Bay Bald Eagle Concentration Area that supports birds from along the entire Atlantic Coast.

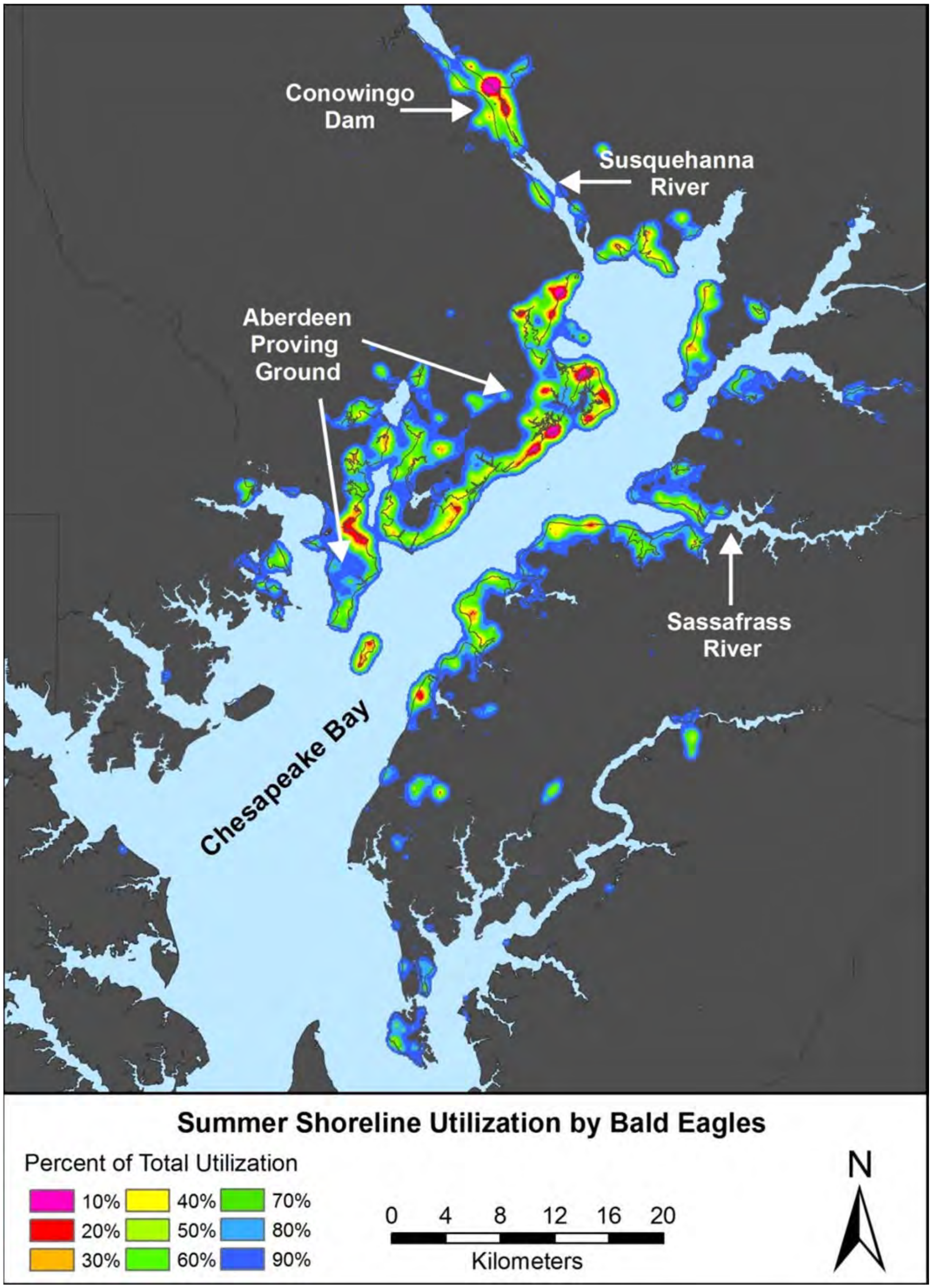

Figure 4.4.2. Map of study area illustrating bald eagle utilization distribution or probability surface for the summer period generated using BBMM. Colors depict different utilization densities. Within this presentation, 10% refers to the minimum area that encloses 10% of the total utilization or the highest density of use. Each successive category depicts to the minimum area that encloses the proportion of utilization.

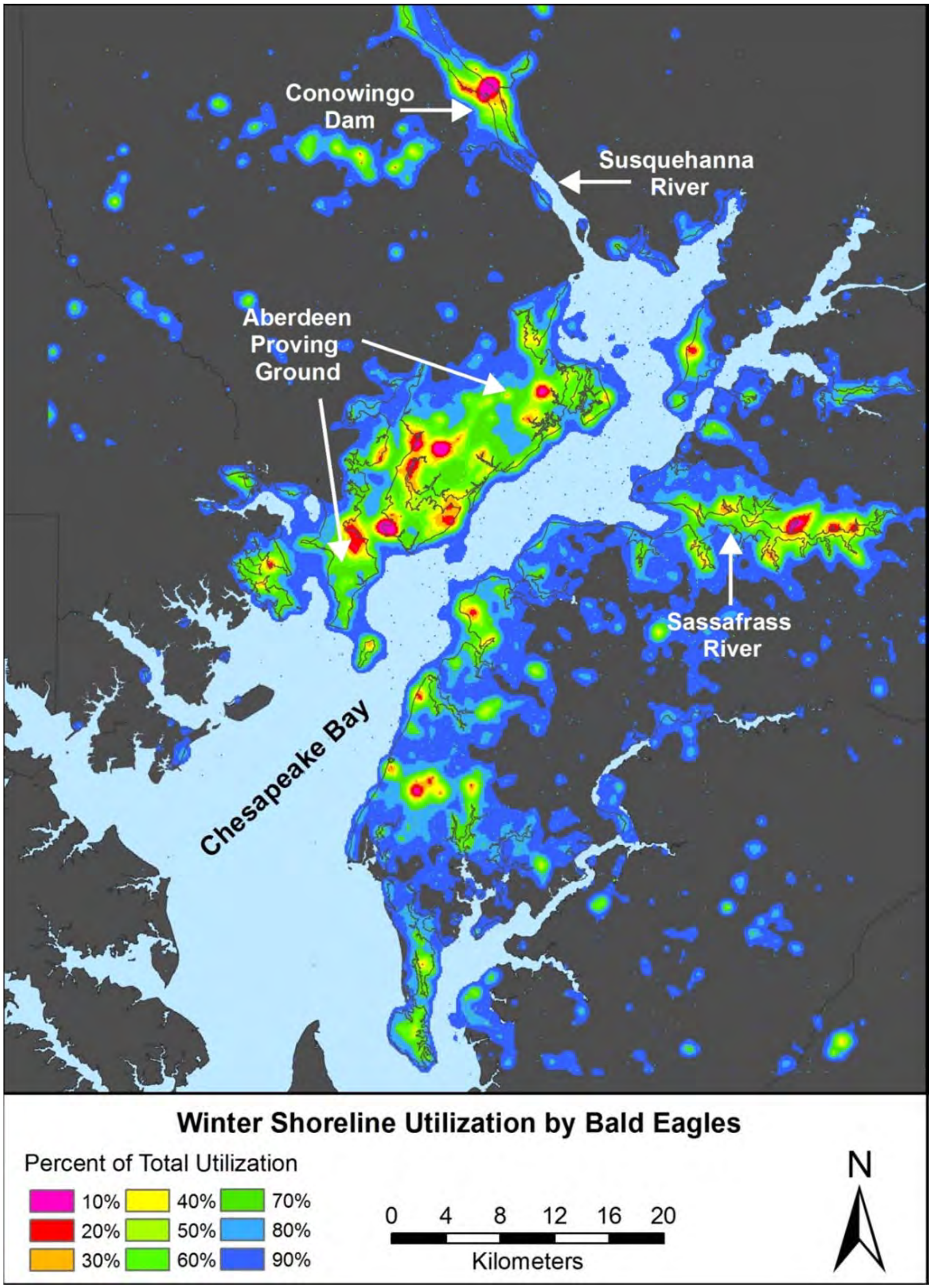

Figure 4.4.3. Map of study area illustrating bald eagle utilization distribution or probability surface for the winter period generated using BBMM. Colors depict different utilization densities. Within this presentation, 10% refers to the minimum area that encloses 10% of the total utilization or the highest density of use. Each successive category depicts to the minimum area that encloses the proportion of utilization.

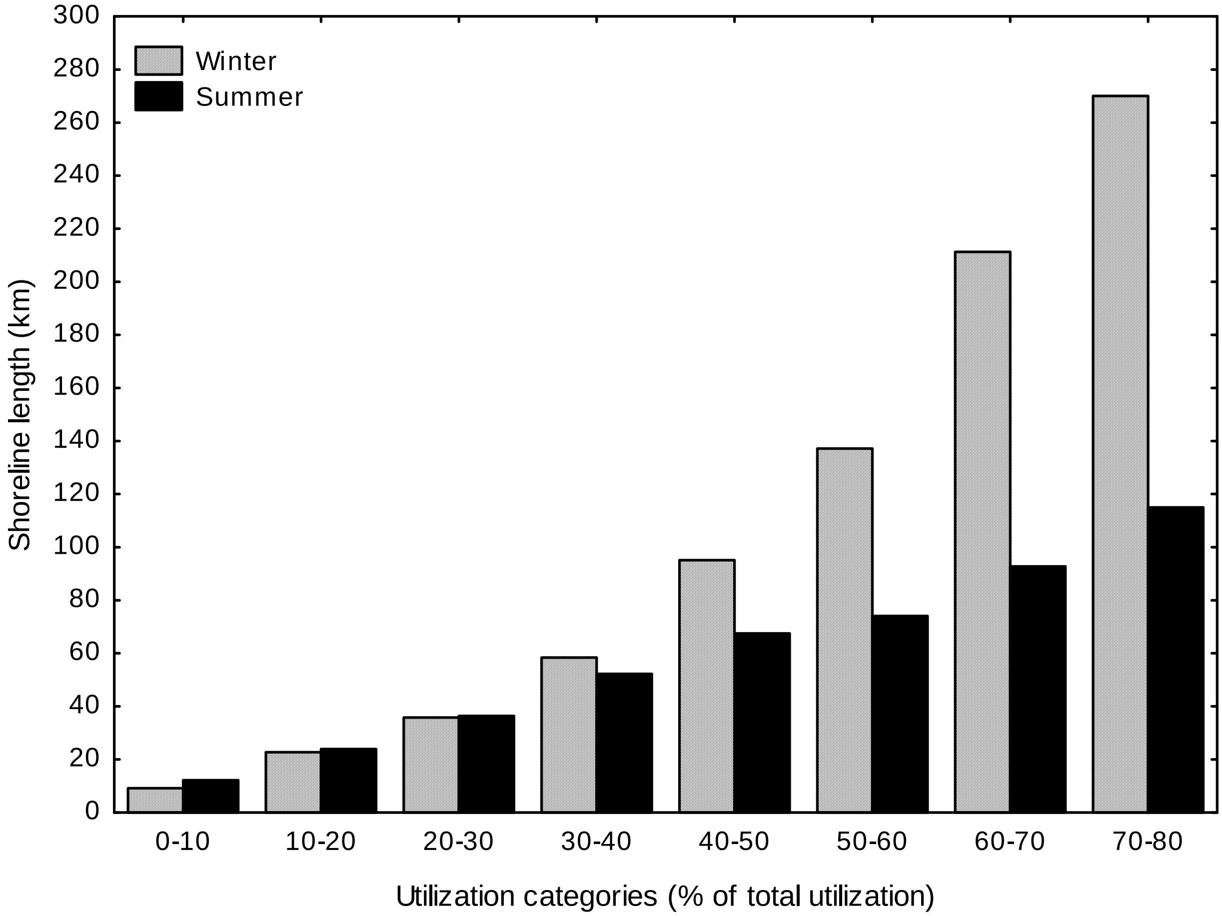

Figure 4.4.4. Minimum shoreline lengths to accommodate successive 10% intervals of bald eagle utilization within the upper Chesapeake Bay during winter and summer. Birds are more dispersed during the winter period requiring more than twice the shoreline length to accommodate the lower density values.

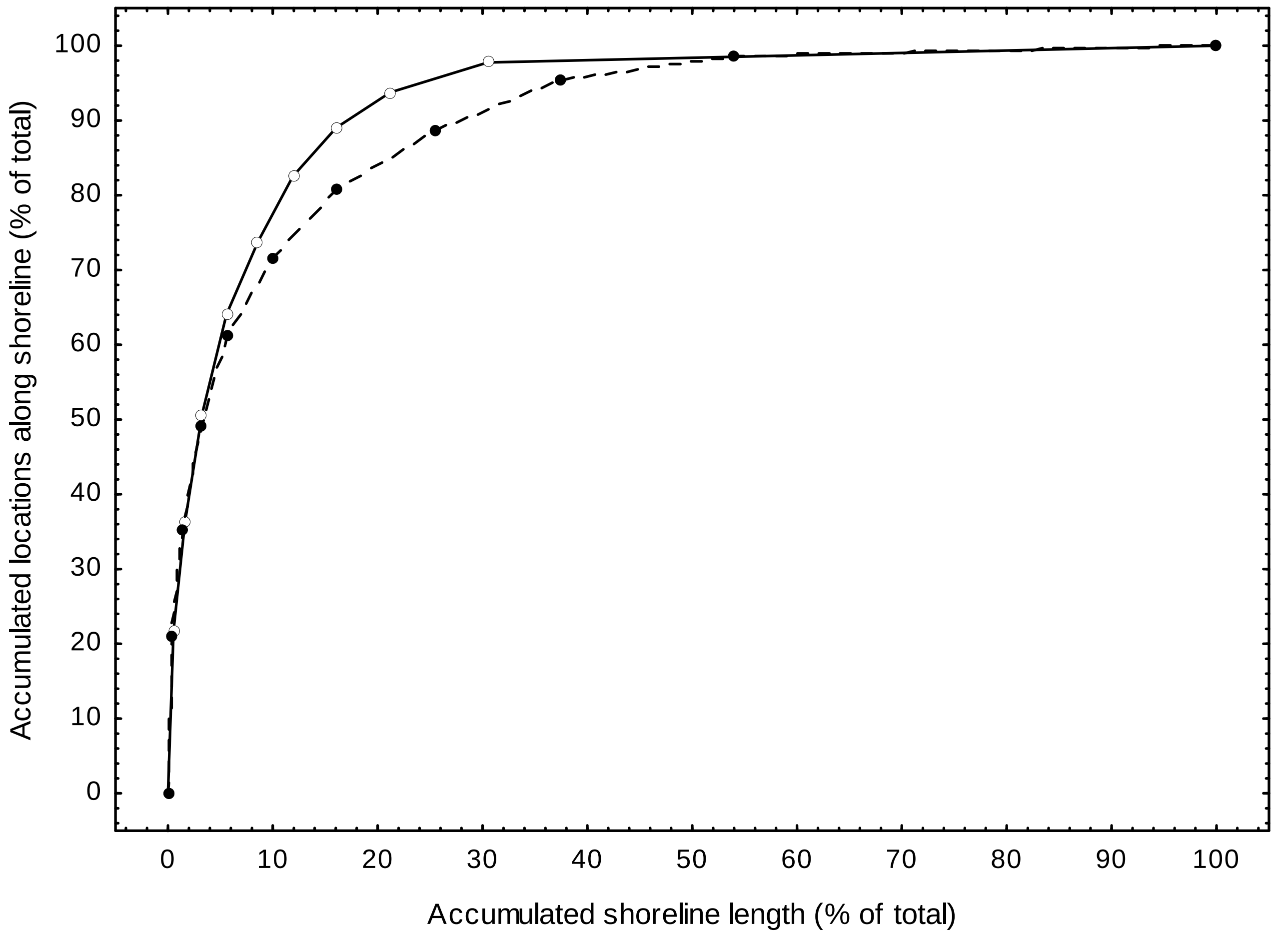

Figure 4.4.5. Relationship between the length of shoreline and the cumulative proportion of eagle locations for winter and summer periods. The graph reflects the minimum length required to support the highest proportion of eagle locations. Shorelines were ordinated from high to low according to density of use (locations/km of shoreline). An accumulation curve was then generated by sequentially by adding each shoreline category and expressing the result as a portion of the total locations against the sum of shoreline included.

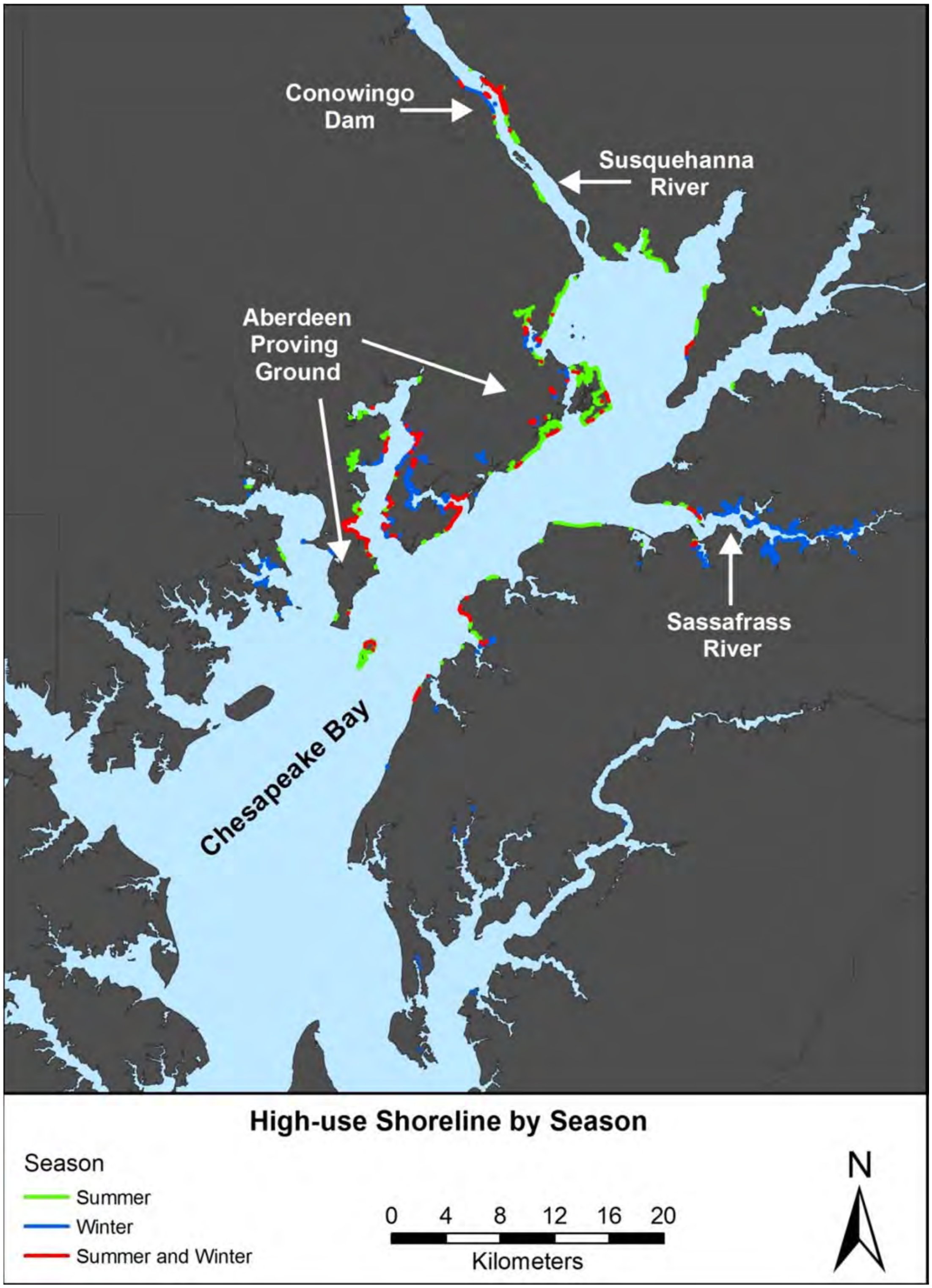

Figure 4.4.6. Map of the study area indicating the location of high-use (40% utilization) shoreline segments by season. Indicated are high-use shorelines that are exclusive to summer and winter and those segments that were used in both seasons.

4.4.3 Aberdeen Proving Ground Study Area

We used Brownian bridge movement models to develop utility distributions from eagle tracking data to identify areas with high activity and movement corridors between these areas. On APG, we modeled this distribution during summer (May-August) and winter months (November – March). The top 40% of the total utilization were selected as representing the high use activity centers on APG. Activity centers should be prioritized for eagle management and conservation with emphasis on shoreline areas used in both seasons (Figure 4.4.6).

Eagles concentrated movements on APG shorelines during summer months along the Chesapeake Bay, and Bush River (Table 4.4.1, Figures 4.4.6 & 4.4.7). During winter months eagles moved into more protected areas inland on APG and upstream into creeks like Romney, Coopers, Mosquito, Woodrest, and Swan (Table 4.4.2, Figure 4.4.8). The winter activity centers on the shoreline occurred in areas with trees greater than 30 cm dbh that provide year-round shelter for roosting. Use of these eagle activity centers varies throughout the day. Some are used primarily as roosting areas, some as foraging areas, and a few are used throughout the day and night. Times of day histograms are listed for each seasonal activity center.

4.4.3.1 Summer Activity Centers

Table 4.4.1. Top 40% utilization distribution polygons on APG during summer months.

Polygon	Hectares	Location	Area
1	158	Pooles Island	Pooles Island
2	6	Sandy Point/Bush River	Edgewood
3	32	Towner Cove	Aberdeen
4	394	Doves cove	Edgewood
5	30	Redman Cove	Aberdeen
6	254	Locust Point	Aberdeen
7	15	Delph Creek Mouth	Aberdeen
8	23	Romney Creek	Aberdeen
9	53	Lauderick Creek	Edgewood
10	38	Upper Romney Creek	Aberdeen
11	14	Sod Run Mouth	Aberdeen
12	87	Monks Creek	Edgewood
13	420	Cherry Tree Point	Aberdeen
14	25	Mosquito Creek	Aberdeen
15	88	Bear Point	Aberdeen
16	80	Woodrest Creek	Aberdeen
17	201	Sandy Point/Spesutie Island	Aberdeen
18	263	North Spesutie Island	Aberdeen
19	13	Plum Point	Aberdeen
20	4	Lower Swan Creek	Aberdeen
21	17	Upper Swan Creek	Aberdeen

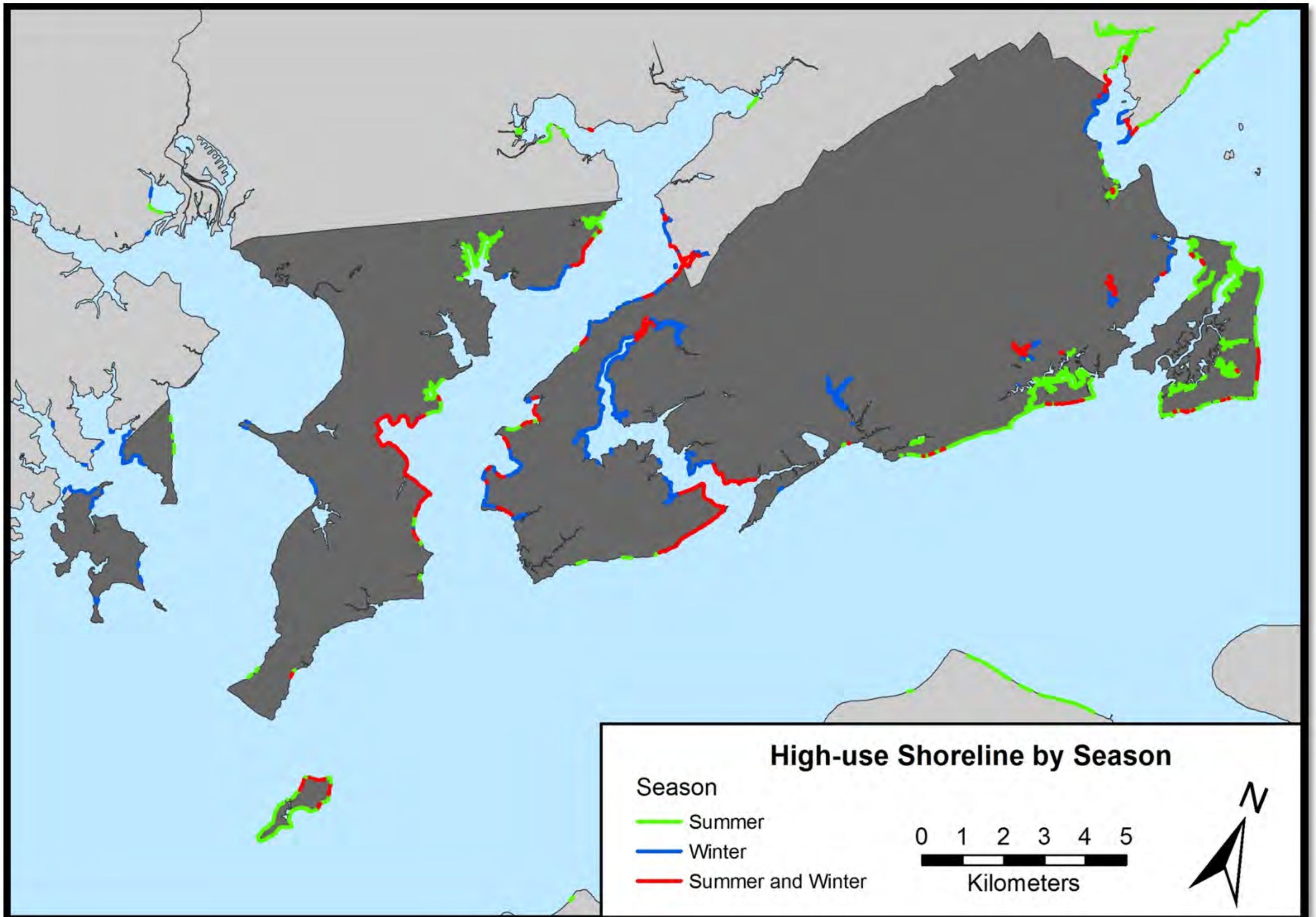

Figure 4.4.6. High use shoreline used by bald eagles on APG.

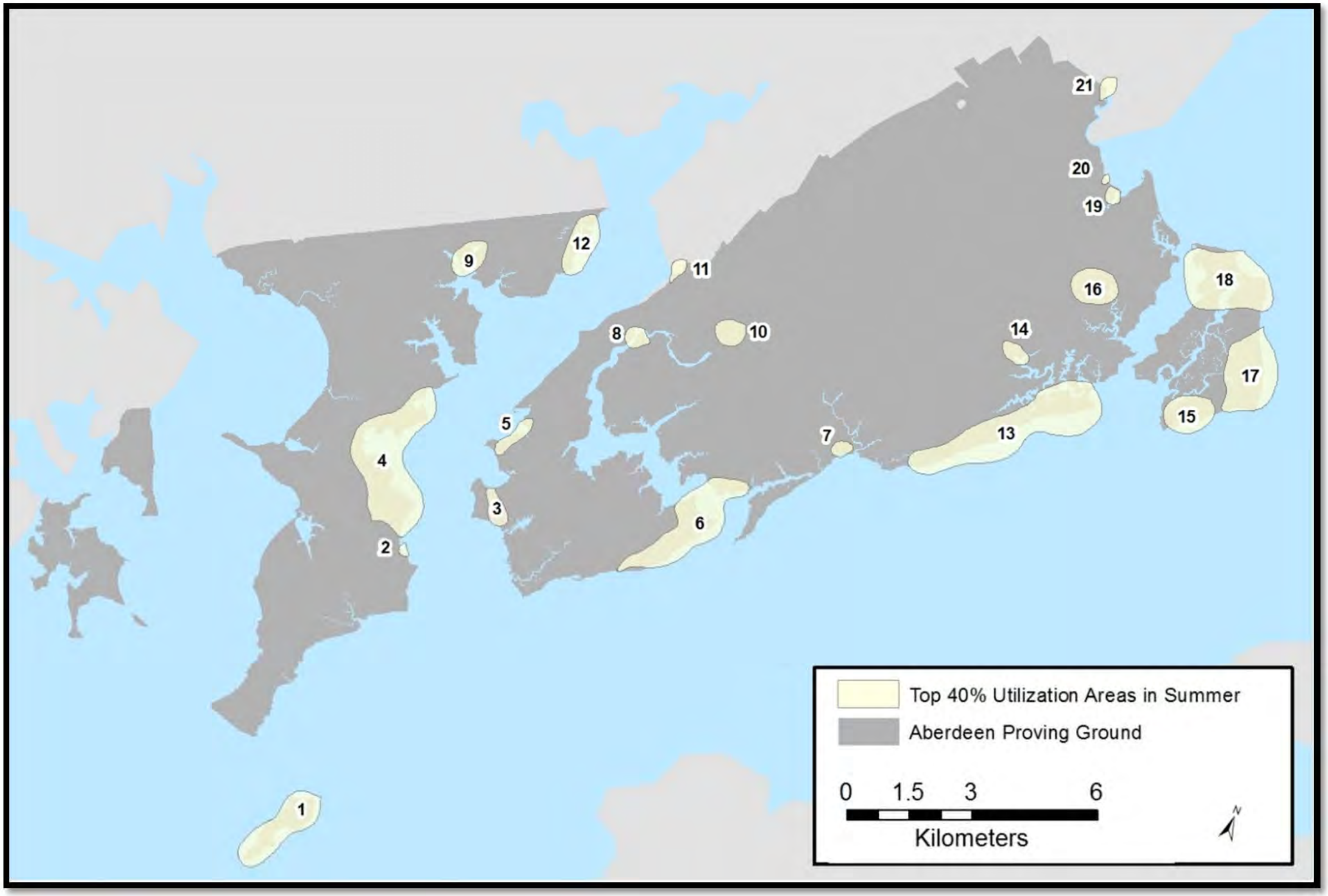

Figure 4.4.7. Top 40% utilization areas for Bald Eagles on APG during summer months (May – August).

4.4.3.2 Winter Activity Centers

Table 4.4.2. Top 40% utility distribution polygons on APG during winter.

Polygon	Hectares	Location	Area
1	38	Pooles Island	Pooles Island
2	37	Carroll Island	Carroll Island
3	95	Graces Quarter	Graces Quarter
4	526	Doves Cove	Edgewood
5	351	Towner Cove	Aberdeen
6	6	Redman Cove	Aberdeen
7	506	Locust Point	Aberdeen
8	14	Delph Creek Mouth	Aberdeen
9	4	Delph Creek East	Aberdeen
10	87	Delph Creek West	Aberdeen
11	135	Fairview Point	Edgewood
12	26	Black Point	Aberdeen
13	1,214	Romney Creek	Aberdeen
14	16	Bear Point	Aberdeen
15	131	Mosquito Creek	Aberdeen
16	8	Dynomometer	Aberdeen
17	31	Sandy Point	Aberdeen
18	208	Woodrest Creek	Aberdeen
19	11	Spesutie Narrows	Aberdeen
20	106	Swan Creek	Aberdeen

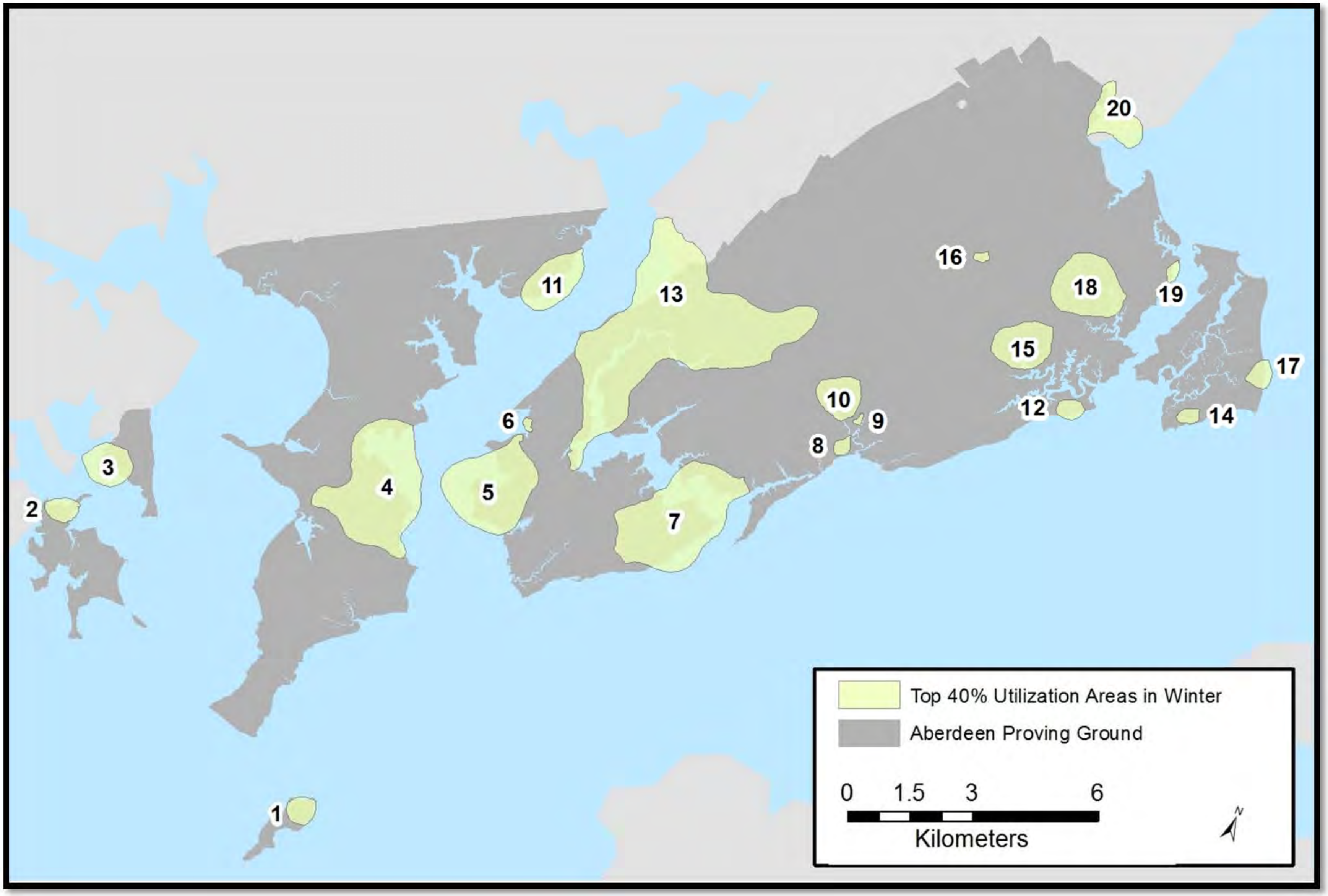

Figure 4.4.8. Top 40% utilization areas for Bald Eagles on APG during winter months (November - March)

4.5 Bald Eagle Mortality on APG

4.5.1 Chapter Background

As part of an adaptive management strategy implemented by APG environmental staff, eagle mortalities have been documented and reported to regulatory agencies since the mid-1980s. A database of eagle mortalities has been compiled and maintained that includes date, location, cause of death (if determined), and surrounding circumstances. This database provides a history of documented mortality but also an opportunity to evaluate causal factors that may inform mitigation efforts.

Work Presented

We have interpreted mortality events documented by APG staff and have examined landscape features that may help to explain spatial patterns. The complete database of documented bald eagle mortalities is provided in Appendix 10. Results of analyses of landscape features related to line-associated mortalities have been detailed in a manuscript included here that was published in the Journal of Raptor Research with the following citation -

Mojica, E. K., B. D. Watts, J. Pottie, J. T. Paul, and S. Voss. 2009. Factors contributing to bald eagle electrocutions on Aberdeen Proving Ground, Maryland. *Journal of Raptor Research* 43:80-83.

A reprint of this paper is provided in Appendix 13

4.5.2 Factors Contributing to Bald Eagle Electrocutions and Line Collisions on Aberdeen Proving Ground, Maryland

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***Abstract*.**-- We evaluated factors contributing to Bald Eagle (*Haliaeetus leucocephalus*) electrocutions and electrical line collisions on Aberdeen Proving Ground, an important eagle concentration area in the Chesapeake Bay. During 1985-2007, we documented locations of 62 dead and injured eagles recovered under electrical lines. Using a simple two-way design, we overlaid eagle mortalities on line segments classified by proximity to shoreline and height of surrounding vegetation. We documented significantly more mortality associated with lines closer to shorelines compared to lines inland than was expected based on relative line length (χ^2 = 119.71, df = 2, P <0.001). In addition, the number of eagle deaths associated with exposed electrical lines (no vegetation concealing line) was greater than expected based on relative line lengths (χ^2 = 11.54, df = 2, P <0.005). The presence of vegetation surrounding electrical lines appeared to significantly reduce mortality events. Electrical lines within 1 km of shoreline and unconcealed by vegetation pose a significant risk to eagles. We recommend systematically monitoring high-risk lines in known eagle concentration areas to determine if mitigation efforts are needed.

KEY WORDS: *Bald Eagle*; Haliaeetus leucocephalus; *Chesapeake Bay*; *collision*; *eagle concentration area*; *electrocution*; *electrical line*; *mortality.*

Avian electrocution is a widespread conservation problem affecting many taxonomic groups worldwide (Bayle 1999, Bevanger 1998, Lehman et al. 2007). The specific biological and technical aspects of electrocution are well documented, particularly for raptors. Several factors influence the risk of bird electrocution or collision, including design of electrical poles and lines, weather, visibility, wingspan, and bird age and experience (Avian Power Line Interaction Committee [APLIC] 2006). Electrocution can occur when a bird perches on a crossarm and completes an electrical circuit with two or more body parts (APLIC 2006). Line collisions (birds flying directly into electrical lines) are increasingly documented as a cause of avian mortality (Bevanger 1994, Bevanger 1998, Bayle 1999, Olendorff and Lehman 1986). Birds die either from the impact of hitting the line or from electrocution when they contact two lines simultaneously and complete the electrical circuit (Harness et al. 2003).

Placement of electrical lines on the landscape is increasingly recognized as an important factor contributing to avian mortality (APLIC 1994, APLIC and USFWS 2005, APLIC 2006, Bayle 1999, Lehman et al. 2007, Schomburg 2003). Birds are more susceptible to line collisions if lines cross flight paths or movement corridors (Bevanger 1994, Thompson 1978). This could be compounded if vegetation surrounding the lines is not tall enough to reach the line, as with early successional habitat (Thompson 1978). A solid row of vegetation at or above the height of the line acts as a flight barrier to large birds forcing flight paths above the electrical lines, thereby reducing the risk of collision (APLIC 1994, Bevanger 1994).

Our objective was to investigate the landscape factors that influence mortality of Bald Eagles (*Haliaeetus leucocephalus)* related to electrical lines. We hypothesized that line proximity to shoreline and surrounding vegetation height would affect the distribution of eagle mortality on the landscape. We suspected lines close to open water and not surrounded by vegetation would have the highest rates of electrocution and collision.

4.5.2.1 Study Area

Our study was conducted on the U.S. Army's Aberdeen Proving Ground (APG) located on the shore of the upper Chesapeake Bay, Maryland (39°23' N, 76°13' W). Aberdeen Proving Ground is home to one of the largest concentrations of Bald Eagles on the east coast of North America (Watts et al. 2007). The property supports 42 resident pairs and seven known communal roosts used by migrants from the north and south during the winter and summer months respectively (Buehler et al. 1991, General Physics 2004, E. Mojica and B. Watts unpubl. data). This study focused on the Edgewood and Aberdeen areas of the installation (total ca. 16,000 ha). Shoreline habitat includes stands of mixed hardwoods, tidal marsh, human-maintained grasslands, and urbanized areas (Maryland Department of Natural Resources 2002).

The electrical infrastructure on Aberdeen Proving Ground is composed of three-phase distribution lines ($\leq$ 40 kv) with three phases on a 6' crossarm and one neutral line located 5' below the energized wires (General Physics 2004, APLIC 2006). This pole configuration was not classified as "avian-safe" (APLIC 2006) and the wingspan of eagles is sufficient to touch multiple conductors and lines simultaneously (General Physics 2004). Of the approximately 1500 km of overhead lines on APG, 91 km run along shoreline areas, which are important foraging habitat for resident and migrant eagles (Buehler et al. 1991, General Physics 2004).

4.5.2.2 Methods

We used records of dead or injured eagles to evaluate the influence of surrounding vegetation and proximity to shoreline on the likelihood that eagles would be killed by the electrical infrastructure. We initiated a database in 1985 to record the location and circumstances of eagle mortalities as part of the installation's Bald Eagle management plan. Data from 1985 to 2007 was included in this analysis. Dead or injured eagles were discovered during routine maintenance, but no systematic surveys were conducted. We included reports of carcasses in our analysis if the cause of the eagle's death was identified as electrocution through necropsy or examination, or if there was strong circumstantial evidence that death was due to the electrical infrastructure. We excluded from analysis any eagle with injuries unrelated to electrical lines or located outside of the main Edgewood or Aberdeen study areas of APG ($N = 15$). Reports of eagles whose death or injuries were associated with the electrical infrastructure were pooled for analysis ($N = 62$). We assumed that carcass detection rates were equal across the study area. We feel that this is a reasonable assumption because all lines were subject to regular maintenance and the majority of electrical lines parallel well-traveled roads with mowed grass beneath the lines.

We used a simple two-way design with proximity to shoreline and surrounding vegetation height to evaluate the influence of line characteristics on eagle electrocutions. We classified all electrical lines according to proximity to bay shorelines by overlaying shoreline buffers on an electrical line map using ArcMap 9.1 (E.S.R.I., Redlands, CA U.S.A.). We used three proximity categories including near shore (<300 m), mid-range (300 m - 1000 m), and interior (>1000 m). We evaluated vegetation associated with electrical lines by visual inspection. We classified lines as "exposed" if there was no vegetation (except mowed grass) within 100 m of the lines, "below" if vegetation existed within the surrounding area but was lower than the height of the line, or "concealed" if vegetation within the surrounding area was even with or above the line height. We assumed APG staff maintained consistent vegetation heights around lines from 1985 to 2007 except where natural shoreline erosion kept vegetation low on areas of Spesutie Island and at the mouths of creeks where they entered the Chesapeake Bay. A majority (92%) of lines were within 100 m of heavily trafficked roads with 32--72 km/hr (25--45 m/hr) speed limits. A mowed grass corridor 3--10 m wide was maintained directly under the lines and aided in visual detection of dead or injured eagles.

We evaluated the influence of proximity to shorelines and vegetation on mortality by overlaying eagle electrocutions and collisions on electrical lines and grouping mortality events according to landscape characteristics surrounding the line. We compared the distribution of electrocutions according to proximity and vegetation categories with distributions expected based on the length of lines within these categories using χ^2 goodness-of-fit test. We hypothesized that eagle electrocutions and collisions were more likely to occur close to the shoreline as eagles sought perches near water. Because many of the mortalities were mid-line collisions, we also hypothesized that exposed lines may have a higher probability of being struck by flying eagles compared to concealed lines.

4.5.2.3 Results

During 1985-2007, we documented 77 eagle mortalities and injuries on APG. We confirmed that 62 were directly related to the electrical infrastructure. Forty-five had visible signs of electrocution (burn marks on foot pads, bill, or feathers; $N = 24$;) or collision (feathers on lines directly above carcass, signs of blunt-force trauma; $N = 21$). We assumed an additional 17 eagles were killed after contacting electrical structures because they were found decomposed under an electrical line or pole. The single injury was witnessed by base staff and occurred when an eagle flew into a line and lay paralyzed on the ground after being shocked. We excluded eagle mortalities from disease ($N = 2$), intraspecific aggression ($N = 3$), nest tree collapse ($N = 2$), electrocution outside study area ($N = 3$), and unknown ($N = 5$). In addition to eagles, carcasses of an Osprey (*Pandion haliaetus*), owls, swans, and a Great Blue Heron (*Ardea herodias*) were found under electrical lines and poles.

Bald Eagle electrocutions and collisions on APG were not randomly distributed with respect to shoreline proximity or surrounding vegetation (Table 4.5.1). Significantly more detected mortality was associated with lines closer to shorelines compared to lines inland than was expected based on the relative line lengths ($\chi^2 = 119.71$, df = 2, $P < 0.001$). Lines falling within the near shore and mid-range categories both accounted for a greater number of mortalities than expected based on the availability of line. In contrast, inland lines accounted for fewer mortalities than expected.

The characteristics of vegetation surrounding electrical lines had a significant influence on the likelihood that lines would be associated with mortality events ($\chi^2 = 11.54$, df = 2, $P < 0.005$). We documented a higher number of eagle deaths associated with exposed electrical lines than expected based on their relative lengths. The presence of vegetation appeared to significantly reduce mortality events. The likelihood of mortality was particularly low when lines were concealed below the height of vegetation.

4.5.2.4 Discussion

The location of electrical lines relative to both vegetation and the shoreline had a significant influence on Bald Eagle mortality patterns within APG. Detected mortalities were higher than expected along exposed lines with no vegetative cover than along lines partially or completely concealed by vegetation. Our findings supported the current view that vegetation shields the lines and forces flight paths safely above lines (APLIC 1994, Bevanger 1994). Mortalities were also higher than expected along lines within 1 km of the shoreline compared to those further inland. Eagles concentrate on shoreline habitat at APG to forage and perch (E. Mojica and B. Watts unpubl. data). Placement of lines within these high-use areas appears to increase the risk of eagle electrocutions and line collisions (Bayle 1999).

In addition to the general influence of vegetation height and shoreline proximity on eagle mortality, we believe that the placement of lines perpendicular to major flight lines contributed to mortality patterns within APG. This was illustrated by two areas on the installation where we documented relatively large mortality clusters. Exposed lines on Spesutie Island occurred between two communal roosts and a segment of shoreline that was heavily used for foraging and loafing. The shoreline vegetation on the island consisted of mid-successional trees and shrubs that were not preferred perching substrates. More than 48% of the installation's mortalities occurred here, over half of which were line collisions. This finding is consistent with other studies that have documented heavy mortality along lines that were placed between foraging and roosting habitat (Anderson 1978, APLIC 1994, Harness et al. 2003, Olendorff and Lehman 1986). A second mortality cluster occurred where a line was placed across the mouth of Watson Creek. This site accounted for 8.1% of the total mortalities. We believe that eagles used Watson and similar creeks as flight corridors between inland roosts and shoreline foraging areas.

Mortality studies can greatly underestimate mortality rates by using inadequate carcass detection methods (Thompson 1978). We did not systematically survey for carcasses. However, we believe that most eagle mortalities associated with the electrical infrastructure were documented. Within the APG, electrical lines generally run parallel and in close proximity to the roadways. Roadways are frequented by APG personnel several times per day at low vehicle speeds such that the likelihood of discovering a carcass is high. In addition, there is a heightened awareness of eagle mortalities on the property, which we believe increased the rate of detection. Although it is likely that some carcasses were not detected because they were removed by scavengers, and that some of the injured eagles were not counted because they were capable of moving away from lines (APLIC 1994, Thompson 1978); however, we do not believe that these circumstances represent systematic sources of bias that would invalidate the comparisons presented here.

Interactions between eagles and electrical lines can be expected to increase as additional lines are erected within eagle habitat (Anderson 1978, Newton 1979). However, raptor line collisions and electrocutions can be reduced on both new and existing facilities by using "avian-safe" construction designs and siting techniques (APLIC 1994, APLIC and USFWS 2005, APLIC 2006). Retrofitting existing poles with perches and guards was a successful mitigation technique at APG. Lines were fitted with orange balls and swinging plate diverters to increase line visibility (General Physics 2004, Harness et al 2003). Even with these retrofitting measures, line collisions continued to occur at Spesutie Island, until the lines were moved underground.

The National Bald Eagle Management Guidelines recommend siting lines away from eagle foraging and roosting concentration areas (Thompson 1978, USFWS 2007). This would reduce the risk of exposing large numbers of eagles to the hazards of electrical lines, as would avoiding perpendicular placement of lines, particularly <1 km from shorelines. Vegetation height and distance to foraging and roosting areas may be important factors influencing line-related mortality at other eagle concentration areas in the Chesapeake Bay and throughout the species range. We recommend siting new power lines to minimize collision risk near eagle roosts, monitoring existing lines in eagle concentration areas, and retrofitting lines and poles as needed using accepted and effective methods (APLIC 1994, 2006).

4.5.2.5 Acknowledgments

This work was funded by the U.S. Army. We thank the many Army personnel and game wardens who documented carcasses. Three anonymous reviewers provided comments and suggestions that improved the manuscript.

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Table 4.5.1. Bald Eagle injuries and mortalities associated with electrical lines on Aberdeen Proving Ground, MD, 1985--2007. Mortality events were significantly higher than expected for exposed lines within 1 km of shorelines.

HABITAT VARIABLE	EAGLE MORTALITIES	ELECTRICAL LINE (km)	DEVIATION (%)
Vegetation Height			
No Vegetation (Line exposed)	9	91.8	138
Vegetation below line	17	652.8	-37
Vegetation above line (Line concealed)	36	758.7	15
Shoreline Distance			
<300 m	16	75.0	417
300m--1000m	26	179.7	251
>1000 m	20	1248.6	-61

4.6 Chemical Contaminants

4.6.1 Chapter Background

Chemical contamination on APG has been widespread and complex for decades. The site was proposed to the National Priorities List (NPL) of the most serious uncontrolled or abandoned hazardous waste sites requiring long term remedial action on 10 April, 1985 and formally added to the list on 21 February, 1990. Documented contaminants include various volatile and semi-volatile organic compounds, metals, PCBs, pesticides, chemical warfare agent and their degradation products, and unexploded ordnance. Many of these compounds were implicated in bald eagle declines that lead to the initial listing of the species under the Endangered Species Act. One of the risks identified in the designation to the NPL was that the area is used by Bald Eagles.

Work Presented

Collection of tissues that were later analyzed for a limited range of contaminants was incidental to work being carried out on this project. However, we report on the findings of these analyses in the hope that results may be of some long-term value in assessing the risk of contaminants to the bald eagle breeding population. Two rounds of collections were performed. While banding and deploying transmitters on nestlings, we collected 1) addled eggs from nests, 2) feathers from nestlings, and 3) blood from nestlings. Addled eggs were used to assess contaminant burdens of adult females and remaining tissues were used to assess contaminant exposure of nestlings. Details of collections and results of analyses are presented in a report included here with the following citation –

Mojica, E.K. and B.D. Watts. 2008. Environmental Contaminants in Blood, Feathers, and Eggs of Bald Eagles on Aberdeen Proving Ground, Maryland in 2008. Center for Conservation Biology Technical Report Series, CCBTR-08-09. College of William and Mary, Williamsburg, VA. 18 pp.

Individual sample results are provided in Appendix 14. While visiting nests on APG, shed adult feathers were collected from the base of nest trees. These feathers were added to a larger set of feathers that had been collected over several years throughout the Chesapeake Bay to investigate mercury loads in breeding adults. Results of analyses are presented in a manuscript included here that was published in the journal Ecological Indicators with the following citation –

Cristol, D. A., E. K. Mojica, C. W. Varian-Ramos, and B. D. Watts. 2012. Molted feathers indicate low mercury in bald eagles of the Chesapeake Bay, USA. Ecological Indicators 18:20-24.

A reprint of this paper is provided in Appendix 15.

4.6.2 Environmental Contaminants in Blood, Feathers, and Eggs of Bald Eagles on Aberdeen Proving Ground

4.6.2.1 INTRODUCTION

Bald Eagle (*Haliaeetus leucocephalus*) populations across the lower 48 states have rebounded from 417 breeding pairs in 1963 (Sprunt 1963) to an estimated 5,478 in 1998 (Millar 1999). The Chesapeake Bay population grew exponentially from 73 pairs in 1977 to 601 pairs in 2001 (Watts et al. 2008). The population has continued to grow and now is estimated at over 1,000 breeding pairs (Maryland Department of Natural Resources 2004, Watts and Byrd 2008).

The recovery of eagle populations throughout most of their range prompted the US Fish and Wildlife Service (USFWS) to remove the species from the Endangered Species List in 2007 (USFWS 2007, Watts and Byrd 2008). Eagles remain protected under the federal Bald and Golden Eagle Protection Act, Migratory Bird Treaty Act, and Lacey Act (Millar 1999). Although breeding populations have recovered, many threats continue to affect breeding and non-breeding eagles. Current threats include electrocutions, line strikes, disease, contaminants, habitat loss, and vehicle collisions (Millar 1999, Millsap et al. 2004).

Concern over Bald Eagle deaths related to the electrical infrastructure at the US Army's Aberdeen Proving Ground (APG) prompted a Biological Assessment (BA) of the species under the Endangered Species Act in 2004. As a result of recommendations in the BA, the Army contracted with The Center for Conservation Biology at the College of William and Mary to study the mortality problems at APG.

APG manufactures, stores, and tests chemicals during military programs. Improper disposal of these chemicals in the past has led to the presence of contaminants in the soil and water on base. APG is actively cleaning up contaminated sites through the federal Superfund program but many contaminants continue to persist in the environment. Bioaccumulation of contaminants in Bald Eagles can reduce productivity and hatching rates and cause death by poisoning (Henny & Elliott 2007). In spring 2008, CCB biologists conducted a preliminary study of contaminants in APG eagles while visiting eagle nests on base.

4.6.2.2 Objectives

1. To determine mercury, pesticide, and PCB contaminant levels in nestling eagles
2. To determine contaminant levels in adult females by testing levels in non-viable eggs

4.6.2.3 Methods

Banding

Nests were accessed using standard arborist equipment when the chicks were between 32 and 45 days old. Chicks were lowered to the ground for banding, measurements, and tissue collection. The following morphometric measurements were taken on all chicks: weight, wing length, tail length, culmen length, culmen depth, hallux length, and tarsus length. Wing and tail length were measured with a ruler (± 1 mm) and culmen length, culmen depth, hallux length, and tarsus length were measured with dial calipers (± 0.1 mm). Eagles were weighed on a digital scale (± 1 g). Nestlings were marked with numeric federal bands (USGS Bird Banding Lab, Laurel, MD) on the right tarsus and purple alpha-numeric color bands (ACRAFT, Edmonton, Alberta) on the left tarsus. Banding and tissue collection was in accordance with state and federal permits.

Blood Sampling

One chick from each nest was selected for blood and feather contaminants sampling (Figure 4.6.1). Blood samples were collected from the brachial vein in the wing using 23 gauge butterfly needles and 4cc heparinized BD Vacutainers©. A maximum of 6cc of blood was collected from each eagle. Blood samples were immediately packed on ice and frozen within 4 hours of collection. Feathers were sampled from every chick handled and banded. Two feathers were pulled from the breast area and stored in a paper envelope. All samples were labeled with the eagle's band number and unique nest code. Eggs were washed with tap water and allowed to air dry, then wrapped in aluminum foil and frozen. Methodology for tissue collection was in compliance with protocols approved by the Institutional Animal Care and Use Committee at the College of William and Mary.

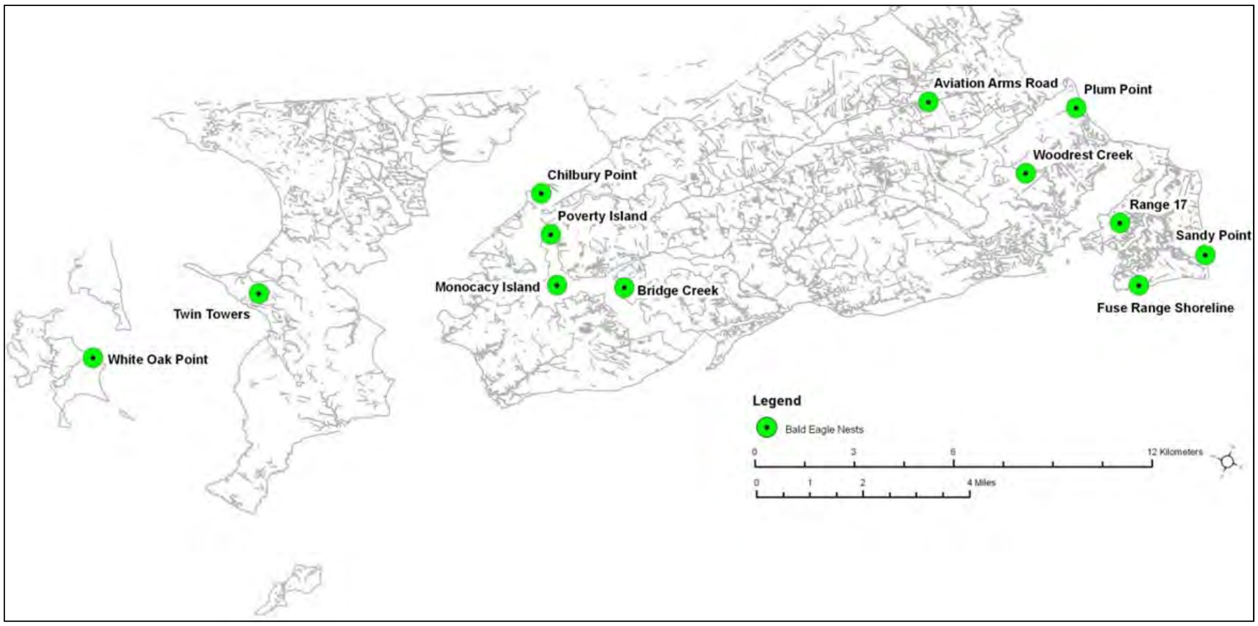

Figure 4.6.1. Bald Eagle nest climbed during the 2008 breeding season at APG.

Mercury

Mercury analysis took place in the Cristol Lab at the Department of Biology, College of William and Mary. Total mercury values of whole blood, breast feathers, and freeze-dried egg were analyzed using a Milestone® DMA 80 (direct mercury analyzer) using cold vapor atomic absorption spectroscopy (Brasso & Cristol, 2008). Two replicates from each sample were analyzed to validate homogeneity of Hg in samples. A blank was run every 20 samples to standardize equipment (Cristol *et al.*, 2008). Methyl mercury (MeHg), the form most available for uptake by birds, was assumed to compose 95% of the total Hg present in samples (Evers *et al.*, 2005) and was not analyzed separately. Feather mercury levels represent total body burden from the time of the last molt, which in nestlings was 2-3 weeks prior to sampling. Blood mercury represents recent dietary uptake (DeSorbo *et al.*, 2008). All Hg data are reported as wet or fresh weight values.

Persistent organic pollutants

Persistent organic pollutants were analyzed at the Hale Lab at the Virginia Institute of Marine Science, College of William and Mary. Whole blood and egg samples were freeze-dried for 48 hours before compound extraction. Extracts were analyzed using gas chromatography and mass spectrometry (Chen *et al.*, 2008). Blood and egg samples were analyzed the following pesticides: *trans*-chlordane, MC5, *cis*-chlordane, *trans*-nonachlor, *cis*-nonachlor, DDMU, p,p'-DDE, p,p'-DDD, p,p'-DDT. Egg samples were additionally tested for heptachlore epoxide isomer B, oxychlordane, MC6, MC8, and MC3. Samples were also tested for polychlorinated biphenyls (PCBs) including: PCB-28/31, PCB-33/20, PCB-22, PCB-52, PCB-49, PCB-47/48/75, PCB-44, PCB-42/59, PCB-71, PCB-103, PCB-100, PCB-63, PCB-74, PCB-70/95/66, PCB-91, PCB-56/60, PCB-92, PCB-84, PCB-101/90, PCB-99, PCB-119, PCB-83, PCB-97, PCB-117, PCB-87/115, PCB-85, PCB-136, PCB-110, PCB-77, PCB-151, PCB-135, PCB-144, PCB-147, PCB-107/123, PCB-149, PCB-118, PCB-134, PCB-114, PCB-165, PCB-146, PCB-153/132, PCB-105, PCB-179, PCB-141, PCB-137, PCB-176, PCB-130, PCB-164/163, PCB-138/158, PCB-178, PCB-175, PCB-187, PCB-183, PCB-128, PCB-167, PCB-185, PCB-174, PCB-177, PCB-202, PCB-171, PCB-156, PCB-201, PCB-172, PCB-197, PCB-180/193, PCB-191, PCB-200, PCB-170/190, PCB-199, PCB-203/196, PCB-189, PCB-208, PCB-195, PCB-207, PCB-194, PCB-205, PCB-206, and PCB-209.

4.6.2.4 Results

Banding

A total of 19 nestlings from 12 eagle nests were banded and processed during the 2008 breeding season. The single chick in the Fuze Range Shoreline nest (ATC 72, MDDNR HA-08-06) exhibited symptoms of poor nutrition or health. All 19 chicks survived to fledging age (60-75 days old; EA Engineering pers. comm.).

Mercury

Mercury levels were subacute in all eagles sampled. Individual Hg blood values ranged from 0.0149-0.0369 ($\bar{x}$ = 0.0288) mg/kg (ppm). Individual feather mercury values ranged from 0.4761-1.1925 ($\bar{x}$ = 0.8163) mg/kg (Appendix 14). The single addled egg had a mercury value of 0.0995 mg/kg (Table 4.6.1).

Table 4.6.1. Mean mercury values sampled from Bald Eagle chicks by nest territory. Values are in mg/kg (ppm) fresh wet weight.

Nest Territory	ATC	MD DNR	*n*	Feather Hg	*n*	Blood Hg	*n*	Egg Hg
Bridge Creek	69	HA-08-03	2	0.7365	1	0.0300	0	------
White Oak Point	59	BA-07-03	3	0.7454	1	0.0223	0	------
Chilbury Point	67	HA-07-07	2	0.5589	1	0.0149	0	------
Poverty Island	19	HA-03-08	2	1.1828	1	0.0363	0	------
Monocacy Tower	65	HA-07-03	1	0.9460	0	------	0	------
Range 17	73	HA-08-07	2	0.9228	1	0.0255	0	------
Fuze Range	72	HA-08-06	1	0.7103	1	0.0302	0	------
Towner Cove	10	HA-00-05	1	0.5290	1	0.0332	0	------
Plumb Point	55	HA-06-01	1	0.8408	1	0.0303	0	------
Woodrest Creek	13	HA-96-02	2	0.8406	1	0.0280	0	------
Aviation Arms	17	HA-95-07	1	0.7570	1	0.0287	0	------
Twin Towers	41	HA-99-08	1	1.0080	1	0.0369	1	0.0995

Persistent organic pollutants

Total PCB levels (sum of all congeners) in nestling blood ranged from 0.037-0.106 ($\bar{x}$ = 0.055) µg/g (ppm) wet weight (Table 4.6.2, Appendix 14). Total Chlordane levels in blood ranged from 0.007-0.017 ($\bar{x}$ = 0.010) µg/g (ppm) wet weight (Appendix 14). DDE values ranged 0.009-0.300 ($\bar{x}$ = 0.016) µg/g (ppm) wet weight. Egg levels were higher with total PCB levels at 33.69 ppm (Figure 4.6.2) and DDE at 8.10 ppm (Table 4.6.3).

Table 4.6.2. Organic pollutant values in nestling Bald Eagle blood by nest territory. Values in µg/g (ppm) wet weight.

Nest Territory	*n*	ATC	MD DNR	Σ PCBs	Σ Chlordane	Σ DDT
Aviation Arms	1	17	HA-95-07	0.0451	0.0084	0.0118
Chilbury Point	1	67	HA-07-07	0.1060	0.0173	0.0356
Fuze Range	1	72	HA-08-06	0.0568	0.0079	0.0180
Plumb Point	1	55	HA-06-01	0.0614	0.0098	0.0207
Poverty Island	1	19	HA-03-08	0.0636	0.0090	0.0164
Range 17	1	73	HA-08-07	0.0450	0.0091	0.0123
Towner Cove	1	10	HA-00-05	0.0367	0.0065	0.0196
Twin Towers	1	41	HA-99-08	0.0547	0.0089	0.0162
White Oak Point	1	59	BA-07-03	0.0422	0.0115	0.0214
Woodrest Creek	1	13	HA-96-02	0.0382	0.0089	0.0189

Table 4.6.3. Organochloride contaminants detected in a single Bald Eagle egg from the Twin Towers nest during the 2008 breeding season.

Contaminant	µg/g ww
Heptachlore epoxide isomer B	0.041
MC3	0.144
MC5	0.690
MC6	0.038
MC8	0.029
Oxychlordane	0.152
Cis-chlordane	0.285
Trans-chlordane	0.041
Cis-nonachlor	0.345
Trans-nonachlor	1.580
Σ Chlordane	**3.345**
DDMU	0.688
p,p'-DDE	8.070
p,p'-DDD	0.602
p,p'-DDT	0.108
Σ DDT	**9.468**
Σ PCBs	**33.693**

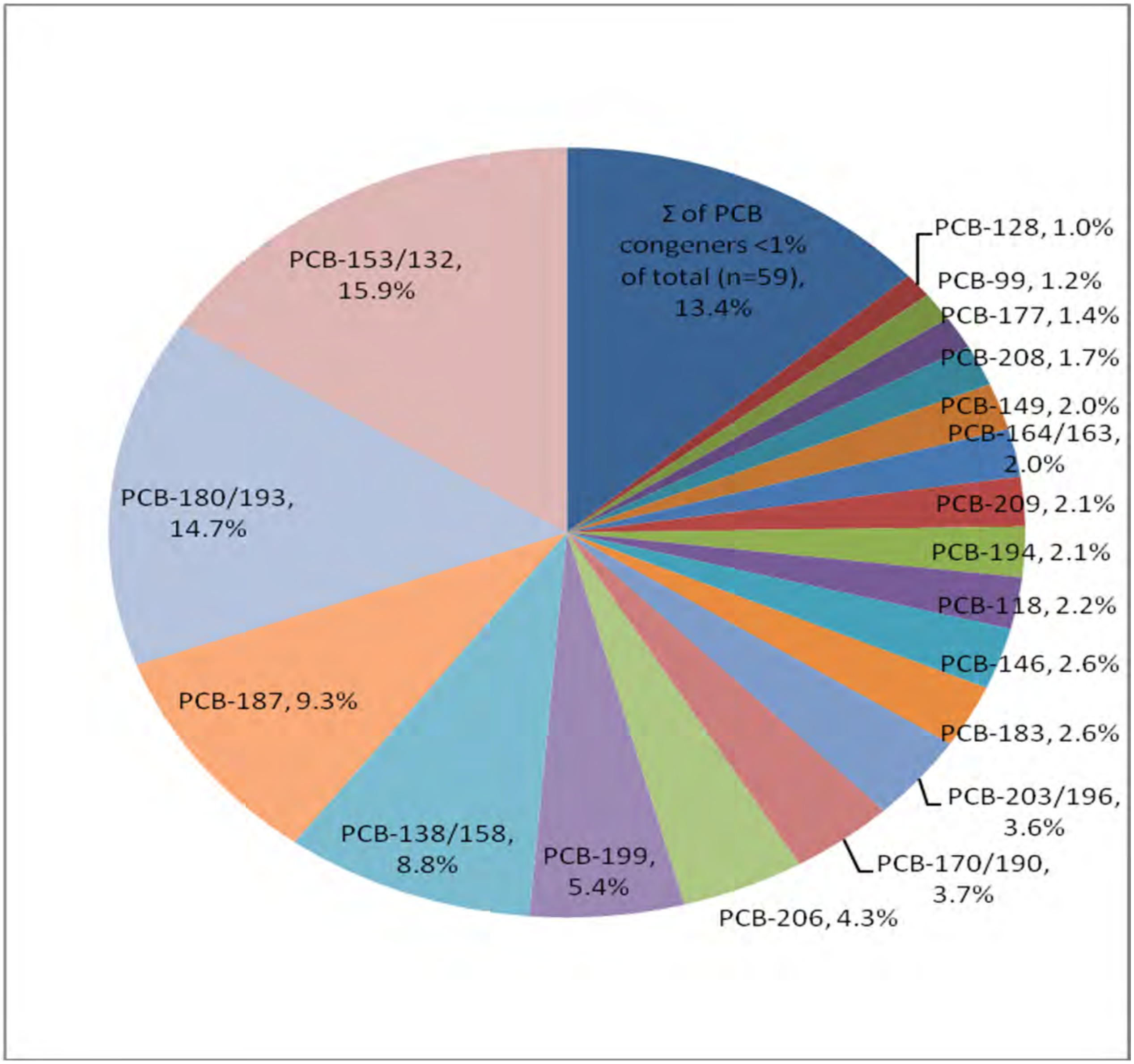

Figure 4.6.2. PCB congeners in a Bald Eagle egg collected from Twin Towers nest, Aberdeen Proving Ground, MD in May 2008.

4.6.2.5 Discussion

Mercury

Contaminant levels in eagle blood represent a short-term view of overall contaminant exposure because nestling eagles deposit ingested contaminants into growing feathers, organs, and other tissues (DeSorbo *et al.*, 2008). Mercury contamination in nestling blood and feathers was minimal and less than values reported from other nestling studies in North America (Table 4.6.4). The single egg had a mercury level of 0.09 ppm, less than the 0.5-1.5 ppm historically thought to reduce productivity rates in eagles (Wiemeyer *et al.*, 1984). Toxicity thresholds are unknown for nestling eagles based on blood and feathers and the threshold is uncertain in adult eagles. A recent Bald Eagle study near a mercury mine in British Columbia, observed no reproductive effects or signs of MeHg toxicity in adults with blood concentrations near 10 µg/ml (ppm) (Weech *et al.*, 2006). A similar study in the Great Lakes did not find a relationship between elevated mercury levels (3.7-66.0 mg/kg) in adult eagle feathers and reproduction, productivity rates or nesting success (Bowerman *et al.*, 1994). The egg from APG had a mercury level of <0.1 mg/kg, suggesting the adult female also had low levels of mercury at the time of laying.

Persistent organic pollutants

Organochloride blood levels at APG were within the range of values reported by other eagle nestling studies (Table 4.6.5) and below toxicity thresholds for the species (Elliott & Harris, 2002; Henny & Elliott, 2007). The single addled egg collected from the Twin Towers nest, however, had levels above toxicity thresholds for both DDE and PCBs (Elliott & Harris, 2002; Henny & Elliott, 2007). Levels were above the embryo lethality level for DDE (5.5 mg/kg) and reproductive impairment level for PCB (20 ppm) (Elliott & Harris, 2002; Henny & Elliott, 2007).

DDE and PCBs bioaccumulate over time in adipose tissue and are deposited during egg formation. Because these contaminants bioaccumulate over time, it is unknown whether the Twin Towers adult female ingested the contaminants near the nest or elsewhere. The egg from Twin Towers had over 1.5 times higher PCB levels than the average level recorded in eagle eggs collected from the Chesapeake Bay in the 1970s (Wiemeyer et al., 1984). DDE levels were comparable to the 1970s levels. The toxic PCB and DDE levels found in the Twin Towers egg likely contributed to reproductive failure.

Several PCB congeners are present in APG eagle blood and egg tissue that are not present in eagles sampled from another Maryland military base (Figure 4.6.3). These PCBs may have originated from past chemical manufacturing on APG. A larger sample size of addled eggs and nestling blood is required to determine how widespread the contamination is among APG eagle nests and determine their effects on reproduction rates.

Table 4.6.4. Comparable mercury values from Bald Eagle nestlings and eggs in North America. All values in mg/kg (ppm) wet weight.

Tissue	Region	n	Mean	Range
Feathers				
	APG	**19**	**0.82**	**0.47-1.19**
	NSF Indian Head, MD[a]	18	1.22	0.84-1.80
	Klamath River Basin[b]	5	2.17	------
	South Carolina[c]	34	3.08	0.61-6.67
	Florida[d]	61	4.05	0.76-14.3
	Great Lakes[e]	115	9	1.50-27.0
Blood	**APG**	**10**	**0.03**	**0.01-0.04**
	NSF Indian Head, MD	18	0.05	0.03-0.07
	South Carolina[c]	34	0.10	0.02-0.25
	Florida[d]	48	0.17	0.02-0.61
	Klamath River Basin[b]	9	0.23	0.08-0.65
	Columbia River[f]	15	0.47	0.19-1.40
	New York[g]	16	0.52	0.12-1.19
	Oregon[h]	82	1.2	nd - 4.20
Egg	**APG**	**1**	**0.10**	------
	NSF Indian Head, MD[a]	1	0.09	------
	Chesapeake Bay[i]	26	0.07	0.00 - 0.17
	Columbia River[f]	13	0.2	0.13-0.36
	Toxicity threshold[i]		*0.5-1.5*	

nd = contaminant not detected
[a] Mojica & Watts 2008, [b] Frenzel & Anthony, 1989, [c] Jagoe *et al.*, 2002, [d] Wood *et al.*, 1996, [e] Bowerman *et al.*, 1994, [f] Anthony *et al.*, 1993, [g] DeSorbo *et al.*, 2008, [h] Wiemeyer *et al.*, 1989, [i] Wiemeyer *et al.*, 1984

Table 4.6.5. Comparable organochloride contaminant levels in Bald Eagle nestling blood and eggs. All values in ppm wet weight.

Tissue	Region	*n*	DDE Mean	DDE Range	*n*	PCB Mean	PCB Range
Blood	**APG**	10	**0.016**	**0.009-0.300**	**10**	**0.055**	**0.037-0.106**
	NSF Indian Head, MD[a]	18	0.013	0.01-0.02	18	0.043	0.021-0.080
	Newfoundland[b]	23	0.005	0.002-0.041	23	0.025	0.008-0.133
	British Columbia[c]	31	0.014	0.003-0.057	31	0.029	0.001-0.097
	Oregon[d]	75	0.015	nd-0.15			
	California[c]	3	0.041	0.018-0.123	3	0.011	0.065-0.021
	Columbia River[e]	15	0.050	0.01-0.24	15	0.040	nd-0.130
	Great Lakes[f]				30	0.130	0.009-0.326
	Toxicity threshold[g]		41.000			189.000	
Egg	**APG**	**1**	**8.1**	------	**1**	**33.69**	------
	NSF Indian Head, MD[a]	1	3.8	------	1	18.43	------
	Florida[h]	15	4.7	2.0-18.0	8	7.89	5.7-22.0
	Columbia River[e]	17	9.7	4.0-20.0	17	12.70	4.8-26.7
	Great Lakes[f]	6	10.8	2.7-22.2	6	26.40	11.7-43.7
	Chesapeake Bay[j]	26	11.9	3.3-26.0	26	25.00	8.9-218.0
	Toxicity threshold[g]		*5.5*			*20.00*	

nd = contaminant not detected
[a]Mojica & Watts 2008; [b]Dominguez *et al.* 2003; [c]Cesh *et al.* 2008; [d]Wiemeyer *et al.* 1989; [e]Anthony *et al.* 1993; [f]Donaldson *et al.* 1999; [g]Elliott & Harris 2002, Henny & Elliott, 2007; [h]Forrester & Spalding 2003; [i]Wiemeyer *et al.* 1984

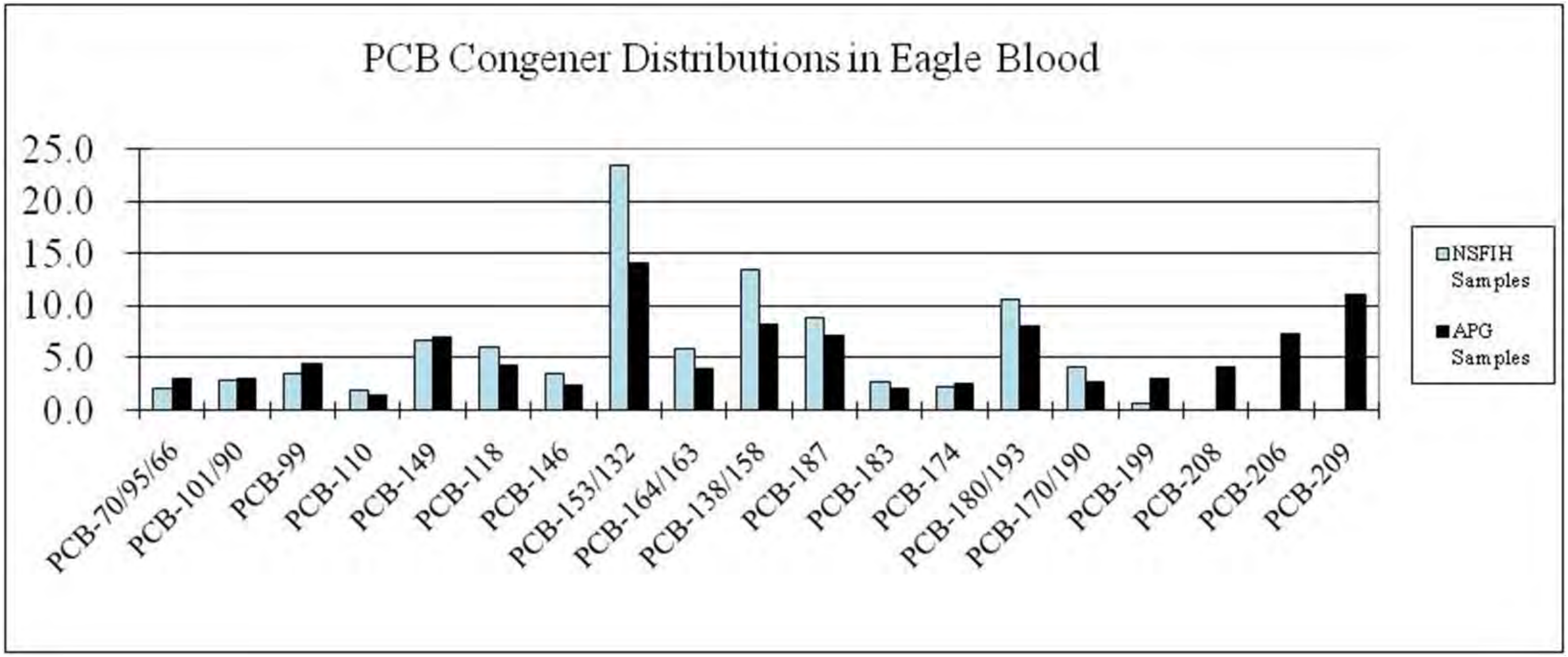

Figure 4.6.3. Comparison of PCB congeners in Bald Eagle nestling blood from Aberdeen Proving Ground, MD and Naval Support Facility Indian Head, MD. Data values in ng/g fresh weight (PPB).

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4.6.3 Mercury in molted eagle feathers

Abstract. Mercury is a potent neurotoxin affecting birds and other wildlife worldwide. Bald eagles (*Haliaeetus leucocephalus*) are vulnerable to mercury bioaccumulation because they are high in the food web and associated with aquatic ecosystems prone to mercury methylation. Eagle populations, long endangered in the continental United States by contaminants and persecution, are recovering throughout their range. We used single adult eagle feathers collected beneath 83 occupied nests to show that mercury levels in the Chesapeake Bay eagle population are the lowest in North America (3.82 ± 5.15 ug/g dry weight). We then used 20 feathers from each of 20 salvaged eagles to calculate a confidence interval around the estimate based on single feathers from nesting eagles. Using an inexpensive and non-invasive method to assess mercury burdens we have demonstrated that few Chesapeake Bay bald eagles were above levels suspected of causing reproductive or survival effects in birds.

Keywords: Bioindicator; Feather; *Haliaeetus leucocephalus*; Mercury

4.6.3.1 Introduction

Mercury contamination poses a threat to wildlife in ecosystems worldwide, particularly large, predatory species such as bald eagles (*Haliaeetus leucocephalus*). Mercury can affect behavior and reproduction in birds, and high levels in the diet can cause mortality (Seewagen, 2010). Bald eagles have been the focus of conservation efforts for decades, and populations are stable or increasing throughout the contiguous United States (Suckling and Hodges, 2008). Because eagles feed on large prey at the top of aquatic food chains they are prime candidates for elevated mercury contamination. Eagle tissues have frequently been monitored for contaminants, and they typically have mercury levels above published levels of concern for birds (Bechard et al., 2009). No data on mercury concentrations in adult eagle tissues have been published for the mid-Atlantic region of the United States (for eggs, see Wiemeyer et al., 1984), which includes Chesapeake Bay and is one of the bald eagle's major population strongholds. Chesapeake Bay (Fig. 4.6.4), the largest estuary in North America, has numerous tributaries that are subject to mercury fish consumption advisories and contains fish species with elevated methylmercury concentrations (Mason et al., 2006).

Recent research on avian mercury concentrations, especially for species of conservation concern, has focused on non-lethal sampling techniques, such as analysis of addled eggs, blood and feathers. Feathers accumulate mercury from the blood supply only during the few weeks that they are growing, but mercury concentration established at that time remains stable indefinitely and can be used to track historical trends in environmental mercury (Appelquist et al., 1984, Thompson et al. 1992). A feather that is grown on a breeding territory one summer, carried throughout the year, and molted near the nest the following summer will provide information about mercury in the diet during the weeks or months prior to the previous breeding season. Because eagles are highly territorial, and use the same territories for multiple years, freshly shed adult feathers collected near nests during the breeding season are likely to bear reliable information about mercury exposure on that territory. Even if the parents migrated, shifted diets, or altered their territory boundaries during the non-breeding season, feather mercury will not be affected by these changes. Sampling freshly molted feathers is a non-invasive and inexpensive way to monitor mercury exposure (Furness et al., 1986), but little has been published about the reliability of this increasingly popular technique (however, see Bond and Diamond, 2009). Thus, one objective of this study was to determine whether sampling a single adult eagle feather near a nest provides meaningful assessment of the overall mercury concentration in the parents' plumage.

The other objective of this study was to determine whether adult bald eagles breeding in the Chesapeake Bay are accumulating mercury at concentrations comparable to those reported for bald eagles in other parts of North America. These results are important because 1) they fill a major gap in the continent-wide assessment of contaminant levels in this important bioindicator species, 2) they establish a baseline against which to compare data gathered after any future change in mercury pollution policy, and 3) they are a first step in determining whether mercury is an ongoing conservation concern for this formerly endangered species.

4.6.3.2 Materials and methods

Sample collection

At 83 occupied eagle nests, a single body feather, determined to belong to an adult bird by wear, color and texture, was collected from the ground within 50 m of the nest in June-October 2007-2009. Chesapeake Bay bald eagles are territorial and resident year-round, and during or after nesting, adults frequently shed molted feathers while roosting or feeding on their nest tree or neighboring trees. It was not known whether the collected feather was from the male or female parent, but sampled feathers had been shed within a few weeks of collection based on condition and location. Because eagles in this population defend nest sites year-round, it is extremely unlikely that birds other than the parents would shed a feather near a nest tree. Feathers were stored at room temperature in a paper envelope until analysis for mercury concentration. Nests were located on all of the major tributaries of the Chesapeake Bay in Maryland and Virginia, USA (Fig. 4.6.4).

To determine the variance among body feathers on individual eagles, 20 body feathers were sampled from each of 20 adult eagles. These were either salvaged after accidental powerline electrocution, by the authors under permit ($n = 6$), or were injured or dead eagles ($n = 14$) found by the public and sampled by staff at The Wildlife Center of Virginia, in Waynesboro (www.wildlifecenter.org). Feathers were plucked or clipped at the base, 10 from the breast and 10 from the back, avoiding feathers from adjacent areas that likely molted simultaneously. Birds that had been in captivity for more than a few days, and thus might have molted feathers on a provisioned diet, were excluded.

Mercury analysis

Samples were analyzed between 17 December 2009 and 5 March 2010 on a Milestone DMA-80 (Milestone, Shelton, CT). Each feather was washed with deionized water for 1 min to remove particulates, dried in a low humidity chamber for 48 h, and chopped into 1 mm pieces and mixed by hand for 1 min. Reported mercury values are for dry weights, although it should be noted that we did not freeze-dry feathers. In most cases, two samples weighing approximately 0.02 g were run from each feather and their mercury value averaged; for smaller feathers the mercury value was based on one sample weighing approximately 0.02 g. Two blanks, two method blanks, and two samples of each of two certified reference materials (DORM-3, DOLT-4, National Research Institute, Canada) were run with each batch of 20 samples. The mercury analyzer was calibrated prior to the first samples being run and monthly thereafter. The factory calibrated minimum detection limit for the analyzer is 0.005 ng mercury. Recovery of standard reference materials was 103.0 ± 3.9% for DORM-3 ($n = 106$) and 99.3 ± 4.8% for DOLT-4 ($n = 106$) (means presented with SD throughout). When we spiked chopped domestic bird feathers with DOLT-4 ($n = 10$), recovery was 100.0 ± 1.5%. The mean relative percent difference between pairs of feather samples run as duplicates was 7.0 ± 6.6% ($n = 111$).

Statistical methods

In order to assess the accuracy of using a single feather to estimate feather mercury levels in an individual eagle, we used the 20 feathers collected from each of 20 eagles found injured or freshly dead. We determined mercury concentration in each feather separately and calculated an average mercury concentration for each bird based on all 20 feathers. We then calculated the coefficient of variance (CV = standard deviation/mean) for each bird and calculated the average CV for all 20 birds. We then used the average CV to approximate a standard deviation (SD) around a single feather measurement (~SD = feather value * average CV).

To evaluate the optimal number of feathers to collect per bird in future studies we used a bootstrap resampling in which we selected a feather value at random from any of the 20 birds from which we had 20 feathers. We then calculated the percent difference of the mercury concentration of that feather from the mean feather mercury concentration based on 20 feathers from the same eagle. We repeated this process 10,000 times and determined mean difference of a single feather from the 20-feather mean for the same bird. We then repeated this process selecting 2 to 20 feathers at random with replacement and calculating a mean based on each number of feathers sampled and comparing that to the 20-feather mean. This allowed us to determine how much accuracy is gained by sampling each additional feather from a bird. It should be noted that this calculation was based on feathers known to be from the same bird.

4.6.3.3 Results and Discussion

Single feathers as bioindicators

Resampling of 20 feathers from 20 eagles indicated that variation in mercury concentration among feathers on a single bird was relatively high. Only 15.1% of feathers had mercury concentrations within 5% of the mean concentration based on 20 feathers from the same bird, 38.3% of feathers were within 10% of the mean, and 71.9% of feathers were within 25% of the mean. The variation in mercury concentrations among feathers from a single individual is likely explained by the fact that Bald Eagles rarely, if ever, replace all body feathers within a single molt (Pyle 2008), thus feathers collected may represent mercury burdens over several years. We calculated a 95% confidence interval around any given feather of 50.1%, which is applicable to the single feathers we collected from eagle nests in evaluating whether they are above or below levels of concern, and has applicability to any estimate based on a single feather. To produce an estimate that was within 10% of the mean based on 20 feathers one would have had to sample >4 feathers from a single bird at each nest (Fig. 4.6.2). It has long been appreciated that collecting more than one feather per individual is desirable for mercury sampling (Furness et al. 1986; Thompson et al., 1991), and high intra-individual variation was reported based on five feathers from individual seabirds (Bond and Diamond, 2010). Our results are the first statistically derived guideline for the minimum number of feathers to sample, and more importantly we are the first to estimate a population-level mercury concentration with a confidence estimate based on collecting single feathers. Because feathers sampled from beneath a nest can come from both members of the pair if they are molting simultaneously, the recommended sample size presented here is applicable when only one member of a pair is molting, when feathers can be collected under a roost used exclusively by one member of the pair, or if feathers are otherwise known to be from the same bird (e.g. collected during capture). It should also be noted that intra-individual plumage variance might be greater in areas with higher mercury exposure than experienced by the 20 injured birds and carcasses we sampled (4.27 ± 3.80 ppm; range 0.51 - 13.1 ppm), and thus more feathers should be sampled from each individual at such sites.

Mercury concentration

There was no indication of particular mercury hotspots or geographic trends, with the birds highest in mercury scattered around the study area (Fig. 4.6.1). However, it should be noted that sampling of the eastern shore of the Chesapeake Bay was not extensive. The average concentration of mercury in the feathers of bald eagles sampled in the Chesapeake Bay region was 3.82 ± 5.15 ppm. Based on the 95% confidence interval calculated, the mean plumage mercury concentration for the nesting eagles we sampled was between 1.91 and 5.73 ppm. Because we washed feathers in water, rather than a solvent, traces of exogenous mercury or mercury from preen gland oil may have been present and this range may be an overestimate.

In a recent study (2004-2006) from the northeastern USA, feathers from adult eagles in freshwater habitats in Maine averaged 38.3 ppm (DeSorbo et al., 2009). A less recent study from the southeastern USA reported 11.5 ppm in Florida in 1991-1993 (Wood et al., 1996). Overall, the levels we report for the Chesapeake Bay are the lowest eagle feather values yet sampled in North America and we have documented the first population in which nearly all individuals are below the typical level of concern for feather mercury (Table 4.6.6). This low mercury level, relative to other regions, is consistent with the robust recovery and rapid population growth rate observed in the region (Watts et al., 2008).

Is mercury affecting bald eagles?

It is not yet possible to set a reliable lowest observed adverse effects level for bald eagles based on literature from this or any other bird species. The lowest level commonly cited in the literature for feather concentrations is 5 ppm (fresh weight, 7.5 ppm dry weight), which is based on a widely cited review by Eisler (1987) but not on data from raptors or free-living birds. Another feather mercury value, 40 ppm, is sometimes cited as being associated with sub-lethal effects in free-living individual birds, based primarily on a study of feather asymmetry in common loons (Evers et al., 2008) and declines in populations of European raptors during a period of heavy environmental mercury exposure (usually attributed to Berg et al., 1966). In contrast, a recent dosing study in which captive raptors ate a diet containing 3 ppm mercury and attained primary feather mercury levels of 275 ppm suggests that reproduction and health were not compromised over a short time span even with exposure resulting in extremely high feather levels (Bennett et al., 2009). The range of values for possible adverse effects spans almost two orders of magnitude and is therefore nearly useless. In addition, the evidence linking effects and particular mercury levels is mostly indirect. Further work is urgently needed to establish lowest observed adverse effects levels for sub-lethal effects in birds.

Recent research on free-living tree swallows (a songbird, *Tachycineta bicolor*) with an average of 14 ppm in primary feathers molted on site suggests that the birds experienced reproductive, immunological and endocrine effects (Brasso and Cristol, 2008; Hawley et al., 2010; Wada et al., 2010). Heinz et al. (2009) compared sensitivity to injected mercury of embryos across many avian species, and found that the two raptors included in the study were highly sensitive to mercury, in contrast to tree swallows, which were moderately sensitive, and mallards (*Anas platyrhynchos*), which had low sensitivity. This suggests that a prudent estimate for the low adverse effects level in adult eagle feathers would be concentrations below the 14 ppm, as this have been shown to affect the less-sensitive tree swallow. A level of 9-11 ppm in primary ("forewing") feathers impacted mallard reproductive behavior when carefully monitored in captivity (Heinz 1979). Because raptors are more sensitive than either tree swallows or mallards (Heinz et al. 2009), it would be reasonable to expect reproductive or health effects in eagles at levels somewhat below the 9-14 ppm range in primary feathers. Bowerman et al. (1996), working with bald eagles, reported no difference in mercury value for body feathers (used in the present study) and primary feathers (used in the mallard and swallow studies cited above), although the timing of migration and location of molt would cause this to be true only for certain individuals, populations and species.

While there was variation in mercury level between individual Chesapeake Bay eagles, only one of the 83 sampled had a mercury level (47.6 ppm) clearly warranting concern based on current literature described above, and only 11 birds (13%) were above 5 ppm, the lowest level of concern ever stated in the literature (Eisler, 1987).

4.6.3.4 Conclusions

We found that collecting single molted feathers from beneath bald eagle nests provides an estimate of mercury concentration that was sufficient to assess whether the population is experiencing exposure to levels of mercury stated to be harmful in the literature on birds. Using larger samples of feathers from injured and dead birds, we showed that for this species, despite considerable variation between individual feathers, collecting five feathers from individual birds should suffice to provide an estimate that is within 10% of the value of that bird’s plumage. Feathers from adult bald eagles nesting on the Chesapeake Bay, Virginia and Maryland, USA, had the lowest mercury levels ever reported for a population of this species in North America. Mercury level in most individuals was below all cited thresholds of concern for sub-lethal effects. Sampling species of conservation concern for contaminants can be expensive and invasive. Many studies have been performed in the past using feathers, typically more than one, to estimate mercury levels (Furness et al. 1986; Thompson et al., 1991, 1992). We suggest that expensive and invasive sampling of blood or other tissues for mercury is sometimes not warranted given the utility of sampling molted feathers.

4.6.3.5 Acknowledgements

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Table 4.6.6. Average bald eagle feather mercury (Hg) levels from North American states and provinces.

Location	Hg (ppm)	Date	Source
Virginia/Maryland	3.8	2007-2009	Body feathers; this study
Alaska	5.1	2004	Wing feathers; Burger & Gochfeld 2009
Florida	11.5	1991-1993	Body feathers; Wood et al. 1996
Idaho	18.7	2004-2006	Mixed feathers; Bechard et al. 2009
British Columbia[a]	21.0	2001-2002	Wing feathers, Weech et al 2006
Michigan	21.5	1985-1989	Mixed feathers; Bowerman et al. 1994
New York	30.9	1998-2006	Mixed feathers; DeSorbo et al. 2008
Maine	38.3	2001-2006	Mixed feathers; DeSorbo et al. 2009

[a]Sites included a lake impacted by a mercury mine.

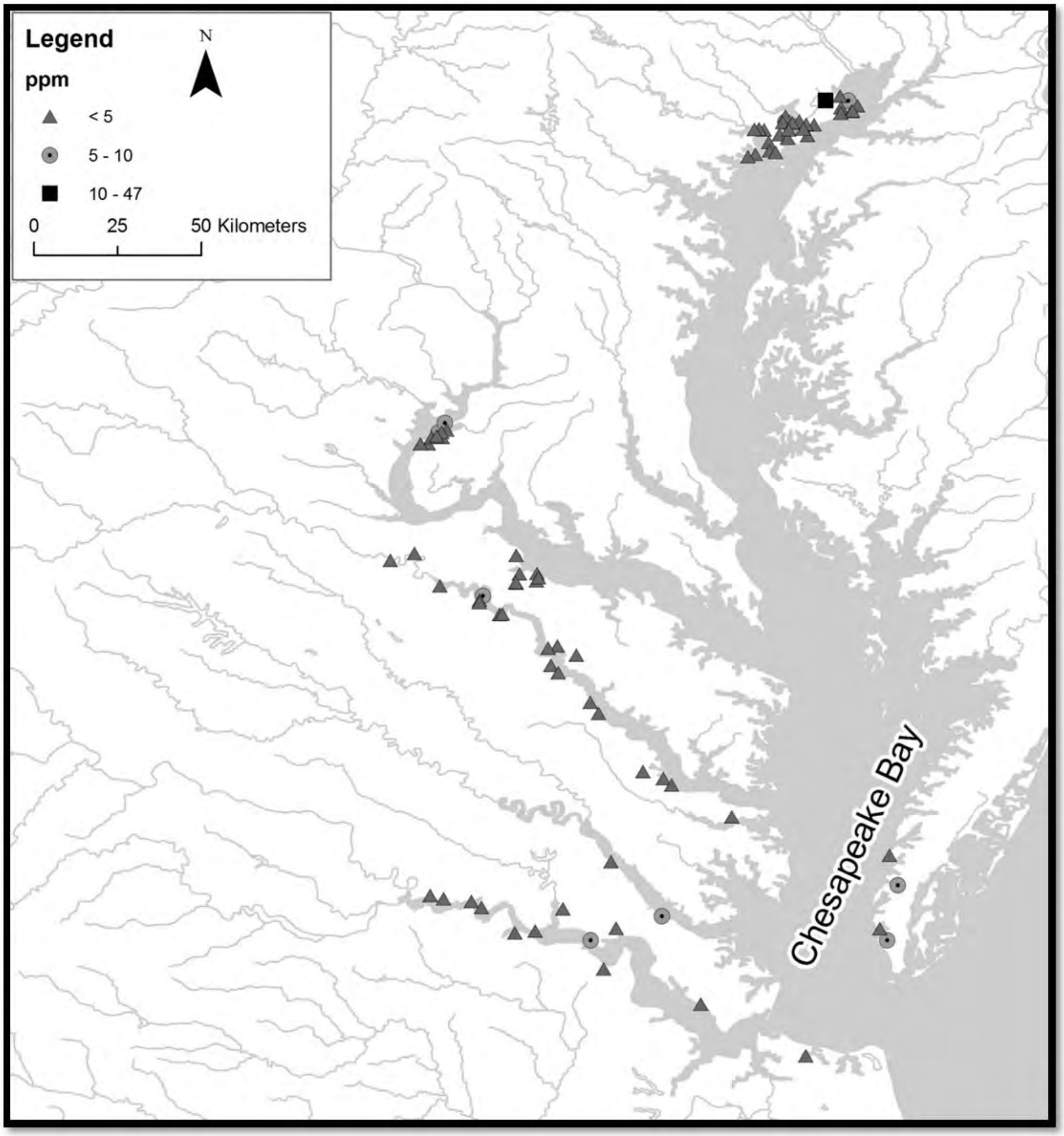

Figure 4.6.4. Distribution of samples across Chesapeake Bay, with each symbol indicating one adult eagle feather mercury level.

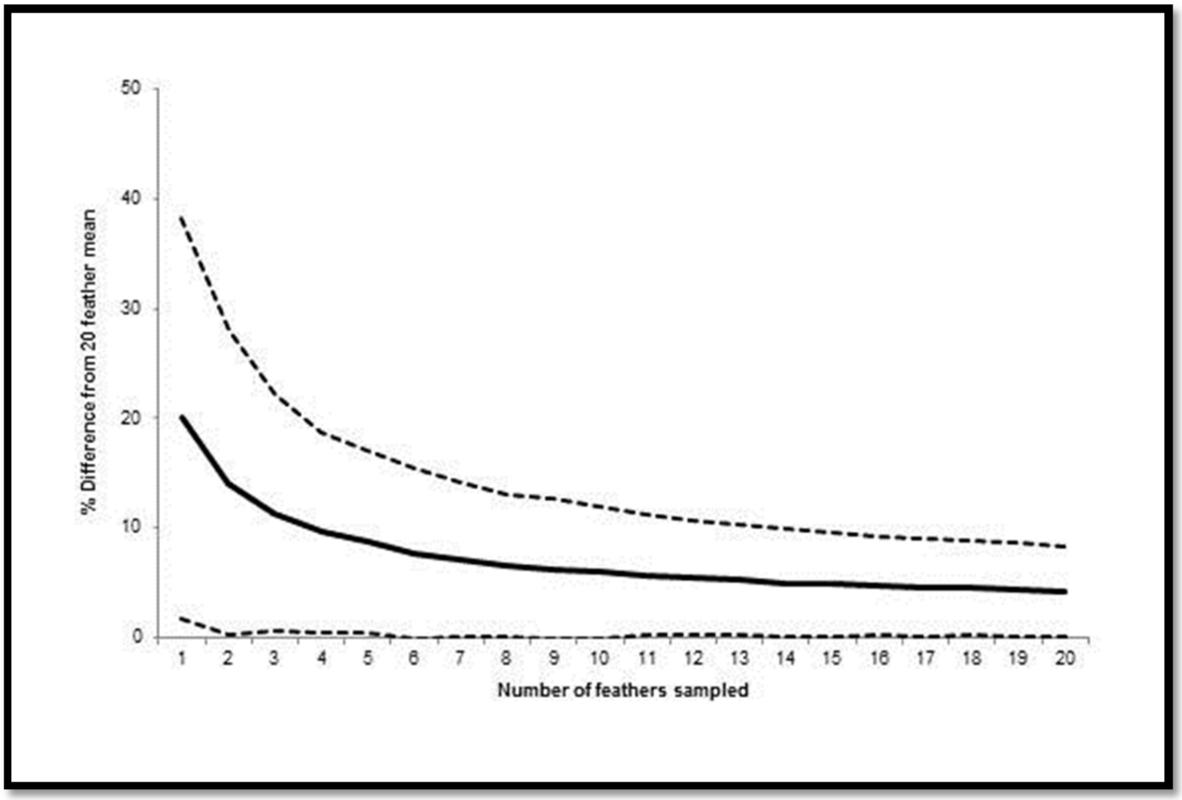

Figure 4.6.5. Results from bootstrapping model of the accuracy of using different numbers of feathers to estimate mean feather mercury. Solid line is the average percent difference of the mean using various numbers of feathers from the 20-feather mean. Dashed lines are one standard deviation around the mean.

4.7 APG Bald Eagle Breeding Population Recovery

4.7.1 Chapter Background

As with several government properties within the Chesapeake Bay, APG is increasingly important to the conservation of eagles within the mid-Atlantic region. The undeveloped shorelines and associated uplands exist in stark contrast to the surrounding urban landscape and represent a stronghold for the breeding population. Over the past 20 years the growth rate of the population on APG has matched some of the fastest growing populations throughout the species range. This growth has been documented through an annual monitoring program that is designed to track the population and is critical to the close management of breeding pairs while maintaining the military mission.

Work Presented

We have interpreted observations from annual surveys and translated them into population parameters that conform to national standards. The population-level results of annual surveys (1991-2011) have been produced and included here as a manuscript for submission to a regional journal. The manuscript has the following citation –

Watts, B. D., E. K. Mojica, J. T. Paul, and J. Pottie. 2012. Recovery of breeding bald eagles on Aberdeen Proving Ground, MD.

4.7.2 Recovery of Breeding Bald Eagles on Aberdeen Proving Ground, MD

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Abstract: We conducted annual aerial surveys (1991-2011) for breeding bald eagles (*Haliaeetus leucocephalus*) within Aberdeen Proving Ground (APG), a 350-km^2 military installation located along the northwestern shoreline of the upper Chesapeake Bay in Maryland. The population increased exponentially from 1 pair in 1977 to 58 pairs in 2011 with an average doubling time of 5.8 years. This rate was higher than that documented for the broader Chesapeake Bay and is comparable to the highest reported throughout the species range. Annual population increase was highly variable and exhibited no indication of any systematic decline. A total of 640 chicks were produced from 464 breeding attempts during this period. The population has exhibited tremendous forward momentum such that more than 50% of young produced over the 21-year period were produced in the last 6 years. Average success rate was high (79.6%) and reproductive rates exceeded conservation targets in nearly all years. Due to the expansion of urban development throughout the Chesapeake Bay watershed, APG plays an increasingly important role in the recovery and maintenance of the Chesapeake Bay bald eagle population.

Keywords: Bald Eagle, *Haliaeetus leucocephalus*, breeding, Aberdeen Proving Ground, recovery, Department of Defense

Bald Eagles (*Haliaeetus leucocephalus)* have likely bred on the land currently occupied by Aberdeen Proving Ground (APG) for thousands of years. However, no assessment of the population is available prior to the 1930s when the National Audubon Society commissioned a survey of a portion of the Chesapeake Bay that included APG (Tyrrell 1936). In 1936, Tyrrell documented nests on Eagle Point, Robbins Point, lower Little Romney Creek (north of Elm Tree Point), upper Little Romney Creek (near intersection with AA-5 road), and Bear Point. Stewart and Robbins (1958) documented nests on APG in the 1950s. Abbott (unpublished field notes) coordinated Bald Eagle nest surveys from the late 1950s through the mid-1970s and documented additional nests at the mouth of Canal Creek, Reardon Inlet (near Westwood Range), Maxwell Point, Swaderick Creek, Leges Point (near Days Point), north of Ricketts Point, Gum Point, Skippers Point (on Lauderick Creek), Coopers Creek, Back Creek (near AA-5 road), and 3 on Spesutie Island (near Locust Point; near Morgan Road; near Sandy Point). Only 4 of these historic breeding sites had evidence of Bald Eagle use when investigated during the early 1960s (Abbott, unpublished data). By the late 1960s no occupied bald eagle territories were known for APG.

Following the first rediscovered breeding of bald eagles on APG in 1977, the Directorate of Safety, Health and Environment contacted the United States Fish and Wildlife Service to initiate consultation under the Endangered Species Act, Section 7(c)(1). This consultation resulted in studies that lead to the first bald eagle management plan in 1986 and subsequent revisions in 1995 and 2009 (Paul 2009). These plans established the need and framework for annual monitoring of the breeding population. Here we provide the results of survey efforts (1991-2011) and discuss changes in the population relative to the breeding population within the tidal reach of the Chesapeake Bay.

4.7.2.1 Study Area

APG is a 350-km^2 United States Department of Defense military installation located along the northwestern shore of the upper Chesapeake Bay, in southern Harford and eastern Baltimore Counties, MD. Since APG's establishment in 1917, the Aberdeen Area has been the site of intense research and development; large-scale testing of munitions, weapons, and materiel; and a training school for ordnance officers and enlisted specialists. Due to the nature of its mission, APG is primarily forested with extensive undeveloped shorelines. The property is embedded within the Upper Chesapeake Bay Bald Eagle Concentration Area, one of several areas within the Chesapeake Bay where bald eagles from along the Atlantic Coast converge (Watts et al. 2007). Throughout the Bay such concentration areas have formed within low salinity, tidal-fresh waters where prey availability is high (Watts et al. 2006). For the resident breeding population, brood provisioning and chick growth tend to be high in these areas (Markham and Watts 2008) leading to high breeding densities, high breeding success and high productivity (Watts et al. 2006).

4.7.2.2 Methods

Aerial, helicopter surveys have been used to survey the entire study area for breeding eagles (1991-2011). Typically 4-6 surveys have been conducted between mid-January and late May to document nests, breeding activity, and productivity. Nests detected were plotted on topographic maps and given unique codes or names. Each nest was examined to determine its condition and status. Notes from field observations were interpreted by the authors to determine activity status according to national standards. We considered a breeding territory to be occupied if a pair of birds were observed in association with the nest and there was evidence of recent nest maintenance (e.g., well-formed cup, fresh lining, structural maintenance). We considered nests to be active if we observed a bird in an incubating posture or if we detected eggs or young in the nest (Postupalsky 1974). The number of eaglets was recorded for each nest. Due to the number of flights, we feel that nesting activity was well documented.

We defined breeding success as the percentage of occupied nests that contained ≥1 young, reproductive rate as the number of young per occupied nest, and average brood size as the number of young per successful nest. We expressed population growth rate using the average time (in years) required for the population to double in size (t_{double}), the intrinsic rate of increase (r), and the average annual percent increase over the study period. We calculated average doubling time using the growth equation $N_t = N_0e^{rt}$ where N_t is the population size in 2011, N_0 is the population size in 1977, e is the base of the natural logarithm, r is the intrinsic rate of increase, and t is the time interval between population estimates. With this configuration, $t_{double} = \ln(2)/r$. We calculated average annual percent increase as $(N_{t+1}-N_t)/N_t$ X 100.

4.7.2.3 Results

Between 1977 and 2011, the bald eagle breeding population on APG increased from 1 pair to 58 pairs (Figure 4.7.1). During this period, the population grew exponentially with an average doubling time of 5.8 years. Intrinsic rate of increase (r) was 0.119. Average annual increase was 13.1± 4.23% (mean ± S.E.). The annual population increase, as expressed by a percentage, was highly variable over the study period and ranged from a low of -20.6% (2005-2006) to a high of 57.9% (1998-1999). There is no indication over the survey period that this rate has shown any directional change ($R^2 = 0.042$, $F[1,17] = 0.75$, $p = 0.395$).

During the study period, we documented 464 breeding attempts that produced 640 young (Table 4.7.1). Average, annualized rates were 79.6 ± 3.89%, 1.29 ± 0.060, and 1.6 ± 0.05 for breeding success, reproductive rate, and brood size, respectively. The population has exhibited tremendous forward momentum such that more than 50% of young produced over the 21-year period have been produced in the 6 years since 2005.

Survey information beween 1991 and 2011 indicates that the breeding population on APG has exceeded the goal of 1.1 chicks/breeding attempt set by the Chesapeake Bay Bald Eagle Recovery Plan (Byrd et al. 1990) every year except 1997 (Table 1). During 1997, recorded reproductive rate was higher than that suggested for maintenance but lower than the recovery goal. For the 11-year period 1991-2001, reproductive rates for APG were virtually identical to those recorded for the broader Chesapeake Bay. The average number of chicks per active nest was 1.4 ± 0.05 (mean ± S.E.) and 1.4 ± 0.09 for the Chesapeake Bay and APG respectively. The average number of chicks per successful nest (average brood size) was 1.8 ± 0.03 and 1.7 ± 0.07 for the Chesapeake Bay and APG respectively. These rates are not statistically distinguishable (for both comparisons, df = 19, F-statistic < 3.2, P > 0.05).

4.7.2.4 Discussion

The recovery of the Bald Eagle breeding population on APG has been dramatic. Population growth rate has been faster (doubling time of 5.8 vs 8.2 years) than that documented for the tidal reach of the larger Chesapeake Bay (Watts et al. 2008). The rate is comparable to other low-salinity reaches of the Bay that represent some of the fastest growing regions throughout the species range (Watts et al. 2006). With the exception of locations that have been developed, virtually all of the breeding territories documented during the 1930s, 1940s and 1950s have now been re-occupied. No specific estimates of the APG bald eagle population are available prior to the onset of the DDT era. However, given the tremendous forward momentum currently exhibited by the breeding population, it seems likely that bald eagles will reach saturation within the installation in a relatively short period of time.

A reproductive rate of 0.7 chicks/breeding attempt has been suggested to represent the threshold for population maintenance for bald eagles (Sprunt et al. 1973). Buehler et al. (1991a) estimated that 1.0 chicks/successful nest (equivalent to brood size) was required for population maintenance in the Bay. A reproductive rate of 1.1 chicks/breeding attempt was set as the recovery goal for the Chesapeake Bay population (Byrd et al. 1990). With the exception of 1997 and 1998, the APG population has met or exceeded the productivity target outlined in the recovery plan in every year that a survey has been conducted. The broader Chesapeake Bay reached this threshold in 1985 and has exceeded the target in all subsequent years (Watts et al. 2008). The reproductive rate documented by Tyrrell in 1936 was nearly 1.5 chicks/breeding attempt. The APG population has approached or achieved this rate in the years after 2005.

APG plays an increasingly important role in the recovery and maintenance of the Chesapeake Bay bald eagle population. The availability of undeveloped waterfront property has become the dominant limiting factor for bald eagles in the region. Human activity is the best predictor of eagle distribution within the tidal portion of the Bay. Indicators of human activity such as housing and road density, shoreline use, and boating activity have been related to nest distribution (Watts et al. 1994), shoreline use (Buehler et al. 1991b, Watts and Whalen 1997), and the likelihood of nest abandonment (Therres et al. 1993) or recolonization (B. D. Watts, Center for Conservation Biology, unpublished data). Since bald eagles began their most dramatic decline in the 1950s, the human population within the tidal reach of the Bay has increased by more than 50% (http://www.census.gov). A preliminary review of development occurring around eagle nests in the lower Chesapeake Bay shows that development had occurred in 55% of shoreline areas by the late 1980s (Byrd et al. 1990). Extensive undeveloped shorelines and associated uplands on APG have allowed the property to become a significant stronghold for the breeding population.

APG will continue to serve as an important bald eagle breeding location for the foreseeable future. APG has been actively working to restore the bald eagle population within the installation since the early 1980s. The Army has adopted environmental stewardship as one of its missions and it is clear that without federal ownership of this land and the demand for the ongoing mission the upper Bay would support considerably less habitat for breeding eagles. The current bald eagle management plan (Paul 2009) provides broad directives to protect significant eagle habitat and outlines specific measures to reduce disturbance within known nesting, foraging, and roosting sites. Management efforts continue that are designed to mesh the needs of eagles with other military missions.

4.7.2.5 Acknowledgments

The U.S. Army has supported breeding population surveys since the 1980s. We thank the long list of observers who have participated in surveys including C. Koppie, J. Ondek, S. Voss, and J. Baylor. We also thank the many individuals who have managed the survey data over time including A. Burgess and L. Hartzell. G. Therres and C. Koppie have contributed to shaping the survey.

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Table 4.7.1. Bald Eagle population size and productivity within Aberdeen Proving Ground, MD (1991-2011). The 1998 survey was incomplete.

Year	Occupied Nests	Active Nests	Success-ful Nests	Young	Successful/ Occupied[a]	Successful/ Active[a]	Young/ Occupied[a]	Young/ Active[a]	Young/ Successful[a]
1991	5	5	4[b]	5	100.0	100.0	1.25	1.25	1.25
1992	5	5	4	8	80.0	80.0	1.60	1.60	2.00
1993	9	8	7	11	77.8	87.5	1.22	1.38	1.57
1994	10	9	7	10	70.0	77.8	1.00	1.11	1.43
1995	13	13	10[d]	18	100.0	100.0	1.80	1.80	1.80
1996	16	16	14[b]	23	93.3	93.3	1.53	1.53	1.64
1997	16	13	5[c]	9	35.7	45.5	0.64	0.82	1.80
1998	8	8	5	6	71.4	71.4	0.86	0.86	1.20
1999	19	19	11[c]	20	64.7	64.7	1.18	1.18	1.82
2000	19	13	10	18	52.6	76.9	0.95	1.38	1.80
2001	20	20	19	32	95.0	95.0	1.60	1.60	1.68
2002	19	18	12[d]	20	80.0	85.7	1.33	1.43	1.67
2003	24	23	23	35	95.8	100.0	1.46	1.52	1.52
2004	29	27	22	32	75.9	81.5	1.10	1.19	1.45
2005	35	35	29	41	82.9	82.9	1.17	1.17	1.41
2006	29	29	28[b]	41	100.0	100.0	1.46	1.46	1.46
2007	31	31	27	42	87.1	87.1	1.35	1.35	1.56
2008	44	37	33	61	75.0	89.2	1.39	1.65	1.85
2009	46	37	35	69	76.1	94.6	1.50	1.86	1.97
2010	44	41	36	60	81.8	87.8	1.36	1.46	1.67
2011	58	57	43[c]	79	76.8	78.2	1.41	1.44	1.84

[a]based on nests with known outcome.
[b]final outcome of 1 nest not determined and not included in totals.
[c]final outcome of 1 nest not determined and not included in totals.
[d]final outcome of <5 nests not determined and not included in totals.

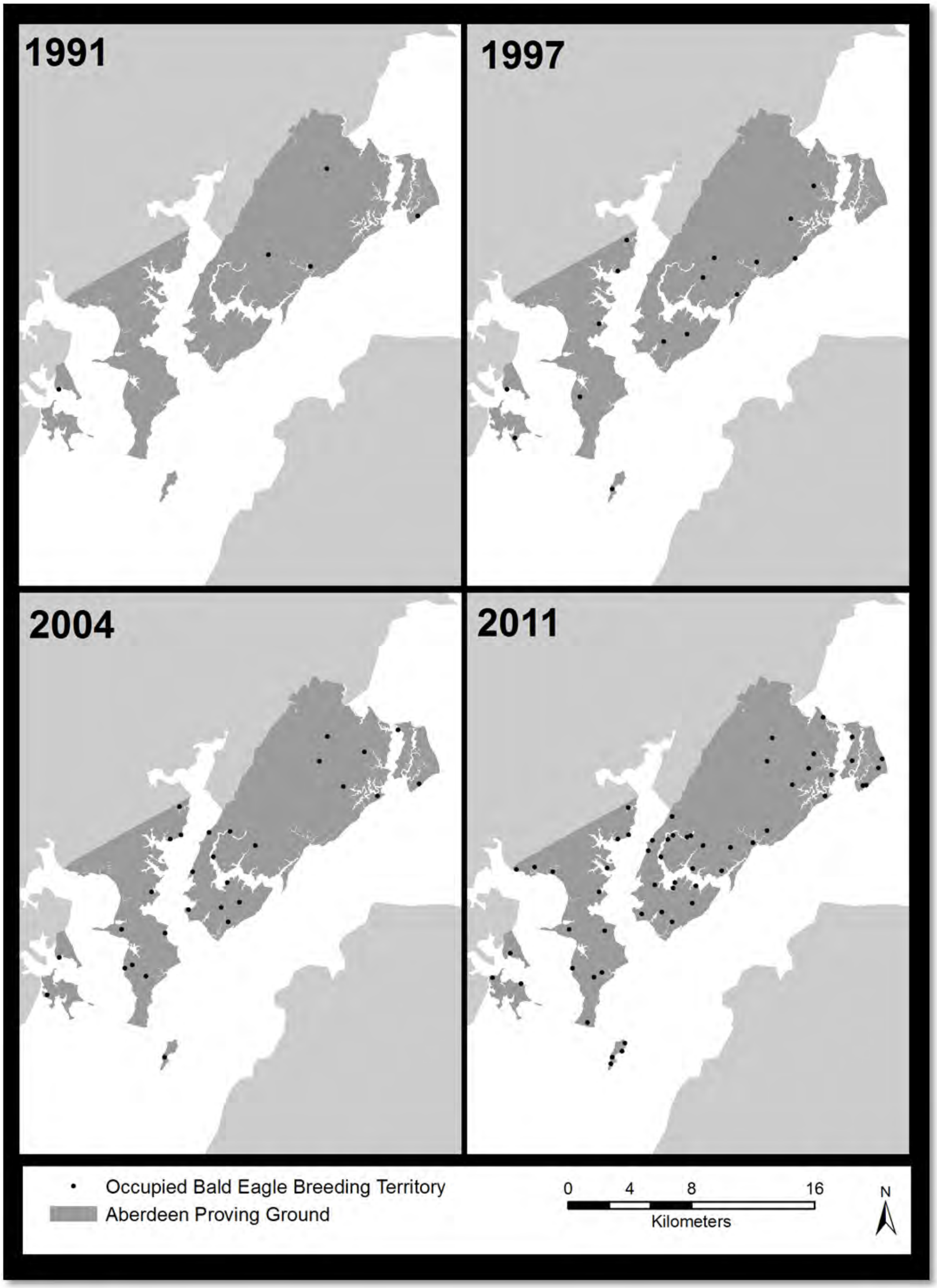


Figure 4.7.1. Occupied bald eagle territories on Aberdeen Proving Ground from 1991-2011.

5 RECOMMENDATIONS

5.1 Management

Adopt standard disturbance buffers for major foraging areas – Results from this study document that APG supports several of the most significant foraging areas located within the Upper Chesapeake Bay Bald Eagle Concentration Area. During the summer months, these areas are located primarily along the primary shoreline of the Chesapeake Bay and major tributaries. Establishment of buffers to protect these areas from disturbance caused by shoreline training, recreational and other activities would be consistent with management recommendations from throughout the species range.

Seasonal closure of narrow waterways supporting major foraging areas – Results from this study document that APG supports several of the most significant foraging areas located with the Upper Chesapeake Bay Bald Eagle Concentration Area. During the winter months, these areas are located primarily along narrow (<100 m wide) waterways. Because mean flush distances from studies throughout the species range exceed the channel width of these tributaries, any activities would likely flush all individuals from these foraging areas, waterway closure would be recommended during the winter period.

Establish disturbance buffers around major communal roosts – Results from this study document a complex network of communal roosts used by eagles on APG. These roosts vary considerably in both the magnitude and seasonality of use. A subset of these roosts serves as both night roosts and hubs for social interactions. These roosts are vital components of the Upper Chesapeake Bay Bald Eagle Concentration Area. Establishment of buffers to protect these areas from disturbance would be consistent with management recommendations from throughout the species range.

Maintain disturbance buffers for roosts throughout the day – Results from this study document that locations supporting communal roosts are more than sites for night roosting. Temporal profiles of roost sites demonstrate that these sites are used throughout the day. Inter-roost movements throughout the day suggest that these sites serve as places for social interactions and possibly information exchange.

Mitigate mortality risk in locations where electric lines intersect with activity centers – Results from this study document that historic mortality rates are more than an order of magnitude higher where lines intersect with eagle activity centers suggesting that hazard mitigation should be focused in these locations. A combination of perch excluders, flight diverters, and line burial should be used to mitigate mortality risk in these locations as appropriate and feasible.

Avoid establishing hazards within bald eagle activity centers – Results from this study document and a large portion of locations classified as high-use activity centers are located away from any electrical infrastructure. Results also demonstrate that mortality rates have been higher where electric lines and activity centers intersect on the landscape. These results suggest that activity centers should be avoided when planning future infrastructure projects or new lines should be placed under ground.

Monitor bald eagle activity centers with satellite transmitters – Results from this study illustrate that transmitter technology is an effective tool for delineating and monitoring eagle activity centers including communal roosts, foraging areas, and movement corridors. Because the technology works in all time periods, locations, and weather conditions, it is more effective than ground-based observations in providing information on activity patterns over time. Maintaining a minimum cohort of birds with transmitters would be a cost-effective approach to activity monitoring on APG.

5.2 Research

Clarify the role of hubs within roost networks – Results from this study document that the relative use of roosts on APG vary dramatically and that they may differ in their roles within a network setting. Understanding the role of "super roosts" within roost networks would have broad management application and would help to inform management decisions on APG. Existing tracking data is adequate to perform such an investigation but the analysis was beyond the scope of this effort.

Cost effectiveness of using transmitters for activity monitoring – Results from this study demonstrate the effectiveness of satellite transmitters for delineating bald eagle activity centers. However, a large cohort of eagles made this assessment possible and the use of such a cohort would not be cost-effective for long term monitoring. Existing tracking data could be used to conduct a retrospective power analysis to assess the relationship between cost (number of transmitters required) and the confidence in delineating all activity centers within the installation. The analysis would clarify the cost of using this technology with a monitoring objective. Such an analysis has never been performed.

Use of GSM transmitter technology to examine response of eagles to munitions testing – This study used the state-of-the-art transmitters technology that was available at the time of initiation. The transmitters used here pushed the temporal resolution of the data to a new high of hourly positions. Even so, this resolution is inadequate to evaluate correspondence between eagle movements and specific events on the landscape in a cause and effect manor. Emerging GSM transmitter technology provides nearly real-time tracking with enough temporal resolution to allow for such assessments.

Appendix 1: Summary of banding information for bald and golden eagles captured on APG (2007-2011) including date of capture, band number, transmitter number, age, gender, and morphometric information.

Species	Federal Band	Color Band	Transmitter	Origin	Date	Sex	Age	Weight (g)	Culmen Length (cm)	Culmen depth (cm)	Halux Length	Wing cord (cm)	Tail (cm)
BAEA	0679-01324	D8	74375	Southern Migrant	10/17/2008	M	TY	3280	58.1	29.2	37.7	56.4	26.0
BAEA	0679-01325	E8	74376	Local	12/31/2008	M	TY	3501	60.4	33.4	38.8	53.4	25.4
BAEA	0679-01326	K8	74377	Local	1/2/2009	F	AD	5300	69.2	35.6	42.8	60.9	28.2
BAEA	0679-01327	P8	74378	Local	1/3/2009	M	TY	3691	61.4	31.2	36.9	57.8	30.1
BAEA	0679-01328	R8	74379	Local	1/3/2009	M	FY	4325	65.6	33.0	39.2	58.7	29.5
BAEA	0679-01330	V8	74380	Local	1/4/2009	M	TY	4688	62.4	33.2	41.0	59.0	31.2
BAEA	0679-01331	B9	74381	Local	1/4/2009	M	FY	3655	61.5	31.8	37.7	56.0	26.5
BAEA	0679-01348	HN	74382	Local	4/26/2009	F	L	4415	62.9	34.4	37.8	47.2	23.5
BAEA	0679-01349	HP	74383	Local	4/26/2009	M	L	3437	58.4	29.5	34.4	44.0	26.2
BAEA	0679-01354	HV	74384	Local	5/10/2009	F	L	4060	61.7	32.7	36.7	34.5	13.8
BAEA	0629-30514	VC	74385	Local	8/1/2007	F	AD	4550	69.6	35.8	43.8	57.0	28.5
BAEA	0629-30517	VD	74386	Local	8/3/2007	M	AD	3730	64.7	34.8	38.9	54.0	27.0
BAEA	0629-30518	VE	74387	Local	8/15/2007	F	HY	4500	67.9	38.8	42.6	62.5	34.1
BAEA	0629-30519	VH	74388	Local	8/16/2007	U	SY	3500	60.9	33.6	36.6	57.8	25.6
BAEA	0629-30520	VK	74389	Southern Migrant	8/16/2007	M	SY	3290	58.9	32.2	38.5	57.9	30.8
BAEA	0629-30521	VM	74390	Local	8/19/2007	F	HY	4260	64.6	35.5	40.6	62.9	35.4
BAEA	0629-30522	VN	74391	Local	8/19/2007	F	TY	3800	60.8	36.5	39.8	55.1	26.0
BAEA	0629-30524	VR	74392	Local	10/4/2007	M	SY	3540	61.2	32.1	36.1	56.5	31.0
BAEA	0629-30523	VP	74393	Local	9/23/2007	F	HY	4733	64.5	36.8	39.4	60.6	33.0
BAEA	0629-30525	VS	74394	Local	10/4/2007	M	FY	3695	60.2	31.5	36.1	54.5	26.5
BAEA	0629-30526	A2	74395	Local	10/5/2007	F	HY	5045	69.4	38.8	43.5	62.3	35.1
BAEA	0629-30527	B2	74396	Local	10/7/2007	M	HY	3500	61.1	35.5	37.4	57.7	31.9
BAEA	0629-30528	C2	74397	Local	10/11/2007	M	HY	3699	60.9	32.7	39.5	60.6	28.3
BAEA	0629-30529	D2	74398	Local	10/11/2007	F	HY	4218	67.3	38.1	40.7	61.5	34.4

Species	Federal Band	Color Band	Transmitter	Origin	Date	Sex	Age	Weight (g)	Culmen Length (cm)	Culmen depth (cm)	Halux Length	Wing cord (cm)	Tail (cm)
BAEA	0629-30530	E2	74399	Southern Migrant	10/12/2007	M	HY	3495	57.9	31.5	36.7	57.8	27.5
BAEA	0629-30532	K2	74400	Local	11/29/2007	F	AD	5200	71.4	38.8	46.2	62.2	29.0
BAEA	0629-30533	M2	74401	Northern Migrant	1/12/2008	F	AD	5365	70.4	34.2	43.4	60.1	27.9
BAEA	0629-30534	N2	74402	Northern Migrant	1/18/2008	M	TY	4890	67.7	34.0	39.2	61.7	32.5
BAEA	0629-30536	P2	74403	Northern Migrant	1/18/2008	F	AD	5350	67.2	35.1	45.8	64.2	26.5
BAEA	0629-30535	R2	74404	Local	1/24/2008	F	AD	5485	66.4	36.2	42.7	57.8	26.0
BAEA	0629-51799	R38	74405	Northern Migrant	1/25/2008	M	SY	4265	66.7	31.3	37.9	62.1	33.3
BAEA	0629-30538	S2	74406	Northern Migrant	1/25/2008	F	SY	5250	69.3	35.2	44.5	64.4	33.9
BAEA	0629-52769	S47	74407	Northern Migrant	1/26/2008	M	SY	4525	64.9	35.0	41.1	62.1	35.0
BAEA	0629-30537	V2	74408	Northern Migrant	1/26/2008	F	SY	5850	68.2	34.4	44.4	66.2	34.9
BAEA	0679-01209	A3	74409	Local	2/2/2008	F	AD	5179	67.0	34.9	41.9	58.4	30.0
BAEA	0629-30541	X2	74410	Local	1/31/2008	M	AD	4269	62.3	33.5	38.1	54.5	27.1
BAEA	0679-01210	B3	74411	Northern Migrant	2/2/2008	F	AD	6170	68.8	35.9	46.1	64.3	32.1
BAEA	0629-30543	D3	74412	Northern Migrant	2/9/2008	F	AD	6320	75.6	35.1	46.8	62.6	30.9
BAEA	0629-30546	K3	74413	Northern Migrant	2/9/2008	F	TY	5035	67.5	35.1	42.5	60.5	30.1
BAEA	0629-30547	M3	74414	Local	2/23/2008	F	AD	5266	61.2	34.9	31.7	59.1	30.0
BAEA	0629-30548	N3	74415	Local	2/29/2008	M	FY	4198	62.7	32.4	40.2	59.1	28.8
BAEA	0679-01213	U3	74416	Local	3/2/2008	F	SY	4820	68.3	36.1	38.4	64.7	36.8
GOEA	0679-01214	V3	74417	Northern Migrant	3/7/2008	F	SY	4395	62.1	30.2	56.5	65.0	35.8
GOEA	0679-01217	-----	74419	Northern Migrant	3/21/2008	F	TY	4760	58.0	30.0	55.2	62.5	32.2
BAEA	0679-01218	A4	74420	Local	3/21/2008	M	FY	5010	67.7	36.0	40.4	60.5	31.0
BAEA	0679-01219	B4	74421	Northern Migrant	3/22/2008	M	SY	4708	69.7	36.0	45.4	68.8	36.0

Species	Federal Band	Color Band	Transmitter	Origin	Date	Sex	Age	Weight (g)	Culmen Length (cm)	Culmen depth (cm)	Halux Length	Wing cord (cm)	Tail (cm)
BAEA	0679-01226	M4	74422	Northern Migrant	3/23/2008	F	AD	NM	70.7	33.1	47.3	57.0	27.0
BAEA	0679-01229	R4	74423	Northern Migrant	3/23/2008	M	FY	4938	62.9	34.1	39.3	62.5	32.0
BAEA	0679-01239	K5	74424	Local	4/26/2008	F	L	4110	62.7	32.2	36.6	39.0	18.7
BAEA	0679-01248	X5	74425	Local	5/3/2008	F	L	4385	62.7	31.2	38.5	40.5	19.9
BAEA	0679-01250	D6	74426	Local	5/4/2008	F	L	4250	62.3	33.0	39.0	41.9	22.0
BAEA	0679-01306	P7	74427	Local	5/13/2008	M	L	3170	58.9	30.0	33.1	42.7	21.6
BAEA	0679-01307	R7	74428	Local	5/13/2008	F	L	4390	60.2	31.2	35.6	38.0	17.1
BAEA	0679-01246	V5	74429	Local	5/2/2008	M	L	3044	56.6	29.0	32.2	30.4	12.0
BAEA	0679-01312	X7	74430	Local	5/17/2008	F	L	4510	62.7	32.8	37.2	44.3	20.5
BAEA	0679-01313	Z7	74431	Local	5/18/2008	M	L	3825	58.8	30.3	36.5	38.0	17.5
BAEA	0679-01314	E7	74432	Local	5/27/2008	M	L	3490	58.9	29.3	36.3	43.2	23.0
BAEA	0679-01315	K6	74433	Local	5/28/2008	M	L	3190	55.3	29.4	35.4	42.5	21.5
BAEA	0679-01317	R6	74434	Local	5/28/2008	M	L	3650	61.7	28.7	34.3	44.7	23.9
BAEA	0679-01318	U2	74435	Local	5/31/2008	F	L	4558	65.7	33.6	38.3	49.5	25.4
BAEA	0679-01319	V6	74436	Southern Migrant	8/31/2008	M	TY	3245	58.1	30.4	39.7	52.6	30.4
BAEA	0679-01320	B7	74437	Local	9/1/2008	F	AD	4577	67.1	34.7	44.3	60.8	28.2
BAEA	0679-01322	B8	74438	Local	9/12/2008	F	TY	4220	67.3	34.0	34.4	62.8	30.7
BAEA	0679-01363	K1	74399b	Local	5/16/2009	F	L	4480	34.1	33.8	35.9	41.0	18.1
BAEA	0679-01365	R1	74410b	Local	5/16/2009	M	L	3622	59.2	30.3	32.9	42.0	20.9
BAEA	0679-01298	KC	GSM2	Local	2/5/2011	M	SY	NM	60.6	31.1	37.5	57.3	24.5
BAEA	0679-01299	KD	GSM6	Local	2/7/2011	F	SY	NM	65.2	35.0	41.8	59.1	32.1
BAEA	0679-01211	C3	None	Northern Migrant	2/3/2008	F	FY	4570	68.5	35.9	42.1	62.7	31.5
BAEA	0629-30549	P3	None	Local	3/2/2008	F	FY	3760	60.1	32.1	39.5	56.1	27.6
BAEA	0629-30531	H2	None	Local	11/17/2007	F	HY	5200	66.4	34.9	43.1	62.8	32.0
BAEA	0679-01247	W5	None	Local	5/2/2008	F	L	3642	57.2	30.7	34.9	29.5	9.0
BAEA	0679-01301	E7	None	Local	5/4/2008	F	L	3795	59.8	31.8	37.2	37.1	15.5

Species	Federal Band	Color Band	Transmitter	Origin	Date	Sex	Age	Weight (g)	Culmen Length (cm)	Culmen depth (cm)	Halux Length	Wing cord (cm)	Tail (cm)
BAEA	0679-01308	S7	None	Local	5/13/2008	F	L	3630	57.9	29.6	34.1	39.8	20.5
BAEA	0679-01362	E1	None	Local	5/16/2009	F	L	4470	61.1	32.5	36.2	38.6	16.4
BAEA	0679-01296	KA	None	Local	5/29/2010	F	L	4350	NM	NM	NM	45.0	21.8
BAEA	0629-30515	VA	None	Local	5/31/2007	F	SY	NM	64.9	34.6	42.6	56.9	29.0
BAEA	0679-01368	-----	None	Local	3/14/2010	F	TY	NM	64.5	33.5	41.9	60.9	26.0
BAEA	0629-30545	H3	None	Local	2/9/2008	M	AD	3606	62.7	31.1	37.1	55.5	26.5
BAEA	0679-01369	NB	None	Local	3/14/2010	M	AD	NM	62.1	31.4	37.6	56.9	22.6
BAEA	0629-30539	U2	None	Local	1/26/2008	M	FY	4250	61.7	30.9	41.7	62.2	31.5
BAEA	0629-30542	Z2	None	Local	2/2/2008	M	FY	4225	61.0	31.6	37.3	57.5	29.3
BAEA	0629-30544	E3	None	Local	2/9/2008	M	FY	3690	61.1	30.7	38.0	58.0	27.1
BAEA	0679-01220	D4	None	Local	3/23/2008	M	FY	4211	63.5	32.2	37.5	56.3	26.6
BAEA	0679-01222	C4	None	Local	3/23/2008	M	FY	3490	61.6	38.8	36.4	57.0	26.0
BAEA	0679-01321	C7	None	Local	9/11/2008	M	HY	3220	62.8	30.1	39.9	57.4	32.5
BAEA	0679-01323	C8	None	Local	9/13/2008	M	HY	3640	61.8	32.0	39.8	59.4	33.2
BAEA	0679-01240	M5	None	Local	4/26/2008	M	L	3200	57.4	28.8	32.7	34.5	17.0
BAEA	0679-01245	U5	None	Local	5/2/2008	M	L	3073	58.1	29.4	33.6	36.5	16.1
BAEA	0679-01249	Z5	None	Local	5/3/2008	M	L	3480	58.6	30.3	36.3	42.1	20.8
BAEA	0679-01316	P6	None	Local	5/28/2008	M	L	2980	56.5	28.6	35.3	43.8	23.1
BAEA	0679-01353	HU	None	Local	5/10/2009	M	L	3145	55.0	28.9	33.2	30.4	12.7
BAEA	0679-01361	D1	None	Local	5/16/2009	M	L	3545	28.7	30.5	34.5	42.4	20.0
BAEA	0679-01364	P1	None	Local	5/16/2009	M	L	4160	58.6	31.8	33.8	42.0	17.2
BAEA	0679-01297	KB	None	Local	5/29/2010	M	L	3300	NM	NM	NM	41.0	23.2
BAEA	0629-30540	W2	None	Local	1/31/2008	M	SY	4450	61.5	32.2	39.1	59.1	30.4
BAEA	0629-30550	R3	None	Local	3/2/2008	M	SY	3430	61.5	30.9	38.1	57.0	31.0
BAEA	0679-01221	Z3	None	Local	3/21/2008	M	SY	4300	59.4	31.4	36.9	60.0	33.5
BAEA	0679-01223	E4	None	Local	3/23/2008	M	SY	3655	61.0	31.5	37.8	58.5	32.1
BAEA	0679-01224	H4	None	Local	3/23/2008	M	SY	4268	61.6	32.2	40.0	61.5	32.6
BAEA	0679-01225	K4	None	Local	3/23/2008	M	SY	3645	59.9	31.4	37.8	58.7	32.0

Species	Federal Band	Color Band	Transmitter	Origin	Date	Sex	Age	Weight (g)	Culmen Length (cm)	Culmen depth (cm)	Halux Length	Wing cord (cm)	Tail (cm)
BAEA	0679-01227	N4	None	Local	3/23/2008	M	SY	3466	60.6	30.4	36.5	57.0	32.0
BAEA	0679-01366	UI	None	Local	3/14/2010	M	SY	NM	60.0	29.9	37.7	56.9	32.2
BAEA	0679-01367	VI	None	Local	3/14/2010	M	SY	NM	60.5	31.3	38.0	56.4	27.8
BAEA	0679-01212	S3	None	Local	3/2/2008	M	TY	3463	62.8	30.5	37.2	58.6	31.4
BAEA	0679-01228	P4	None	Northern Migrant	3/28/2008	M	TY	4567	66.5	34.5	40.4	59.5	31.0
BAEA	0679-01329	U8	None	Local	1/4/2009	M	TY	3800	63.3	31.8	40.2	61.0	33.5
BAEA	0629-30516	VB	None	Local	6/1/2007	U	SY	NM	65.9	35.3	43.6	58.5	29.8

NM = not measured

----- = not banded with color band

Appendix 2: Disposition of bald and golden eagles captured on APG as of June 2012 including period of tracking, population of origin, and available information on status.

Transmitter	Species	Transmitter Status	Start Transmission	End Transmission	Population of Origin	Fate
74375	BAEA		10/17/2008		Southern Migrant	
74376	BAEA		12/31/2008		Local	
74377	BAEA	Transmitter stationary near Tolchester Beach, MD. Searched communal roost but no sign of carcass or PTT.	1/2/2009	4/8/2009	Local	Unknown Fate
74378	BAEA	Sudden loss of signal near Lake Erie, NY.	1/3/2009	10/7/2011	Local	Unknown Fate
74379	BAEA		1/3/2009		Local	
74380	BAEA	Electrocuted on road to J-field. Carcass found by Officer Volz. Transmitter recovered.	1/4/2009	7/14/2010	Local	Dead - electrocution
74381	BAEA		1/4/2009		Local	
74382	BAEA	Transmitter stationary in Kent county, DE.	4/26/2009	3/29/2012	Local, HA-06-04	Unknown Fate
74383	BAEA	Loss of transmissions near Bel Air, MD.	4/26/2009	4/25/2011	Local, HA-08-08	Unknown Fate
74384	BAEA		5/10/2009		Local, HA-08-09	
74385	BAEA	Missing at Fairview Pt. Fate Unknown. New unbanded female at nest in March 2008.	8/1/2007	2/7/2008	Local	Unknown Fate
74386	BAEA	Sudden loss of signal in Delaware farm field. Not recoverable.	8/3/2007	1/26/2012	Local	Unknown Fate
74387	BAEA		8/15/2007		Local	
74388	BAEA	Transmitter stationary in Somerset Co, MD.	8/16/2007	2/15/2012	Local	Unknown Fate
74389	BAEA	Transmitter stopped sending signals in Florida on the eagle's wintering grounds.	8/16/2007	2/24/2009	Southern Migrant	Unknown Fate
74390	BAEA	Transmitter stationary in remote area of Labrador (Canada) for 6 weeks before battery died. Fate unknown. PTT sending signal again 6/2010 and 7/2011 in same location in Labrador. Unrecoverable transmitter.	8/19/2007	6/10/2008	Local	Unknown Fate
74391	BAEA		8/19/2007		Local	
74392	BAEA	Transmitter recovered with harness severed by eagle in marsh on Plum Creek, Cecil Co, MD. Assumed alive.	10/4/2007	1/27/2010	Local	Harness Severed

Transmitter	Species	Transmitter Status	Start Transmission	End Transmission	Population of Origin	Fate
74393	BAEA	PTT stopped transmitting at roost on Romney Creek. Transmitter recovered, harness severed.	9/23/2007	5/21/2010	Local	Harness Severed
74394	BAEA	Sudden loss of signal in Harford Co, MD.	10/4/2007	10/22/2011	Local	Unknown Fate
74395	BAEA	Transmitter stationary in roost near Wye Mills, MD.	10/5/2007	2/2/2012	Local	Unknown Fate
74396	BAEA		10/7/2007		Local	
74397	BAEA	Eagle found dead with transmitter on private land in Dorchester Co, MD.	10/11/2007	10/12/2010	Local	Dead - unknown
74398	BAEA	sudden loss of transmissions in phrag marsh near H/I field. Ground search improbable.	10/11/2007	10/22/2010	Local	Unknown Fate
74399	BAEA	Harness severed by eagle. Transmitter recovered near Conowingo Dam in residental area.	10/12/2007	10/1/2008	Southern Migrant	Harness Severed
74399b	BAEA	Sudden loss of transmissions near nest.	5/16/2009	7/28/2009	Local, HA-04-05	Dead - unknown
74400	BAEA	Last location in breeding territory. Sudden loss of signal.	11/29/2007	8/1/2011	Local	Unknown Fate
74401	BAEA	Hit by car in New York state. Euthanized. Transmitter Recovered.	1/12/2008	6/30/2010	Northern Migrant	Dead - collision
74402	BAEA		1/18/2008		Northern Migrant	
74403	BAEA		1/18/2008		Northern Migrant	
74404	BAEA	Searched for transmitter in communal roost in swamp surrounding the Marshyhope River, MD. Possible PTT and or eagle fell in water.	1/24/2008	10/22/2008	Local	Unknown Fate
74405	BAEA		1/25/2008		Northern Migrant	
74406	BAEA		1/25/2008		Northern Migrant	
74407	BAEA		1/26/2008		Northern Migrant	
74408	BAEA		1/26/2008		Northern Migrant	
74409	BAEA	Unsuccessfully searched southern half of Pooles Island. High grass covered ground.	2/2/2008	7/11/2008	Local	Unknown Fate
74410	BAEA	Found dead in grass area of Maxwell Pt. Transmitter recovered.	1/31/2008	4/25/2008	Local	Dead - unknown

Transmitter	Species	Transmitter Status	Start Transmission	End Transmission	Population of Origin	Fate
74410b	BAEA		5/16/2009		Local, HA-07-03	
74411	BAEA		2/2/2008		Northern Migrant	
74412	BAEA	Harness severed by eagle and removed near Cherry Tree Pt, APG. Transmitter recovered.	2/9/2008	2/6/2011	Northern Migrant	Harness Severed
74413	BAEA	Unit photographed partially detached from eagle. 1/12/09 unit probably on ground. Unsuccessful search near Conowingo Dam on 3 occasions.	2/9/2008	1/12/2009	Northern Migrant	Harness Severed
74414	BAEA		2/23/2008		Local	
74415	BAEA	Sudden loss of signal in residential area near Dundalk, MD.	2/29/2008	4/18/2010	Local	Unknown Fate
74416	BAEA	Transmitter stationary in roost at Conowingo Dam.	3/2/2008	3/17/12	Local	Unknown Fate
74417	GOEA		3/7/2008		Northern Migrant	
74419	GOEA		3/21/2008		Northern Migrant	
74420	BAEA	Transmitter stationary along banks of Mosquito Creek. Not able to search because of UXO concerns.	3/21/2008	8/16/2009	Local	Unknown Fate
74421	BAEA	Electrocuted on APG 1/2010.Transmitter lost 6 months preivously in Quebec 6/13/2009.	3/22/2008	6/13/2009	Northern Migrant	Dead - electrocution
74422	BAEA	Transmitter removed by eagle in Sussex Co, DE. Transmitter recovered.	3/23/2008	11/24/2011	Northern Migrant	Harness Severed
74423	BAEA		3/23/2008		Northern Migrant	
74424	BAEA		4/26/2008		Local, HA-08-03	
74425	BAEA		5/3/2008		Local, HA-07-07	
74426	BAEA	Sudden loss of signal on Aberdeen. Not recoverable.	5/4/2008	4/3/2012	Local, HA-03-08	Unknown Fate
74427	BAEA	Transmitter stationary in Queen Anne's Co, MD. Searched area on ground but no sign of eagle or transmitter.	5/13/2008	3/23/2009	Local, HA-02-04	Unknown Fate
74428	BAEA		5/13/2008		Local, HA-08-07	

Transmitter	Species	Transmitter Status	Start Transmission	End Transmission	Population of Origin	Fate
74429	BAEA	Dead. Found on edge of agricultural field, Talbot Co. MD. Scavenged by fox. Unknown COD. Transmitter recovered.	5/2/2008	10/10/2010	Local, BA-07-03	Dead - unknown
74430	BAEA	Transmitter recovered with harness severed by eagle near Earlesville, MD on the Sassafras River.	5/17/2008	1/15/2010	Local, HA-08-06	Harness Severed
74431	BAEA	Sudden loss of signals on Penns Creek, PA. Fate unknown. Not enough transmitter data to attempt search.	5/18/2008	9/21/2010	Local, HA-00-05	Unknown Fate
74432	BAEA	Sudden loss of signal Frederick Co, MD	5/27/2008	11/3/2011	Local, HA-06-01	Unknown Fate
74433	BAEA		5/28/2008		Local, HA-03-02	
74434	BAEA	Sudden loss of signal in upper Romney Creek Roost. Can not search this area because of UXO.	5/28/2008	3/13/2012	Local, HA-95-07	Unknown Fate
74435	BAEA	Transmitter recovered in communal roost Leonardtown, MD. Harness severed by eagle. No sign of carcass.	5/31/2008	5/16/2009	Local, HA-99-08	Harness Severed
74436	BAEA	Sudden loss of transmissions in rural Florida. Ground searched by volunteers.	8/31/2008	12/10/2010	Southern Migrant	Unknown Fate
74437	BAEA	Transmitter stationary in Cecil Co, MD.	9/1/2008	3/29/2011	Local	Unknown Fate
74438	BAEA		9/12/2008		Local	

Appendix 3: Summary of phenology information for nestlings tracked with satellite transmitters including estimated date of hatching, banding date, fledging date, and dispersal date.

Federal Band	Transmitter	Nest	Hatch date	Band date	Banding Age (days)	Fledging Date	Fledging Age (days)	Dispersal Date	Dispersal Age (days)	Notes
0679-01239	74424	Bridge Creek	3/12/2008	4/26/2008	45	5/28/2008	77	8/4/2008	145	
0679-01248	74425	Chilbury Pt	3/12/2008	5/3/2008	52	6/8/2008	88	7/20/2008	130	fledge date provided by EA
0679-01250	74426	Poverty Island	3/9/2008	5/4/2008	56	6/3/2008	86	7/30/2008	143	
0679-01306	74427	Monocacy Island Tower	3/14/2008	5/13/2008	60	5/29/2008	76	7/10/2008	118	
0679-01307	74428	Range 17	3/22/2008	5/13/2008	52	6/15/2008	85	10/4/2008	196	fledge date provided by EA
0679-01246	74429	White Oak Pt	3/18/2008	5/2/2008	45	5/25/2008	68	7/24/2008	128	
0679-01312	74430	Fuze Range Shoreline	3/25/2008	5/17/2008	53	6/2/2008	69	8/6/2008	134	
0679-01313	74431	Towner Cove	3/24/2008	5/18/2008	55	6/3/2008	71	11/23/2008	244	
0679-01314	74432	Plum Point	4/2/2008	5/27/2008	55	6/19/2008	78	9/4/2008	155	fledge date unk, approx
0679-01315	74433	Woodrest Creek	4/2/2008	5/28/2008	56	6/5/2008	64	8/21/2008	141	
0679-01317	74434	Aviation Arms Rd	3/24/2008	5/28/2008	65	6/4/2008	72	7/26/2008	124	
0679-01318	74435	Twin Towers	4/5/2008	5/31/2008	56	6/18/2008	74	9/3/2008	151	fledge date provided by EA
0679-01348	74382	Little Romney Creek	3/2/2009	4/26/2009	55	5/15/2009	74	7/22/2009	142	
0679-01349	74383	Range 8	3/2/2009	4/26/2009	55	5/13/2009	72	6/23/2009	113	
0679-01354	74384	Light Armor	3/16/2009	5/10/2009	55	6/18/2009	94	8/19/2009	156	
0679-01363	74399b	Locust Point	3/22/2009	5/16/2009	55	5/19/2009				died 7/30/09 near nest at 58 days old
0679-01365	74110b	Monocacy Island Tower	3/22/2009	5/16/2009	55	6/6/2009	76	7/7/2009	107	

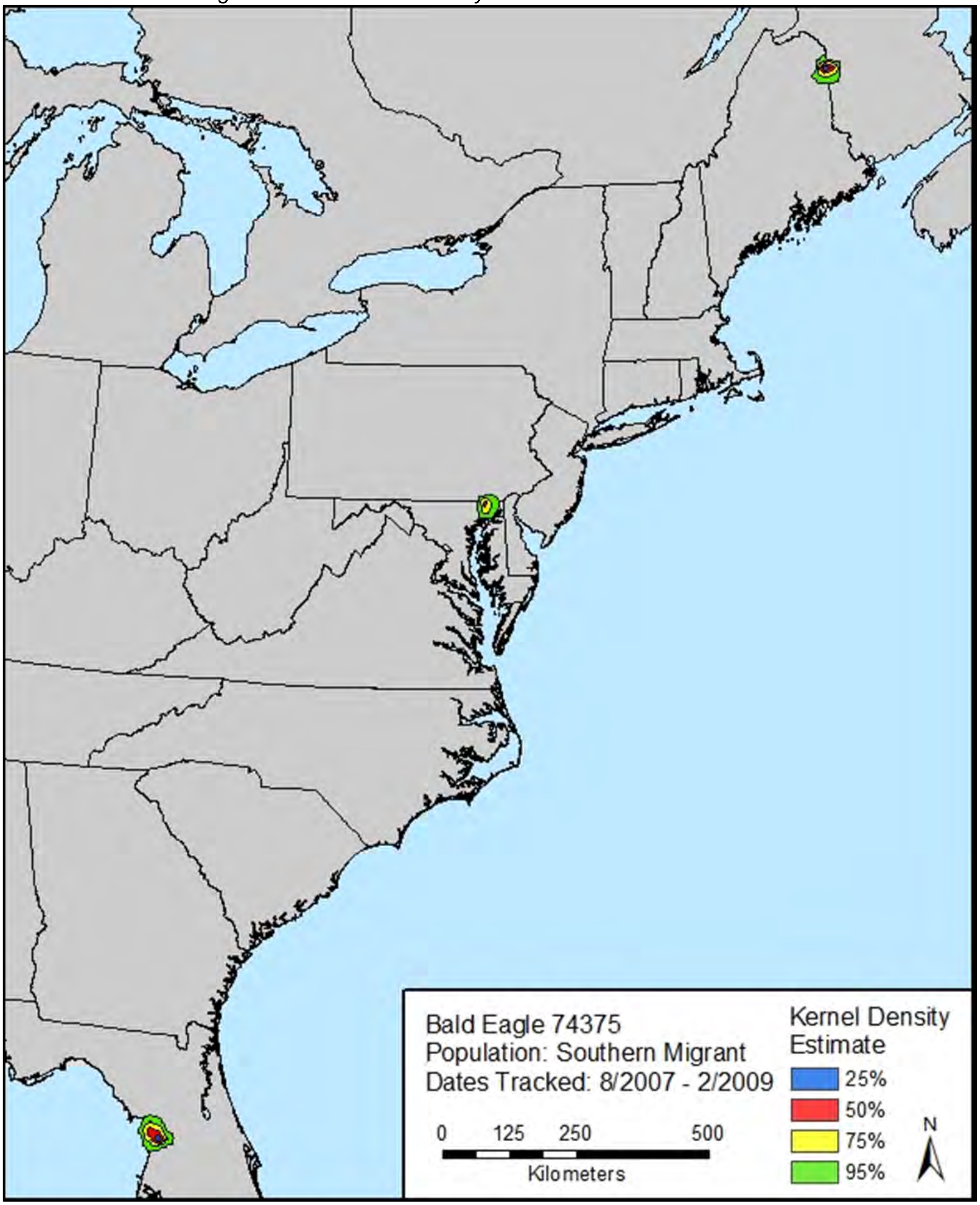
Appendix 4: Summary of GPS locations for bald and golden eagles tracked with satellite transmitters including total locations, locations within upper Chesapeake Bay study area, and APG.

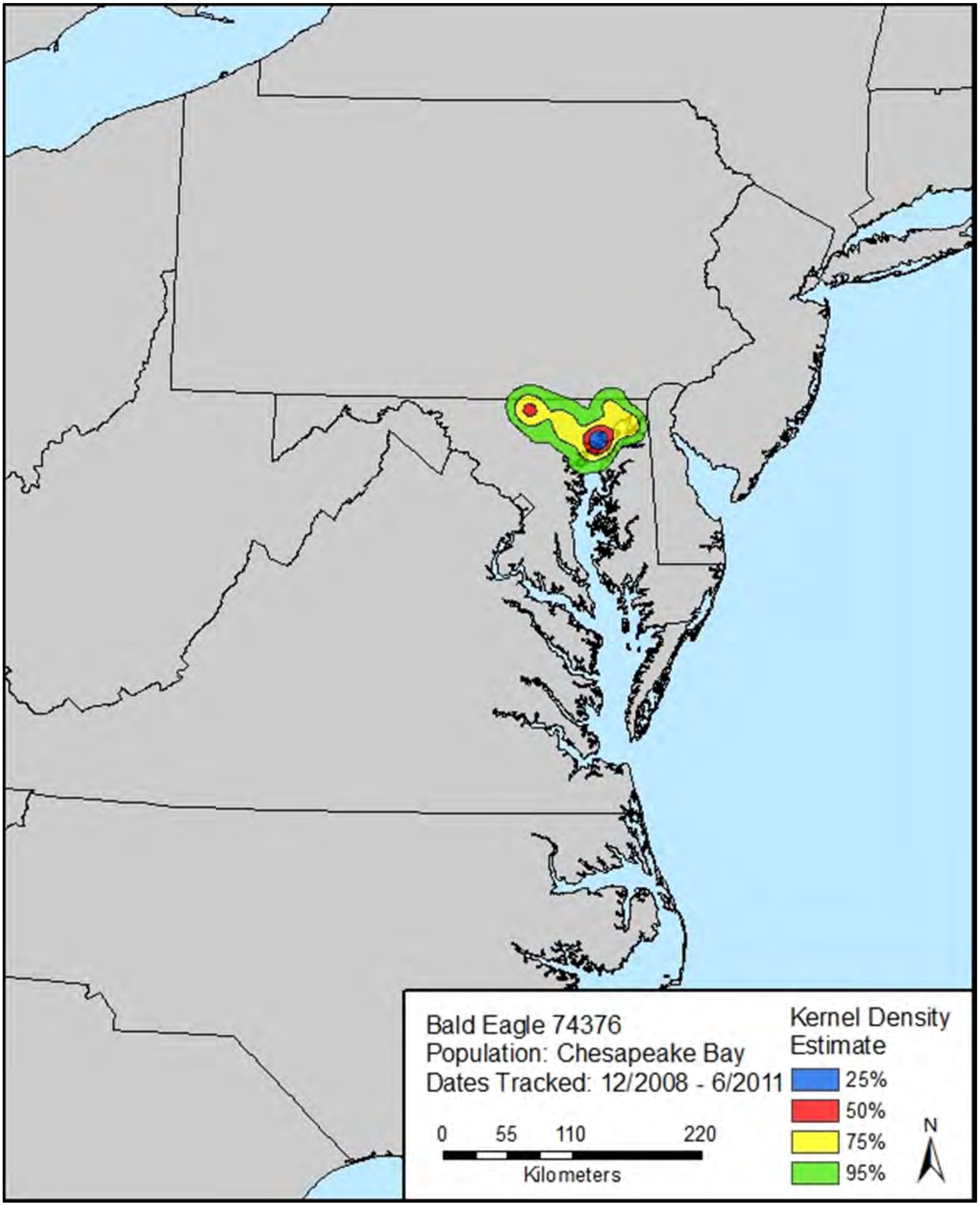
Transmitter	Origin	Total Locations	Locations within Upper Chesapeake Bay	% of locations within Upper Chesapeake Bay	Locations on APG	% of locations on APG
74375	Southern Migrant	13,873	1,908	13.8	3	0.0
74376	Local	12,833	9,538	74.3	2,198	17.1
74377	Local	1,254	1,162	92.7	300	23.9
74378	Local	12,804	2,737	21.4	20	0.2
74379	Local	11,477	1,587	13.8	213	1.9
74380	Local	7,856	5,881	74.9	3,422	43.6
74381	Local	12,842	5,699	44.4	415	3.2
74382	Local	9,549	5,854	61.3	1,515	15.9
74383	Local	9,537	6,885	72.2	2,410	25.3
74384	Local	9,446	6,314	66.8	5,410	57.3
74385	Local	2,387	1,783	74.7	1,519	63.6
74386	Local	18,327	12,730	69.5	815	4.4
74387	Local	18,879	533	2.8	282	1.5
74388	Local	13,093	1,300	9.9	33	0.3
74389	Southern Migrant	7,630	35	0.5	31	0.4
74390	Local	4,175	1,923	46.1	269	6.4
74391	Local	19,019	13,070	68.7	7,071	37.2
74392	Local	11,479	7,807	68.0	485	4.2
74393	Local	13,415	8,280	61.7	3,093	23.1
74394	Local	13,532	8,665	64.0	3,050	22.5
74395	Local	17,425	11,727	67.3	4,493	25.8
74396	Local	18,737	13,136	70.1	463	2.5
74397	Local	15,320	9,497	62.0	3,119	20.4
74398	Local	14,820	5,190	35.0	1,887	12.7
74399	Southern Migrant	4,844	482	10.0	15	0.3
74400	Local	13,996	13,927	99.5	10,326	73.8
74401	Northern Migrant	12,304	6,790	55.2	139	1.1
74402	Northern Migrant	14,069	3,744	26.6	168	1.2
74403	Northern Migrant	11,562	1,198	10.4	1,010	8.7

Transmitter	Origin	Total Locations	Locations within Upper Chesapeake Bay	% of locations within Upper Chesapeake Bay	Locations on APG	% of locations on APG
74404	Local	3,078	1,979	64.3	84	2.7
74405	Northern Migrant	14,254	2,171	15.2	101	0.7
74406	Northern Migrant	14,869	1,937	13.0	61	0.4
74407	Northern Migrant	14,390	1,538	10.7	110	0.8
74408	Northern Migrant	15,559	3,250	20.9	1,510	9.7
74409	Local	1,731	1,460	84.3	505	29.2
74410	Local	1,119	787	70.3	507	45.3
74411	Northern Migrant	8,962	538	6.0	507	5.7
74412	Northern Migrant	10,519	1,410	13.4	861	8.2
74413	Northern Migrant	4,719	717	15.2	170	3.6
74414	Local	17,556	12,987	74.0	3,169	18.1
74415	Local	9,903	6,928	70.0	1,275	12.9
74416	Local	17,473	12,596	72.1	2,191	12.5
74420	Local	7,190	6,022	83.8	5,366	74.6
74421	Northern Migrant	5,553	888	16.0	292	5.3
74422	Northern Migrant	13,317	9,173	68.9	512	3.8
74423	Northern Migrant	11,332	2,325	20.5	1,050	9.3
74424	Local	14,407	5,122	35.6	4,561	31.7
74425	Local	13,993	9,823	70.2	1,479	10.6
74426	Local	14,301	10,114	70.7	9,112	63.7
74427	Local	3,440	1,407	40.9	692	20.1
74428	Local	12,925	9,578	74.1	6,641	51.4
74429	Local	11,175	6,155	55.1	4,835	43.3
74430	Local	6,740	4,504	66.8	2,316	34.4
74431	Local	9,356	7,259	77.6	6,378	68.2
74432	Local	14,285	10,205	71.4	2,824	19.8
74433	Local	14,347	9,465	66.0	6,438	44.9
74434	Local	14,782	10,235	69.2	4,203	28.4
74435	Local	3,550	1,190	33.5	110	3.1
74436	Southern	11,763	519	4.4	14	0.1

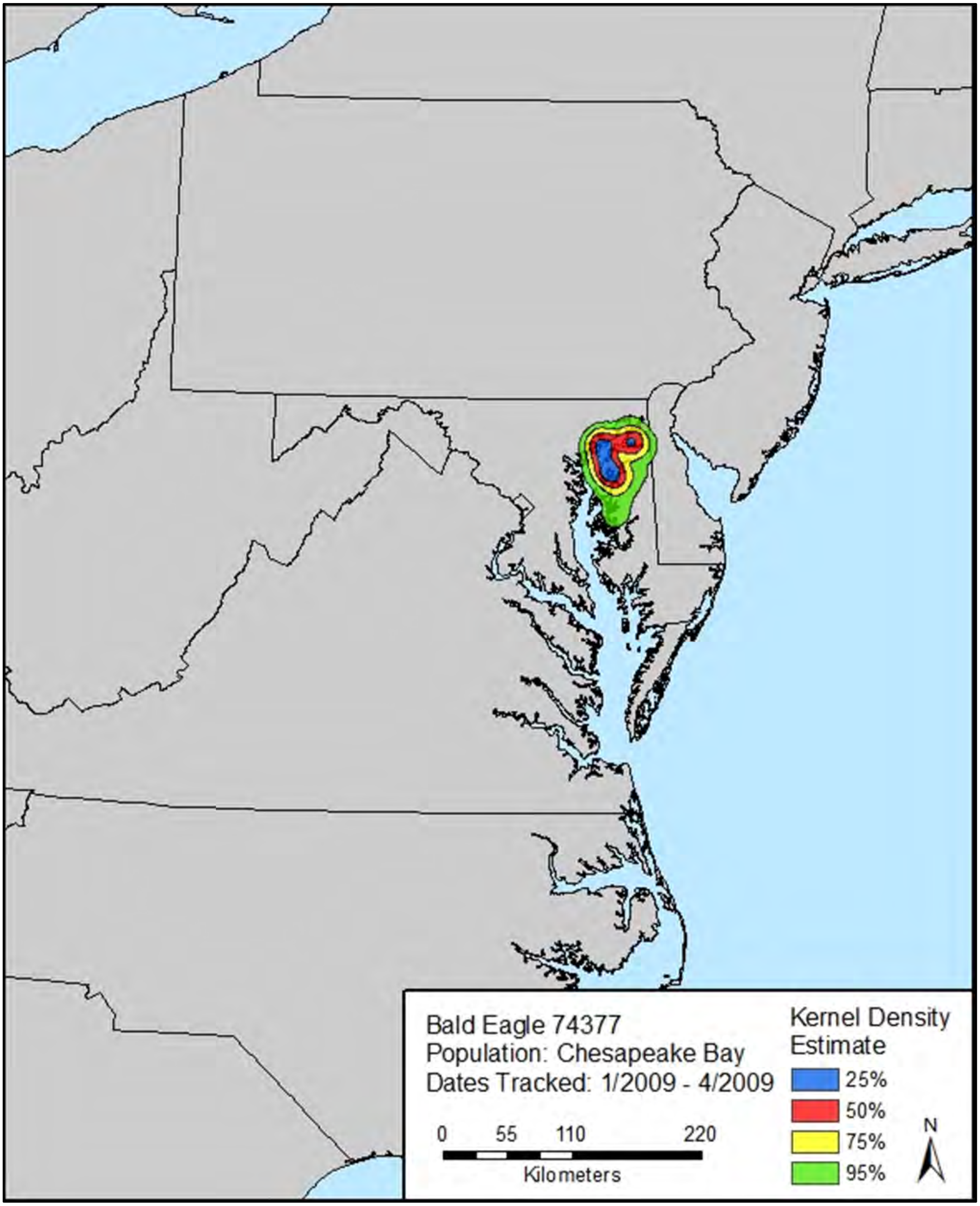
Transmitter	Origin	Total Locations	Locations within Upper Chesapeake Bay	% of locations within Upper Chesapeake Bay	Locations on APG	% of locations on APG
	Migrant					
74437	Local	9,904	6,524	65.9	1,629	16.4
74438	Local	13,143	3,762	28.6	1,257	9.6
74410b	Local	10,130	5,324	52.6	2,780	27.4

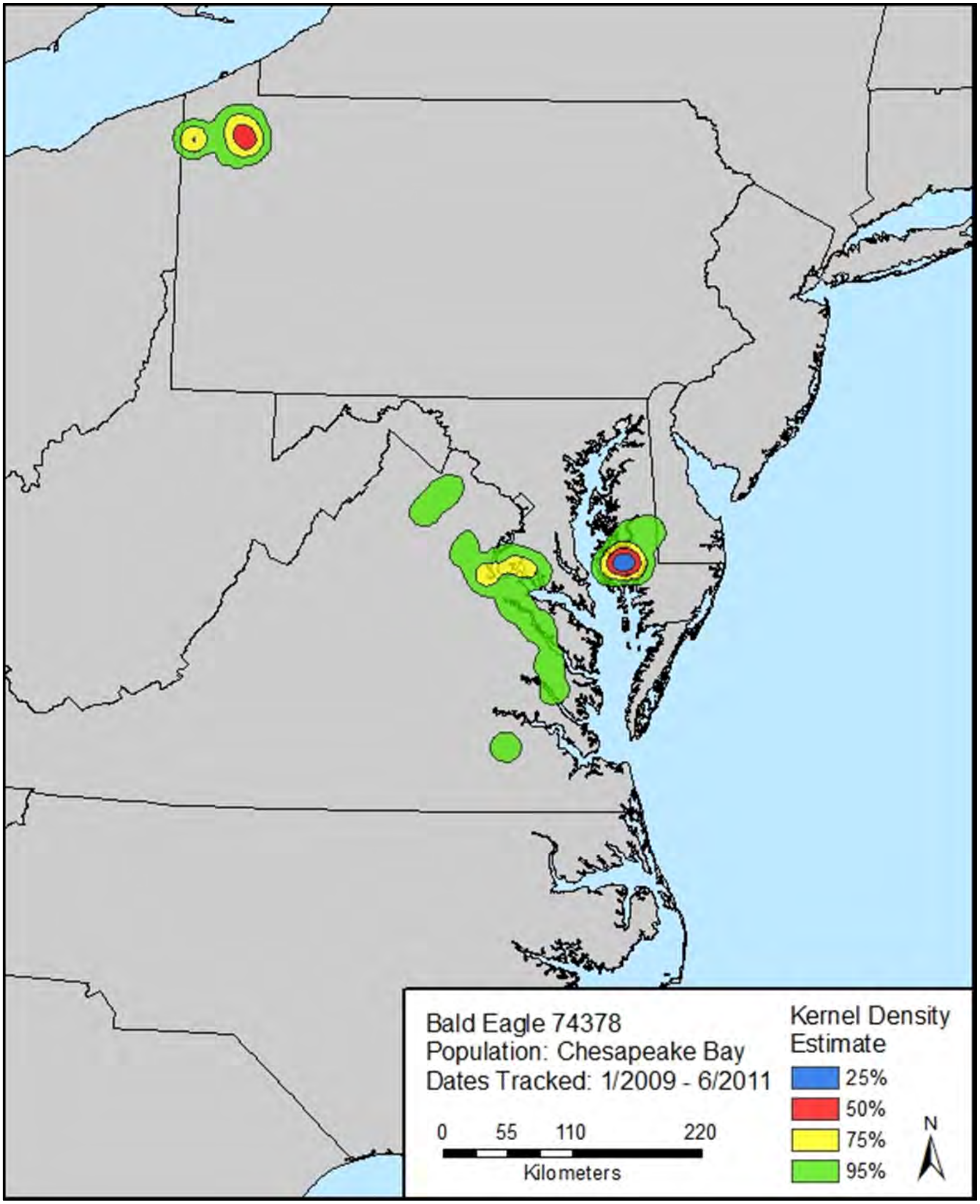
Appendix 5: Kernel home range maps for bald and golden eagles tracked with satellite transmitters illustrating the distribution of activity for each bird.

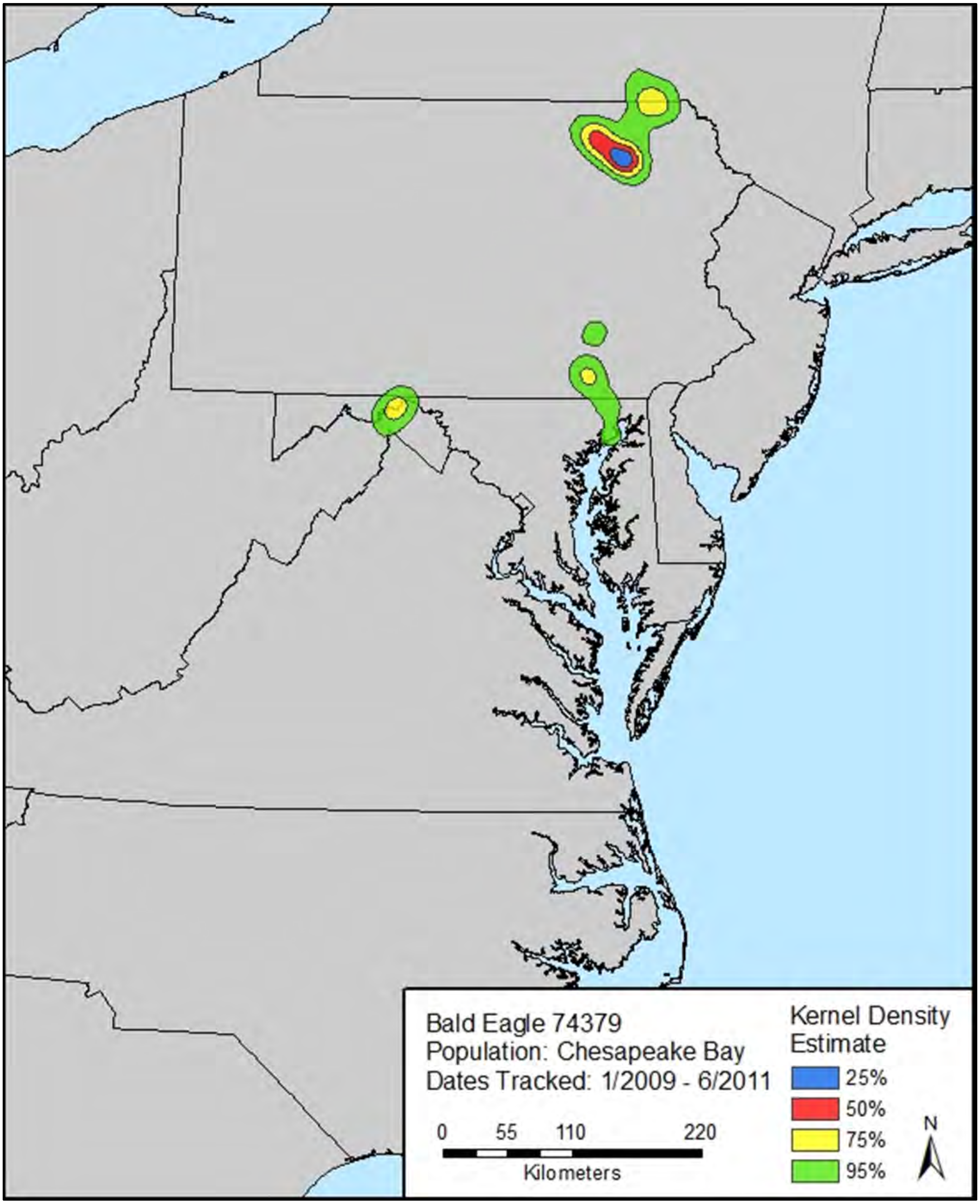




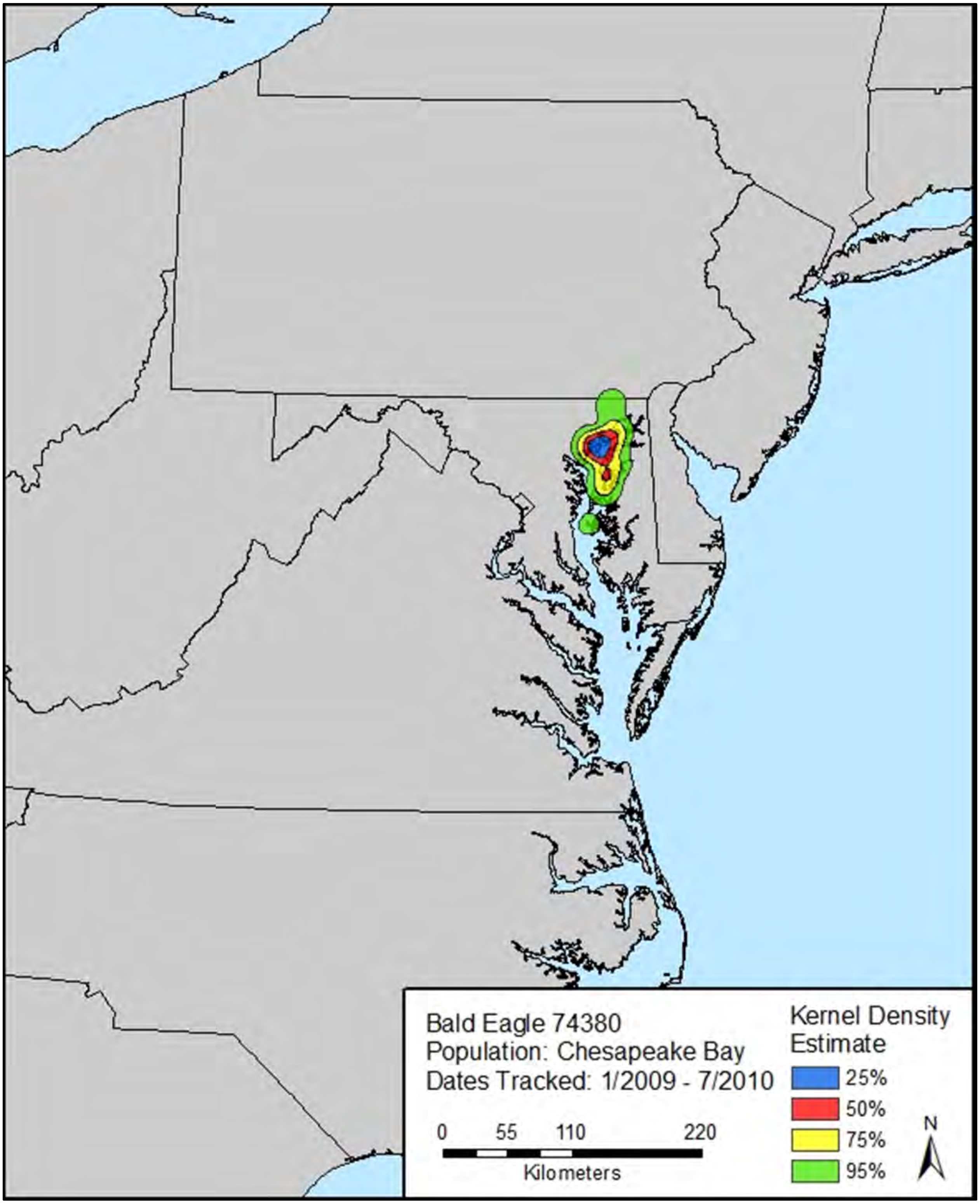
Bald Eagle 74376
Population: Chesapeake Bay
Dates Tracked: 12/2008 - 6/2011
Kernel Density Estimate
25%
50%
75%
95%
0 55 110 220
Kilometers
N


Bald Eagle 74377
Population: Chesapeake Bay
Dates Tracked: 1/2009 - 4/2009
Kernel Density Estimate
25%
50%
75%
95%
0 55 110 220
Kilometers
N

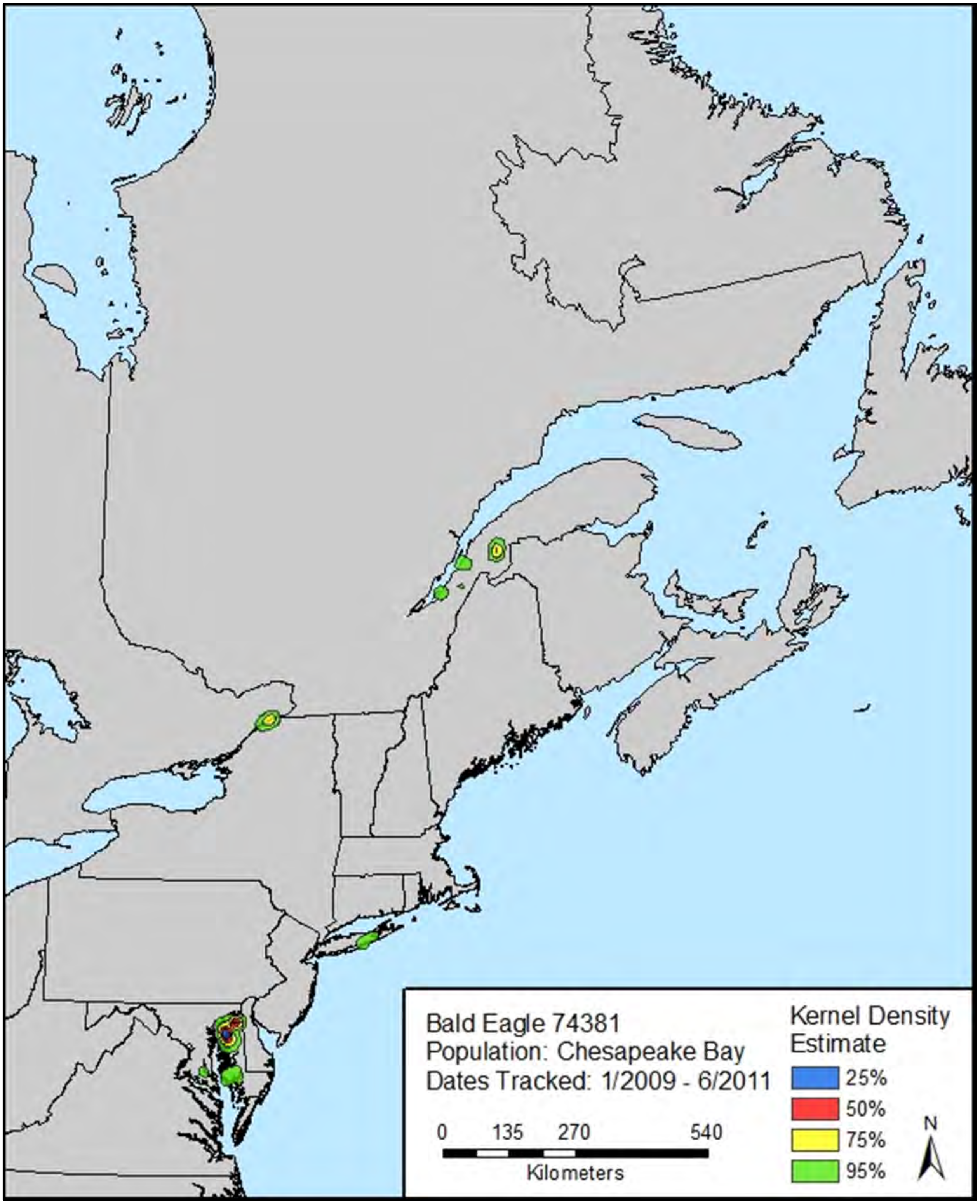

Bald Eagle 74378
Population: Chesapeake Bay
Dates Tracked: 1/2009 - 6/2011
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

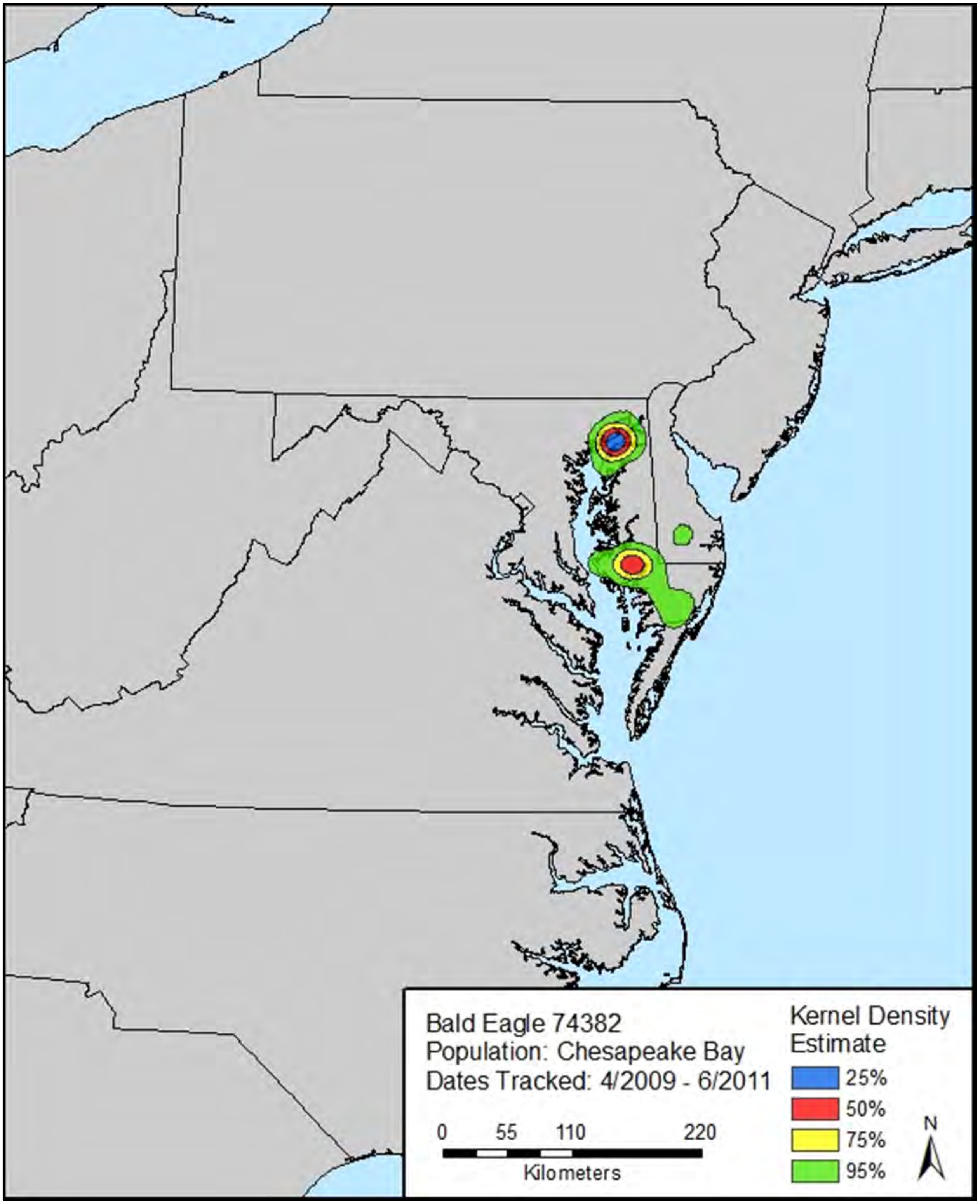


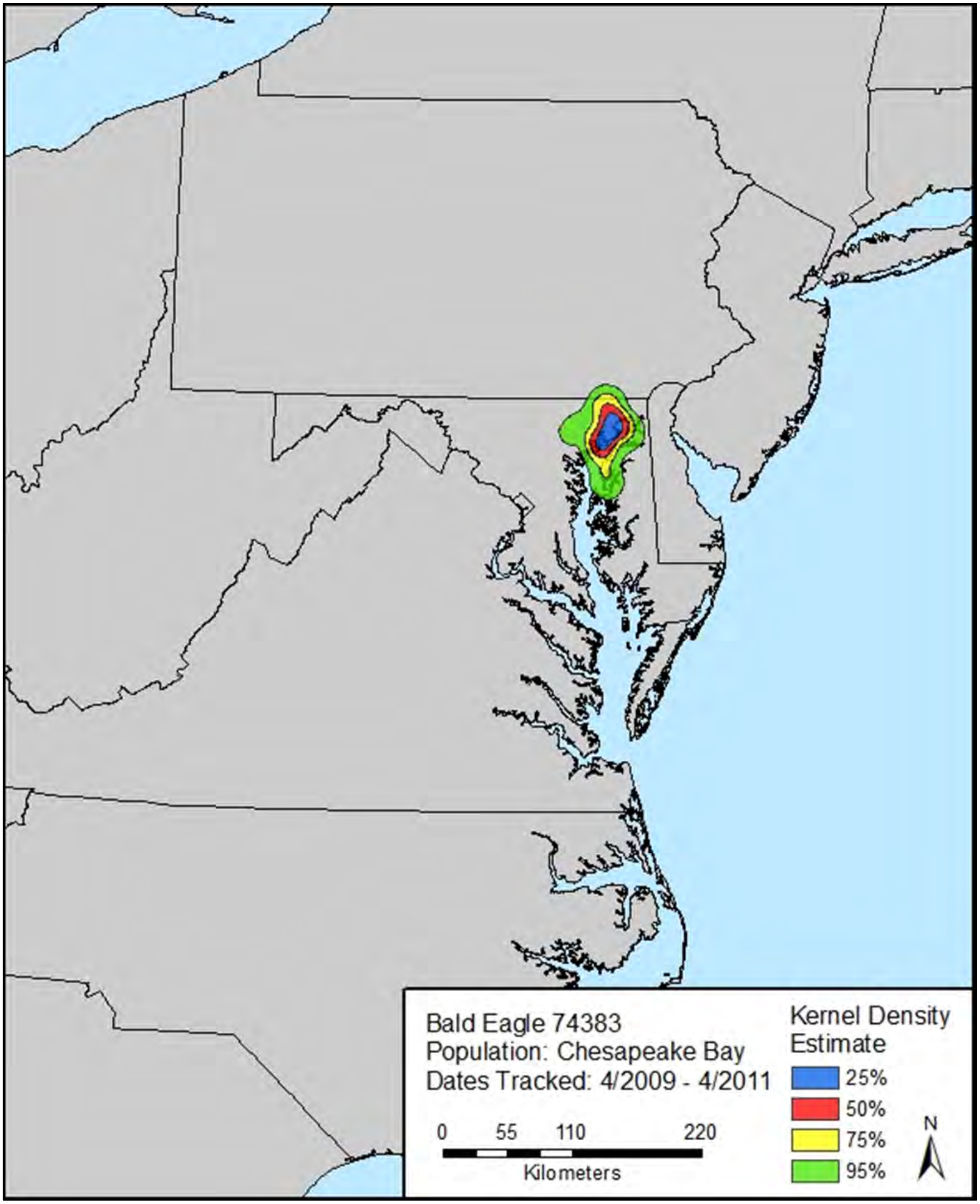
Bald Eagle 74379
Population: Chesapeake Bay
Dates Tracked: 1/2009 - 6/2011
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N



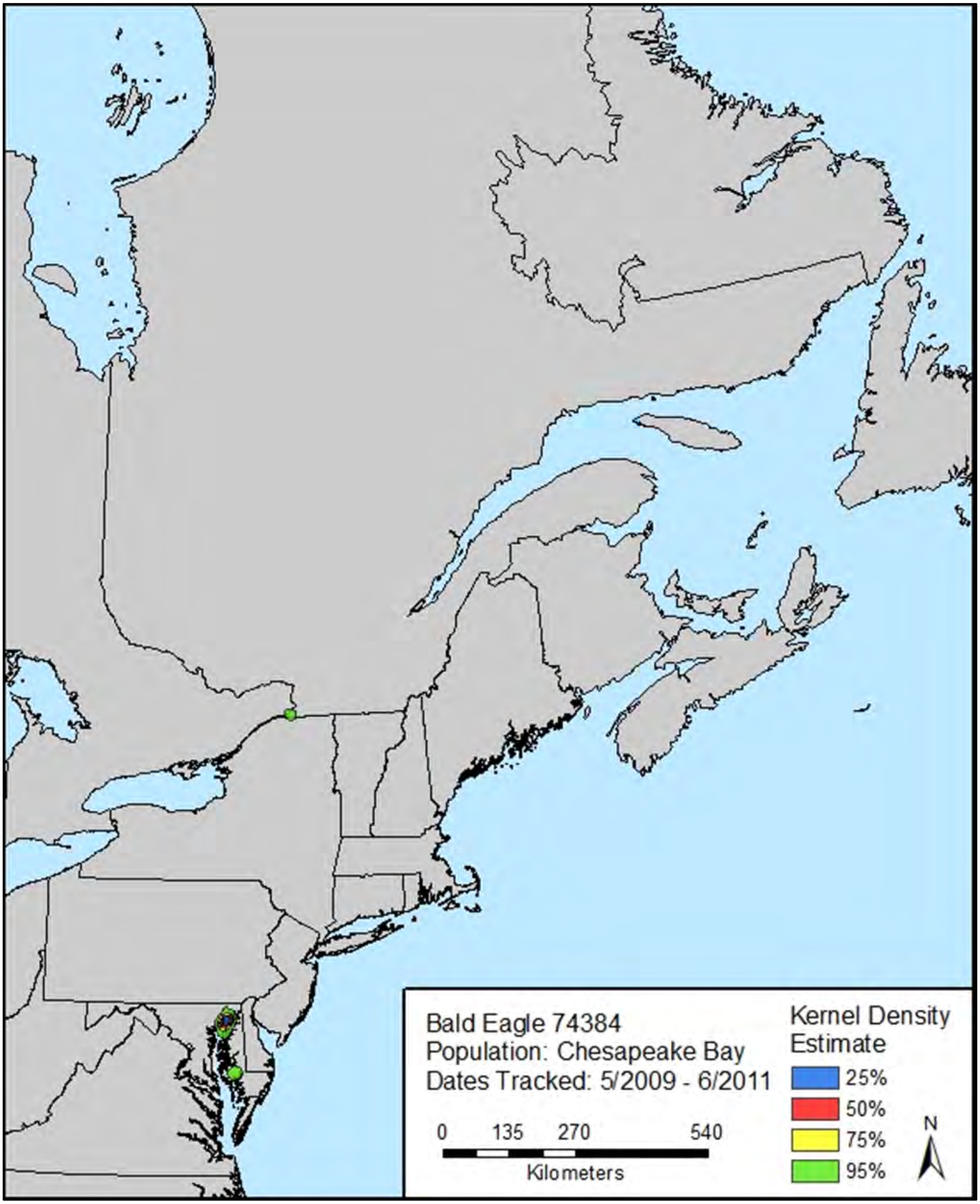
Bald Eagle 74380
Population: Chesapeake Bay
Dates Tracked: 1/2009 - 7/2010
Kernel Density Estimate
25%
50%
75%
95%
0
55
110
220
Kilometers
N

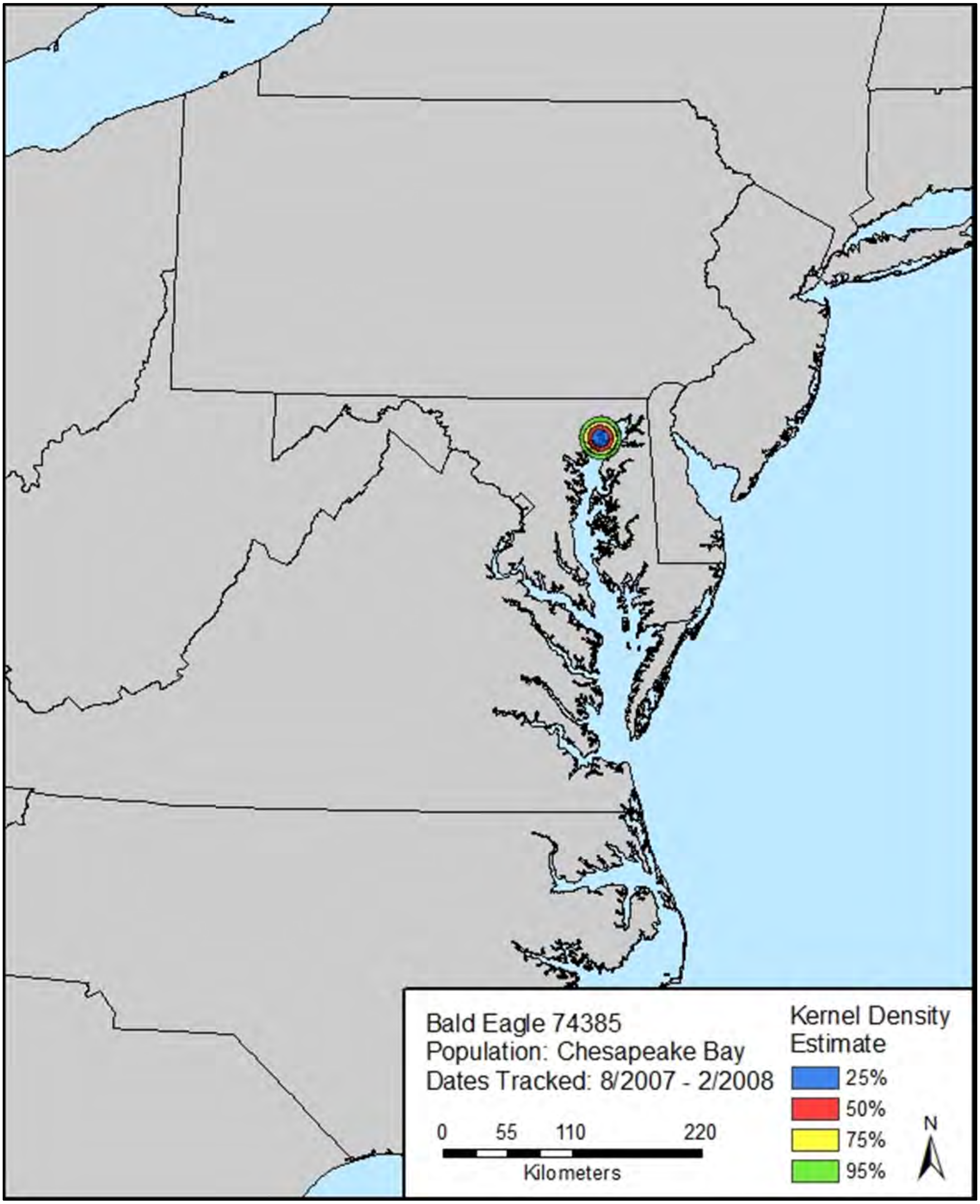

Bald Eagle 74381
Population: Chesapeake Bay
Dates Tracked: 1/2009 - 6/2011
Kernel Density Estimate
25%
50%
75%
95%
0
135
270
540
Kilometers
N

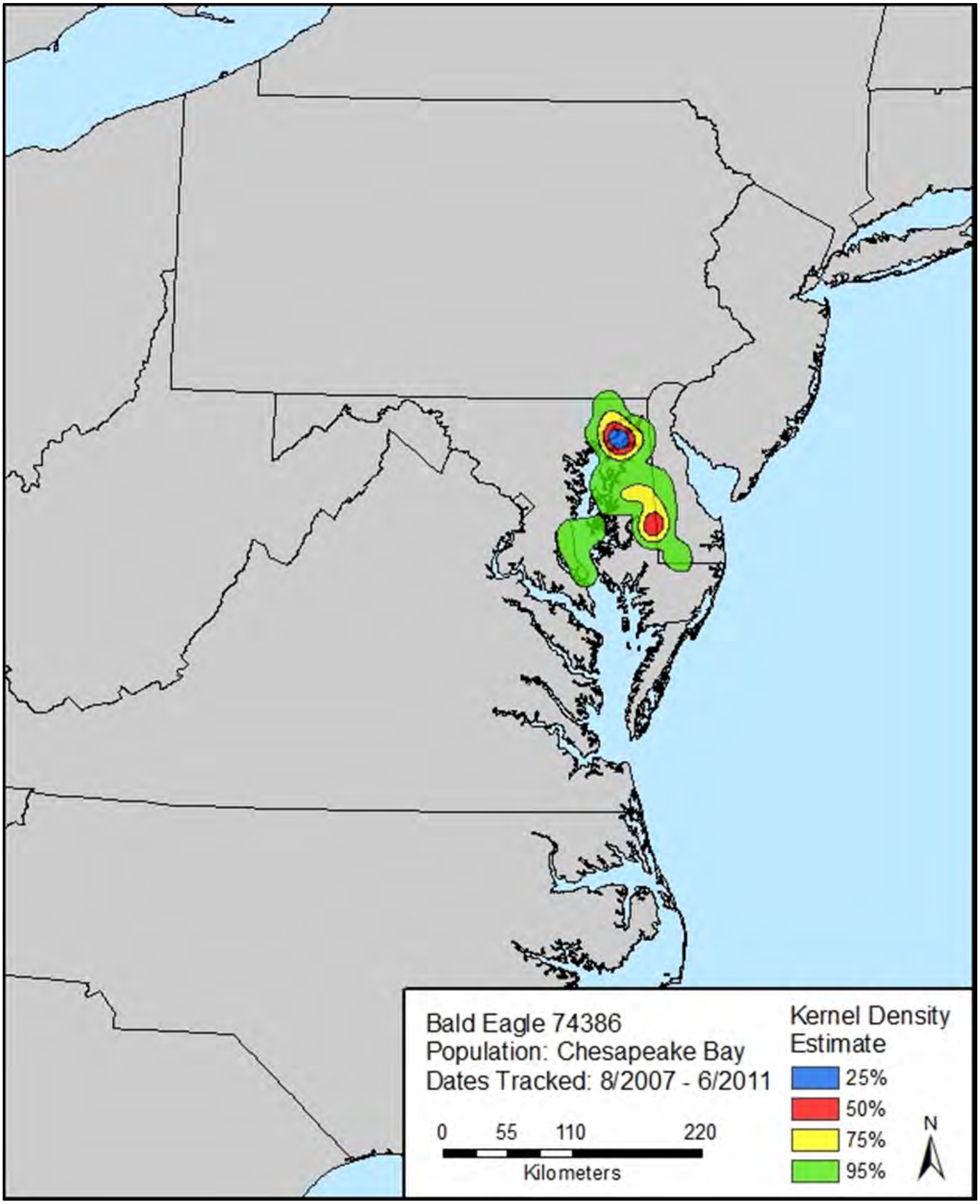

Bald Eagle 74382
Population: Chesapeake Bay
Dates Tracked: 4/2009 - 6/2011
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

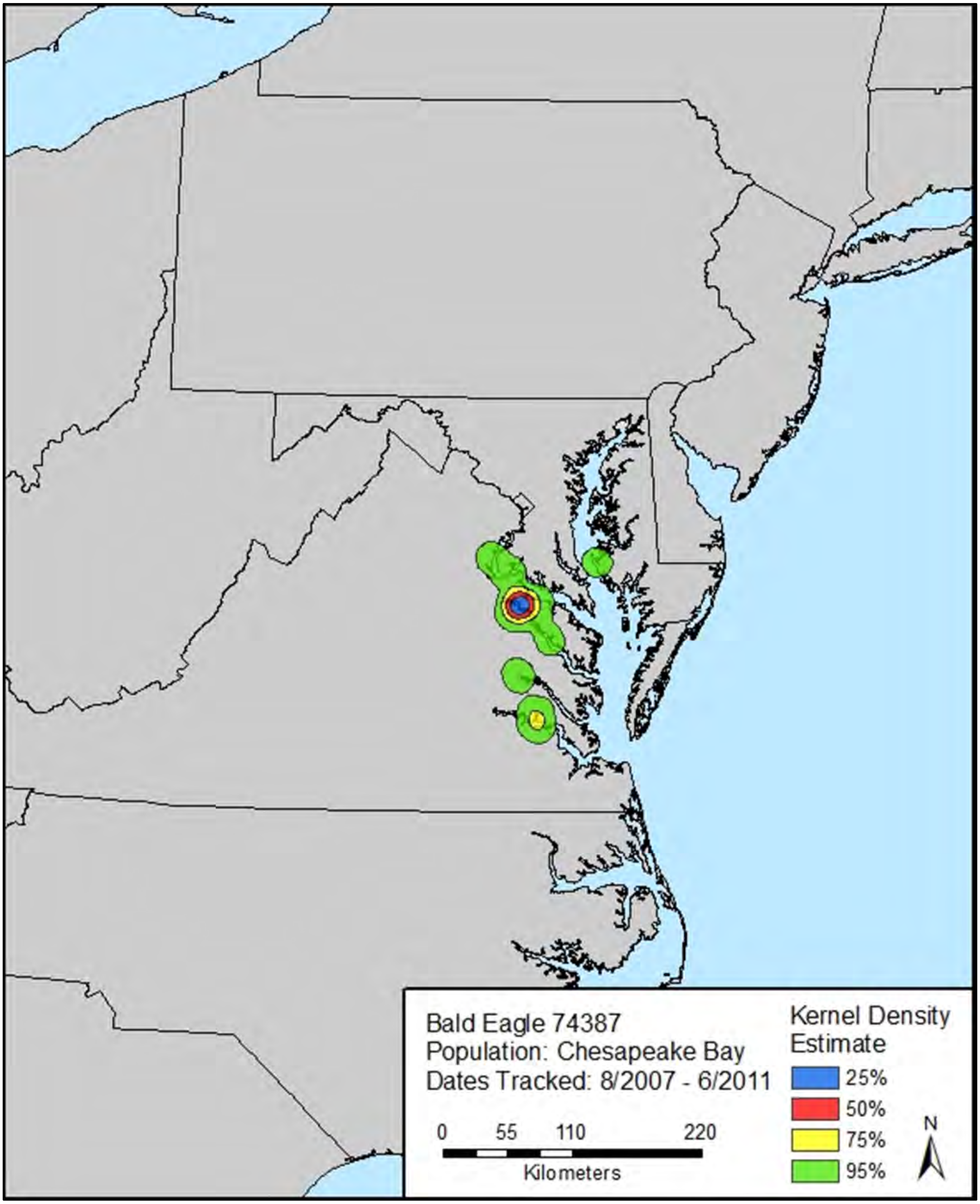


Bald Eagle 74383
Population: Chesapeake Bay
Dates Tracked: 4/2009 - 4/2011
Kernel Density Estimate
25%
50%
75%
95%
0
55
110
220
Kilometers
N

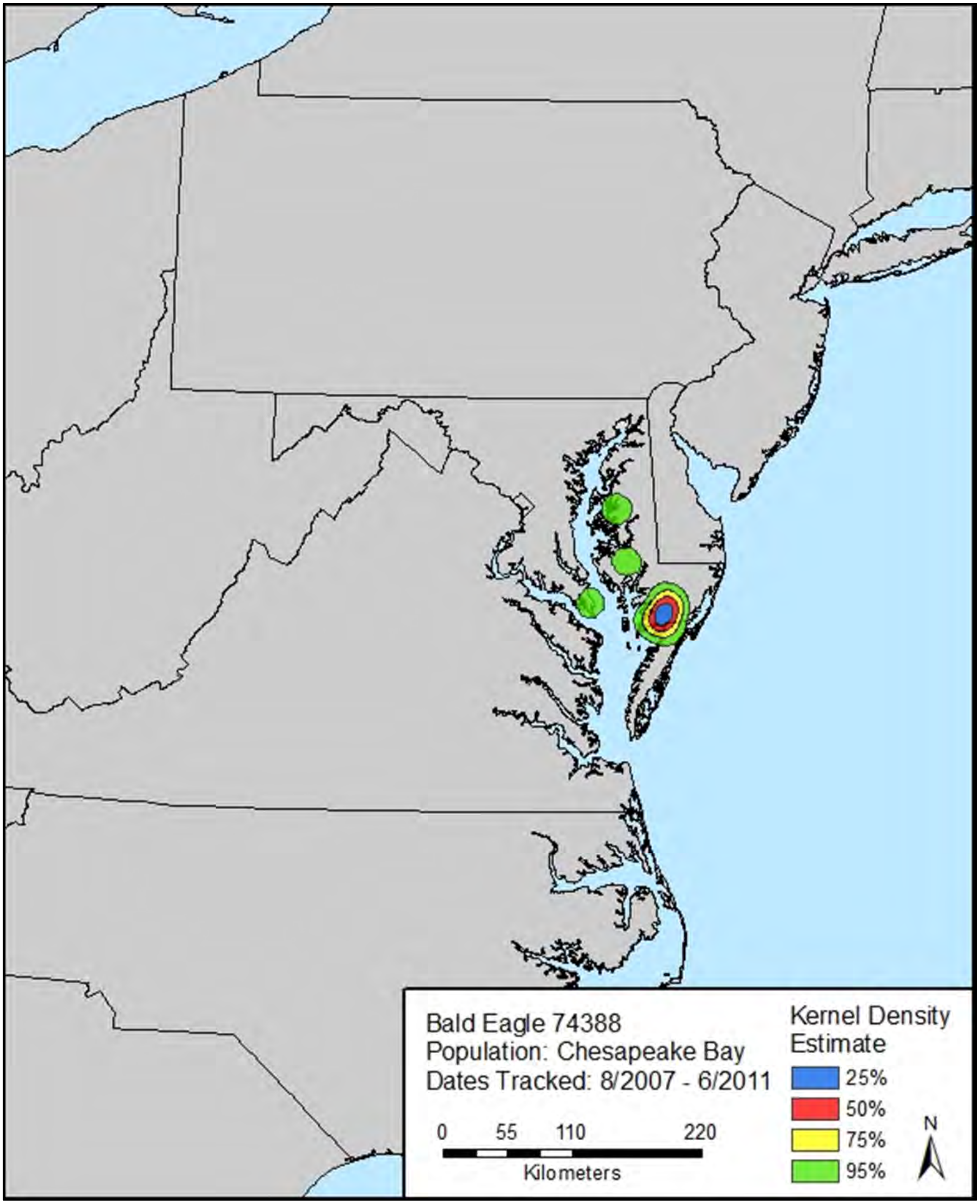

Bald Eagle 74384
Population: Chesapeake Bay
Dates Tracked: 5/2009 - 6/2011
Kernel Density Estimate
25%
50%
75%
95%
0
135
270
540
Kilometers
N

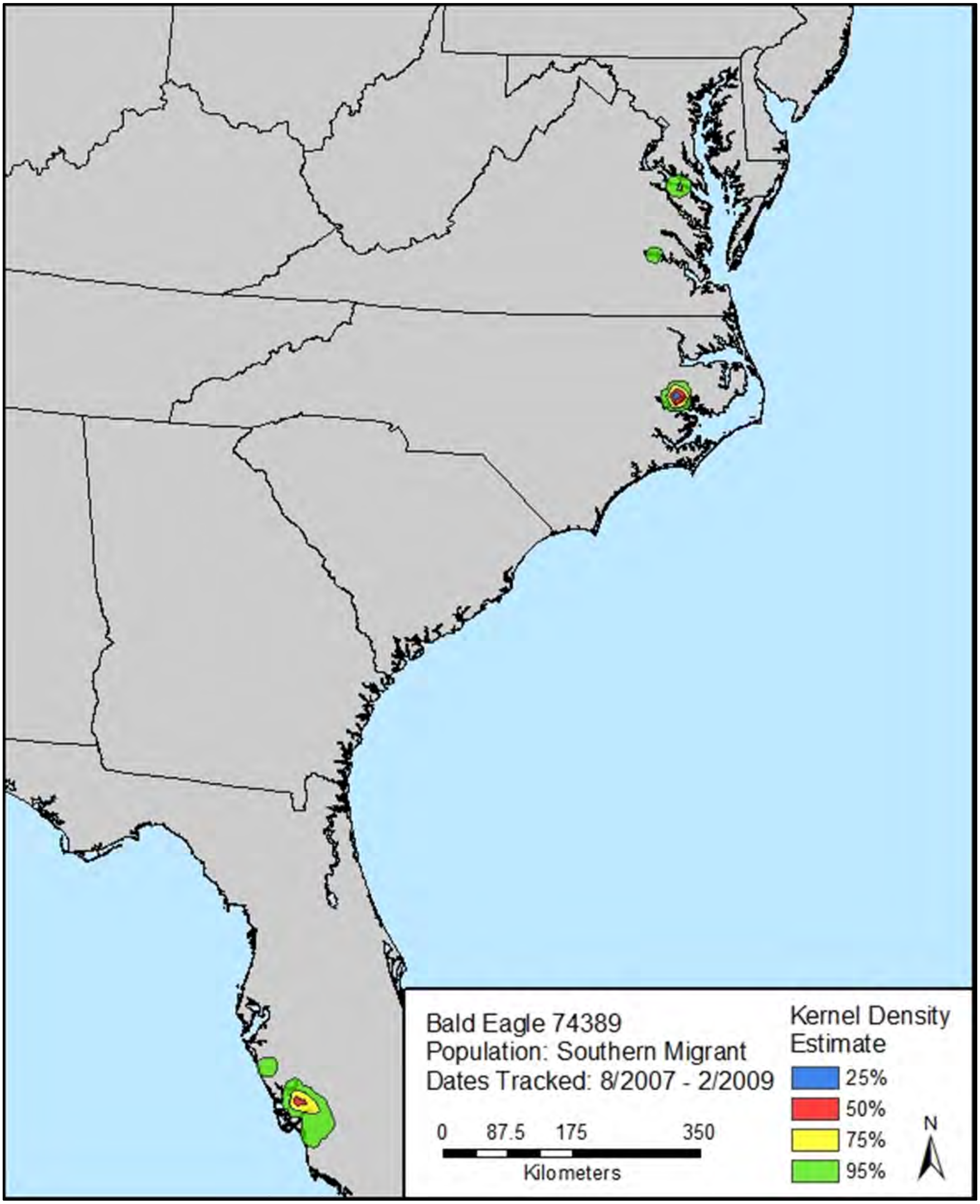

Bald Eagle 74385
Population: Chesapeake Bay
Dates Tracked: 8/2007 - 2/2008
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

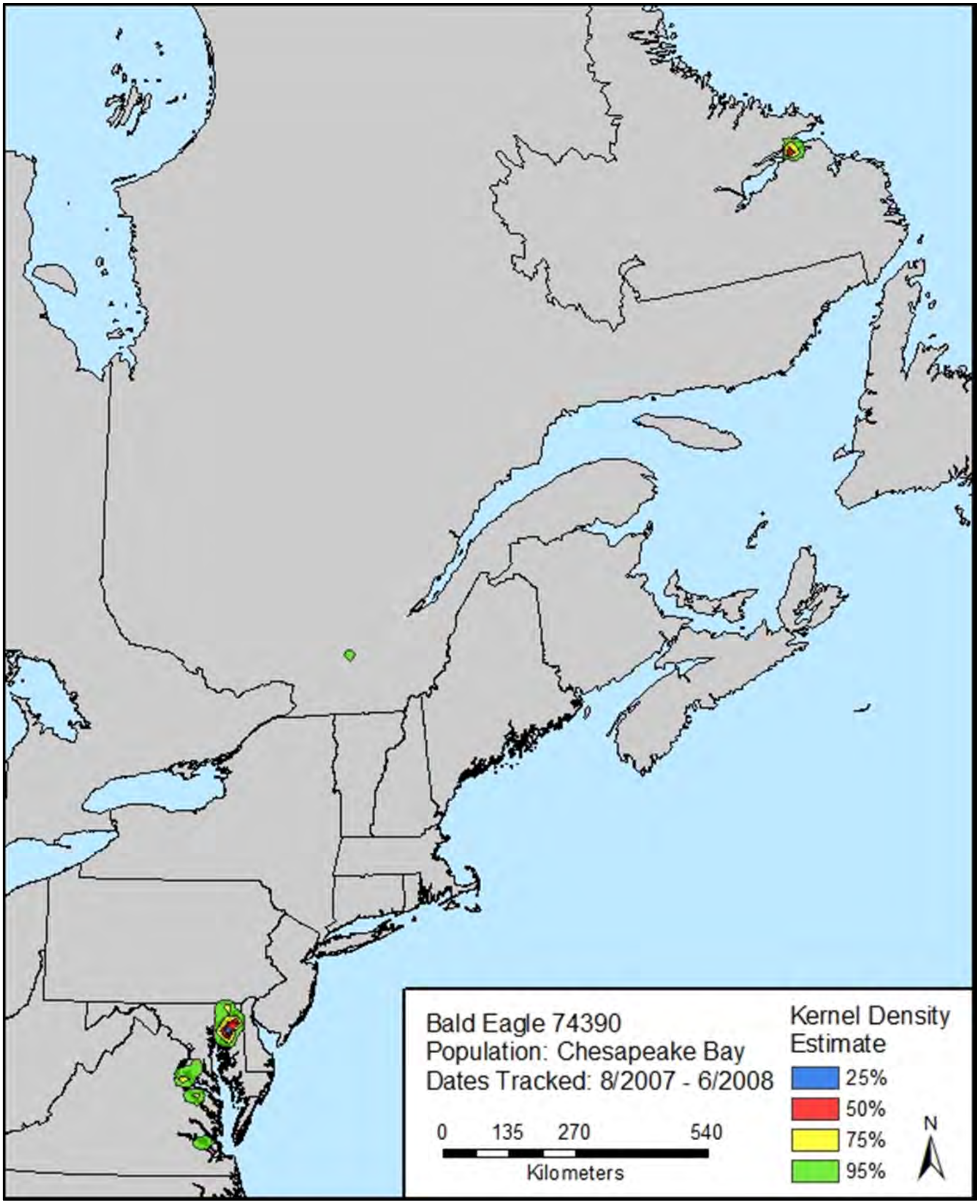

Bald Eagle 74386
Population: Chesapeake Bay
Dates Tracked: 8/2007 - 6/2011
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

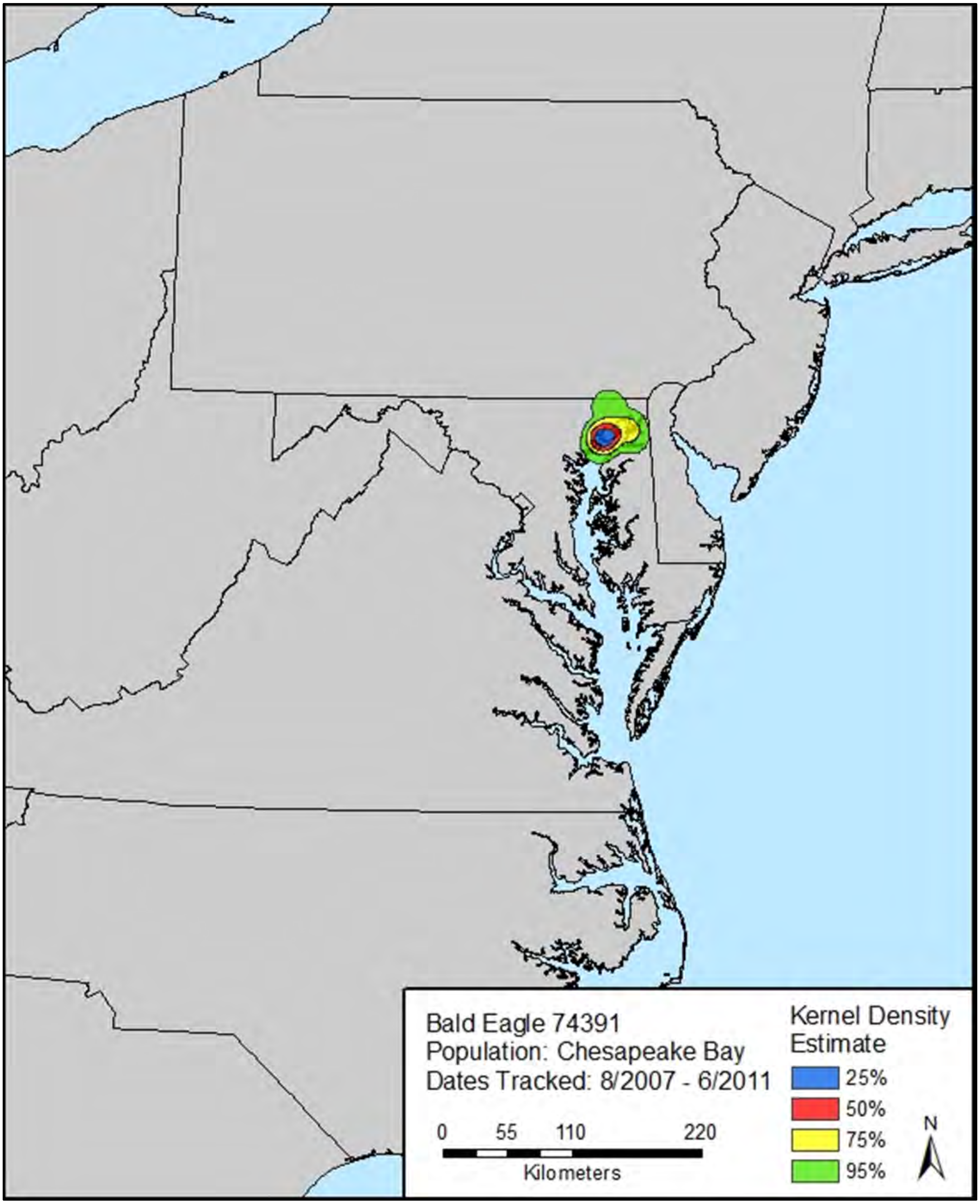


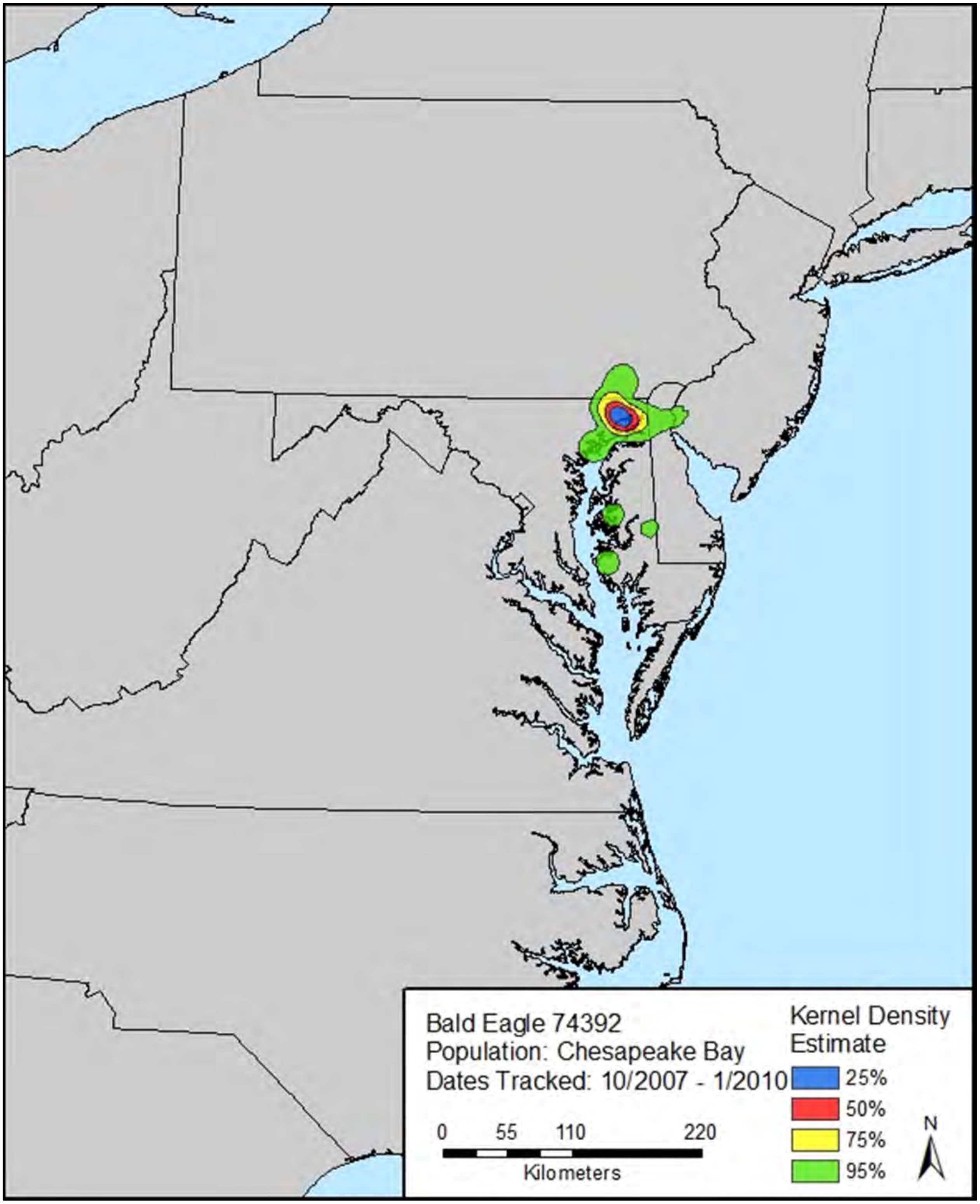
Bald Eagle 74387
Population: Chesapeake Bay
Dates Tracked: 8/2007 - 6/2011
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

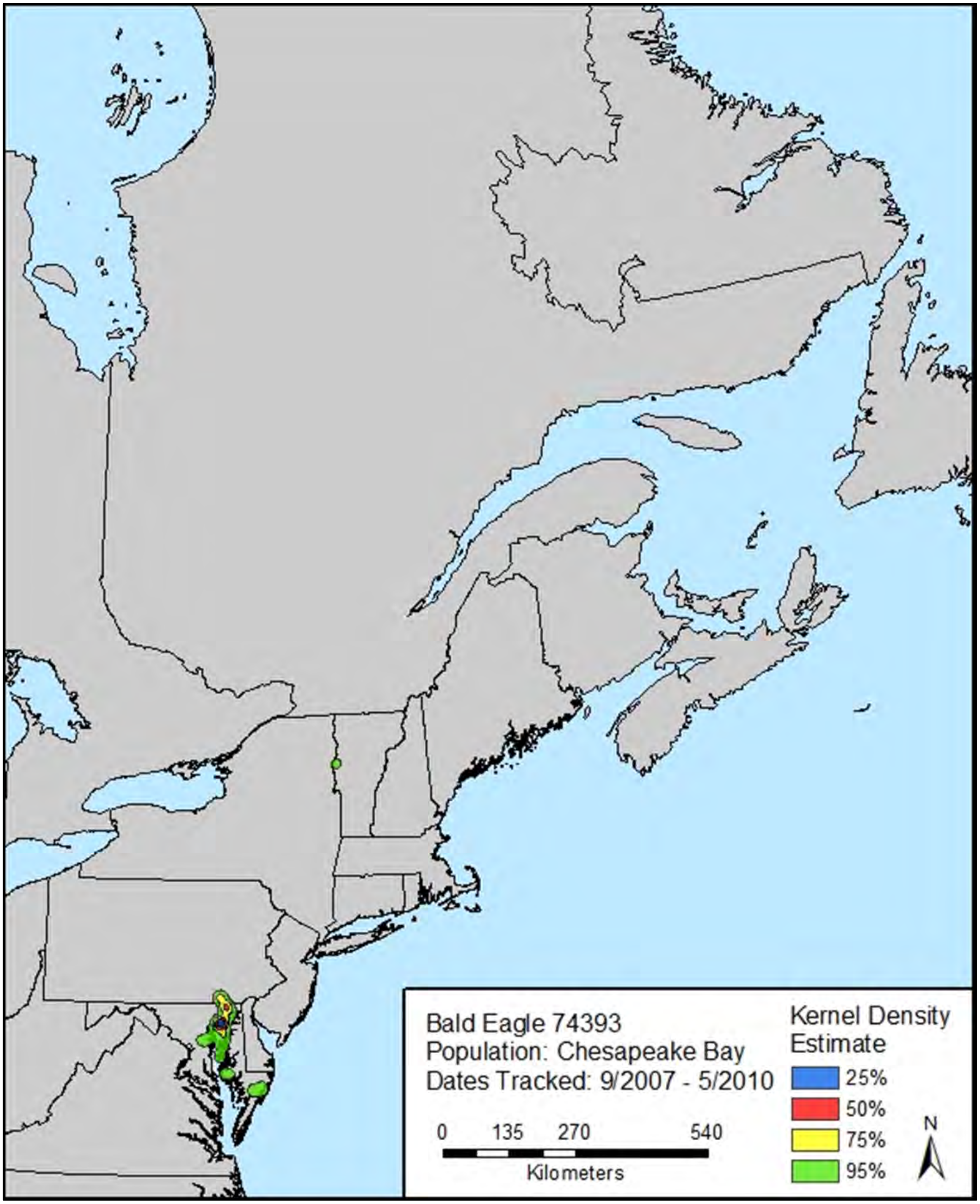

Bald Eagle 74388
Population: Chesapeake Bay
Dates Tracked: 8/2007 - 6/2011
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

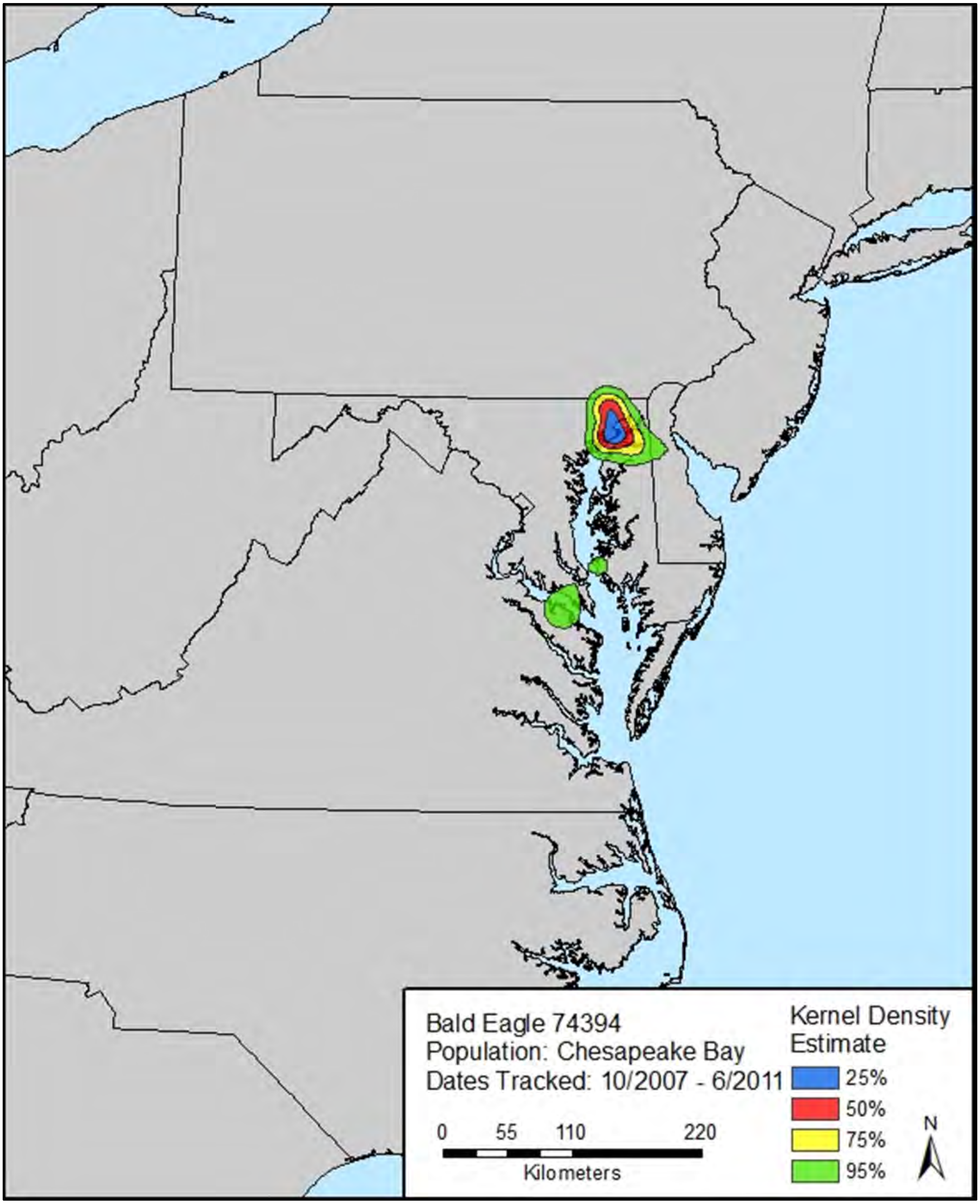

Bald Eagle 74389
Population: Southern Migrant
Dates Tracked: 8/2007 - 2/2009
0
87.5
175
350
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N


Bald Eagle 74390
Population: Chesapeake Bay
Dates Tracked: 8/2007 - 6/2008
Kernel Density Estimate
25%
50%
75%
95%
0
135
270
540
Kilometers
N

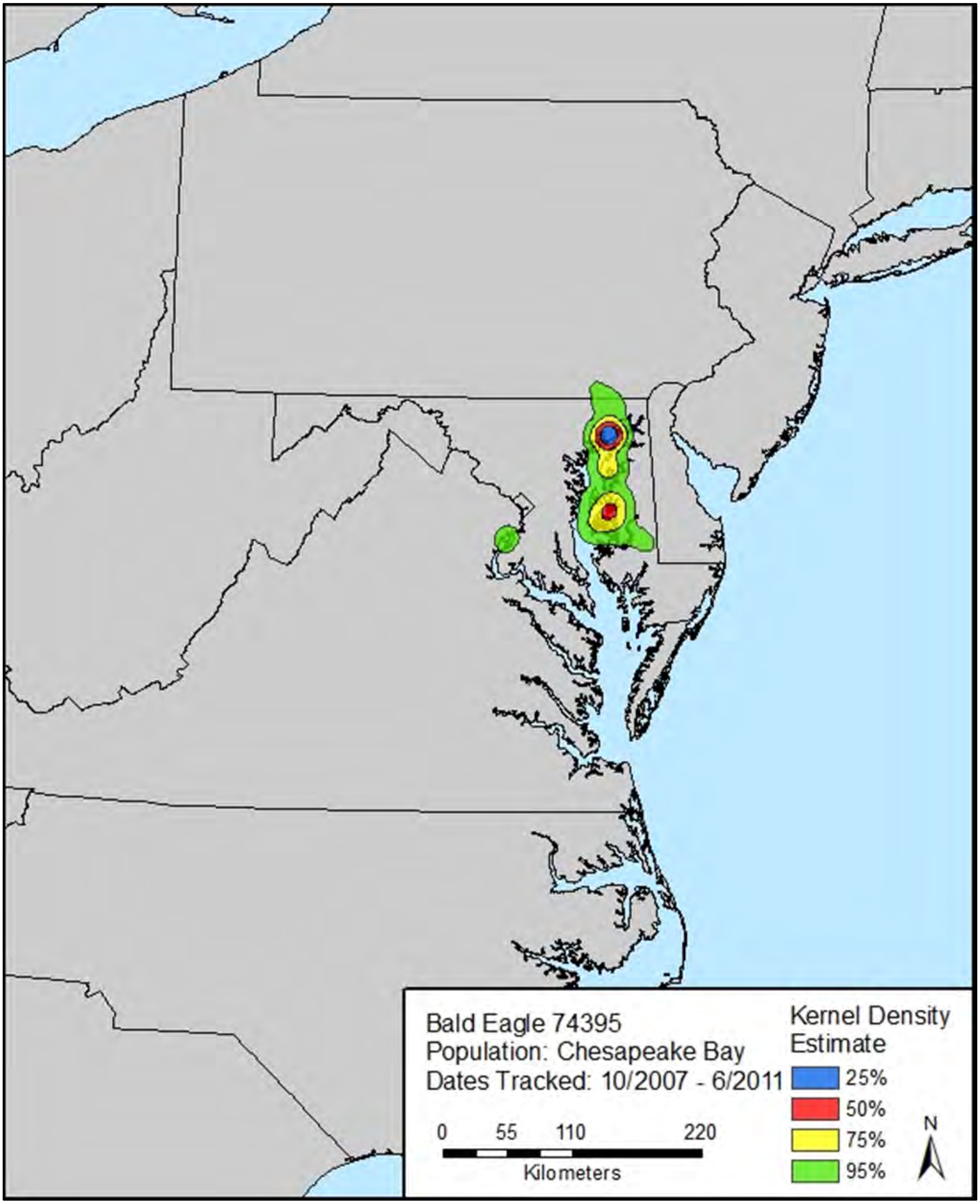

Bald Eagle 74391
Population: Chesapeake Bay
Dates Tracked: 8/2007 - 6/2011
0
55
110
220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

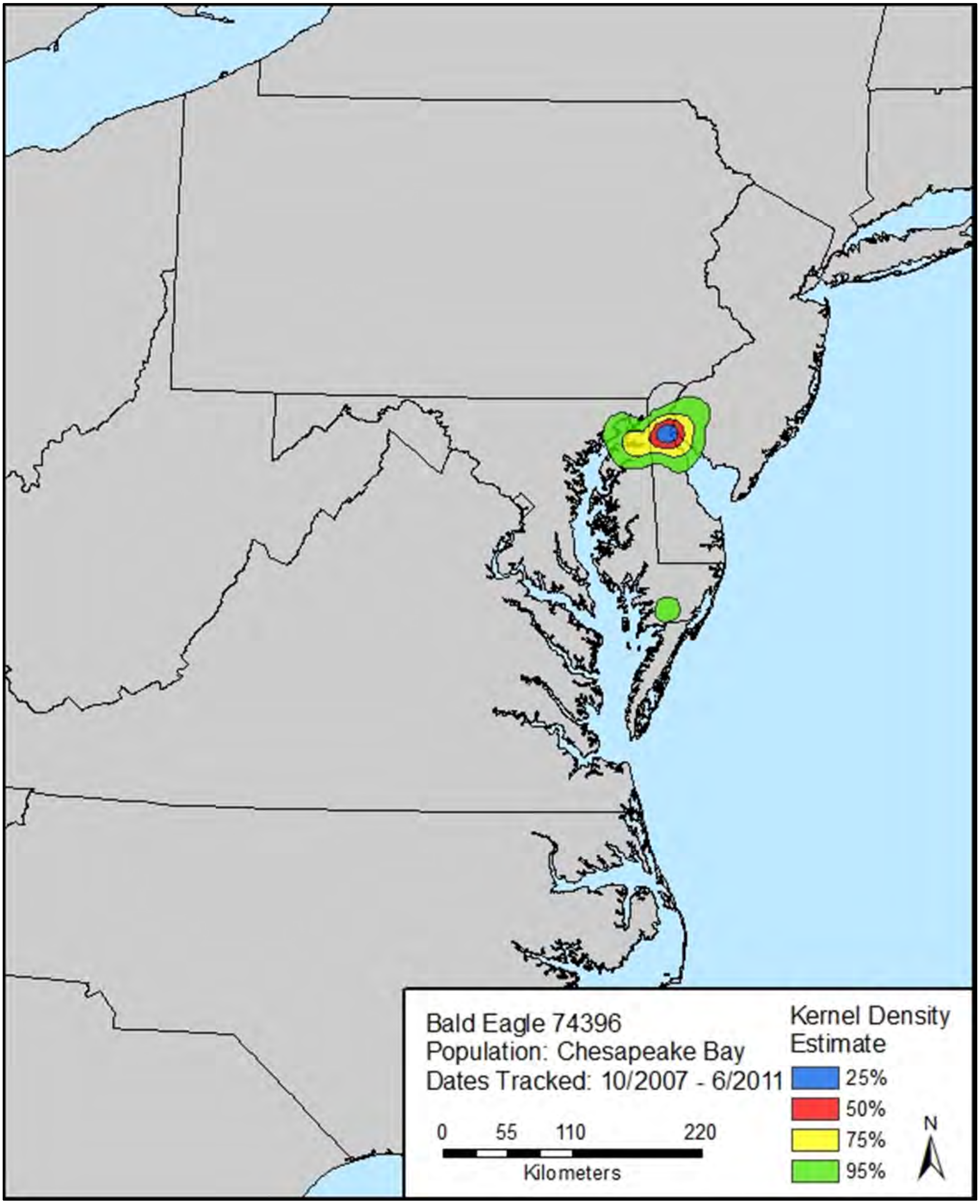

Bald Eagle 74392
Population: Chesapeake Bay
Dates Tracked: 10/2007 - 1/2010
Kernel Density Estimate
25%
50%
75%
95%
0 55 110 220
Kilometers
N

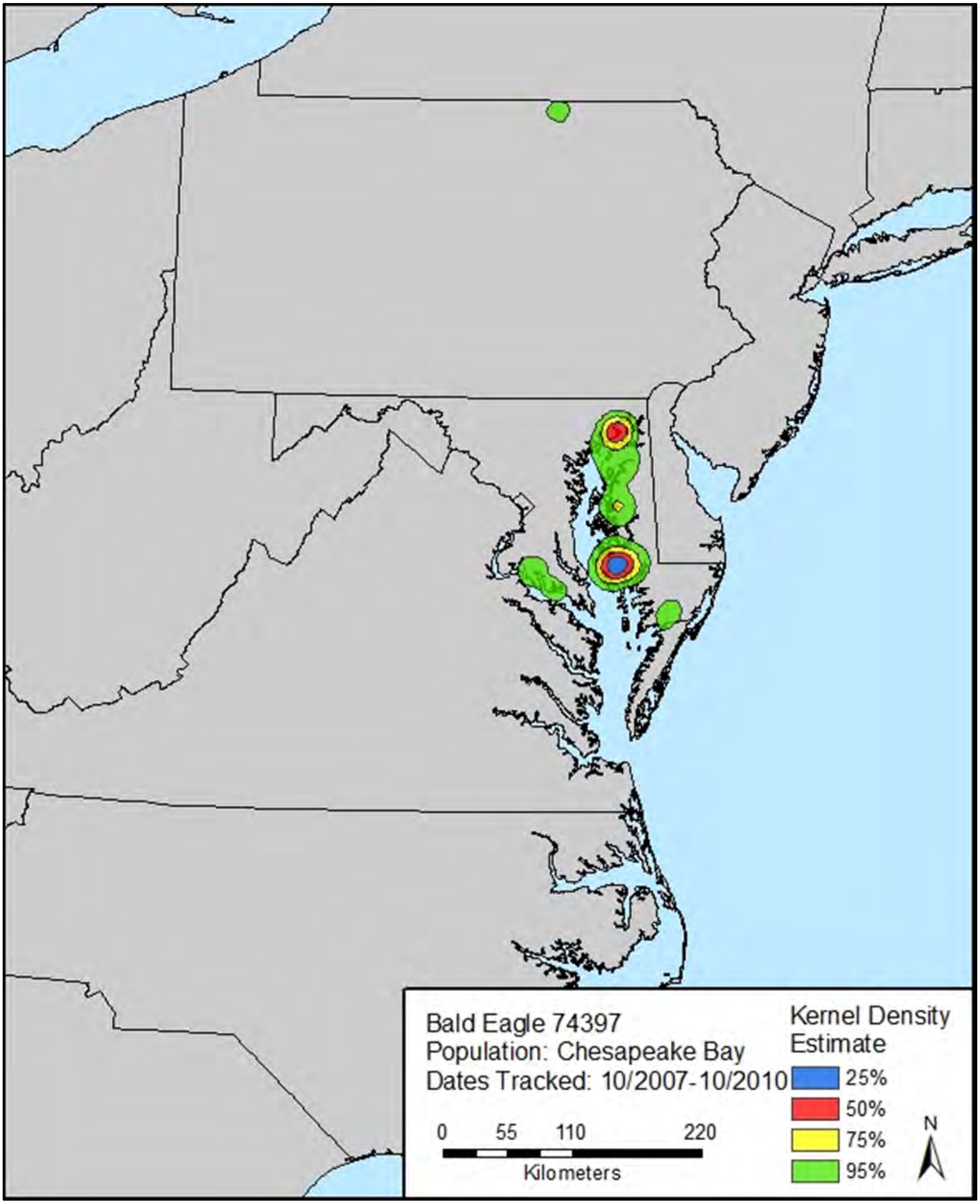

Bald Eagle 74393
Population: Chesapeake Bay
Dates Tracked: 9/2007 - 5/2010
Kernel Density Estimate
25%
50%
75%
95%
0 135 270 540
Kilometers
N



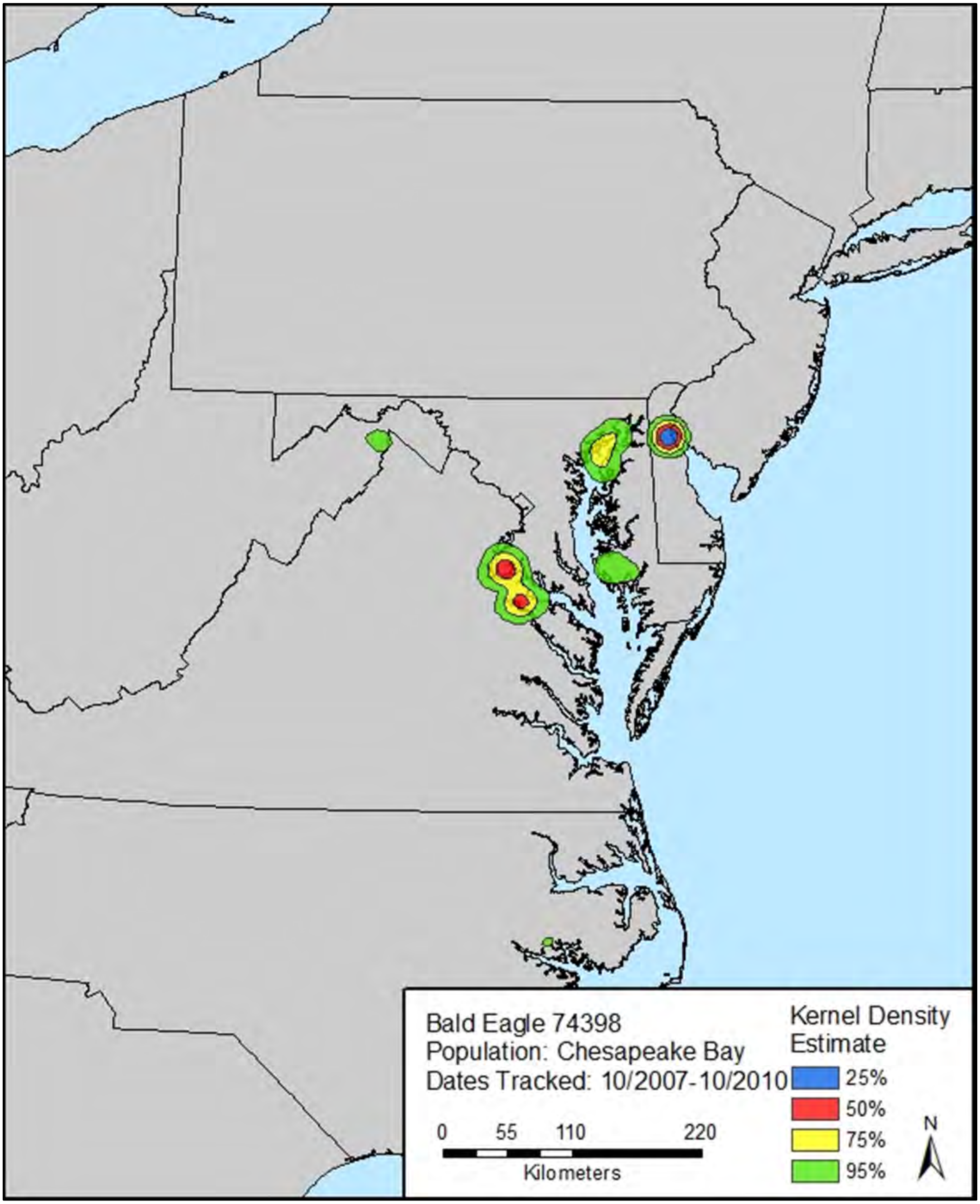
Bald Eagle 74394
Population: Chesapeake Bay
Dates Tracked: 10/2007 - 6/2011
Kernel Density Estimate
25%
50%
75%
95%
0
55
110
220
Kilometers
N

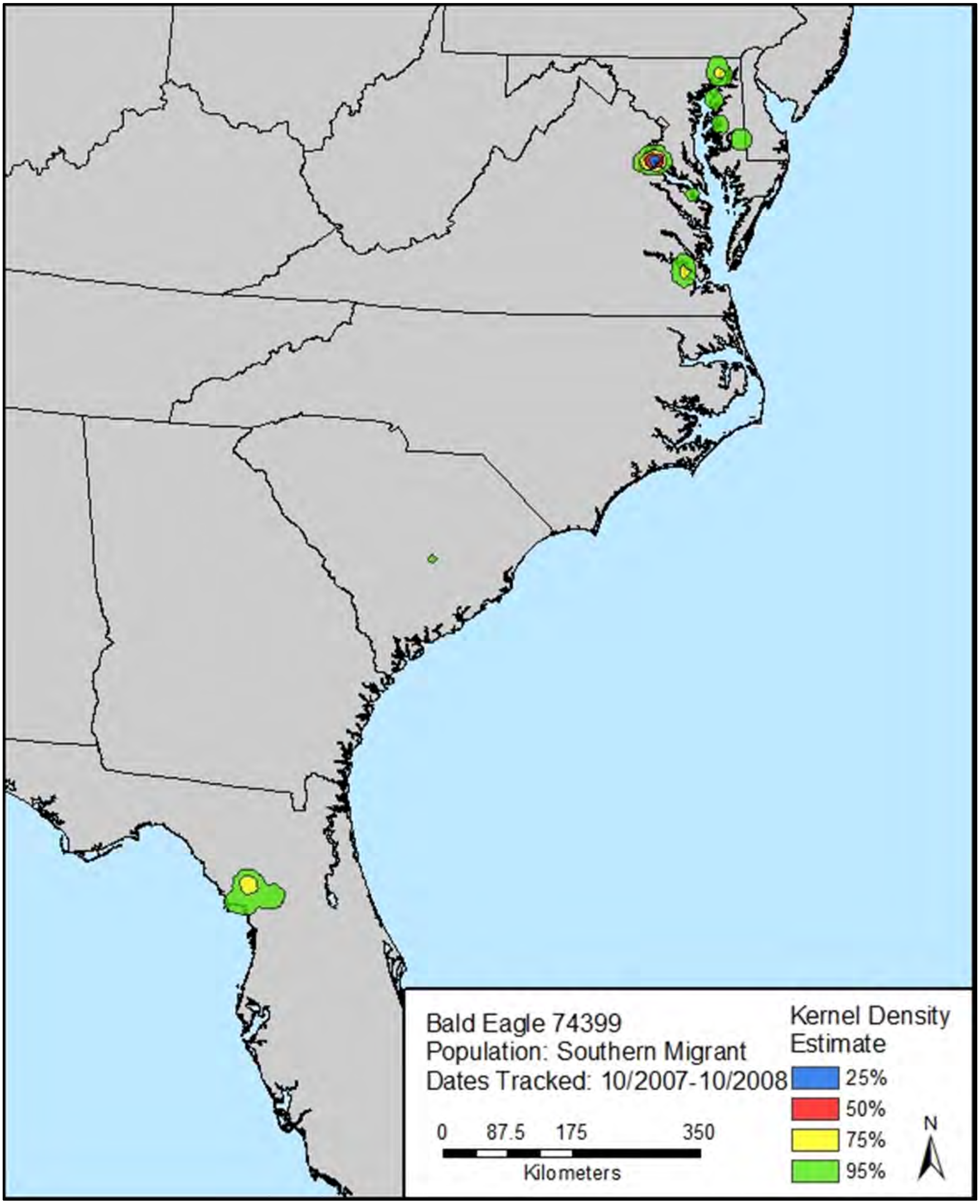

Bald Eagle 74395
Population: Chesapeake Bay
Dates Tracked: 10/2007 - 6/2011
Kernel Density Estimate
25%
50%
75%
95%
0 55 110 220
Kilometers
N

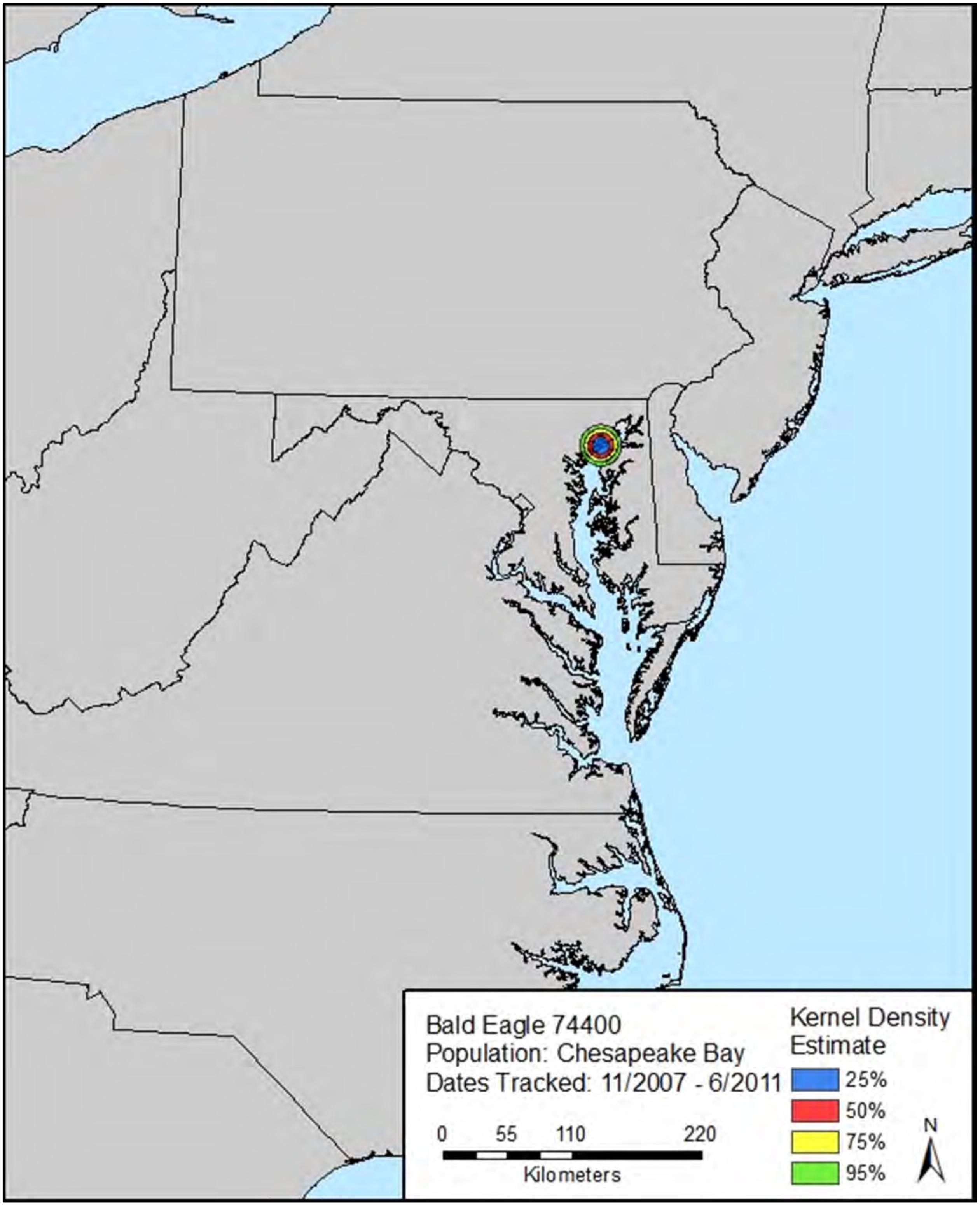

Bald Eagle 74396
Population: Chesapeake Bay
Dates Tracked: 10/2007 - 6/2011
Kernel Density Estimate
25%
50%
75%
95%
0 55 110 220
Kilometers
N



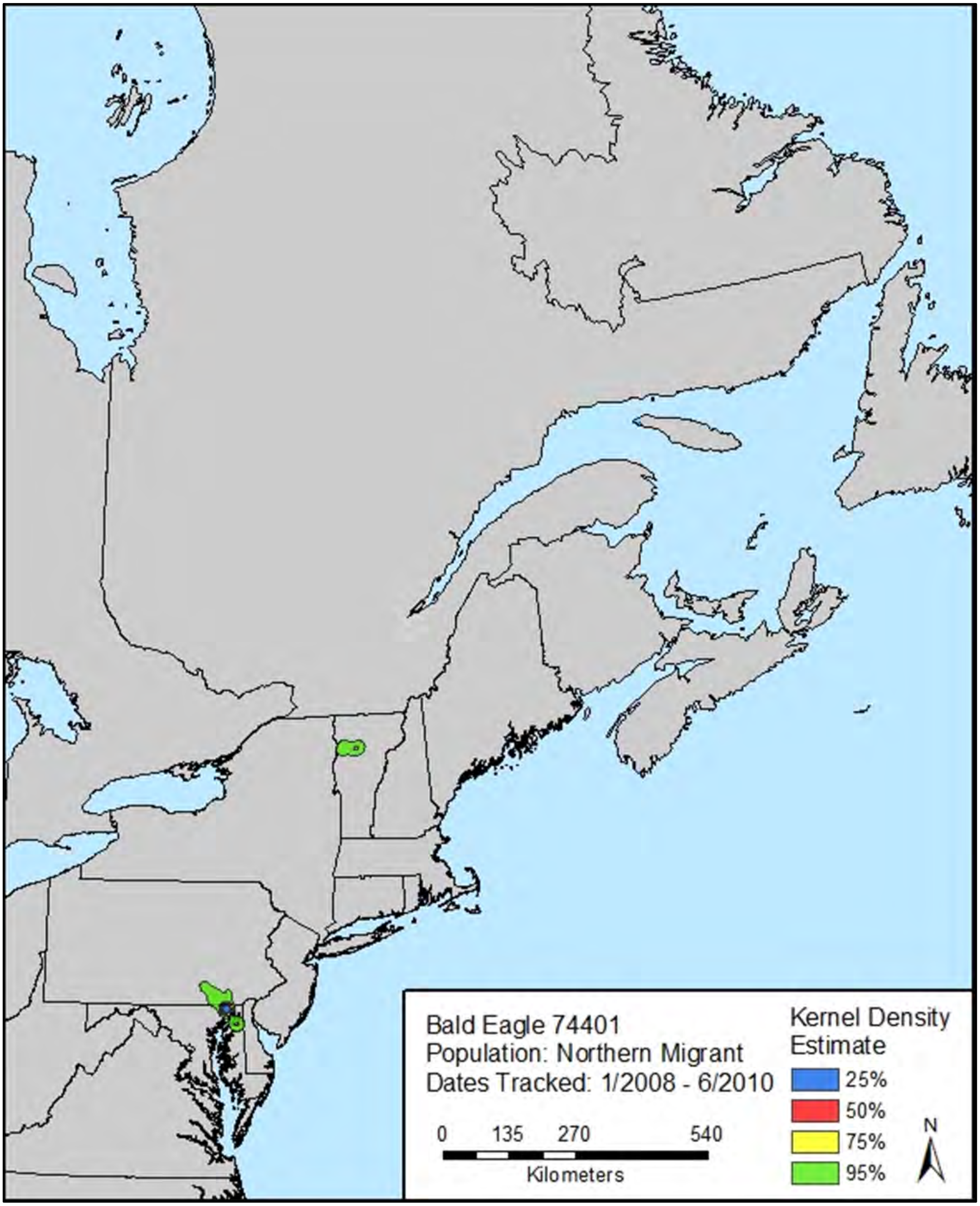
Bald Eagle 74397
Population: Chesapeake Bay
Dates Tracked: 10/2007-10/2010
Kernel Density Estimate
25%
50%
75%
95%
0 55 110 220
Kilometers
N

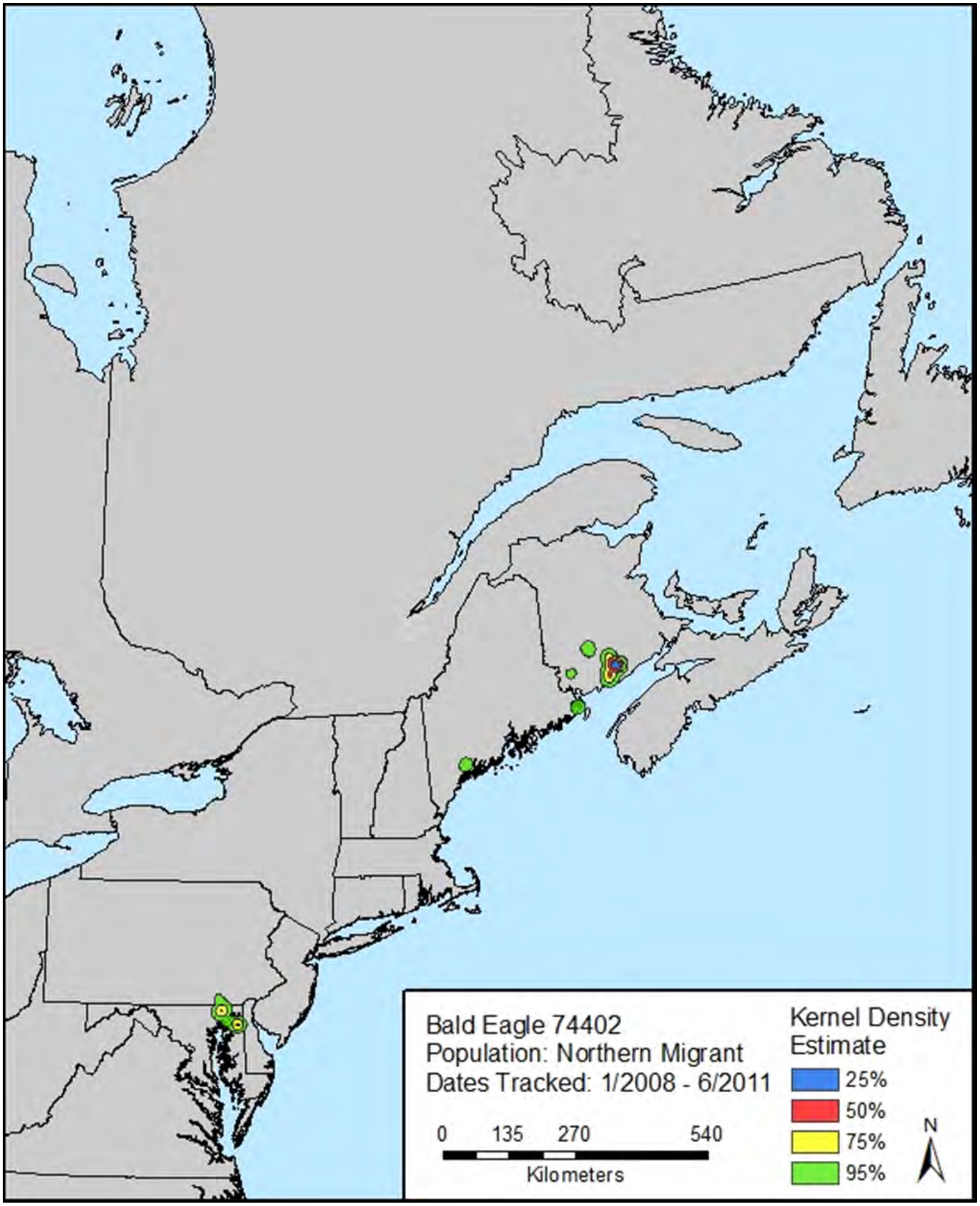

Bald Eagle 74398
Population: Chesapeake Bay
Dates Tracked: 10/2007-10/2010
Kernel Density Estimate
25%
50%
75%
95%
0
55
110
220
Kilometers
N

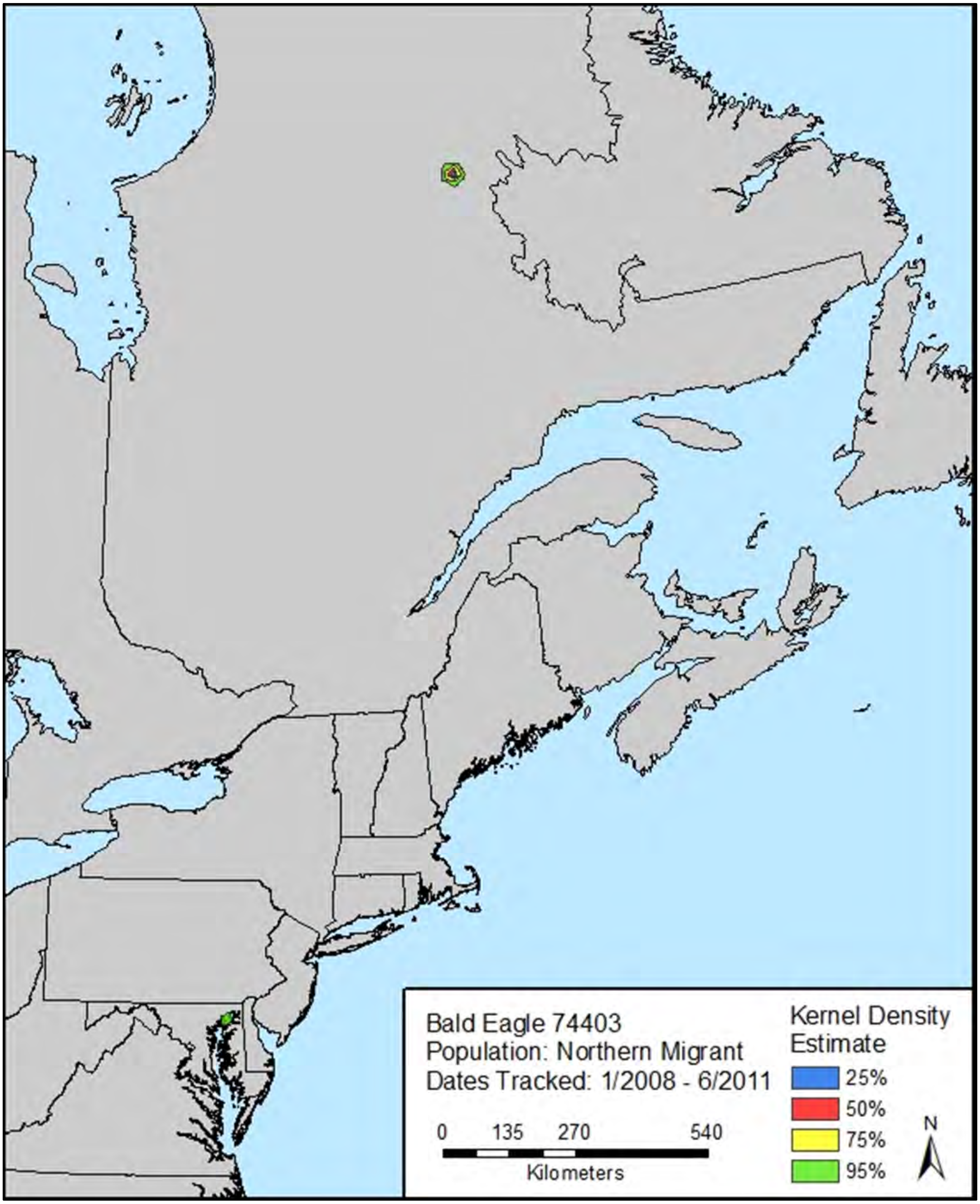

Bald Eagle 74399
Population: Southern Migrant
Dates Tracked: 10/2007-10/2008
0 87.5 175 350
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

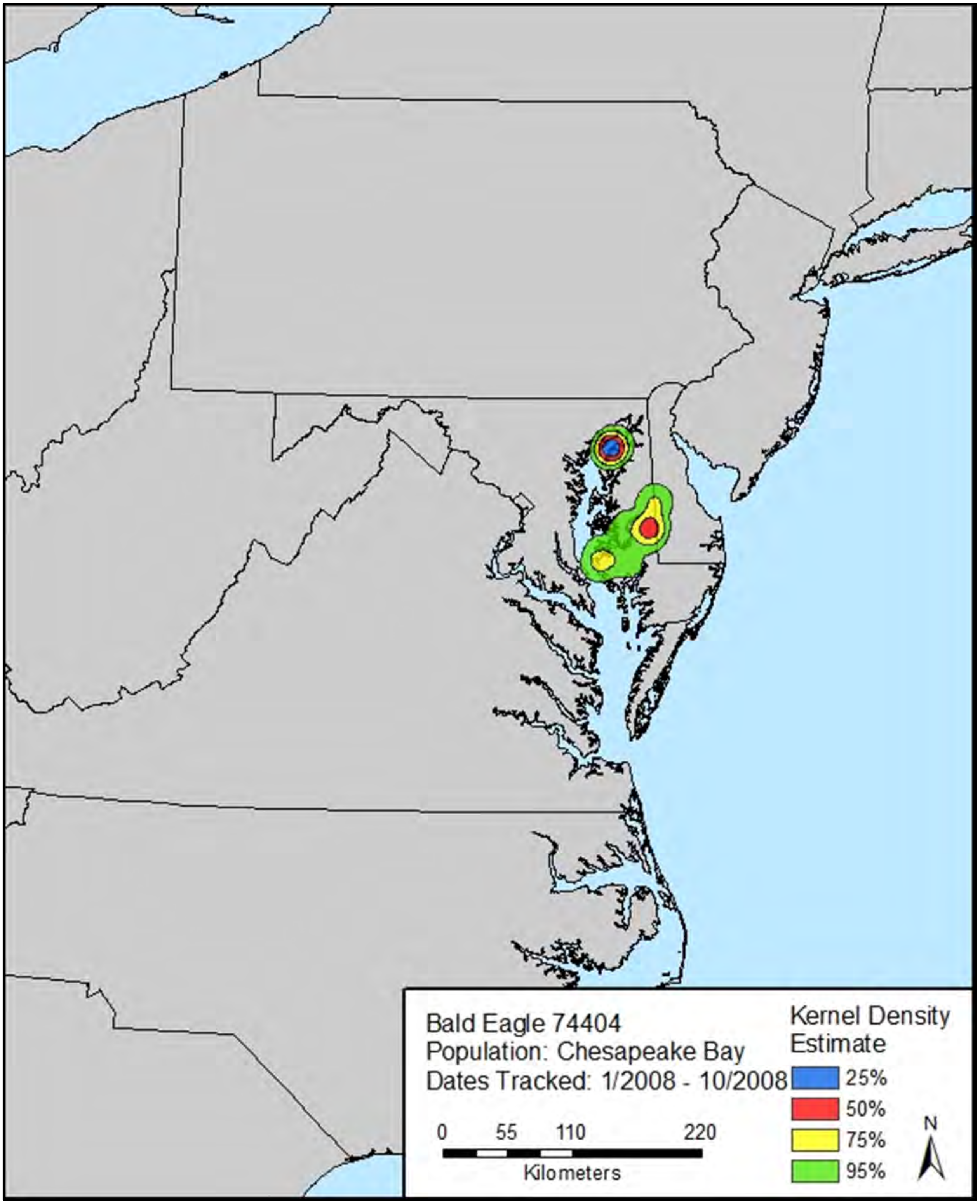


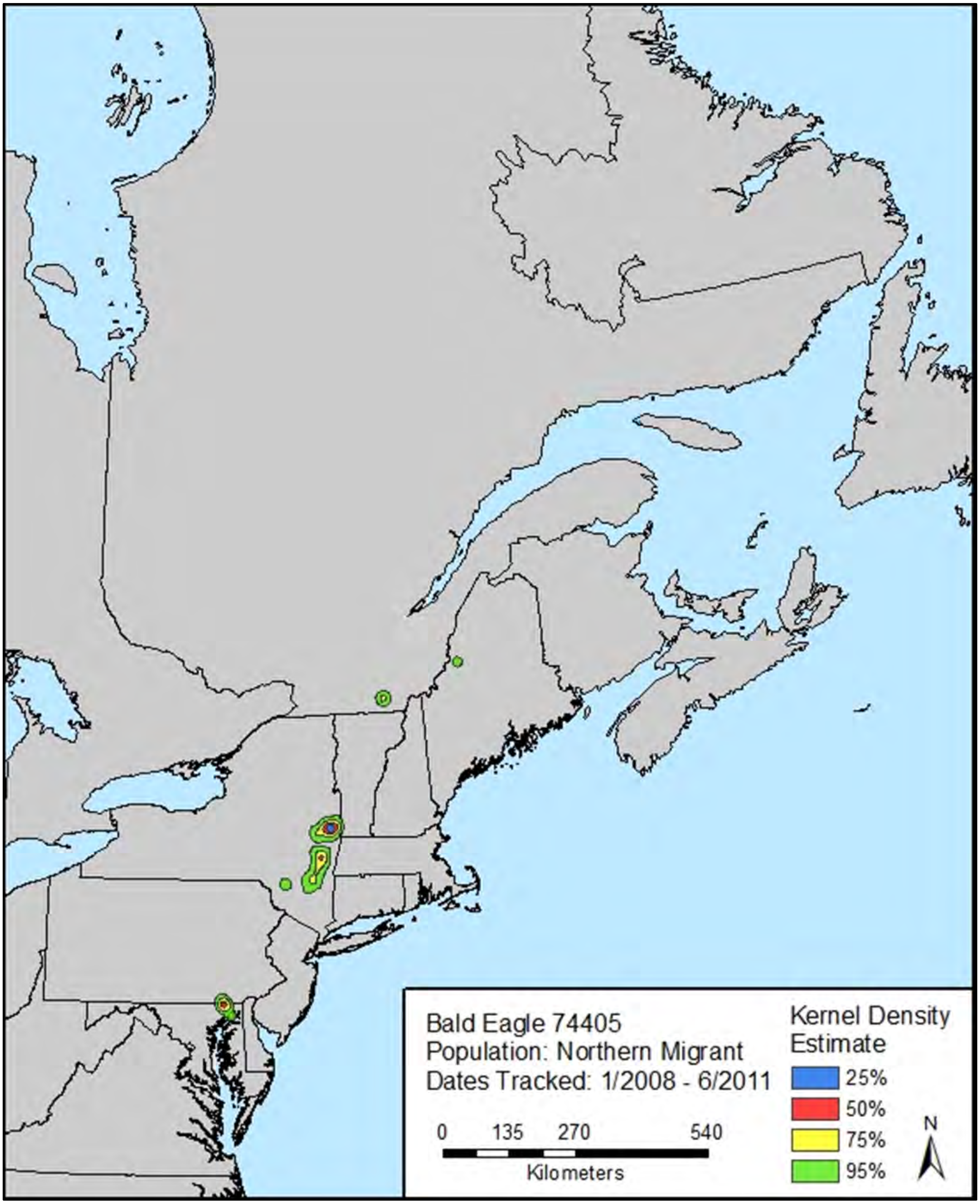
Bald Eagle 74400
Population: Chesapeake Bay
Dates Tracked: 11/2007 - 6/2011
Kernel Density Estimate
25%
50%
75%
95%
0
55
110
220
Kilometers
N


Bald Eagle 74401
Population: Northern Migrant
Dates Tracked: 1/2008 - 6/2010
Kernel Density Estimate
25%
50%
75%
95%
0 135 270 540
Kilometers
N

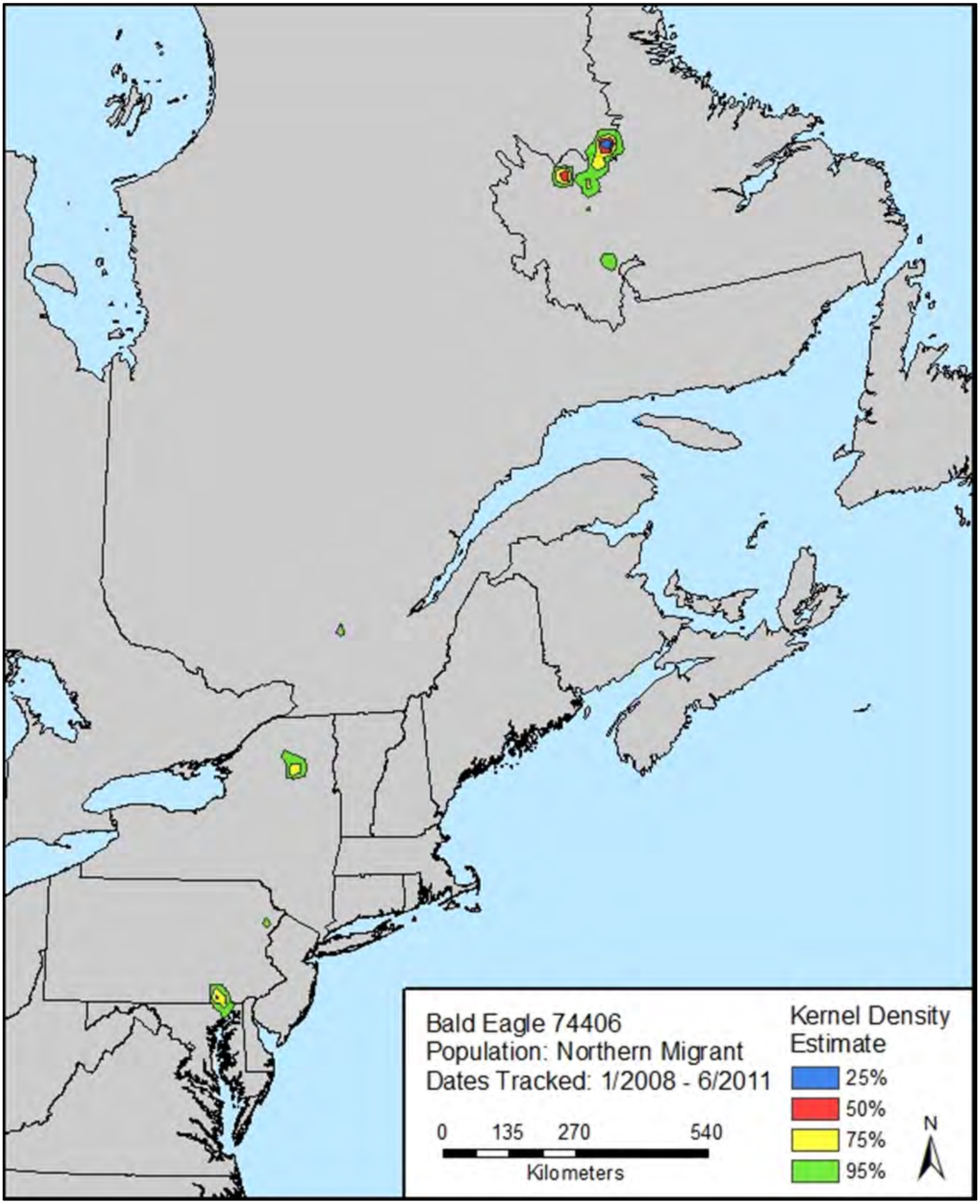

Bald Eagle 74402
Population: Northern Migrant
Dates Tracked: 1/2008 - 6/2011
0
135
270
540
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

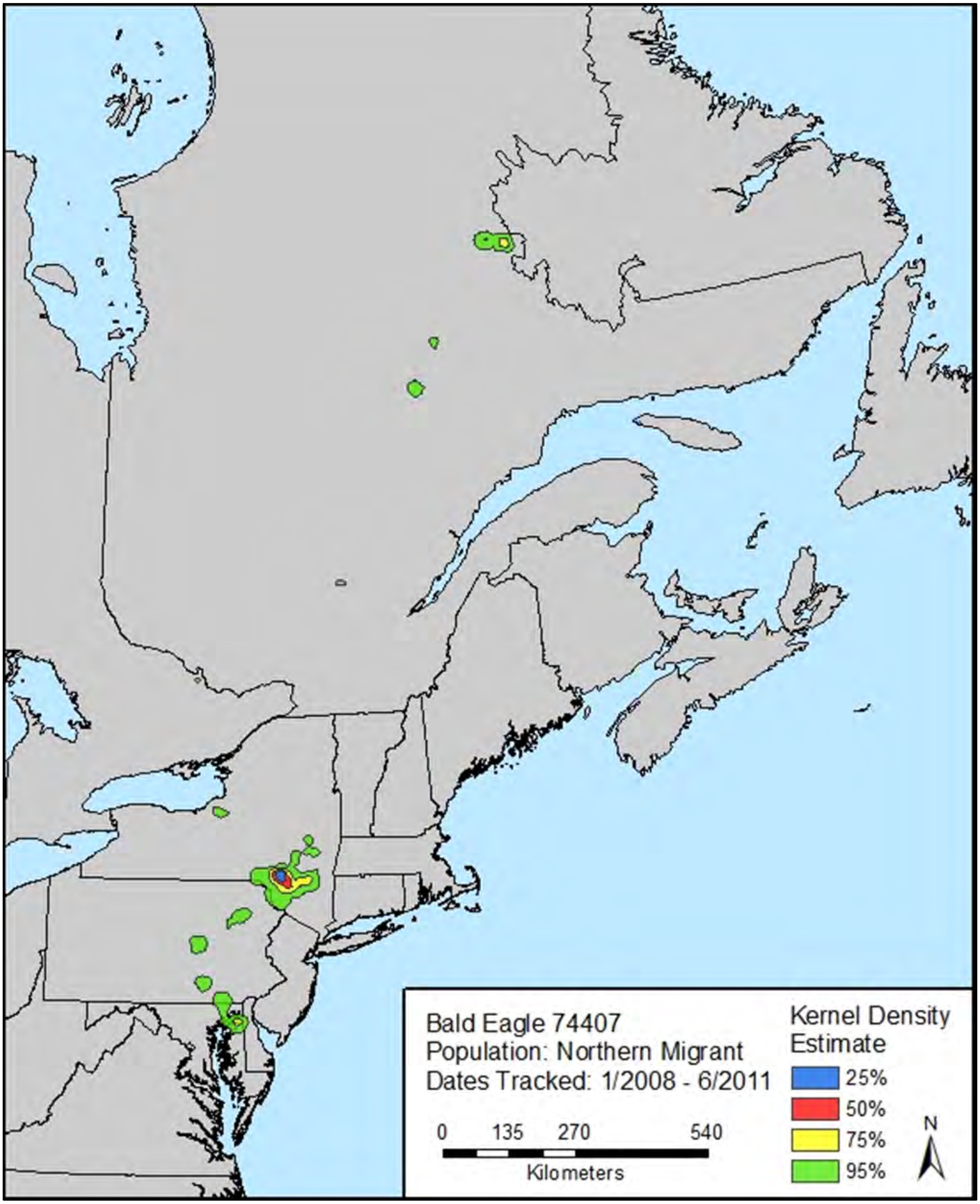

Bald Eagle 74403
Population: Northern Migrant
Dates Tracked: 1/2008 - 6/2011
0
135
270
540
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

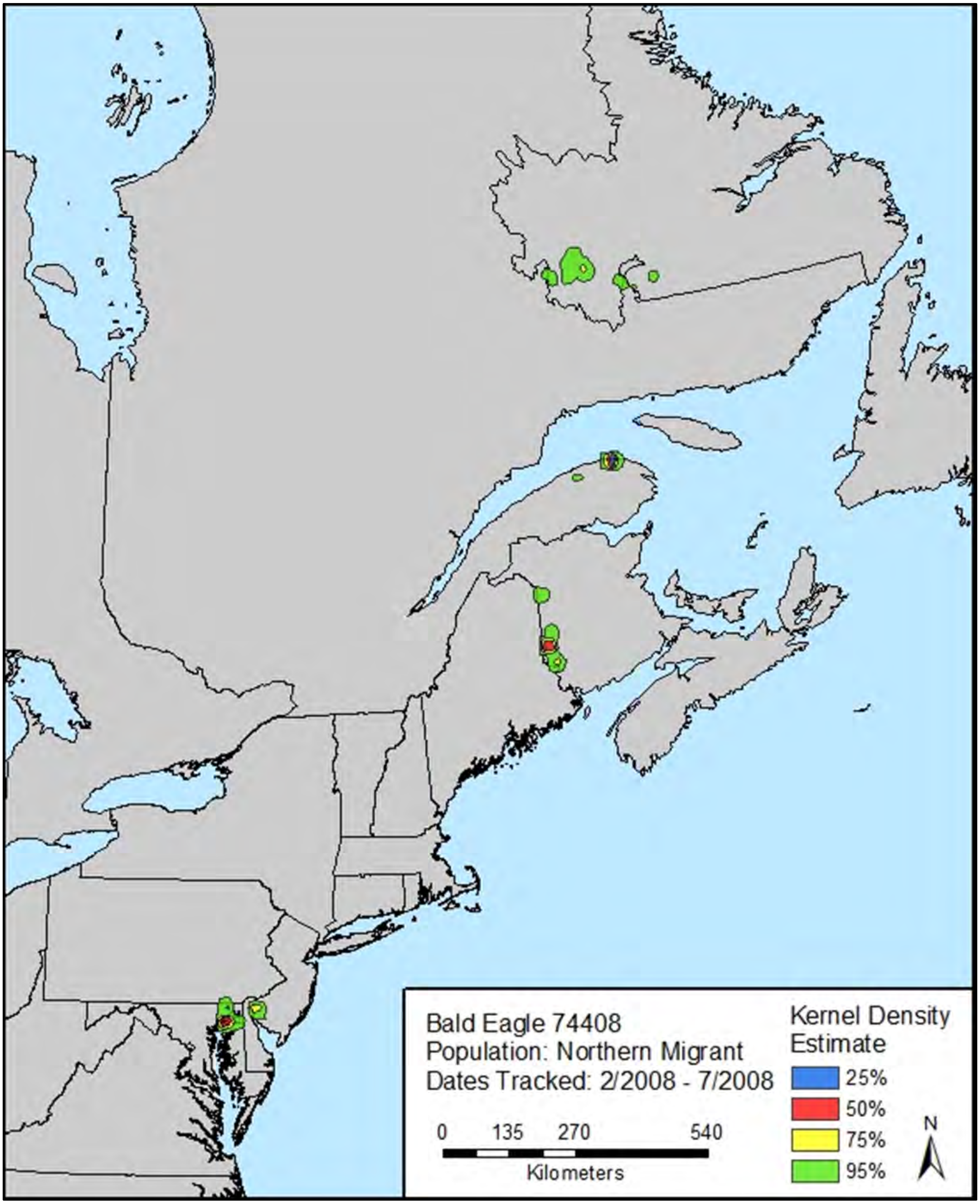

Bald Eagle 74404
Population: Chesapeake Bay
Dates Tracked: 1/2008 - 10/2008
Kernel Density Estimate
25%
50%
75%
95%
0
55
110
220
Kilometers
N

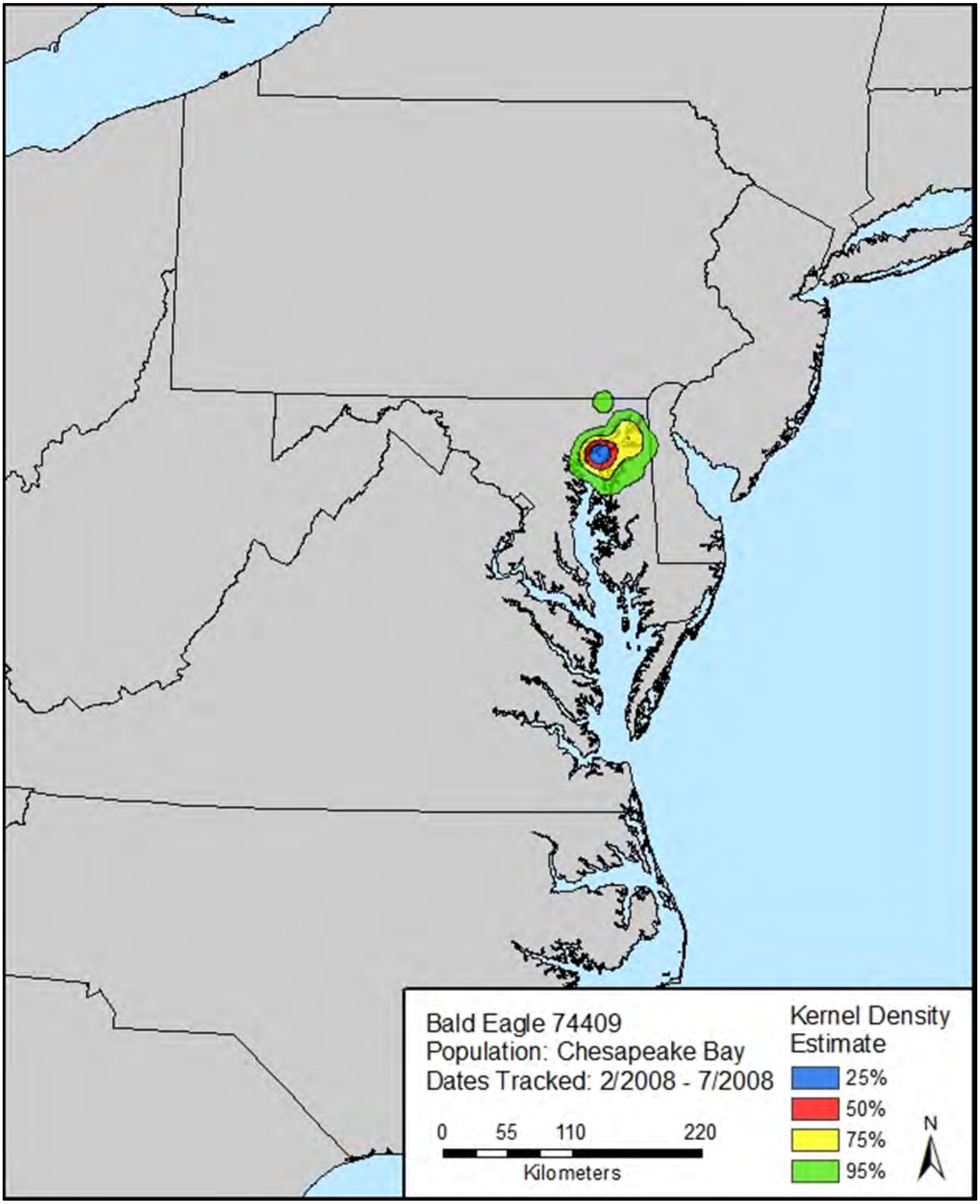


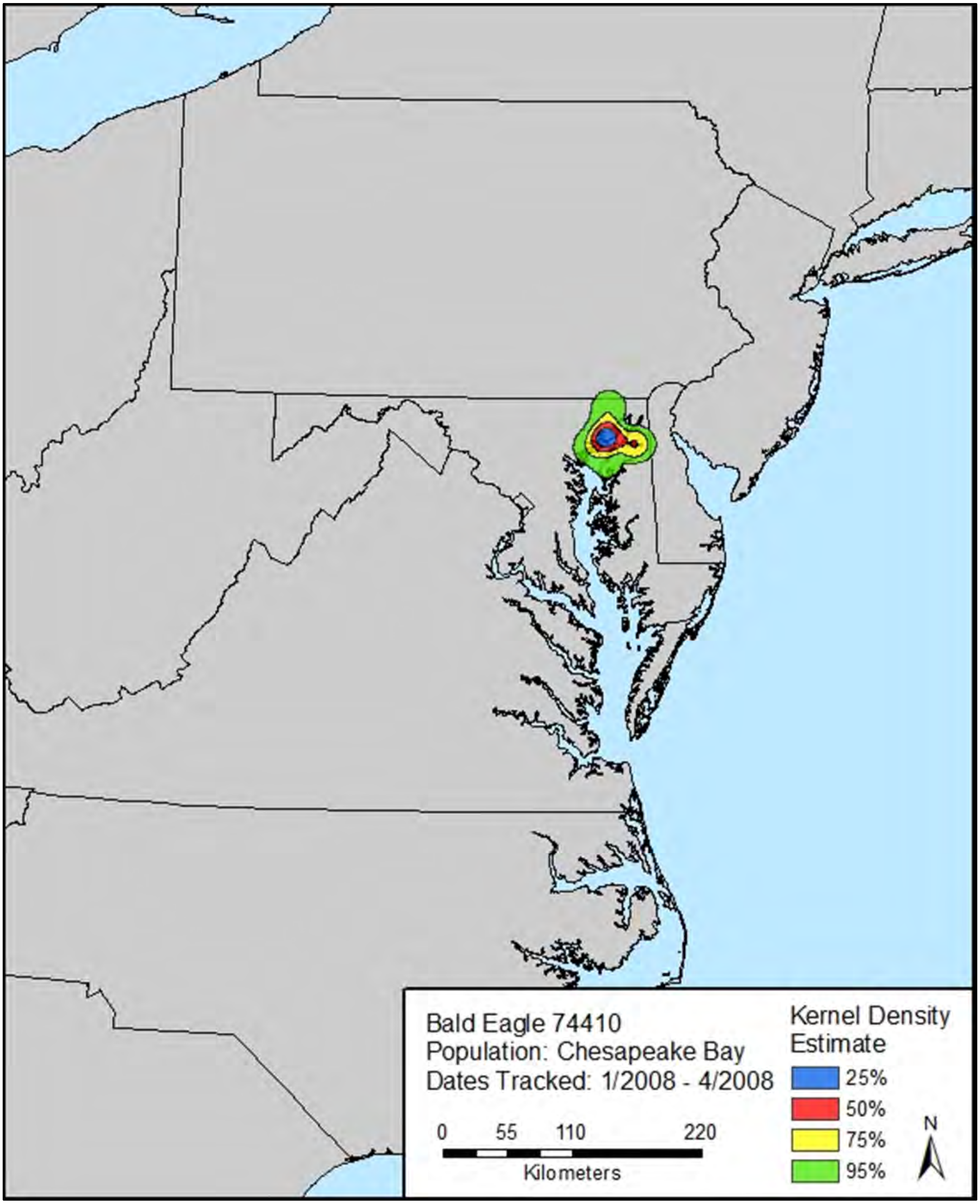
Bald Eagle 74405
Population: Northern Migrant
Dates Tracked: 1/2008 - 6/2011
0 135 270 540
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

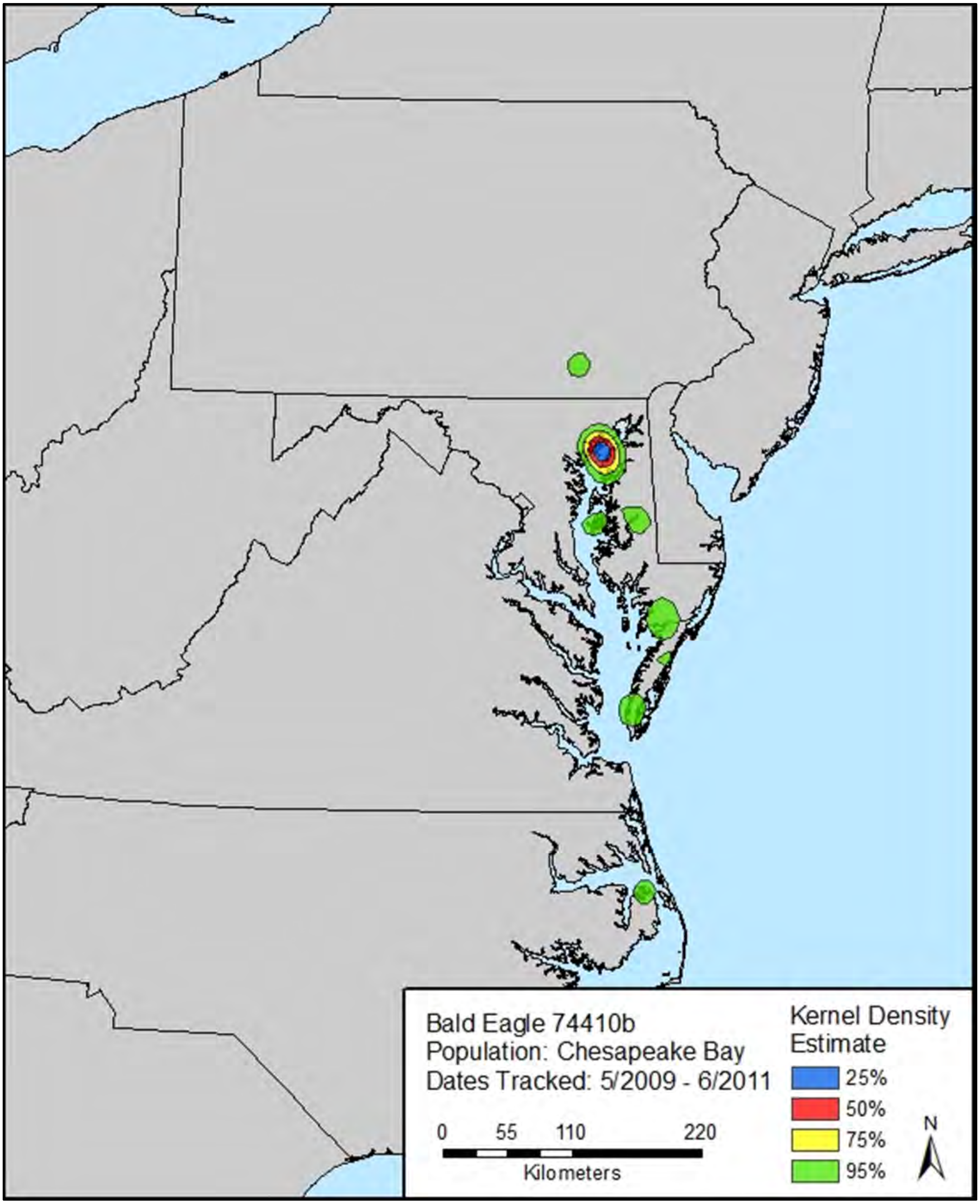

Bald Eagle 74406
Population: Northern Migrant
Dates Tracked: 1/2008 - 6/2011
0 135 270 540
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

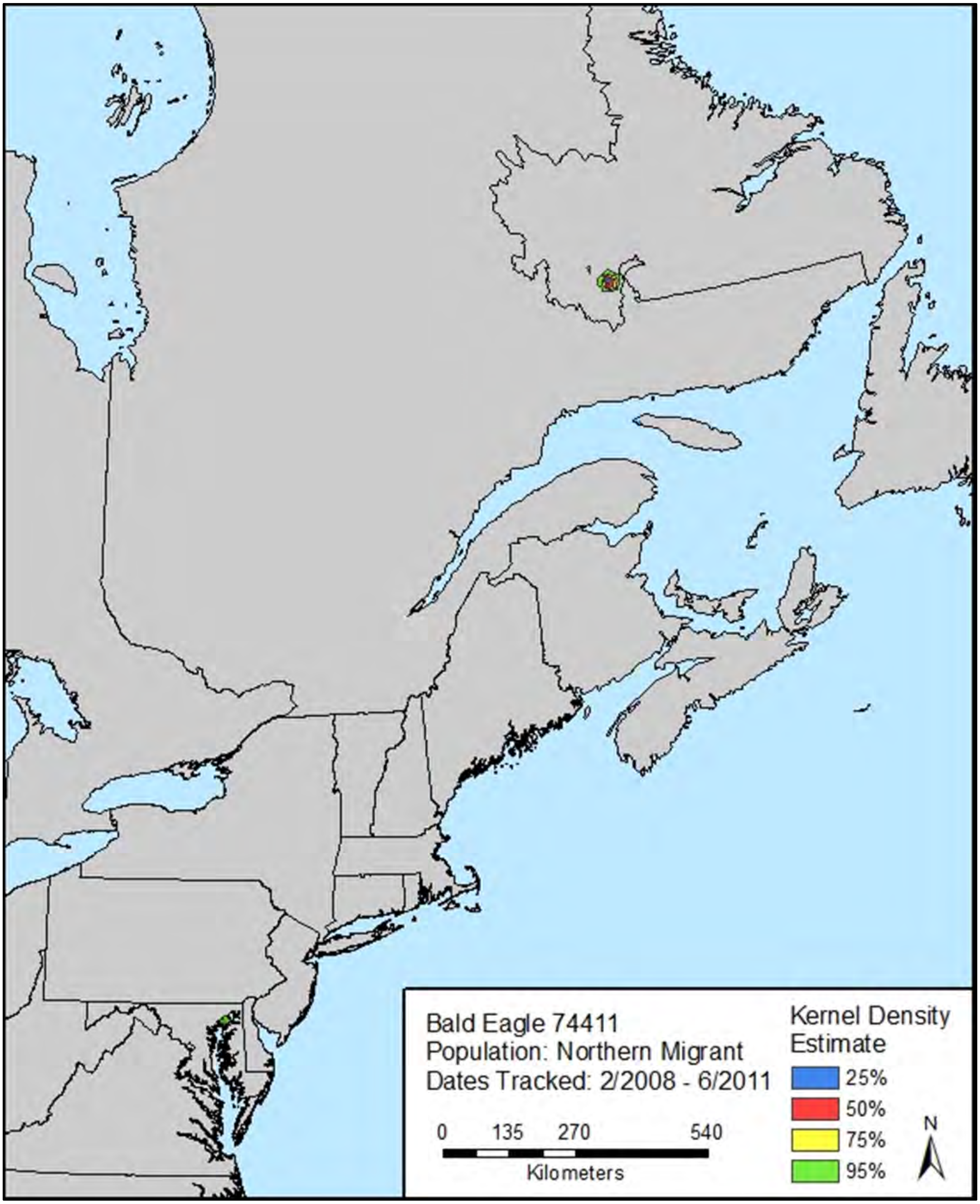

Bald Eagle 74407
Population: Northern Migrant
Dates Tracked: 1/2008 - 6/2011
0 135 270 540
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

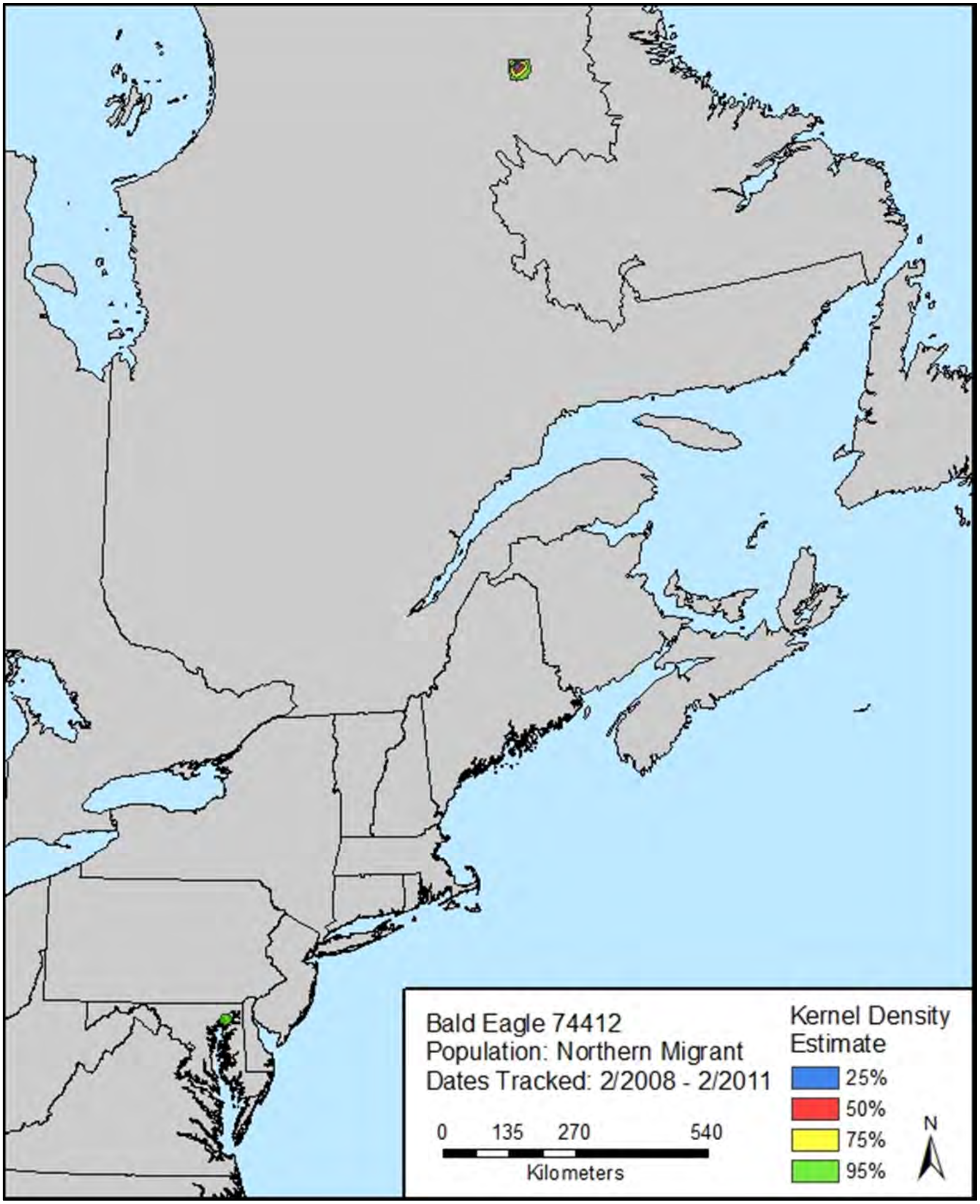

Bald Eagle 74408
Population: Northern Migrant
Dates Tracked: 2/2008 - 7/2008
Kernel Density Estimate
25%
50%
75%
95%
0 135 270 540
Kilometers
N


Bald Eagle 74409
Population: Chesapeake Bay
Dates Tracked: 2/2008 - 7/2008
0
55
110
220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

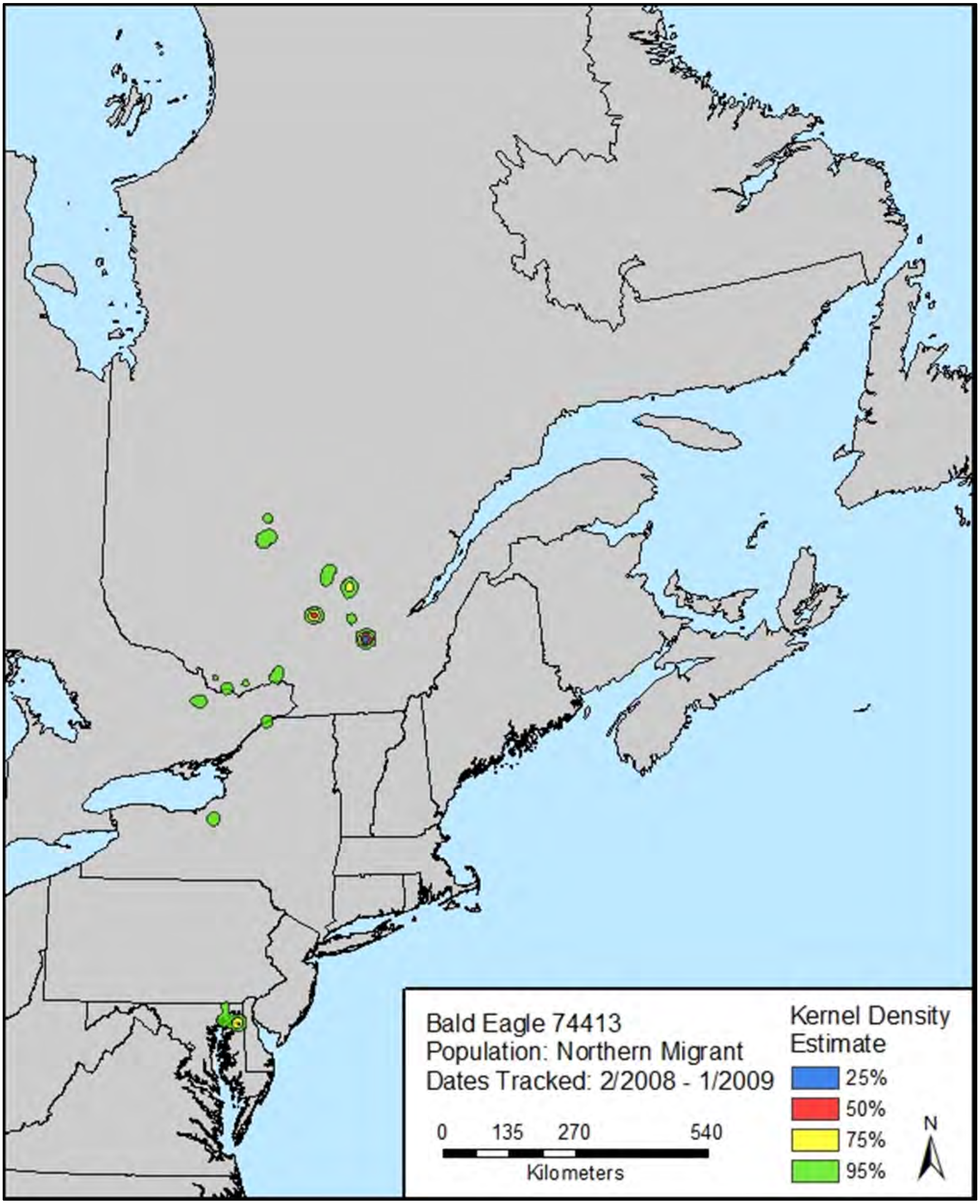

Bald Eagle 74410
Population: Chesapeake Bay
Dates Tracked: 1/2008 - 4/2008
Kernel Density Estimate
25%
50%
75%
95%
0
55
110
220
Kilometers
N


Bald Eagle 74410b
Population: Chesapeake Bay
Dates Tracked: 5/2009 - 6/2011
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

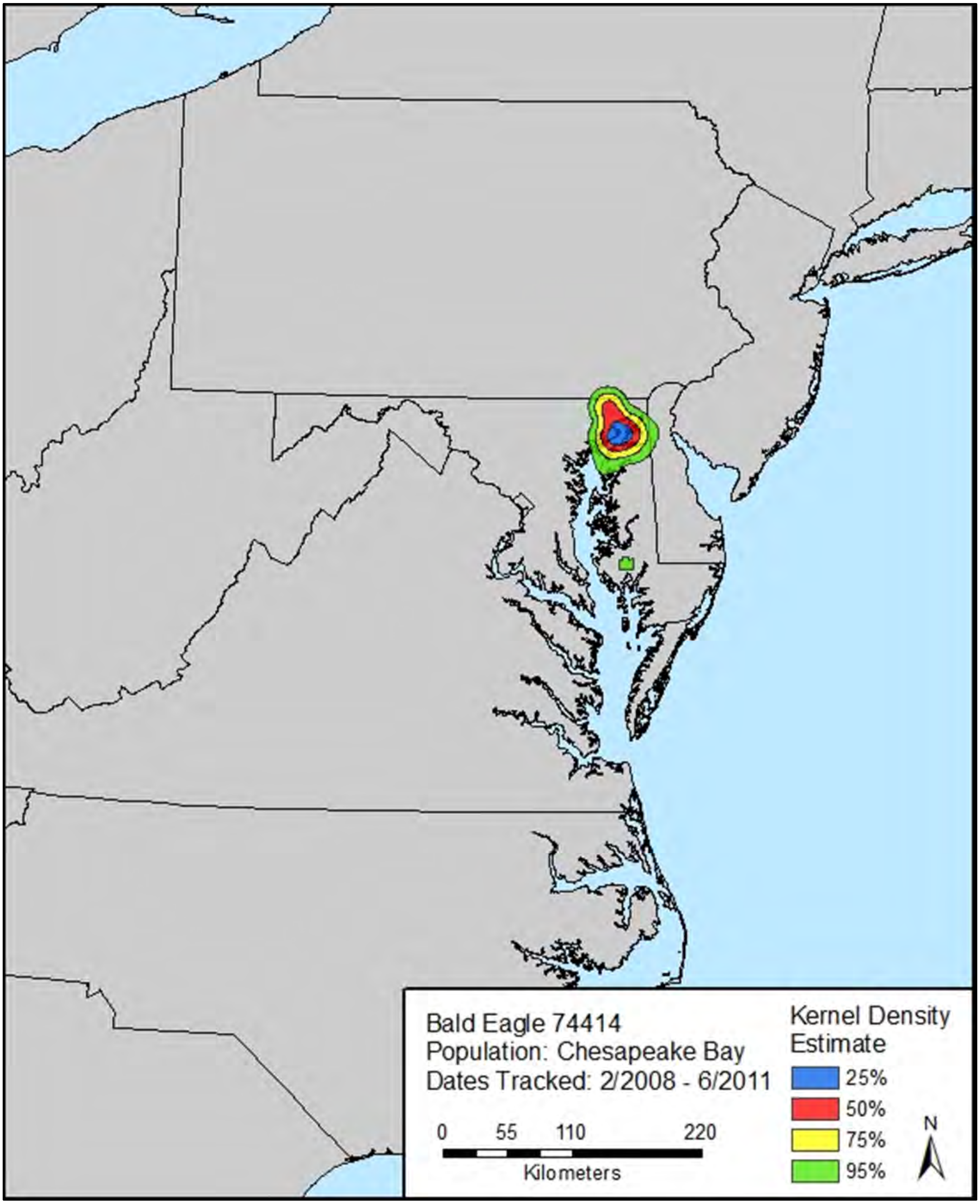

Bald Eagle 74411
Population: Northern Migrant
Dates Tracked: 2/2008 - 6/2011
0 135 270 540
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

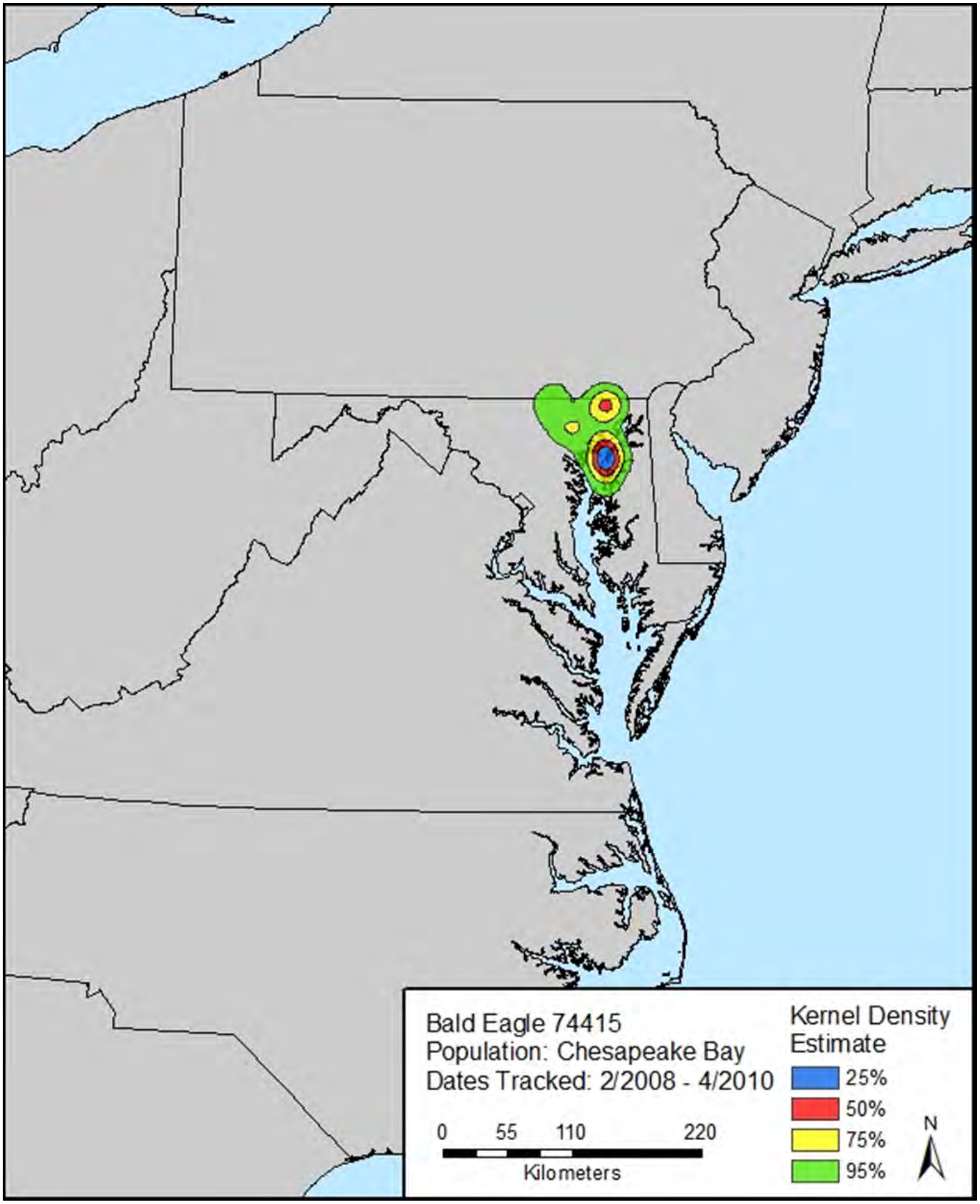


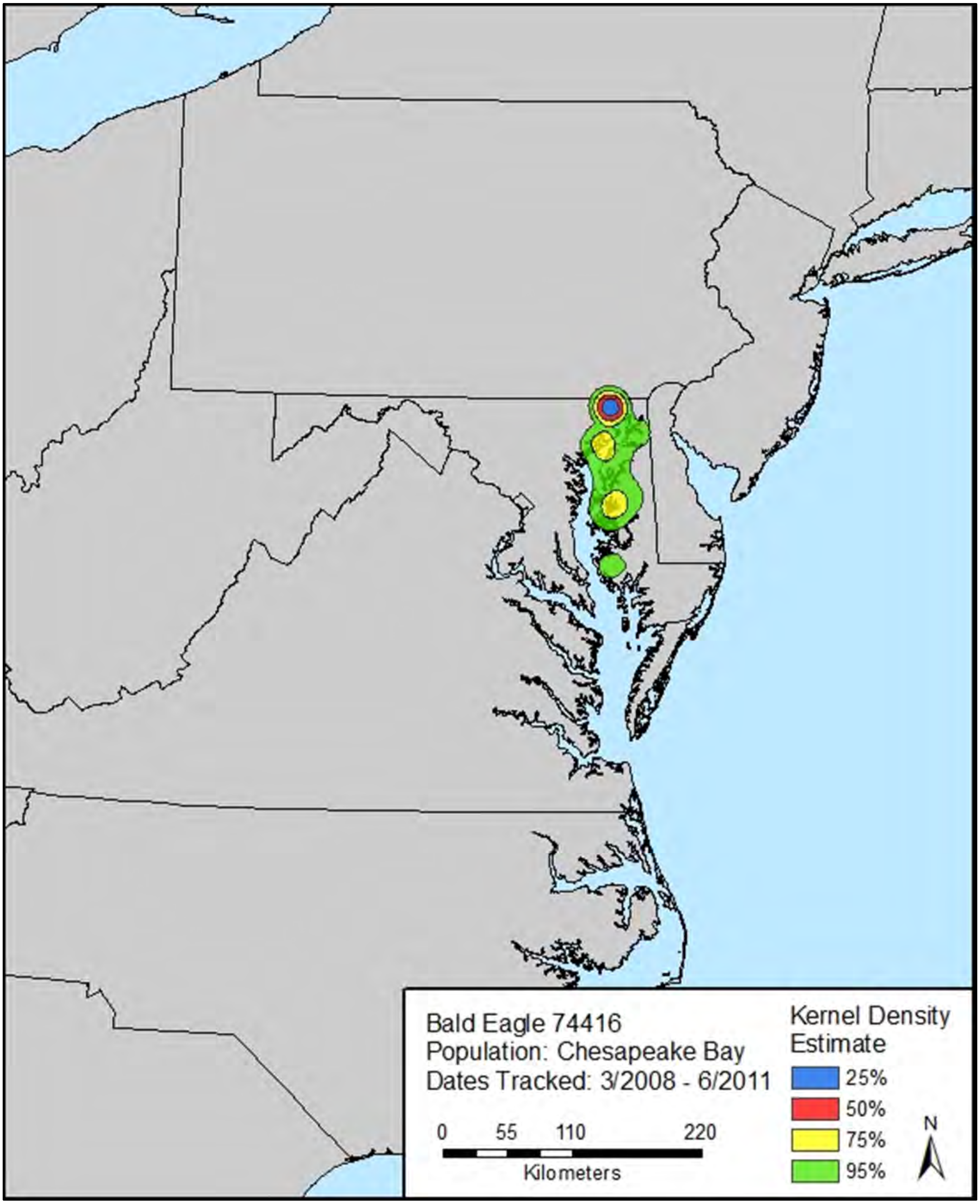
Bald Eagle 74412
Population: Northern Migrant
Dates Tracked: 2/2008 - 2/2011
0 135 270 540
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

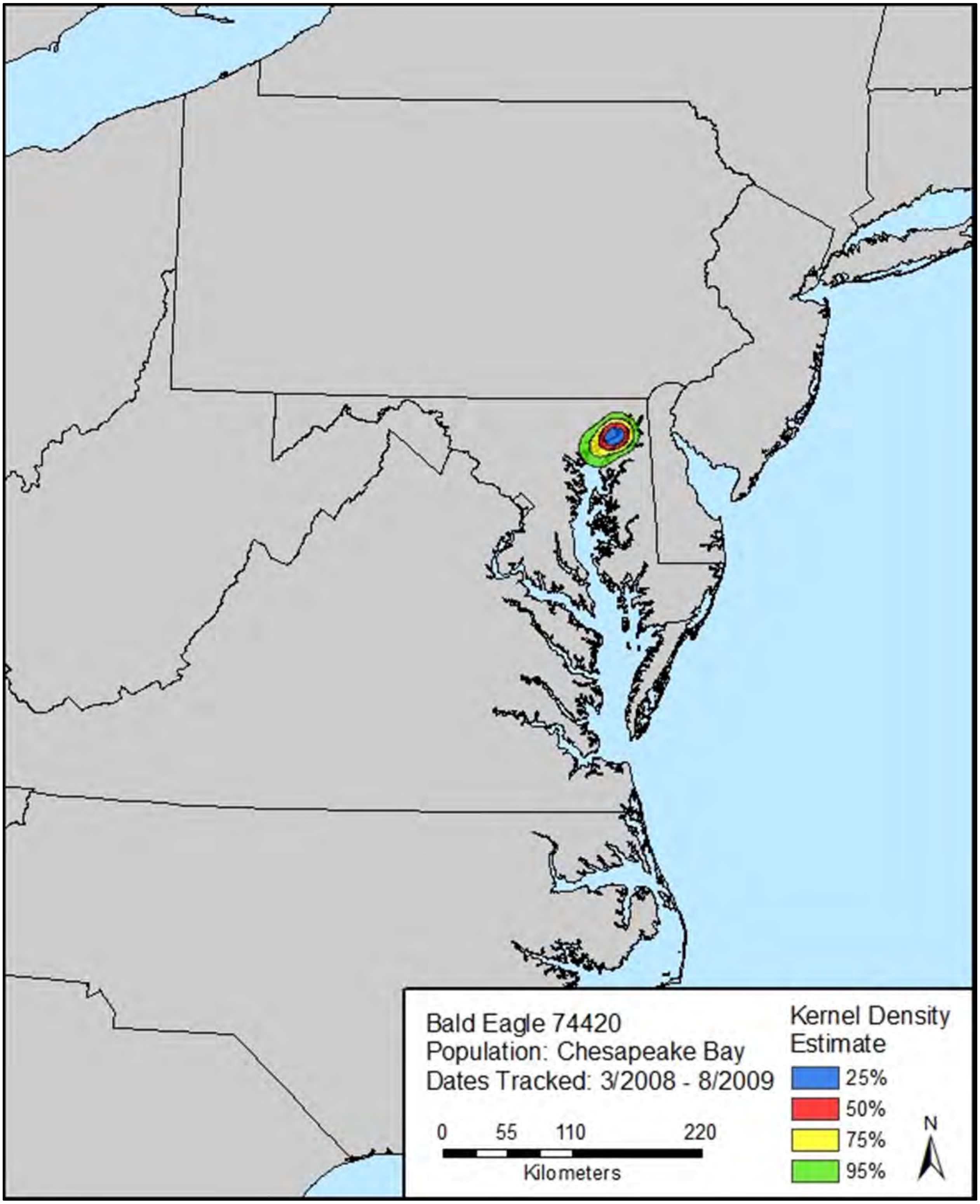


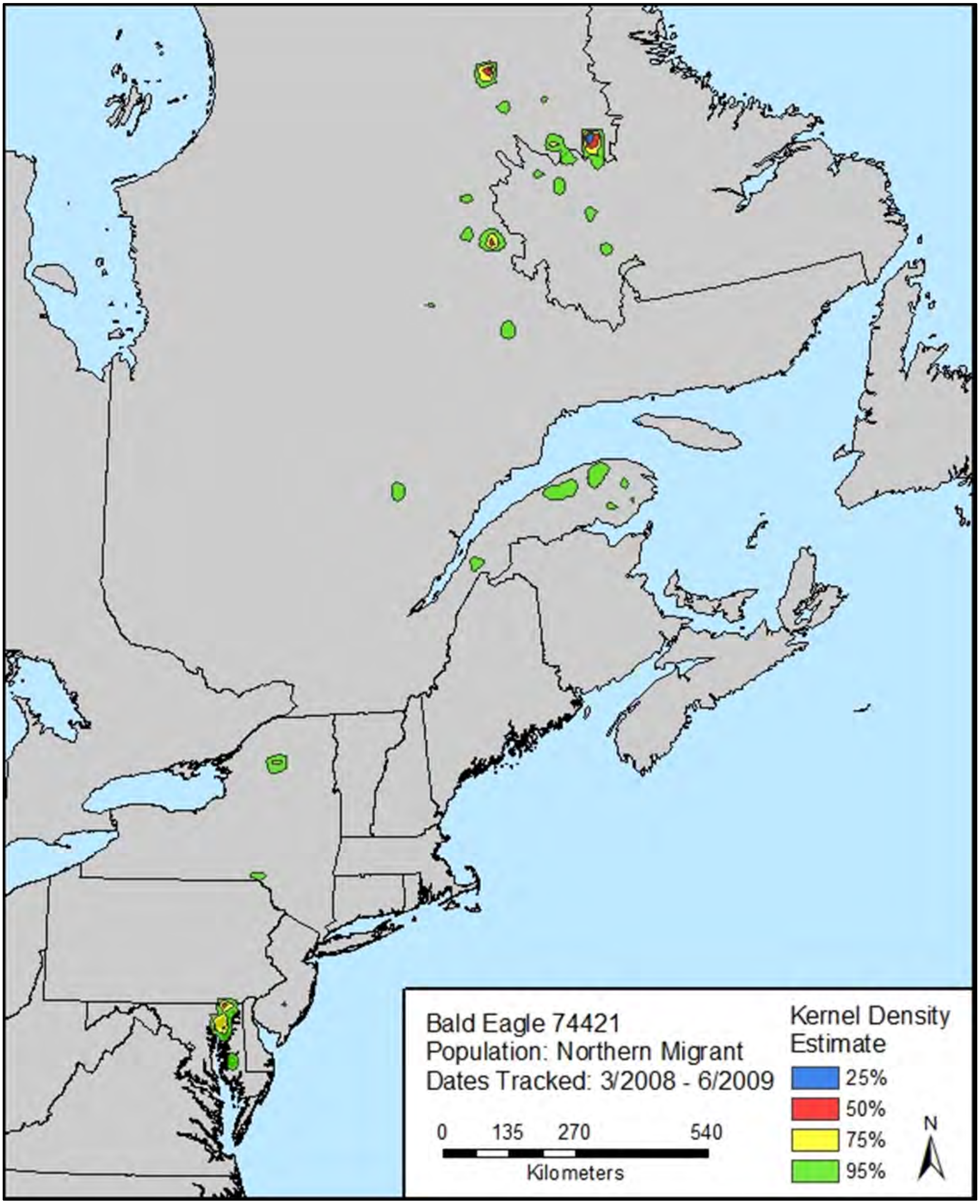
Bald Eagle 74413
Population: Northern Migrant
Dates Tracked: 2/2008 - 1/2009
Kernel Density Estimate
25%
50%
75%
95%
0 135 270 540
Kilometers
N


Bald Eagle 74414
Population: Chesapeake Bay
Dates Tracked: 2/2008 - 6/2011
Kernel Density Estimate
25%
50%
75%
95%
0
55
110
220
Kilometers
N

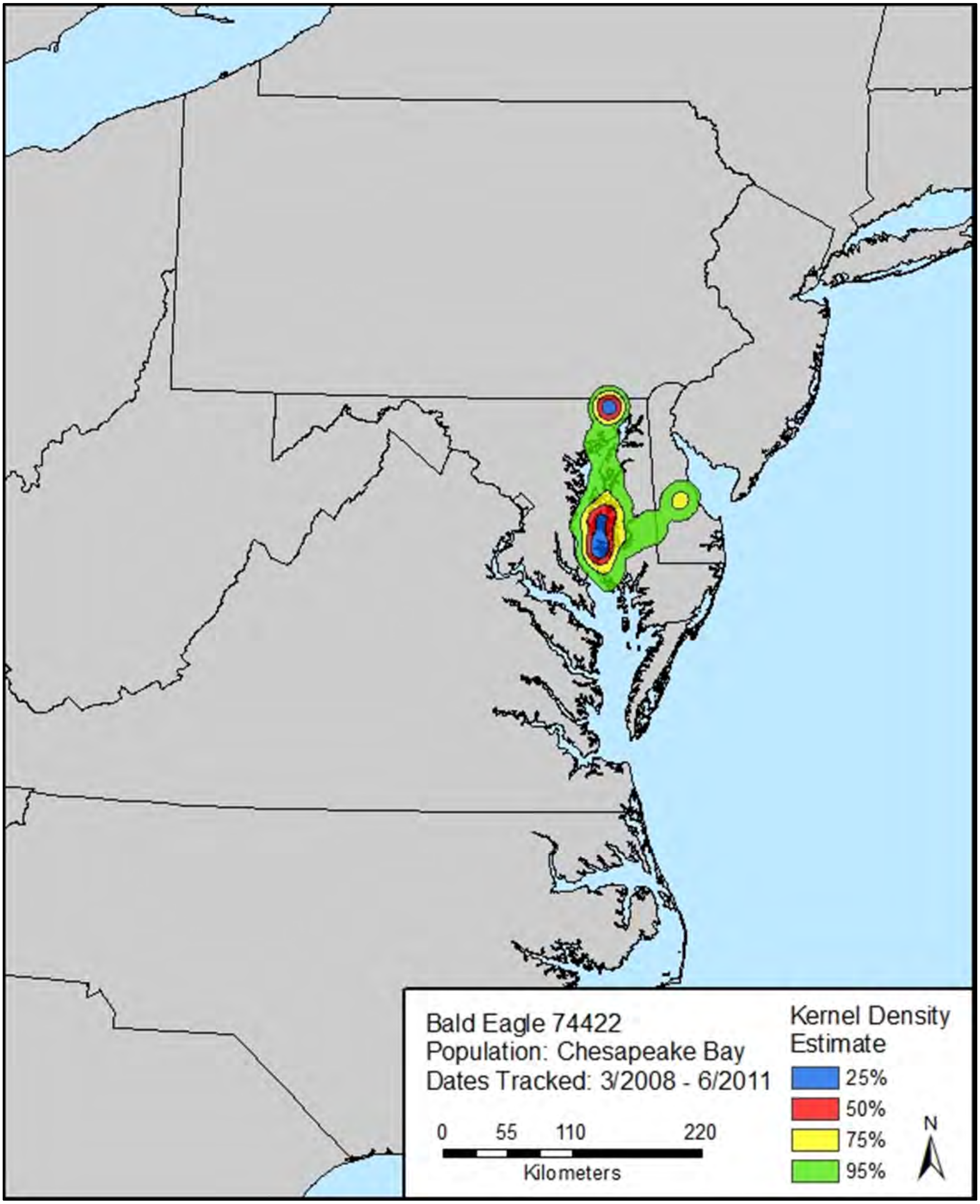

Bald Eagle 74415
Population: Chesapeake Bay
Dates Tracked: 2/2008 - 4/2010
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

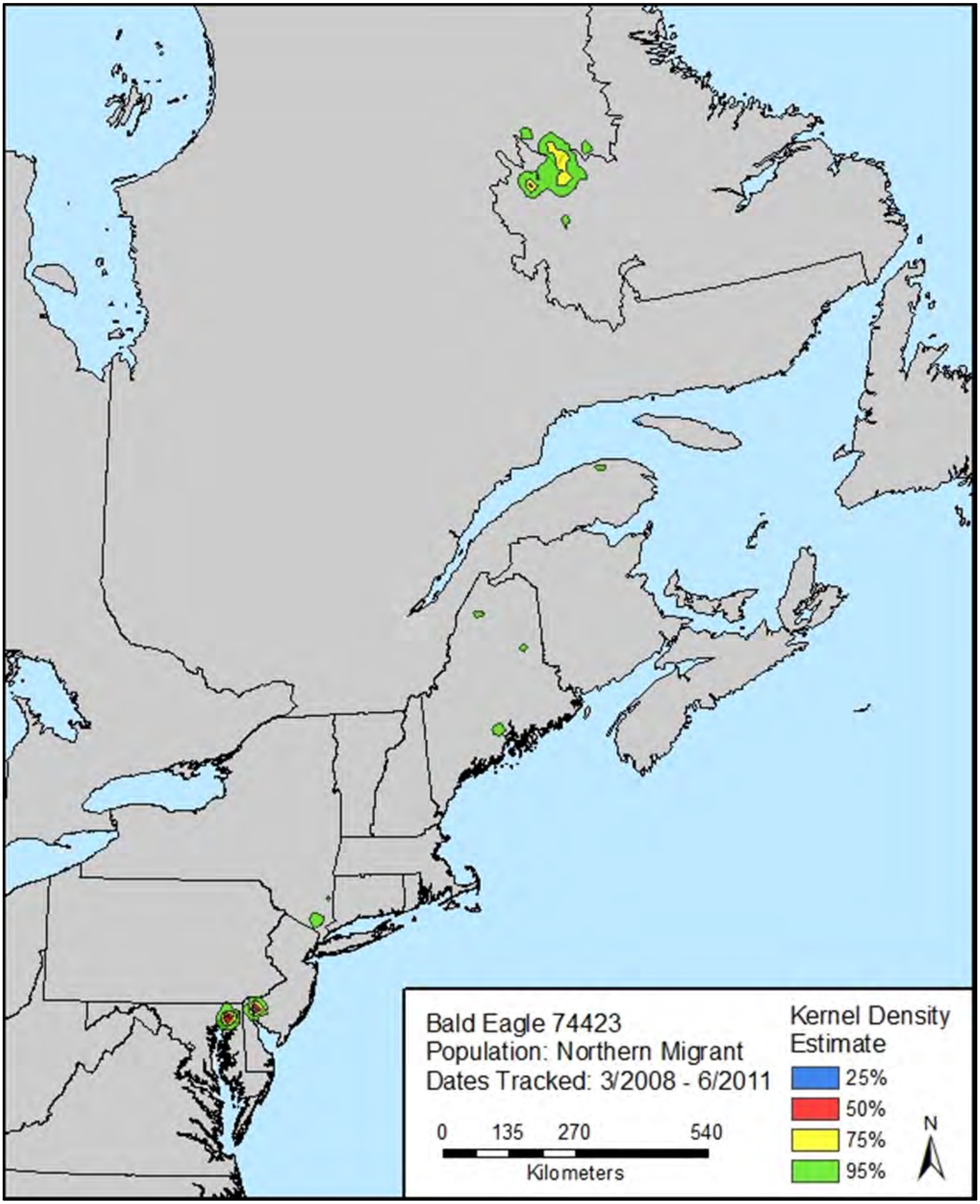

Bald Eagle 74416
Population: Chesapeake Bay
Dates Tracked: 3/2008 - 6/2011
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N


Bald Eagle 74420
Population: Chesapeake Bay
Dates Tracked: 3/2008 - 8/2009
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

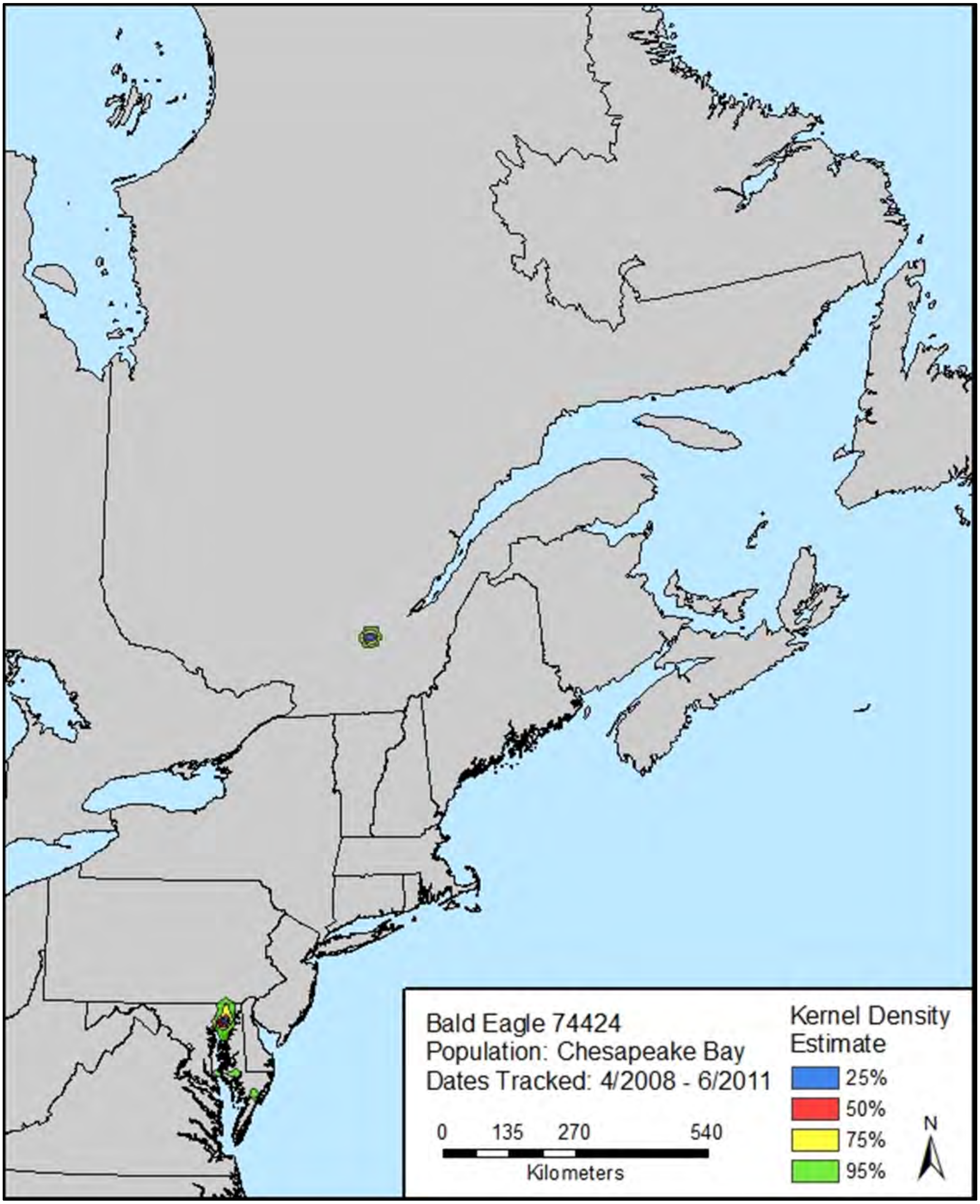


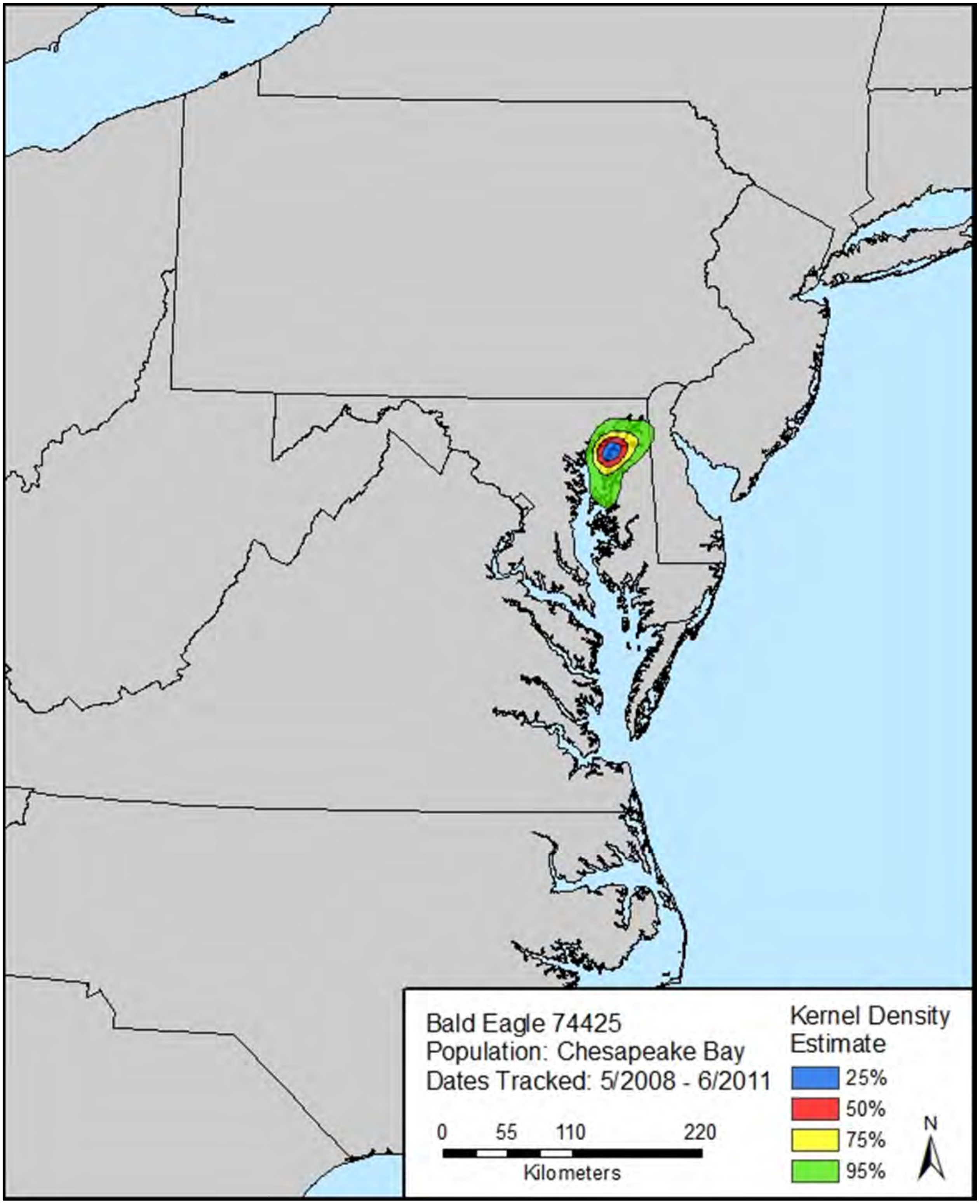
Bald Eagle 74421
Population: Northern Migrant
Dates Tracked: 3/2008 - 6/2009
0 135 270 540
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N


Bald Eagle 74422
Population: Chesapeake Bay
Dates Tracked: 3/2008 - 6/2011
Kernel Density Estimate
25%
50%
75%
95%
0
55
110
220
Kilometers
N

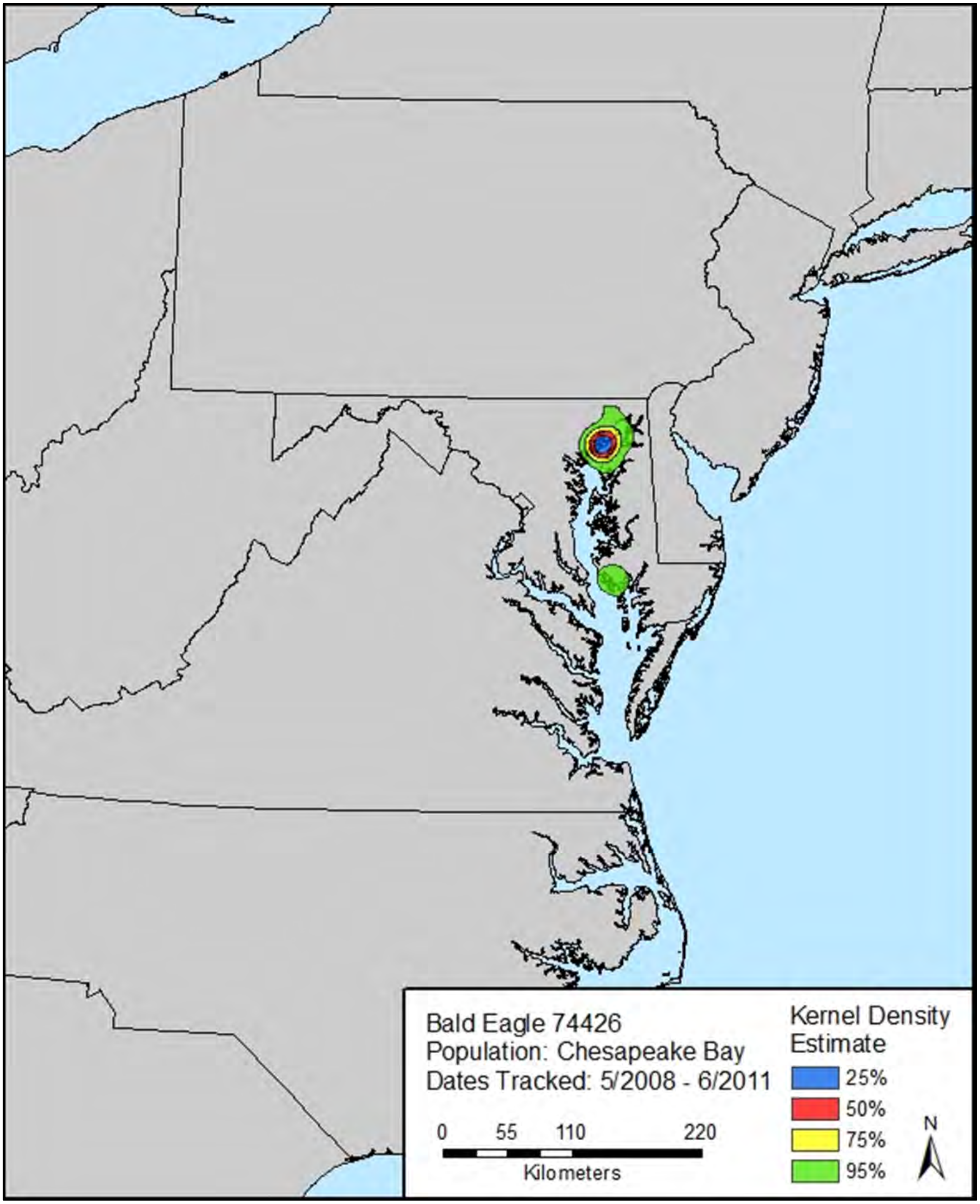


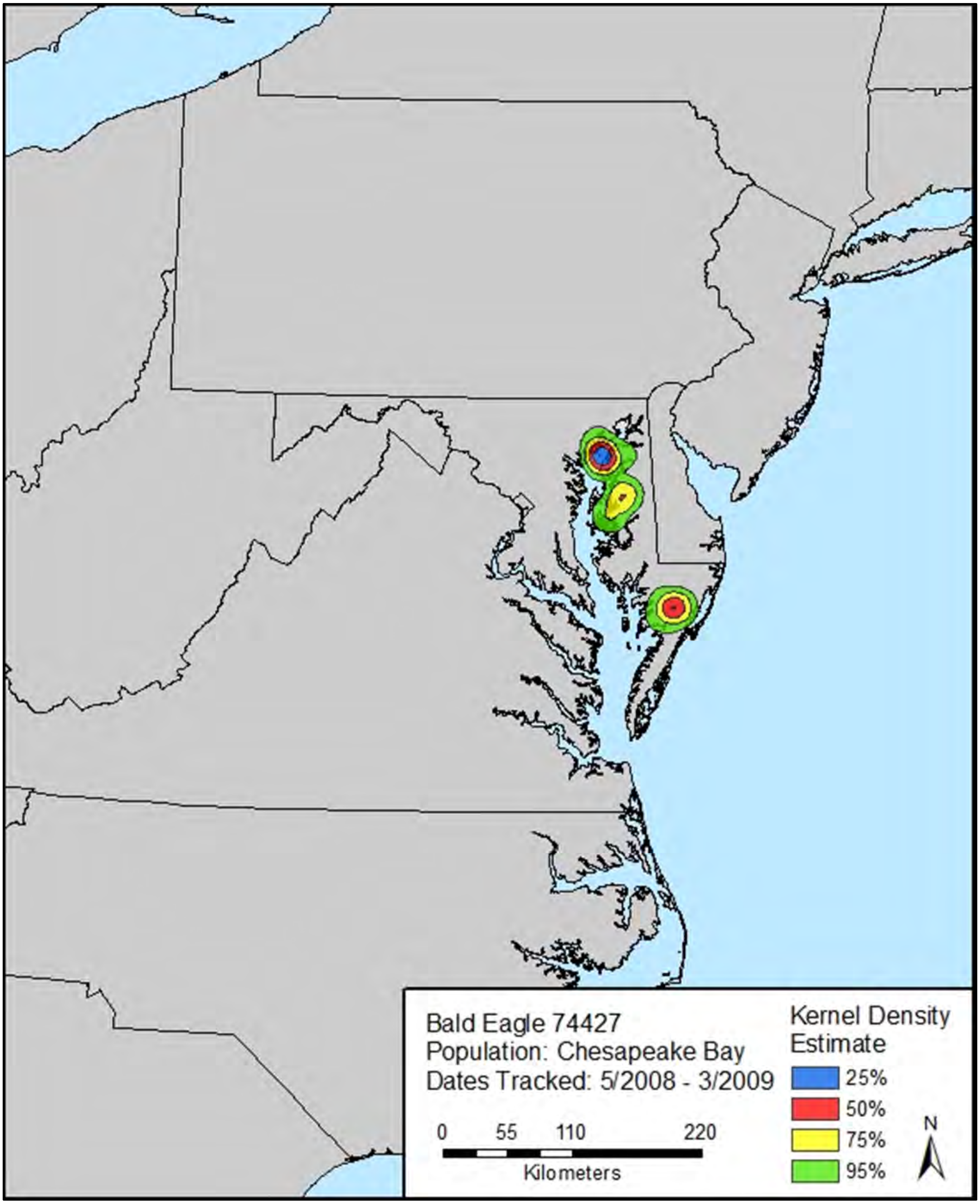
Bald Eagle 74423
Population: Northern Migrant
Dates Tracked: 3/2008 - 6/2011
Kernel Density Estimate
25%
50%
75%
95%
0
135
270
540
Kilometers
N


Bald Eagle 74424
Population: Chesapeake Bay
Dates Tracked: 4/2008 - 6/2011
Kernel Density Estimate
25%
50%
75%
95%
0 135 270 540
Kilometers
N

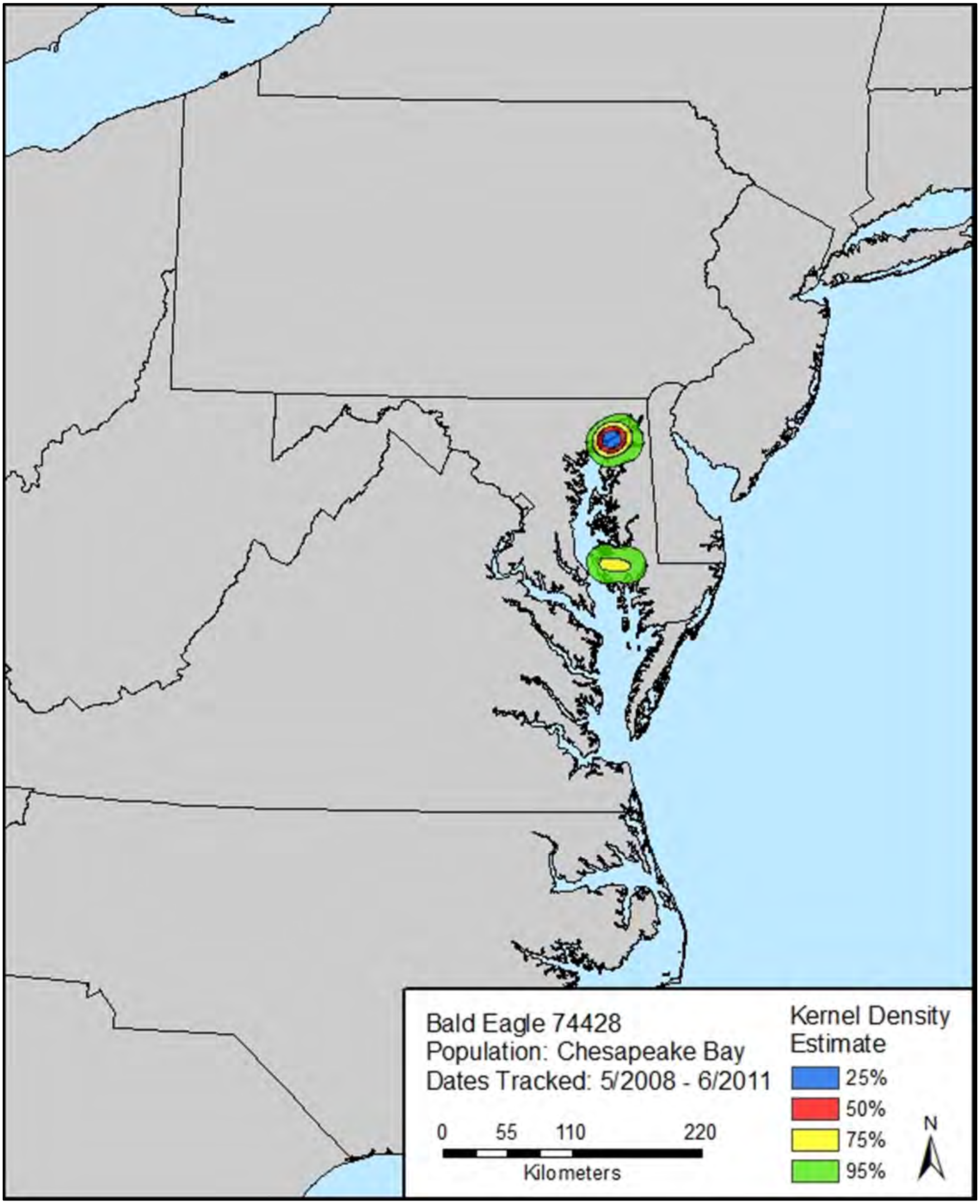


Bald Eagle 74425
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 6/2011
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

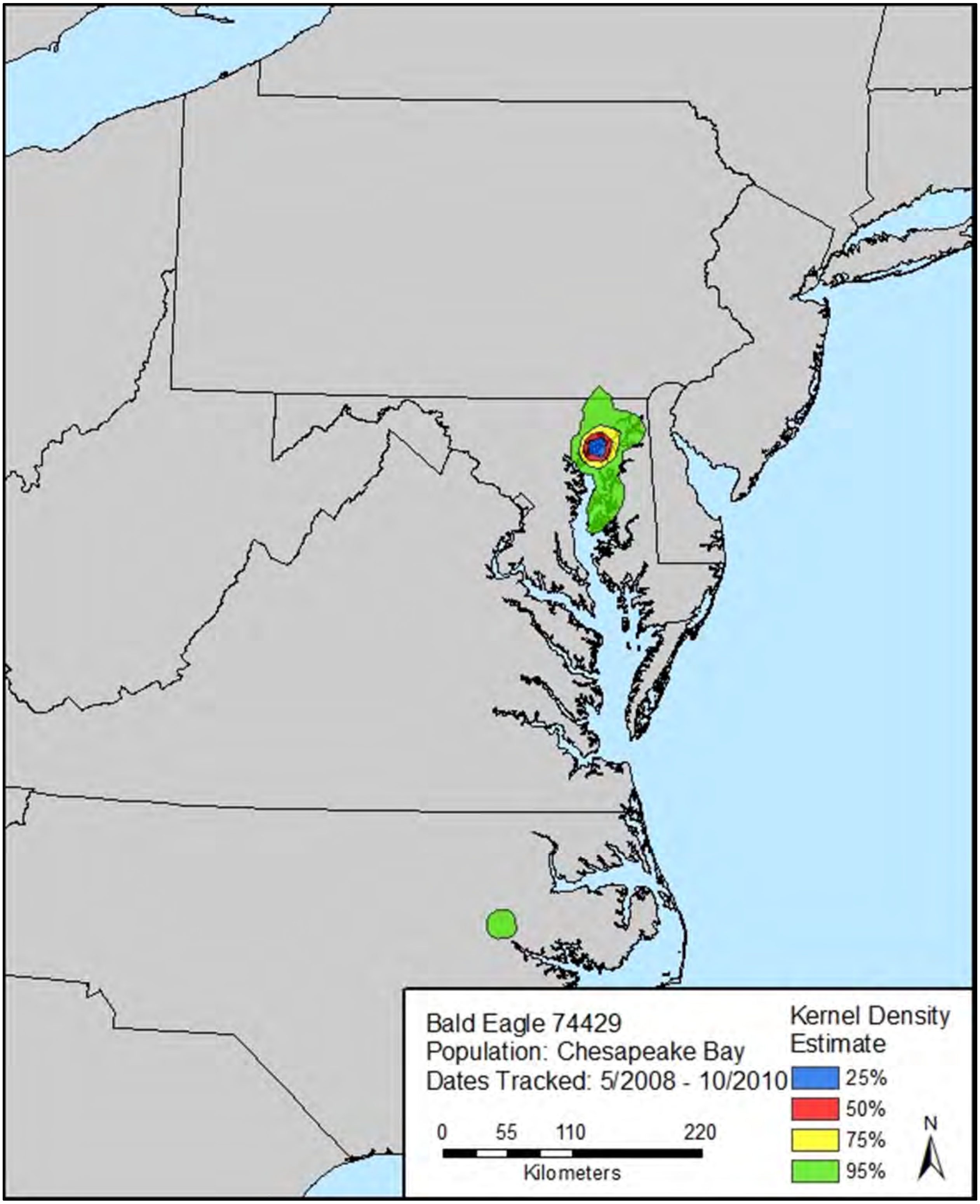

Bald Eagle 74426
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 6/2011
Kernel Density Estimate
25%
50%
75%
95%
0 55 110 220
Kilometers
N



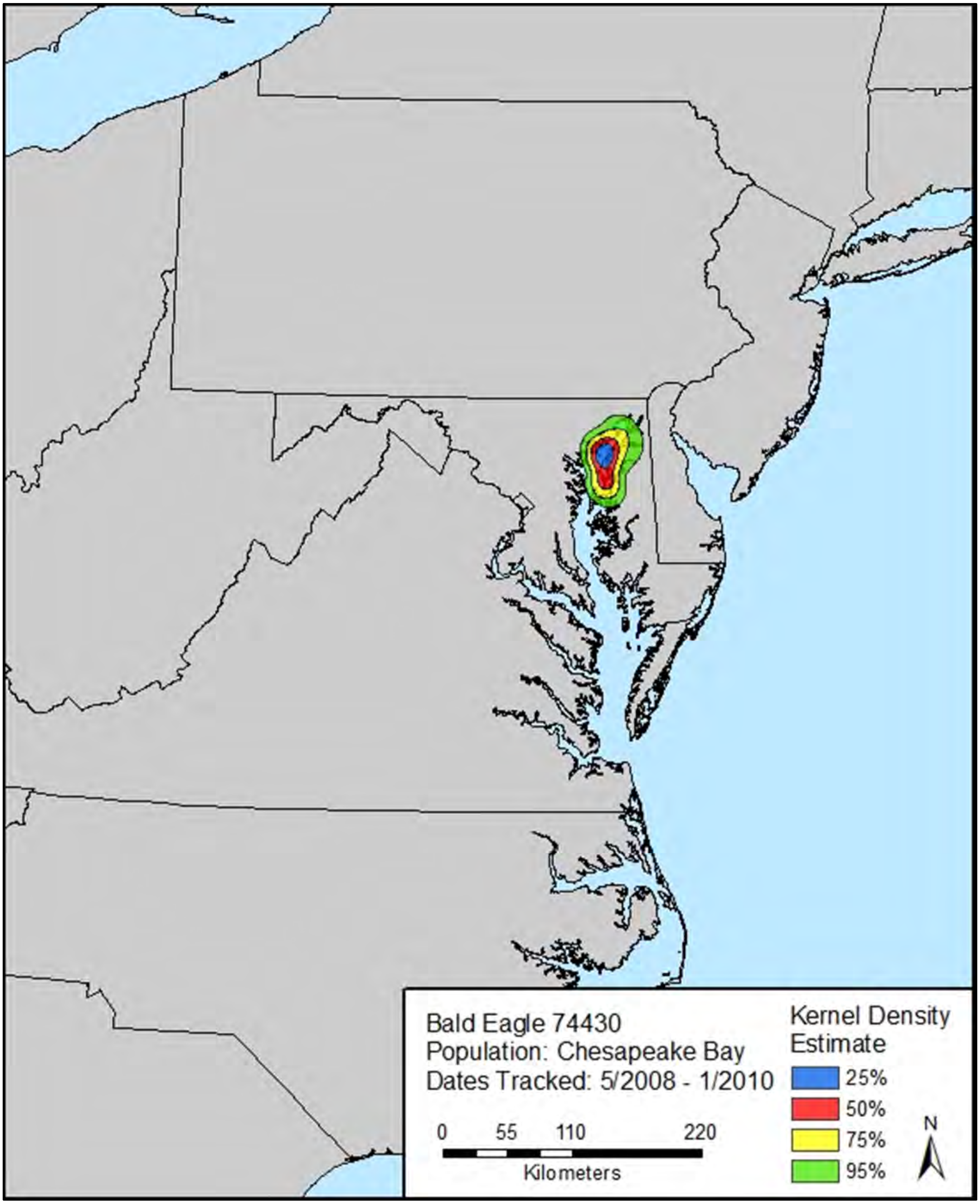
Bald Eagle 74427
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 3/2009
Kernel Density Estimate
25%
50%
75%
95%
0
55
110
220
Kilometers
N



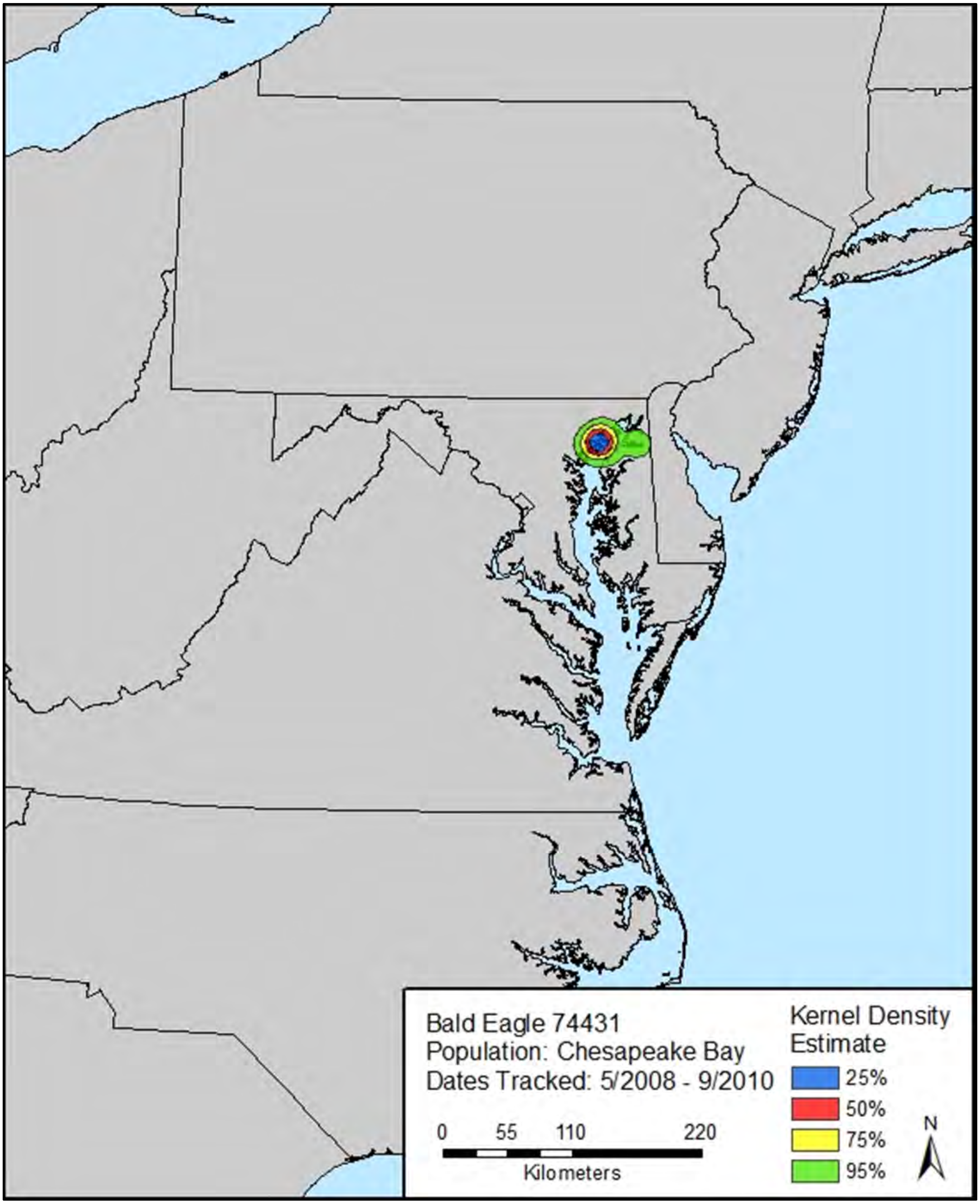
Bald Eagle 74428
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 6/2011
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N



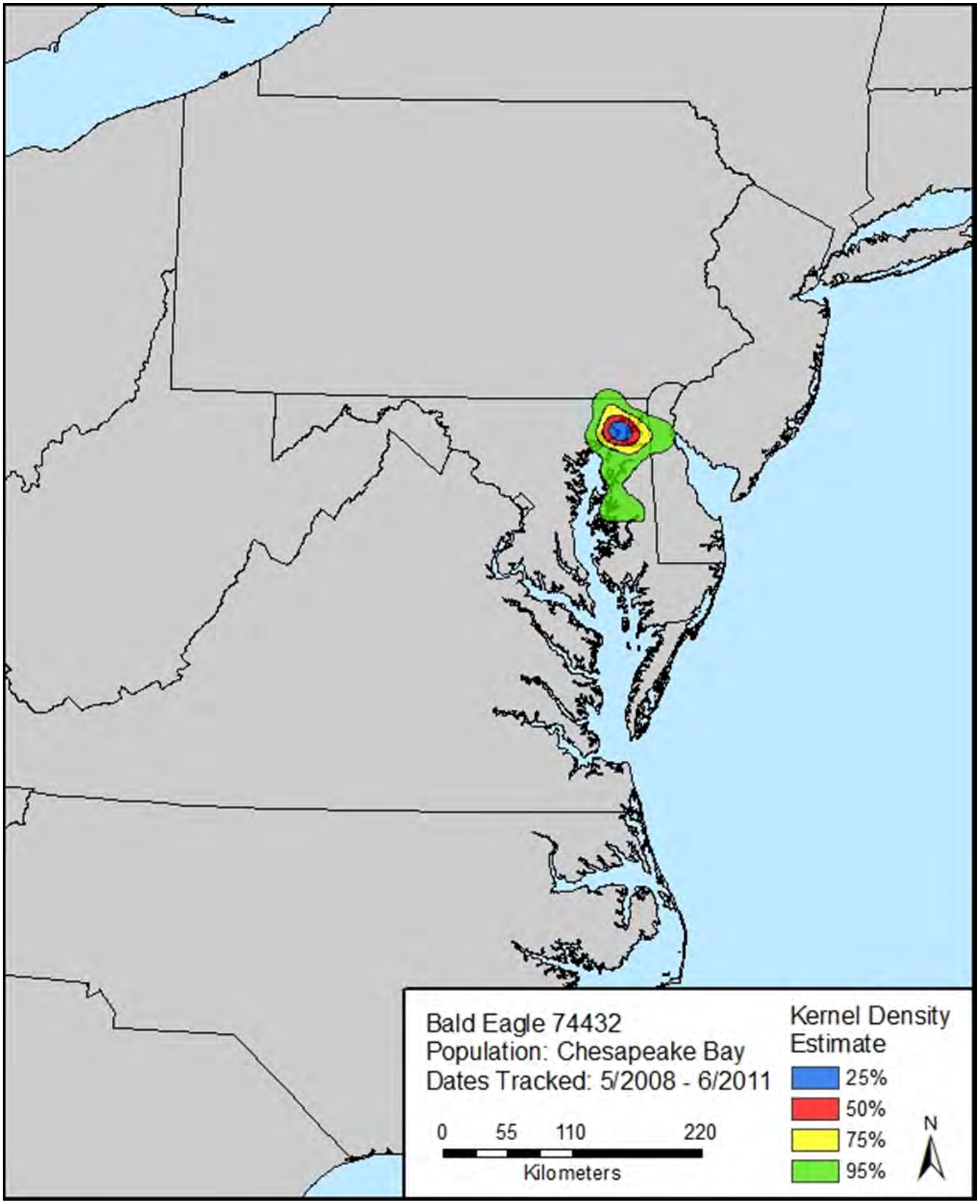
Bald Eagle 74429
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 10/2010
Kernel Density Estimate
25%
50%
75%
95%
0
55
110
220
Kilometers
N



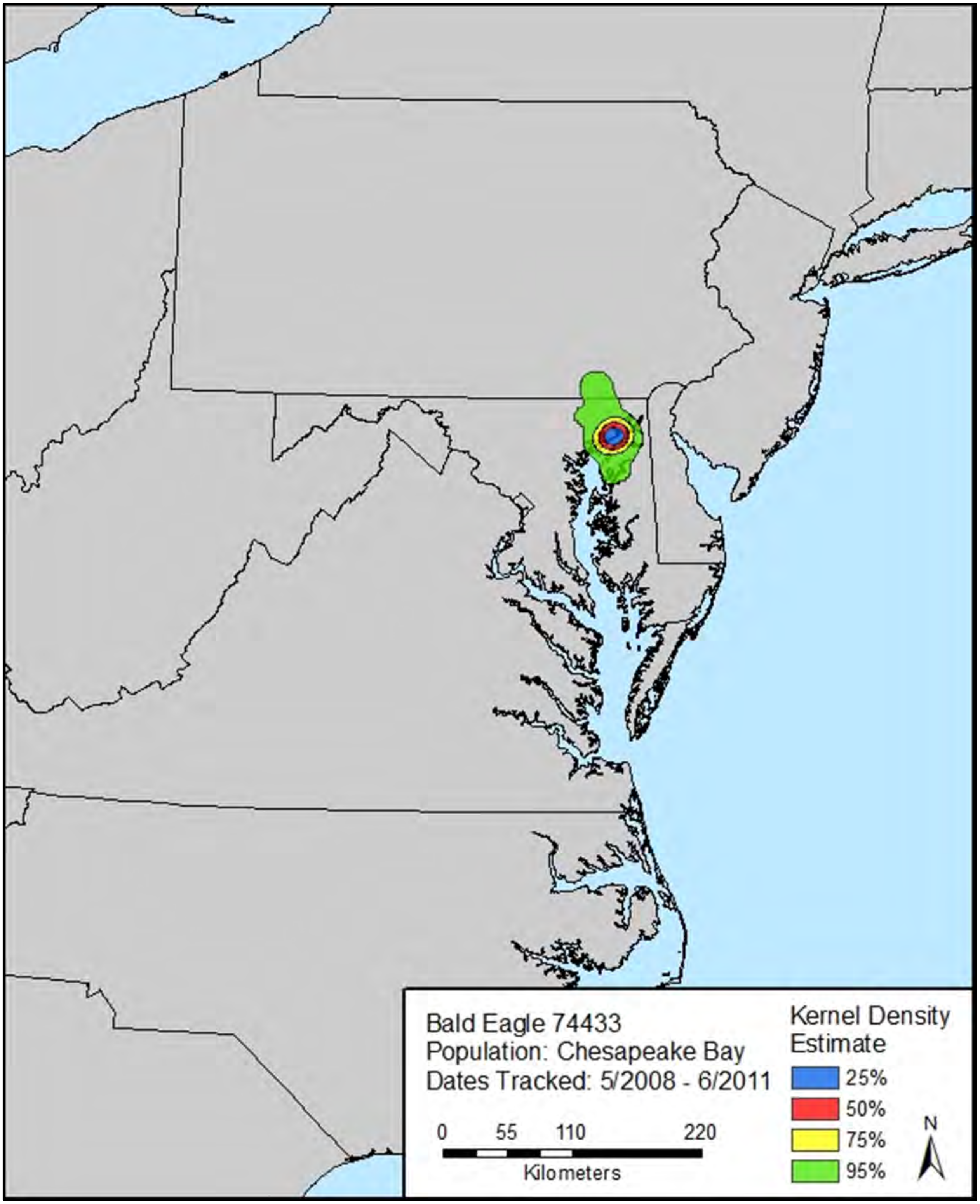
Bald Eagle 74430
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 1/2010
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

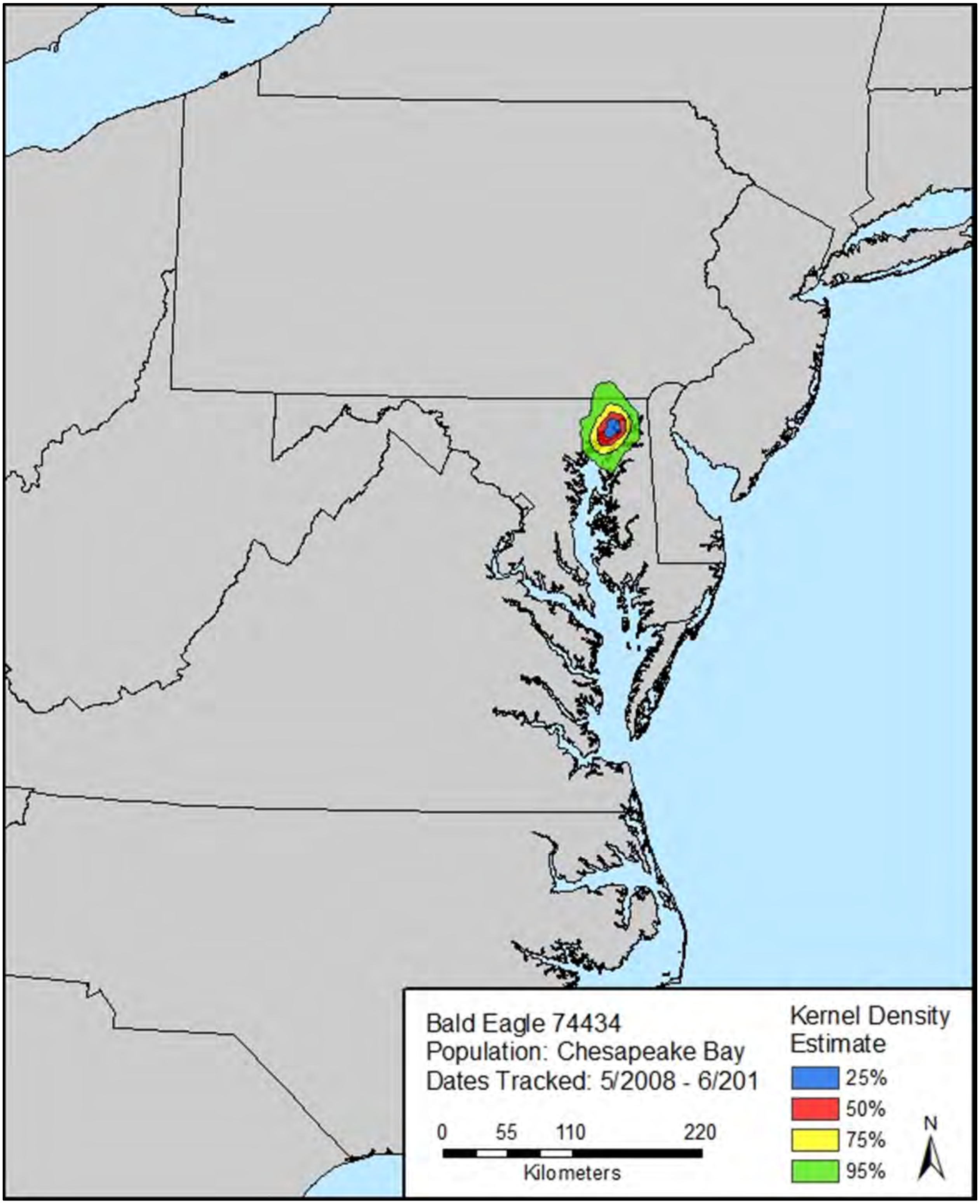


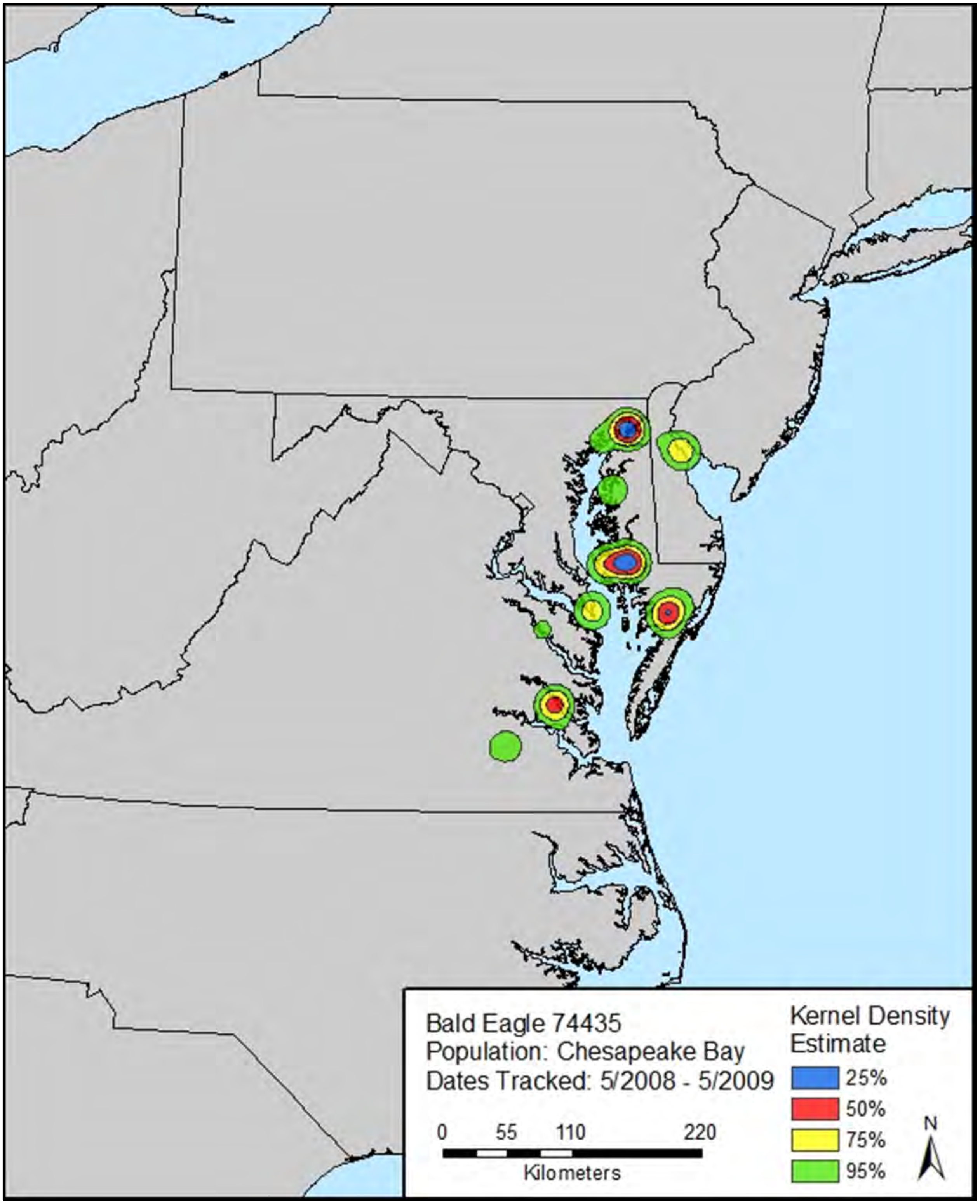
Bald Eagle 74431
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 9/2010
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

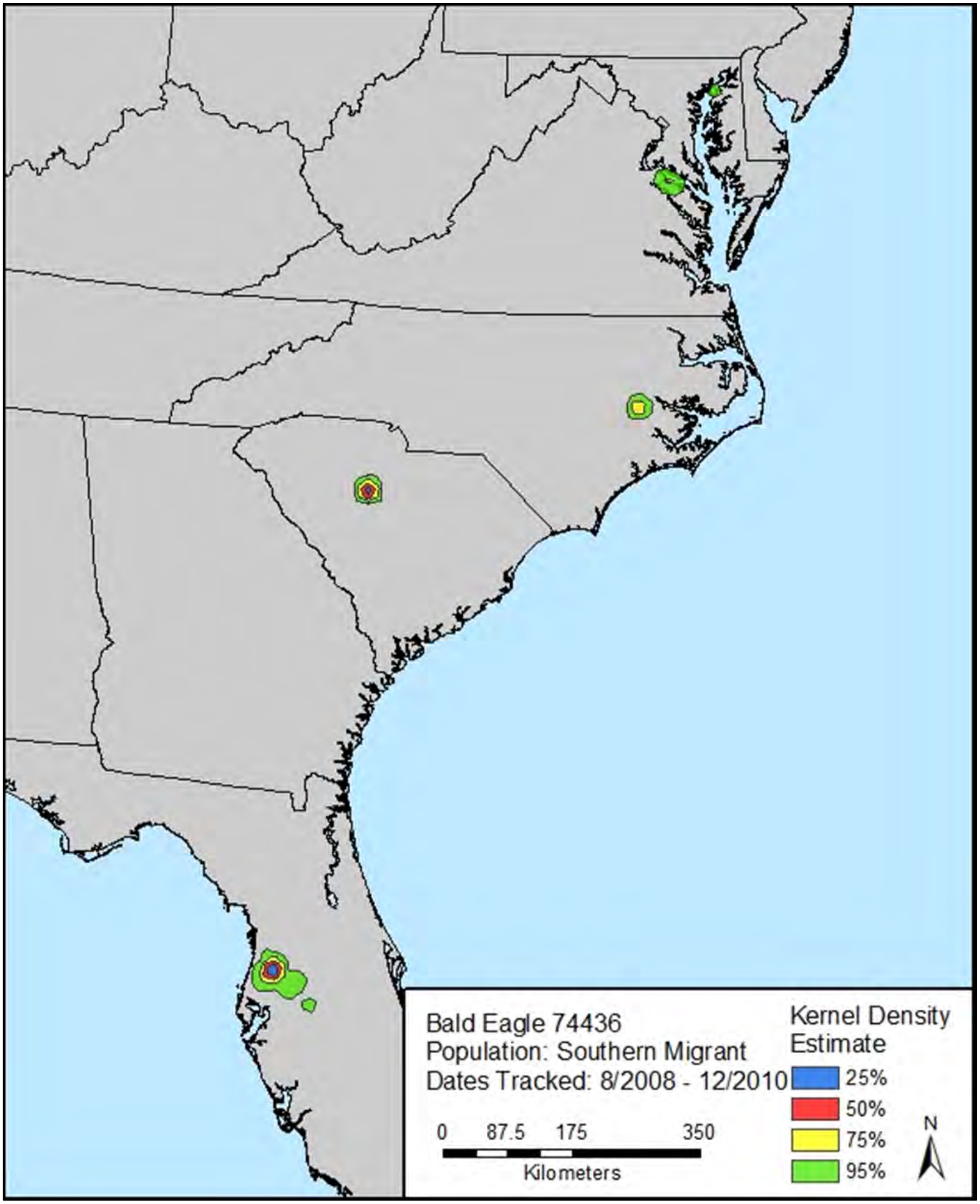


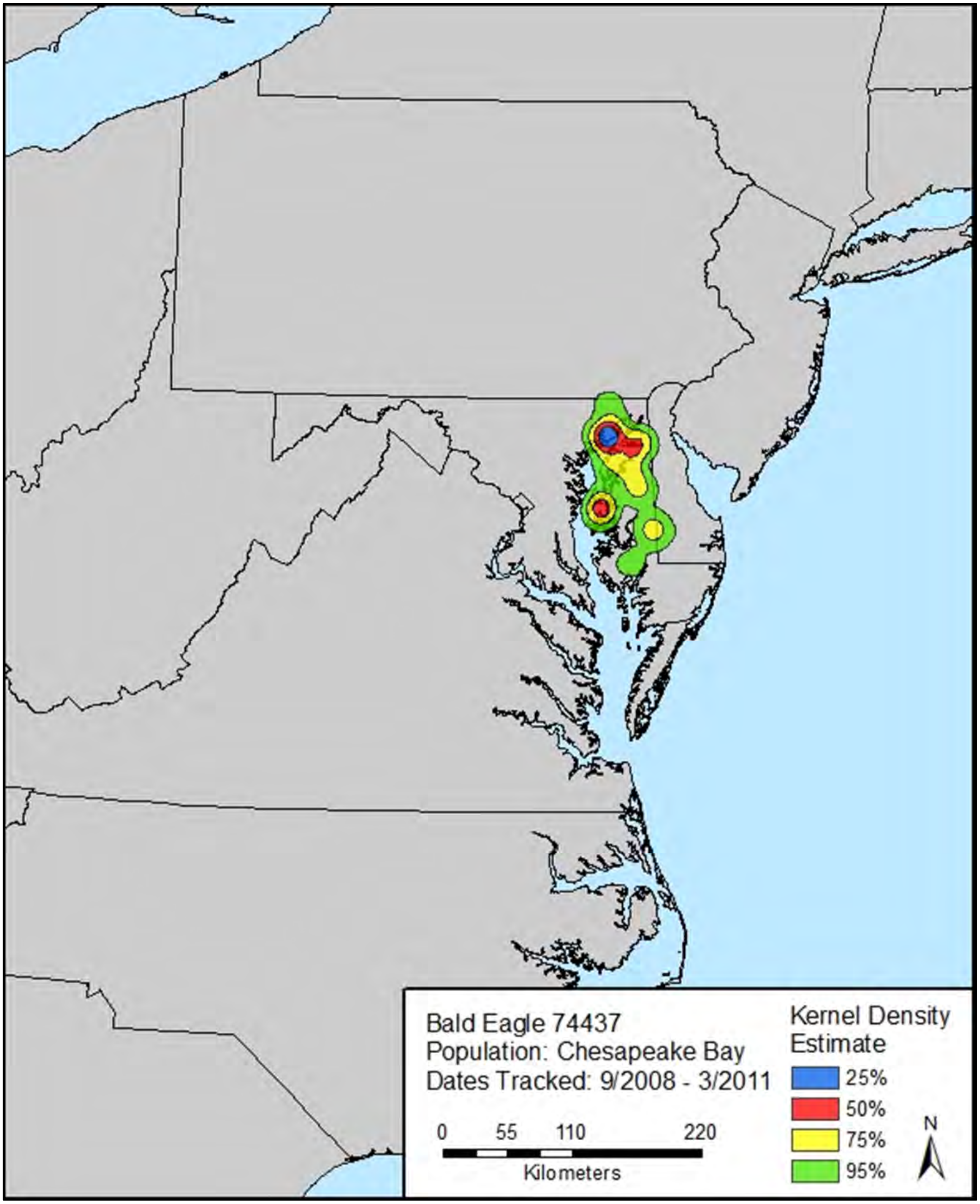
Bald Eagle 74432
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 6/2011
Kernel Density Estimate
25%
50%
75%
95%
0 55 110 220
Kilometers
N


Bald Eagle 74433
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 6/2011
0
55
110
220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

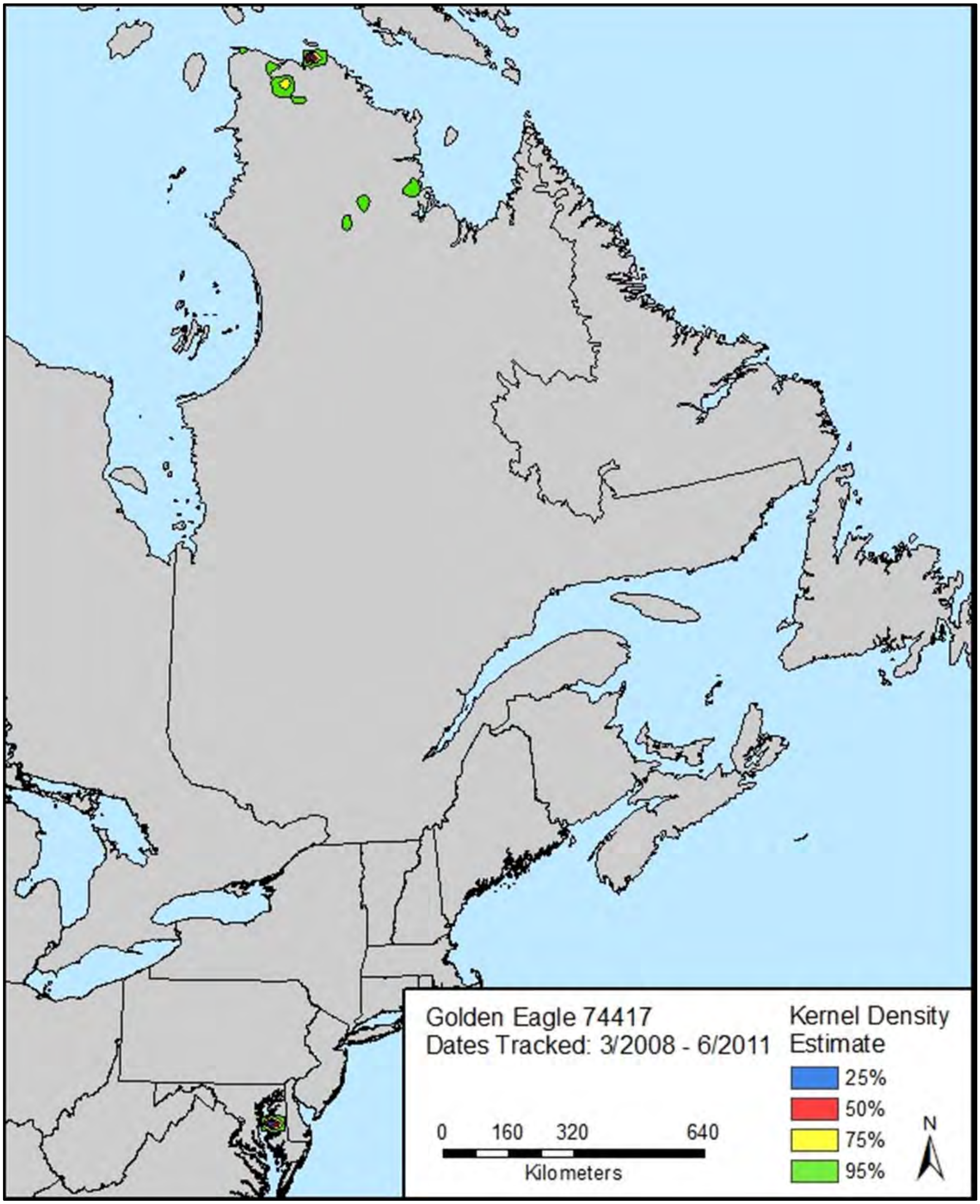

Bald Eagle 74434
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 6/201
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N

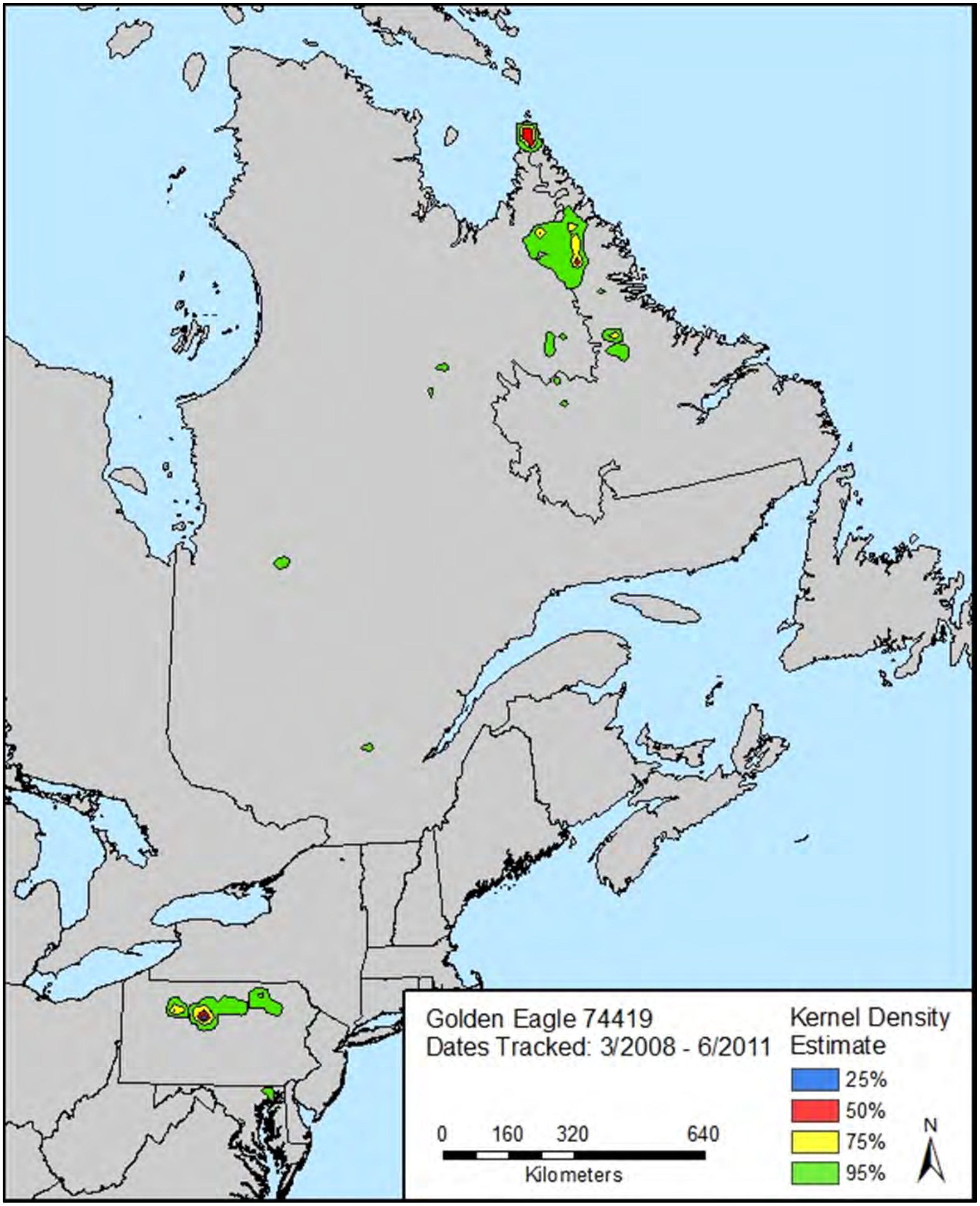

Bald Eagle 74435
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 5/2009
0 55 110 220
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N


Bald Eagle 74436
Population: Southern Migrant
Dates Tracked: 8/2008 - 12/2010
0 87.5 175 350
Kilometers
Kernel Density Estimate
25%
50%
75%
95%
N



Bald Eagle 74437
Population: Chesapeake Bay
Dates Tracked: 9/2008 - 3/2011
Kernel Density Estimate
25%
50%
75%
95%
0 55 110 220
Kilometers
N


Golden Eagle 74417
Dates Tracked: 3/2008 - 6/2011
Kernel Density Estimate
25%
50%
75%
95%
0 160 320 640
Kilometers
N



Golden Eagle 74419
Dates Tracked: 3/2008 - 6/2011
Kernel Density Estimate
25%
50%
75%
95%
0
160
320
640
Kilometers
N

Appendix 6: Catalog of feathers collected under active bald eagle nests on APG indicating nest name and sample of feather type collected.

Date	Nest Code	Nest	Primaries	Secondaries	Retrices	Contours	Year Molted
7/17/2007	HA-95-02	AA5				6	2007
10/5/2008	HA-95-02	AA5	1		1		2008
5/28/2008	HA-95-07	Aviation Arms Road	2	2	1	3	2008
8/9/2009	HA-95-07	Aviation Arms Road		2		6	2009
8/8/2009	HA-09-11	Bear Point		1		5	2009
5/10/2009	HA-99-03	Black Point			1	2	2009
8/9/2009	HA-08-03	Bridge Creek				1	2009
7/17/2007	HA-03-07	C Tower	5	5	2	20	2007
5/27/2008	HA-03-07	C Tower				5	2008
8/12/2009	HA-09-10	Canal Creek		3	2	3	2009
8/10/2009	HA-95-01	C-Field		1			2009
7/17/2007	HA-07-07	Chilbury Point				2	2007
5/3/2008	HA-07-07	Chilbury Point	1	1		1	2008
10/4/2007	HA-05-05	Coopers Creek				2	2007
7/28/2008	HA-05-05	Coopers Creek			1	1	2008
8/7/2009	HA-05-05	Coopers Creek				1	2009
8/9/2009	HA-09-03	C-tower				7	2009
9/27/2007	HA-04-02	Days Point	1			5	2007
10/5/2008	HA-04-02	Days Point			3		2008
7/17/2007	HA-00-04	Dynamometer	1	1		1	2007
9/13/2008	HA-00-04	Dynamometer		1		2	2008
7/17/2007	HA-07-08	Fairview Point				1	2007
5/2/2008	HA-99-07	Fairview Point			1	2	2008
9/13/2008	HA-99-07	Fairview Point		5	3	12	2008
8/7/2009	HA-99-07	Fairview Point	1	4	1	17	2009
5/17/2008	HA-08-06	Fuse Range Shoreline	2	2		10	2008
8/8/2009	HA-08-06	Fuse Range Shoreline	2	2	2	16	2009
10/5/2007	BA-00-01	Graces Quarters			1	2	2007
10/6/2008	BA-07-05	Graces Quarters				6	2008
8/10/2009	BA-07-05	Graces Quarters		1		6	2009
9/27/2007	HA-02-05	I-Field			1		2006
9/27/2007	HA-02-05	I-Field	2	1		9	2007
10/7/2008	HA-02-05	I-Field				3	2008
8/7/2009	HA-02-05	I-Field		1		2	2009
8/7/2009	HA-02-05	I-Field			1	2	2009
10/7/2008	HA-08-05	J-Field				1	2008
10/4/2007	HA-94-03	Lauderick Creek	1	1		1	2006
10/4/2007	HA-94-03	Lauderick Creek	4	5	1	7	2007

Date	Nest Code	Nest	Primaries	Secondaries	Retrices	Contours	Year Molted
9/12/2008	HA-99-03	Lauderick Creek	5	3	2	0	2008
8/7/2009	HA-94-03	Lauderick Creek	1	2		6	2009
5/11/2009	HA-08-09	Light Armor				1	2009
8/9/2009	HA-08-09	Light Armor				1	2009
4/26/2009	HA-06-04	Little Romney	1			6	2009
5/16/2009	HA-04-05	Locust Point	1	2	2	14	2009
10/3/2007	HA-07-01	Monk's Creek					2007
9/11/2008	HA-97-01	Monk's Creek	1	8	3	21	2008
8/7/2009	HA-07-01	Monk's Creek	1	3	1	15	2009
8/4/2007	HA-07-03	Monocacy Island					2007
7/17/2007	HA-03-03	Mulberry Point				8	2007
8/7/2009	HA-09-09	O-field Shoreline		2			2009
7/17/2007	HA-06-01	Plum Point	1				2006
7/17/2007	HA-06-01	Plum Point	1	2	3	26	2007
5/27/2008	HA-06-01	Plum Point	1	10	4	30	2008
8/8/2009	HA-09-06	Plum Point		2		19	2009
8/4/2007	HA-03-08	Poverty Island		1			2007
5/4/2008	HA-03-08	Poverty Island	2			4	2008
5/13/2008	HA-08-07	Range 17			1		2008
8/8/2009	HA-08-07	Range 17				10	2009
4/26/2009	HA-08-08	Range 8				10	2009
7/17/2007	HA-06-05	Reardon Inlet	2			4	2007
10/6/2008	HA-06-05	Reardon Inlet		1			2007
10/8/2008	HA-06-05	Reardon Inlet	1		1	4	2008
10/5/2008	HA-04-08	Sandy Point	2	1		4	2008
8/8/2009	HA-04-08	Sandy Point	3	6	2	10	2009
8/10/2009	BA-04-03	Seneca Creek		4	4	4	2009
5/18/2008	HA-00-05	Towner Cove	1	3	1	4	2008
8/10/2009	HA-00-05	Towner Cove				1	2009
7/17/2007	HA-99-08	Twin Towers		2	2	21	2007
5/31/2008	HA-99-08	Twin Towers				2	2008
10/7/2008	HA-99-08	Twin Towers		1			2008
7/17/2007	HA-04-06	Vertical Camera	1		1	6	2007
10/5/2008	HA-04-06	Vertical Camera			1	2	2008
8/10/2009	HA-04-06	Vertical Camera		1	4	4	2009
10/6/2008	HA-08-02	Westwood	1	1	1	4	2008
10/5/2007	BA-07-03	White Oak Point		1	1	3	2007
5/2/2008	BA-07-03	White Oak Point	2			2	2008
8/10/2009	BA-07-03	White Oak Point	1			5	2009
10/4/2007	HA-96-07	Wilson Point		1	1	5	2007
7/28/2008	HA-96-07	Wilson Point	1				2007

Date	Nest Code	Nest	Primaries	Secondaries	Retrices	Contours	Year Molted
7/28/2008	HA-96-07	Wilson Point					2008
8/10/2009	HA-96-07	Wilson Point				3	2009
9/13/2008	HA-05-01	Wirsing Area		2			2008

Appendix 7: Catalog of feathers collected from 9 communal roosts on APG indicating the date and sample of feather type collected.

Date	Roost Name	Primaries	Secondaries	Retrices	Contours
4/20/2007	Sod Run	5	4	2	32
10/3/2007	Monk's Creek	4	5	5	25
10/3/2007	Monk's Creek	2	1	0	0
10/4/2007	Cooper's Creek	0	0	0	26
11/16/2007	Cooper's Creek	1	0	1	2
1/13/2008	Cooper's Creek	1	0	0	21
1/24/2008	Romney Creek	0	1	1	58
2/11/2008	Sod Run	4	2	0	64
2/28/2008	Romney Creek	2	1	0	34
3/20/2008	Sod Run	3	13	0	98
4/1/2008	Romney Creek	1	2	0	11
4/16/2008	Sod Run	5	16	2	306
4/16/2008	Sod Run	0	1	2	48
5/3/2008	Romney Creek	1	1	1	23
5/28/2008	Woodrest Creek	1	4	2	27
5/28/2008	Sod Run	9	18	9	205
6/16/2008	Romney Creek	1	7	0	80
6/25/2008	Sod Run	0	6	0	26
7/26/2008	Sod Run	1	3	0	17
7/27/2008	Romney Creek	4	17	2	137
7/28/2008	Wilson Point	1	1	1	18
9/1/2008	Sod Run	0	0	0	16
9/1/2008	Romney Creek	0	7	4	49
10/6/2008	Graces Quarters	0	3	0	8
10/8/2008	Sod Run	0	2	0	19
10/8/2008	Romney Creek	1	2	0	28
11/5/2008	Sod Run	0	0	0	4
11/5/2008	Romney Creek	0	0	0	28
12/9/2008	Sod Run	0	0	0	11
12/9/2008	Romney Creek	0	1	1	38
1/15/2009	Romney Creek	1	1	0	28
1/15/2009	Sod Run	0	0	1	6
2/26/2009	Romney Creek	2	8	0	142
2/26/2009	Sod Run	0	8	1	166
8/13/2009	Bear Point	14	35	12	304

Appendix 8. Watts, B.D. and E.K. Mojica 2012. Use of Satellite Transmitters to Delineate Bald Eagle Communal Roosts within the Upper Chesapeake Bay. Journal of Raptor Research 46:121-128.

J. Raptor Res. 46(1):121–128

USE OF SATELLITE TRANSMITTERS TO DELINEATE BALD EAGLE COMMUNAL ROOSTS WITHIN THE UPPER CHESAPEAKE BAY

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ABSTRACT.—Although Bald Eagle (*Haliaeetus leucocephalus*) roosts are protected under the federal Bald and Golden Eagle Protection Act, we have little systematic information on the distribution and abundance of roosts, and a policy framework that governs day-to-day management decisions has not been developed. We used satellite transmitters (n = 63) deployed on Bald Eagles that represented a cross section of age classes and populations present within the study area. The units were programmed to record nocturnal roost locations (n = 10321) to assess roosting behavior and to delineate the boundaries of communal roosts within the upper Chesapeake Bay. More than 27% (n = 2800) of roost locations were not associated with communal roosts and were assumed to reflect solitary roosting. The remaining 72% (n = 7475) of roost locations were clustered within 170 communal roosts that varied in area (0.04–20.13 ha), relative use (5–755 roost-nights), and number of transmittered birds present (2–35). The number of communal roosts within the study area has grown 10-fold over the past 20 yr, presumably reflecting the growth of source populations and eagle use of the area.

KEY WORDS: *Bald Eagle*; Haliaeetus leucocephalus; *Chesapeake Bay; communal roost; satellite transmitter.*

USO DE TRANSMISORES SATELITALES PARA DELINEAR DORMIDEROS COMUNALES DE *HALIAEETUS LEUCOCEPHALUS* EN LA BAHÍA ALTA DE CHESAPEAKE

RESUMEN.—Aunque los dormideros de *Haliaeetus leucocephalus* están protegidos por la Ley Federal de Protección del Águila Calva y Dorada, poseemos poca información sistemática sobre la distribución y abundancia de los dormideros y no se ha desarrollado un marco político de decisiones diarias de manejo. Usamos transmisores satelitales (n = 63) colocados en individuos de *H. leucocephalus* que representaron una muestra cruzada de clases de edad y poblaciones presentes en el área de estudio. Las unidades fueron programadas para registrar las localizaciones de los dormideros nocturnos (n = 10321) y así evaluar el comportamiento vinculado a los dormideros y delinear los límites de los dormideros comunales en la parte superior de la Bahía de Chesapeake. Más del 27% (n = 2800) de las localizaciones de los dormideros no estuvo asociado con dormideros comunales y fueron considerados como dormideros solitarios. El 72% (n = 7475) restante de las localizaciones de los dormideros fue agrupado en 170 dormideros comunales que variaron en superficie (0.04–20.13 ha), uso relativo (5–755 noches dormidero) y número de aves presentes con transmisores (2–35). El número de dormideros comunales dentro del área de estudio ha aumentado 10 veces a lo largo de los últimos 20 años, reflejando presumiblemente el crecimiento de poblaciones fuente y el uso del área por parte de las águilas.

[Traducción del equipo editorial]

Congregations of nonbreeding Bald Eagles (*Haliaeetus leucocephalus*) form around rich food resources (McClelland et al. 1982, Isaacs and Anthony 1987, Hunt et al. 1992), and associated communal roosts typically are clustered around profitable feeding patches (Keister et al. 1987, Wilson and Gessaman 2003). Feeding and roosting are exclusive activities, require different habitats, and are often separated by considerable distances (Swisher 1964, Edwards 1969, Keister and Anthony 1983). The distribution of communal roosts is believed to reflect a dynamic balance between the cost of travel to and from feeding areas, the relative profitability of feeding areas, and the energy savings achieved from roosting within protected microclimates (Stalmaster and Gessaman 1984, Keister et al. 1985). For this reason, loss of communal roosts may negatively impact energy budgets or cause the abandonment of important feeding sites. Because communal roosts play an important role in the life cycle of Bald

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Eagles, they are protected under the "disturb and sheltering" provisions of the federal Bald and Golden Eagle Protection Act (Eagle Act) of 1940 (16 U.S.C. 668-668c) and their management is incorporated into the National Bald Eagle Management Guidelines (U.S. Fish and Wildlife Service 2007a). These guidelines define communal roost sites as areas where Bald Eagles congregate to perch overnight in forested areas protected from inclement weather and close to foraging areas (U.S. Fish and Wildlife Service 2007a).

Bald Eagles throughout the conterminous United States have increased from an estimated low in 1963 of 417 pairs (Sprunt 1963) to 5748 pairs by 1998 (Millar 1999) and 9789 pairs by 2007 (U.S. Fish and Wildlife Service 2007b). Presumably, the subadult population has increased at a comparable rate, and by 2007 likely exceeded 40 000 (based on expected age distribution for a population at equilibrium). Increases in breeding populations are reflected during the nonbreeding period when migrant adults and subadults congregate together within overwintering (Steenhof et al. 2002) and over-summering locations (Chester et al. 1990, Watts and Byrd 1999) and during the breeding season when local subadults congregate within breeding areas (Curnutt 1992). For this reason, population increases likely have resulted in a proliferation of communal roosts throughout the species' range, particularly within regions supporting large numbers of nonbreeders.

The Chesapeake Bay is a convergence area for Bald Eagle populations along the Atlantic coast. In addition to a resident breeding population that has recovered to historic levels (Watts et al. 2008), the Chesapeake Bay supports populations of northern and southern migrants (Watts et al. 2007). In late spring and early summer, eagles migrate north from Florida and other southeastern states to spend the summer months in the bay (Broley 1947, Wood 1992, Millsap et al. 2004, Mojica et al. 2008). In the late autumn, eagles migrate south from New England and the maritime provinces of Canada to spend the winter on the bay (McCollough 1986, Buehler et al. 1991a). Nonbreeders from all three populations congregate in several concentration areas distributed within low-salinity reaches (Watts et al. 2007). Within these areas, communal roosts have been identified that support several to well over 100 birds during different periods of the year (e.g., Wallin and Byrd 1984, Haines 1988, Buehler et al. 1991b).

Despite similar protections afforded under the Eagle Act for roosts and nests, most management activities have focused on nest sites. Furthermore, throughout most of the species' range, we have comparatively little systematic information on the abundance and distribution of Bald Eagle roosts (Isaacs et al. 1996). We here report on our use of satellite transmitters to delineate a network of communal Bald Eagle roosts within the upper Chesapeake Bay.

METHODS

Our study area included the northern part of the Chesapeake Bay from the Bay Bridge at Annapolis, MD to just above the Conowingo Dam on the Susquehanna River (Fig. 1). This area (2729 km^2) includes the Upper Chesapeake Bay Bald Eagle Concentration Area (Watts et al. 2007) and is very similar in distribution and extent to that described by Buehler et al. (1991a). The eastern portion of the study area is primarily rural, with forest lands interspersed with agriculture. The western portion contains the urban areas of Baltimore and Annapolis, but also includes Aberdeen Proving Ground (APG), a 350-km^2 military installation that is primarily forested with extensive shorelines. The northern part of the study area contains the Susquehanna Flats, a historically important site for wintering waterfowl (Lynch 2001). This area, along with the nearby Conowingo Dam, supports a significant number of eagles during the fall and winter months (Steenhof et al. 2008). Eagles within the area feed primarily on fish during the summer months, but switch to waterfowl and mammals during the autumn and winter when fish move to deeper waters and many waterbirds migrate into the bay (DeLong et al. 1989, Mersmann 1989).

We captured resident and migrant Bald Eagles (n = 63) on APG, banded, and fitted them with satellite transmitters between August 2007 and May 2009. Free-flying eagles were trapped on three sandy beaches (n = 10) using padded leg-hold traps (King et al. 1998), in three open fields (n = 26) using rocket nets baited with deer carcasses (Grubb 1988), and on open waters (n =10) using floating fish traps (Frenzel and Anthony 1982, Cain and Hodges 1989, Jackman et al. 1993). We climbed nest trees throughout APG to access broods (8–10 wk of age) and deployed a transmitter on one nestling per brood (n = 17). We conducted floating fish and leg-hold trapping during the summer months to target resident and southern migrants. We conducted rocket-net trapping in the winter months to target

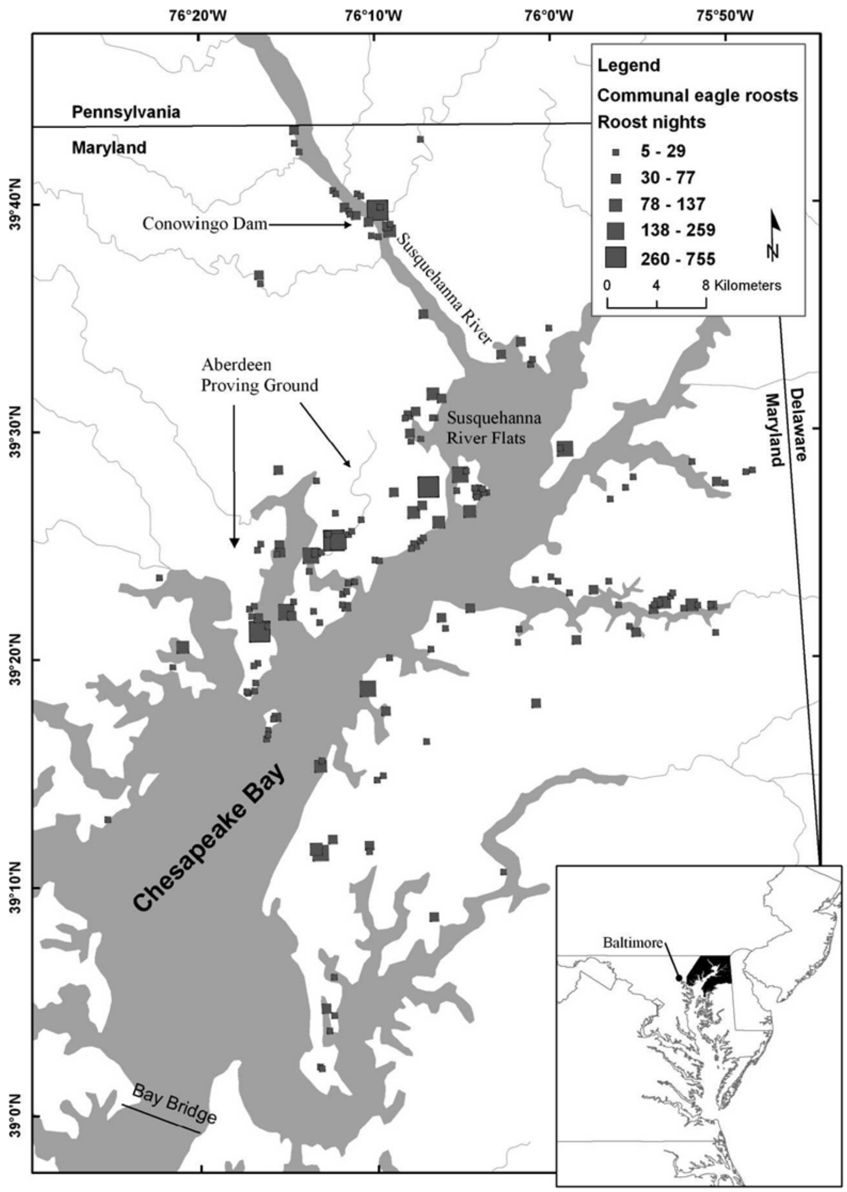

Figure 1. Upper Chesapeake Bay including communal roosts within the study area. This portion of the tidal reach of the bay includes the Upper Chesapeake Bay Bald Eagle Concentration Area.

resident and northern migrants. Eagle capture and handling methods were in compliance with IACUC protocols at the College of William and Mary (IACUC-20051121-3).

We used solar-powered, 70-g, GPS-PTT satellite transmitters (Microwave Telemetry, Inc., Columbia, Maryland, U.S.A.) to track eagle movements. Transmitters were attached using a backpack-style harness constructed of 0.64-cm Teflon® ribbon (Bally Ribbon Mills, Bally, Pennsylvania, U.S.A.). Transmitters were programmed to collect GPS locations (±18 m) every daylight hour and one additional location at midnight. GPS locations were processed by Argos satellites (CLS America, Largo, Maryland, U.S.A.) and stored online by Satellite Tracking and Analysis Tool (Coyne and Godley 2005).

We used midnight locations ($n = 10\,321$) to delineate communal roosts occupied from August 2007 to August 2009. Locations from breeding adults roosting near nests were excluded. Locations from nestlings were not included until after they began roosting away from the natal site. Minimum convex polygons (MCP) of roost boundaries were delineated using a nearest neighbor clustering script in Crimestat III (Levine 2004). Cluster parameters were set to search a fixed distance of 100 m for a minimum of five midnight locations (i.e., roost-nights). At least two individual eagles had to visit a roost during the study period for it to qualify as a communal roost. Roosts used by single eagles were manually removed from the dataset. Landscape features of each roost were evaluated using digital raster graphics in ArcMap 9.3 (Environmental Systems Research Institute, Inc.© 1999–2009, Redlands, California, U.S.A.). Roosts within the same forest patch and within 200 m of one another were merged into a single MCP. Once established, roost boundaries were overlaid on roost locations to evaluate seasonality and relative magnitude (i.e., number of roost-nights, number of individuals) of use.

RESULTS

All of the eagles tracked in this study had nonbreeding home ranges within the study area at the time of capture. We deployed transmitters on 17 local nestlings. Based on the review of positions in the months following transmitter deployment on free-flying birds, we deployed transmitters on an additional 29 residents, 13 northern migrants, and 4 southern migrants.

We delineated 170 communal roosts within the study area (Fig. 1). Eagles roosted widely throughout the upper bay and 7475 (72%) midnight locations fell within the definition of a communal roost used in our analysis. Remaining locations (2846) were not associated with other transmittered eagles and were assumed to be locations resulting from solitary roosting. Communal roosts were skewed to more rural parts of the study area and included the Eastern Shore, the lower Susquehanna River and APG. APG alone accounted for 40% of delineated roosts. In contrast, the metropolitan areas within the southwestern portion of the study area supported very little roosting.

Relative use of communal roosts varied dramatically such that a small number of roosts accounted for a large portion of overall roosting activity. Overall, the number of roost-nights per roost varied from 755 to the established minimum of 5 (44 ± 6.1, mean ± SE), the number of calendar nights from 455 to 5 d (37 ± 4.3 d) and the number of different transmittered birds supported from 35 to 2 (7 ± 0.47). These three parameters were intercorrelated (correlation coefficients Pearson's $r > 0.72$, $P < 0.05$), suggesting that the roosts receiving the highest use were also the most consistently used roosts and accommodated the largest number of individuals. The result of variation in relative use is a "decelerating utility function" such that 10%, 30%, and 50% of roosts support 52%, 78%, and 89% of roost nights respectively (Fig. 2).

The total area encompassed by all roost sites was 322.1 ha, or 0.1% of the study area. Area of communal roosts varied from 0.04 to 20.13 ha (mean = 1.9 ± 0.21 ha) and the density of use ranged from 5.3 to 427.5 roost-nights/ha for the study period. A significant portion (48%) of this area was owned by the government or conservation organizations, including roosts on lands controlled by the military (33%), nongovernmental organizations (7.8%), state and local governments (5.8%), other federal agencies (1.6%). The remaining roosts were on privately owned land (52%). A plot of the minimum area trajectory indicated that 10% and 20% of the roost area supported more than 30% and 50% of the roosting activity, respectively (Fig. 3).

DISCUSSION

The number of communal roosts within the upper Chesapeake Bay appears to have increased dramatically over the past 20 years. Buehler et al. (1991b) used conventional VHF transmitters ($n = 73$) to locate communal roosts within the same study area (1988–89). They followed individuals to nocturnal roost sites twice weekly for 12 mo to reveal the roost network and monitored delineated roosts from the ground. They classified roosts as communal based on visual observations of additional eagles using the roosts. Of the 17 communal roosts described, 13 were still active during our study. In the intervening years, the number of active roosts has proliferated, with an average doubling time of just over 6 yr, representing a 10-fold increase

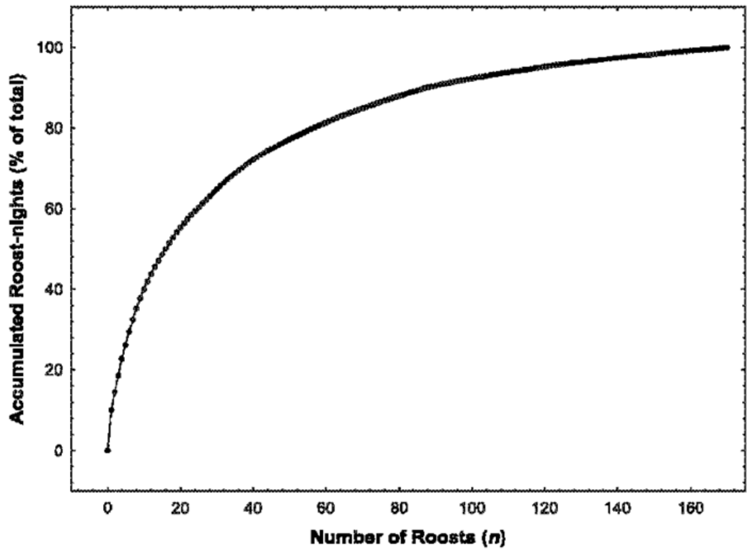

Figure 2. Relationship between the number of roosts and the cumulative proportion of roost-nights supported. The graph reflects the minimum number of roosts to support the highest portion of roost-nights. Roosts were ordinated from high to low according to the number of roost-nights supported. An accumulation curve was then generated by sequentially adding each roost to the total and expressing the result as a portion of the total roost-nights against the number of roosts included.

in 20 yr. Over this same period, the breeding population has exhibited a comparable increase within the portion of the study area that has been surveyed annually (J. Pottie and J. Paul unpubl. data). The distribution of roosts described here was similar to that described by Buehler et al. (1991b), with most roosts occurring along the Eastern Shore, on the lower Susquehanna River, or on APG lands and very little roosting activity in the urbanized landscape including the cities of Baltimore and Annapolis.

Throughout the network of communal roosts, the use of individual sites varied dramatically, such that 10% of the roosts accounted for more than 50% of the total roost activity. Variation in the relative significance of roosts has been noted in other study areas. Keister and Anthony (1983) collected pellets under six communal roosts in the Klamath Basin and found that nearly 49% of the total pellets were from a single roost and that more than 80% were from the two largest roosts. Although the range of use was narrower, Isaacs et al. (1996) found that eagles wintering along the Upper John Day River in Oregon typically used small roosts that were an order of magnitude smaller than the largest roosts. Within the current study site, monthly surveys of four communal roosts (1996–2003) indicated that use varied more than an order of magnitude between sites (General Physics 2004). Here, the use of roosts varied by more than two orders of magnitude. Together, these studies illustrated that roost sites vary considerably in terms of their relative use and presumed value to eagle populations.

More than 2800 (27%) roost-nights were not associated with areas delineated as communal roosts and were assumed to represent solitary roosting events. Solitary roosting has been reported elsewhere (e.g., Southern 1964, Stalmaster 1976, Grubb et al. 1989) and results presented here were comparable to those in other studies that have systematically evaluated roosting behavior. An intensive investigation of roosts and roosting behavior in Oregon classified more than 30% of roosting events as solitary roosts (Isaacs et al. 1996). Within the upper Chesapeake, solitary roosters accounted for 41% of documented ($n = 81$) roost-nights in the 1980s (Buehler et al. 1991b). Because of the large portion of roost-nights attributed to solitary roosters and their wide distribution, they greatly expand the overall portion of the study area used by roosting eagles.

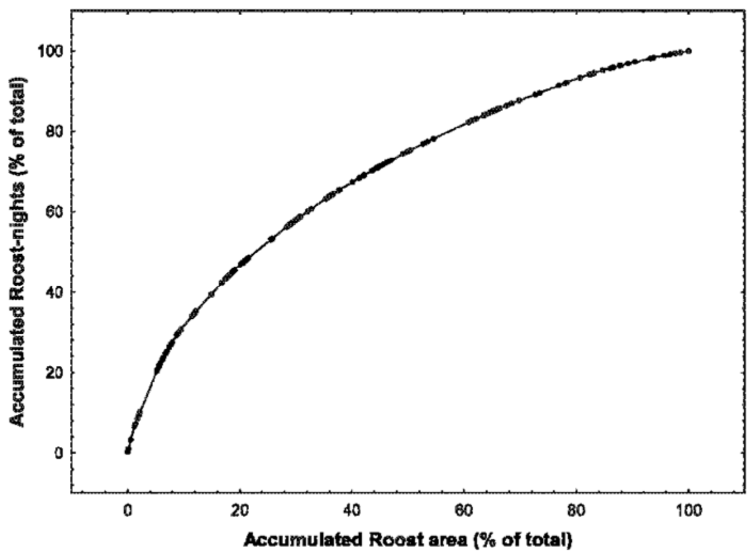

Figure 3. Relationship between the amount of land and the cumulative proportion of roost-nights supported. The graph reflects the minimum area to support the highest portion of roost-nights. Roosts were ordinated from high to low according to roost density (accumulated roost-nights/roost area). An accumulation curve was then generated by sequentially adding each roost to the total and expressing the result as a portion of the total roost-nights against the sum of roost area included.

Variation in the area of communal roost sites was comparable to that documented in other investigations where roost boundaries were mapped. Other studies have shown roosts that vary from a single tree (Isaacs et al. 1993) to a 254-ha forest patch (Keister and Anthony 1983), including roosts in North Carolina (1.3–5.0 ha: Chester et al. 1990), Maryland (0.39–1.0 ha; Buehler et al. 1991b), Florida (20 ha; Curnutt 1992), South Dakota (5 ha; Steenhof et al. 1980), Montana (42 ha; Crenshaw and McClelland 1989), and Oregon (2.4–28.3 ha; Isaacs and Anthony 1987).

Unlike nests that, from a regulatory perspective, are homogeneous in terms of their benefit to populations, the importance of roost sites may vary considerably. Bald eagles employ a wide range of roosting strategies. Here we have demonstrated roosting scenarios that vary from a large number of locations where individuals appear to roost alone to relatively few communal roosts that are used by many individuals throughout the year. Solitary roosts are numerous and cover nearly the entire study area. Small communal ephemeral roosts used on average less than 1 d/mo are widespread and common. Large roosts used throughout the year by individuals from populations along the entire Atlantic coast, are much less common. The most significant roost detected was at the Conowingo Dam, and was used by 28 birds with transmitters, covered 9.8 ha, and accounted for >10% of all communal roosting activity. Ten percent of the roosts accounted for 50% of the roosting activity, but only 30% of the total area of all roosts.

The question of how or whether to manage the continuum of roost sites is central to the formulation of effective policy. Protections afforded to roost sites under the Eagle Act are nonspecific. The act does not define what constitutes a roost. Roosts have been defined as ≥1 eagle for ≥1 night (Grubb et al. 1989, Buehler et al. 1991b), and ≥3 eagles for ≥2 nights (Anderson et al. 1985). Although these definitions clearly describe biological events, they may not be viable from a regulatory perspective. Solitary roosts were numerous and widespread. Placing management buffers around these consumes all of the land within the study area. These sites also are the most likely to be ephemeral, such that managing them provides an uncertain benefit to the population. Although less pronounced, small communal roosts are also widespread and account for a relatively small portion of roosting activity, suggesting that the benefit accrued to eagles for their protection relative to the burden to landowners is small. Within the current roost network, applying a management threshold of 0.5% (i.e., roosts accounting for >0.5% of roosting activity receive protection) would reduce the burden to managers and landowners by more than 75% with only minimal presumed impact to eagles.

Acknowledgments

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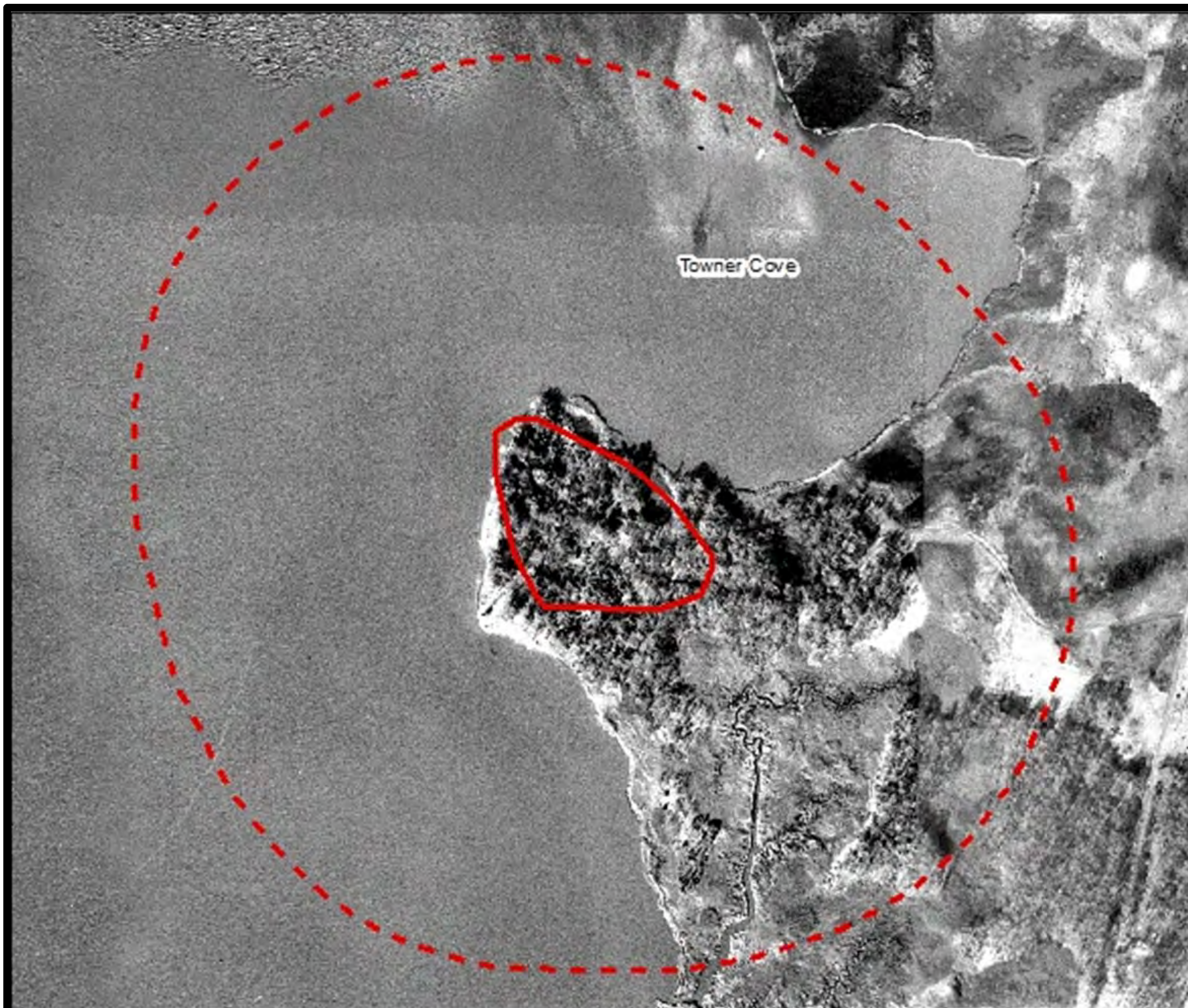
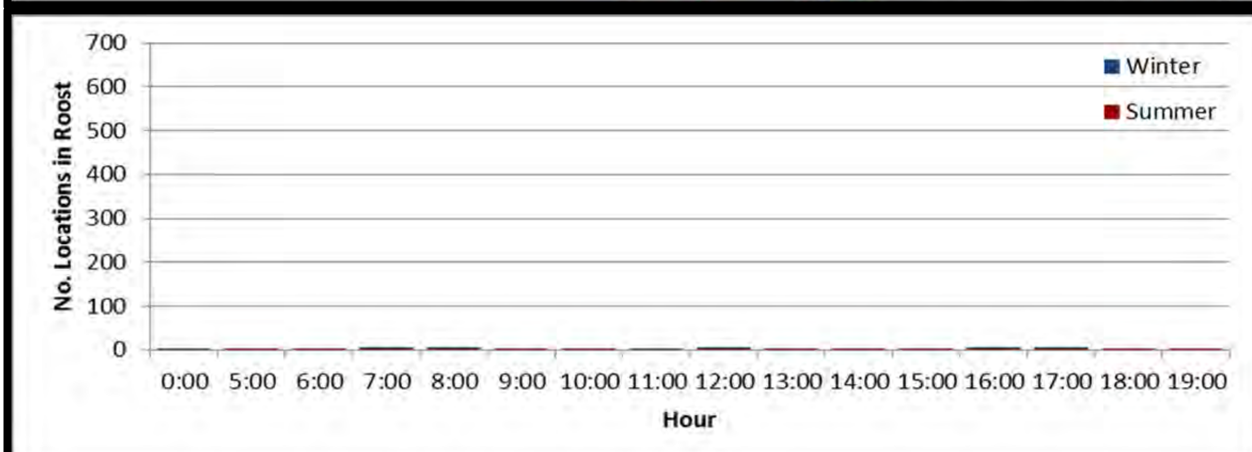
Appendix 9. Boundaries of communal roosts with 500m management buffer. Histogram illustrates time of day eagles were within the roost boundary.

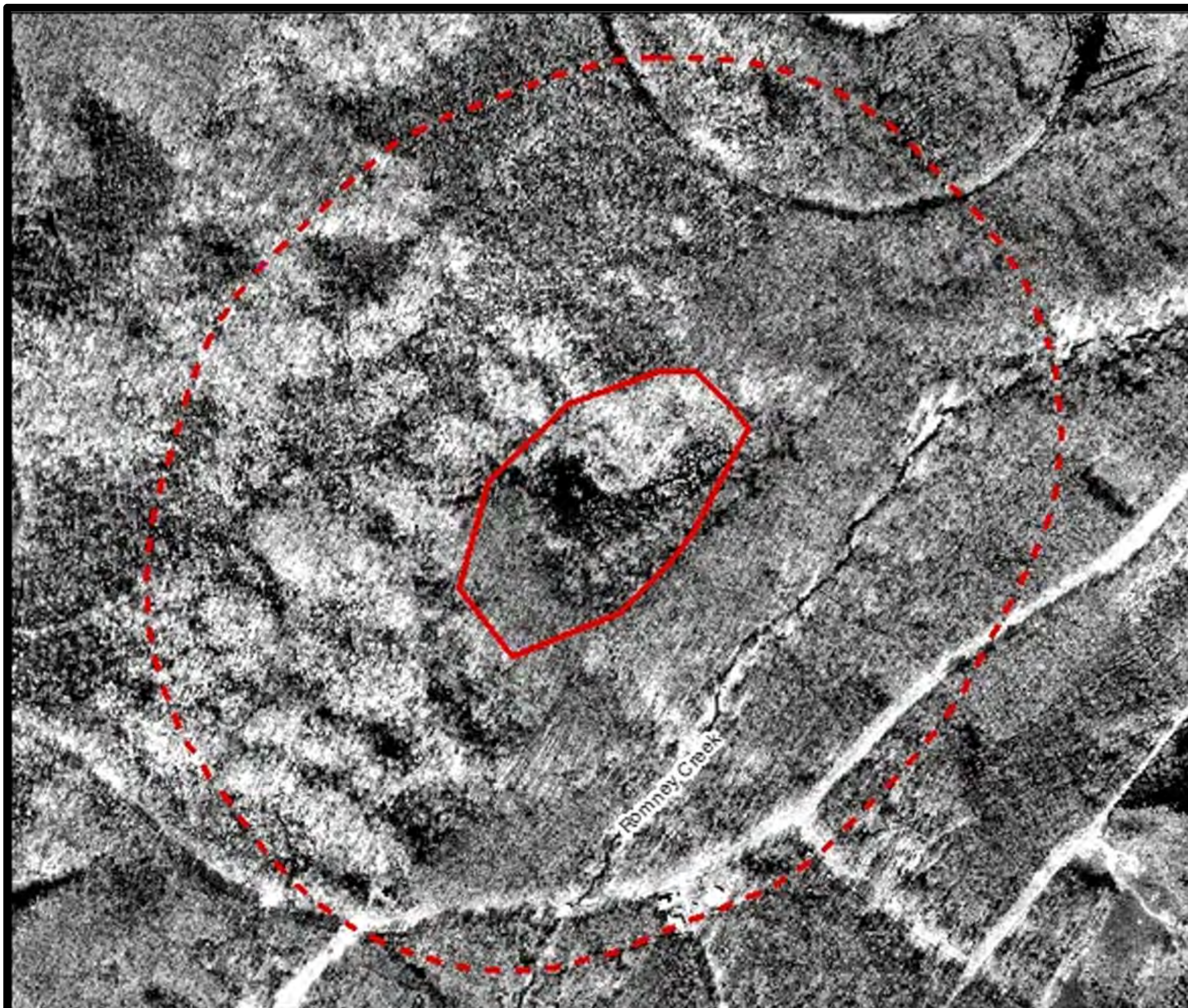


Roost No. 1
Roost Name: Towner Cove
Predominant Season: Summer and Winter

No. Midnight Locations: 20
No. Total Locations: 61
No. Transmittered Eagles: 15

Roost Boundary   500m Buffer
0 62.5 125 250 Meters
N

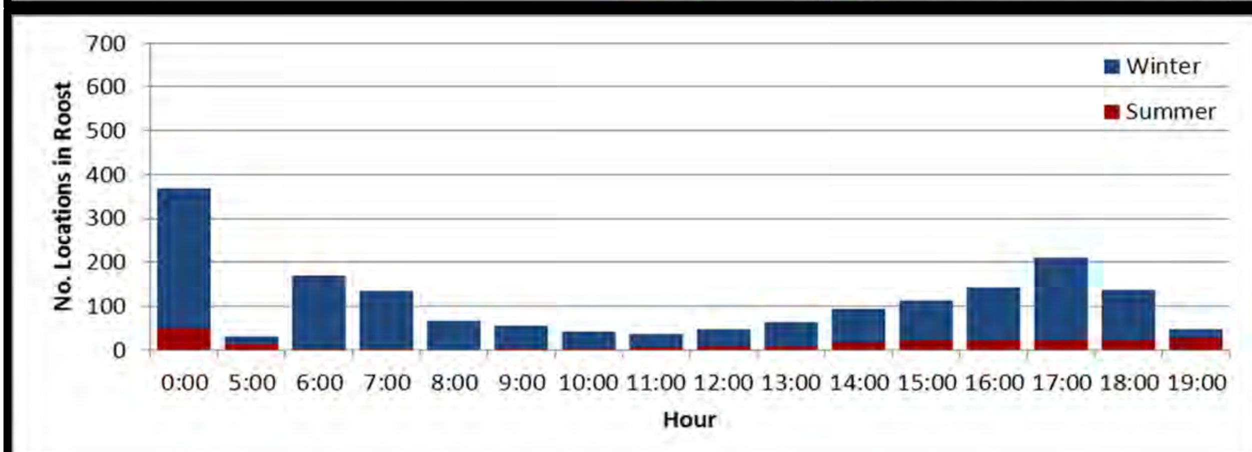


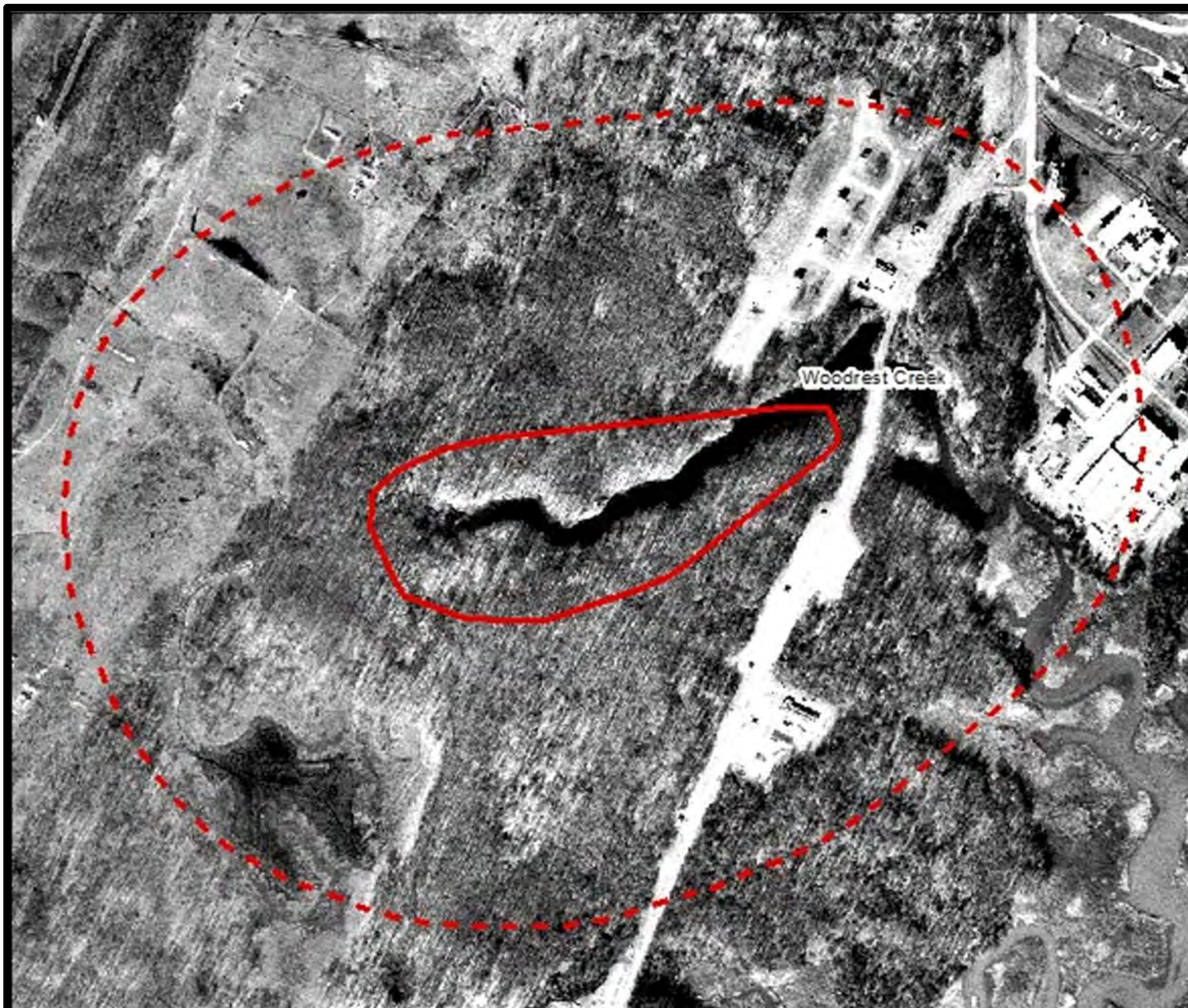


Roost No. 2
Roost Name: Sod Run - A
Predominant Season: Summer and Winter

No. Midnight Locations: 470
No. Total Locations: 2,281
No. Transmittered Eagles: 47

Roost Boundary 500m Buffer
0 75 150 300 Meters
N



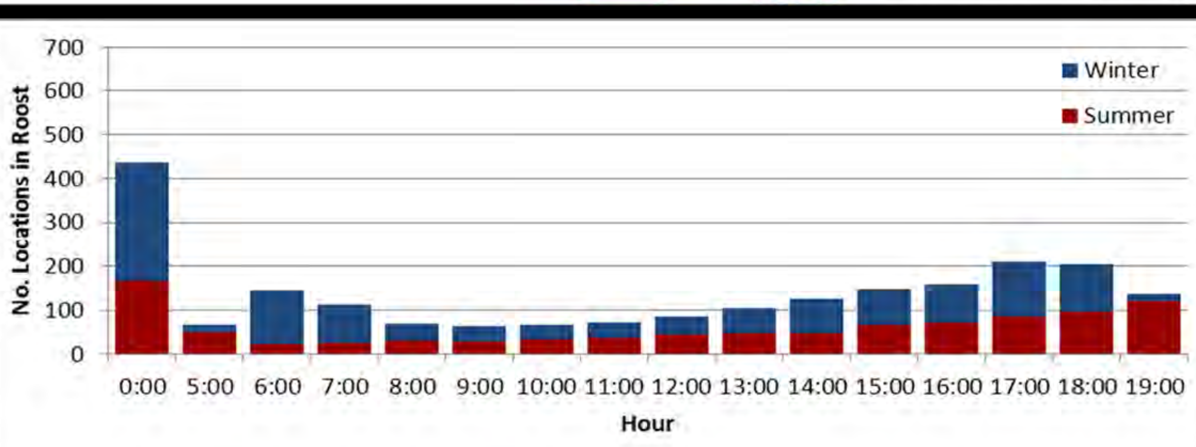


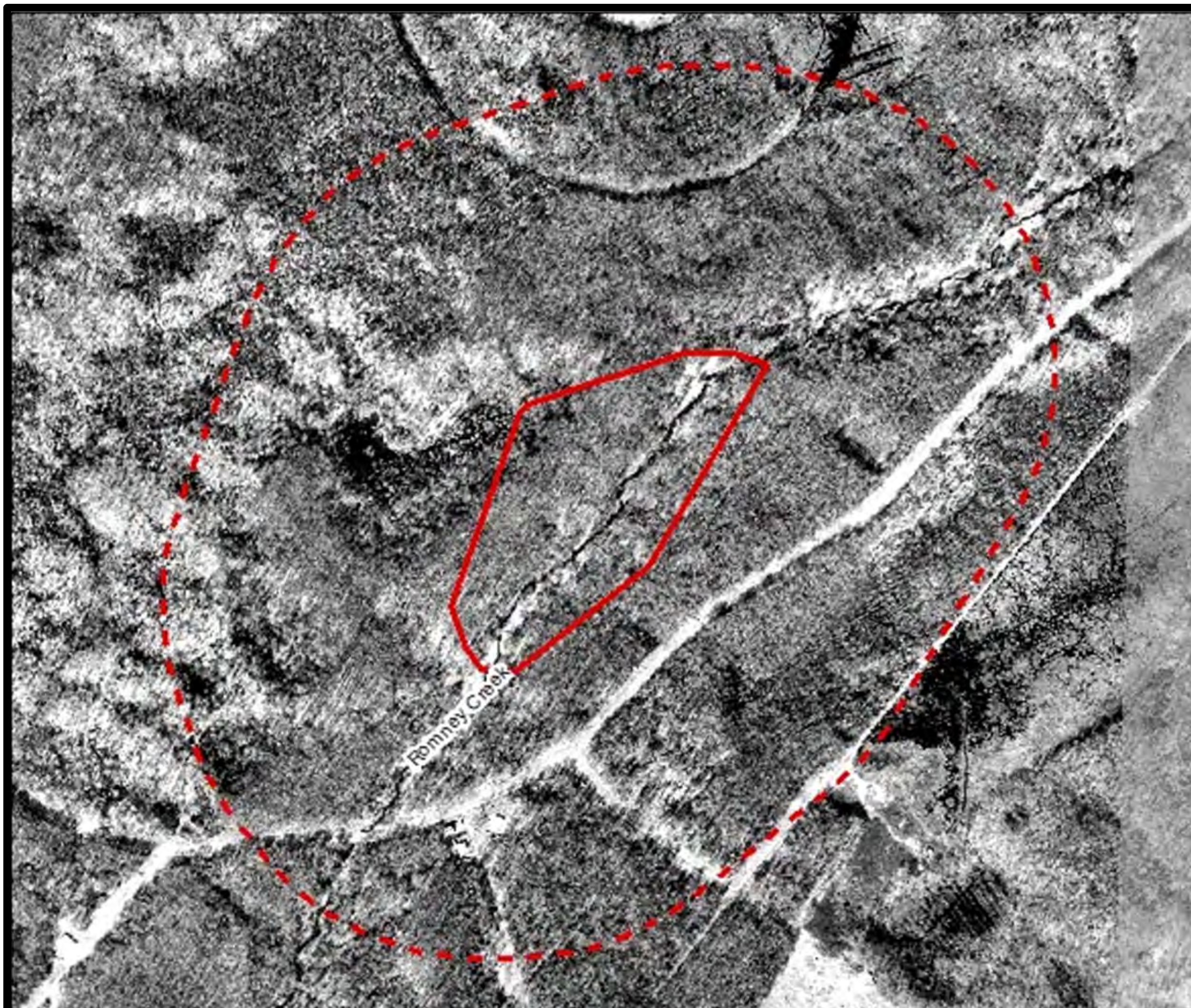
Roost No. 3
Roost Name: Woodrest Creek
Predominant Season: Summer and Winter

No. Midnight Locations: 536
No. Total Locations: 2,797
No. Transmittered Eagles: 38

Roost Boundary 500m Buffer

0 75 150 300 Meters N

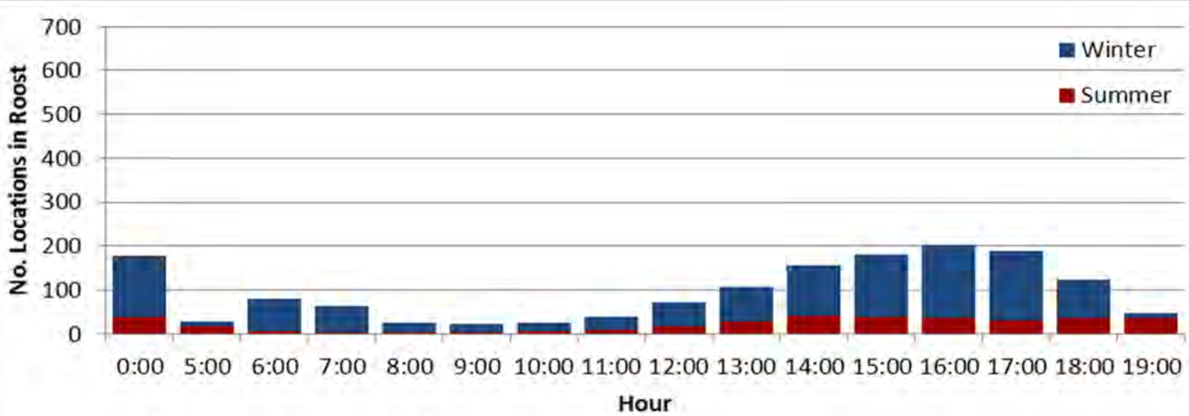




Roost No. 4
Roost Name: Sod Run - B
Predominant Season: Summer and Winter

No. Midnight Locations: 250
No. Total Locations: 2,235
No. Transmittered Eagles: 47

Roost Boundary 500m Buffer
0 80 160 320 Meters
N

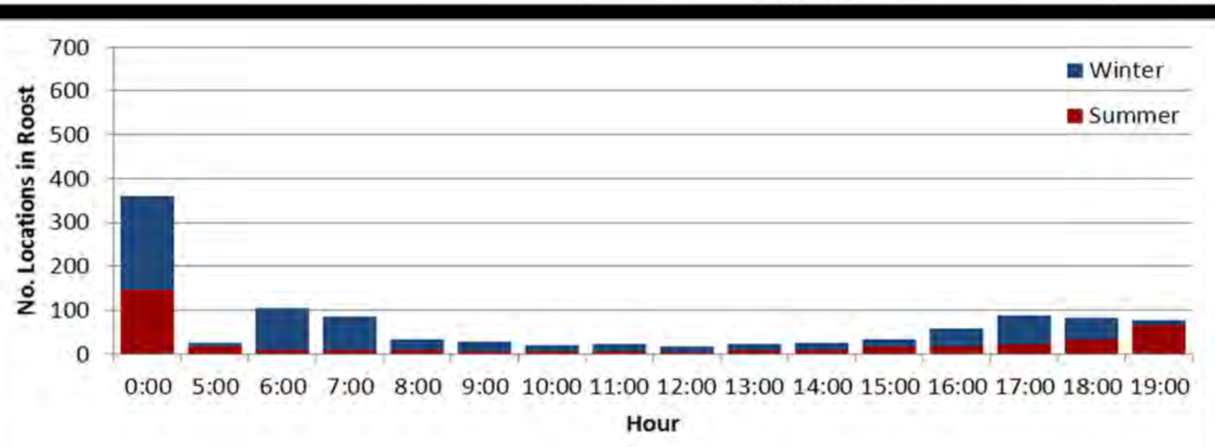


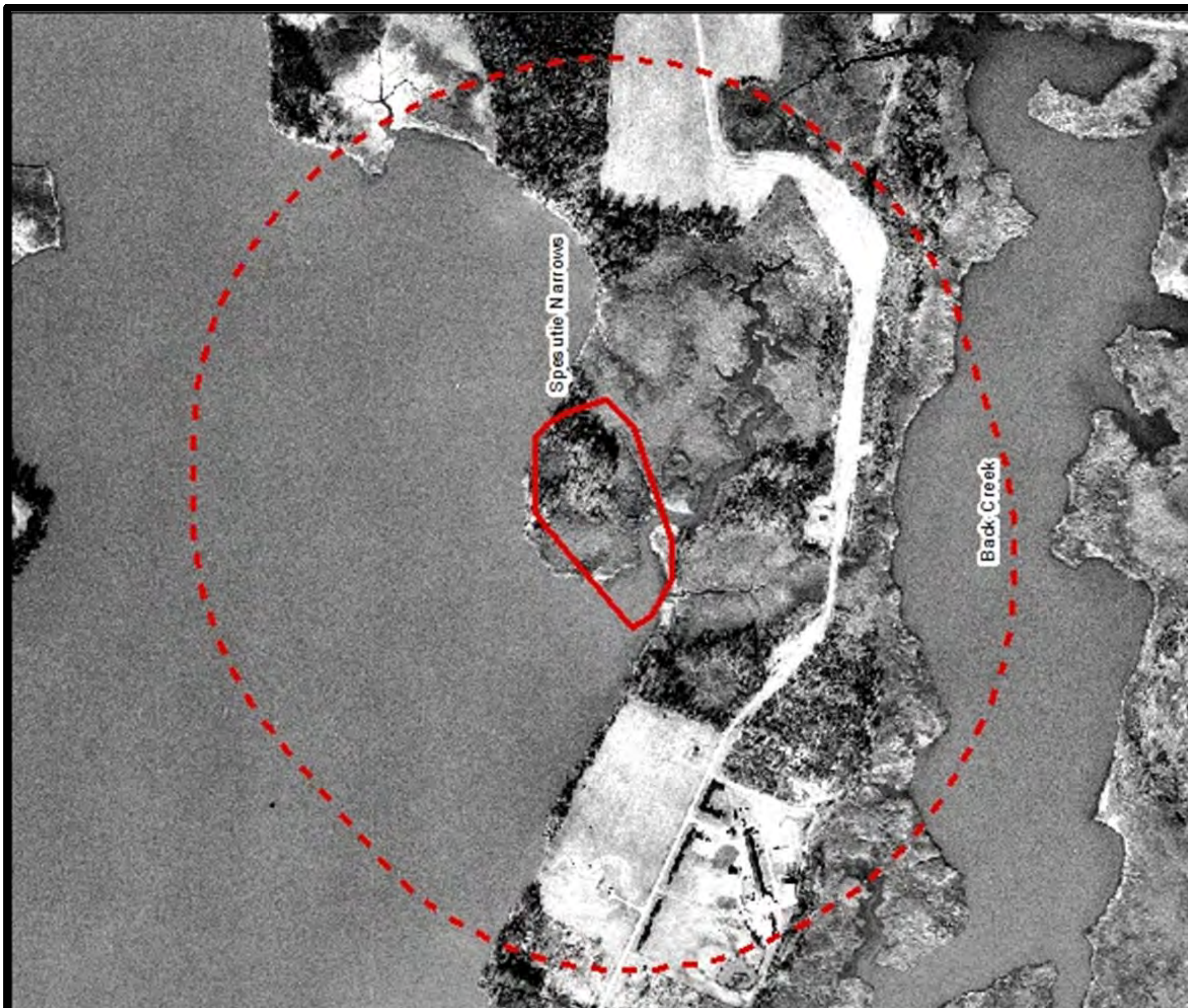
Roost No. 5
Roost Name: Romney Creek - C
Predominant Season: Summer and Winter

No. Midnight Locations: 417
No. Total Locations: 1,314
No. Transmittered Eagles: 45

Roost Boundary 500m Buffer

0 70 140 280 Meters N



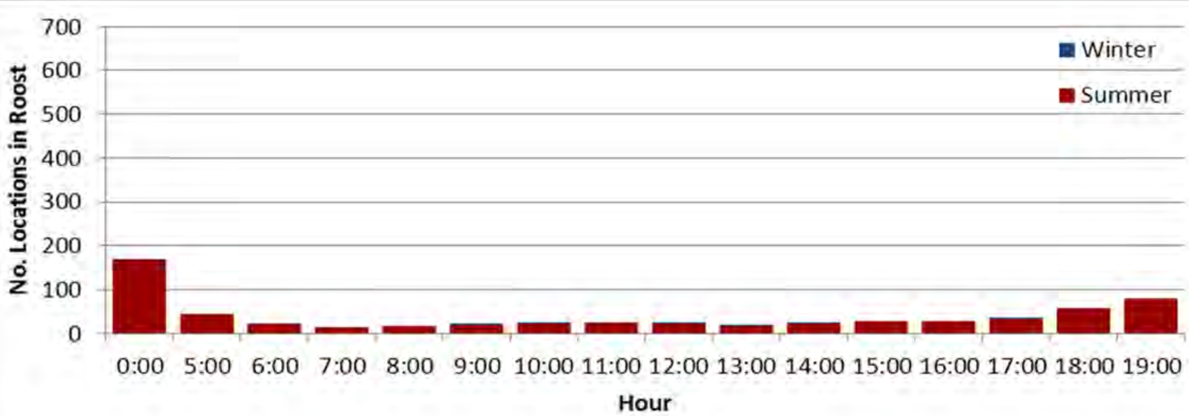


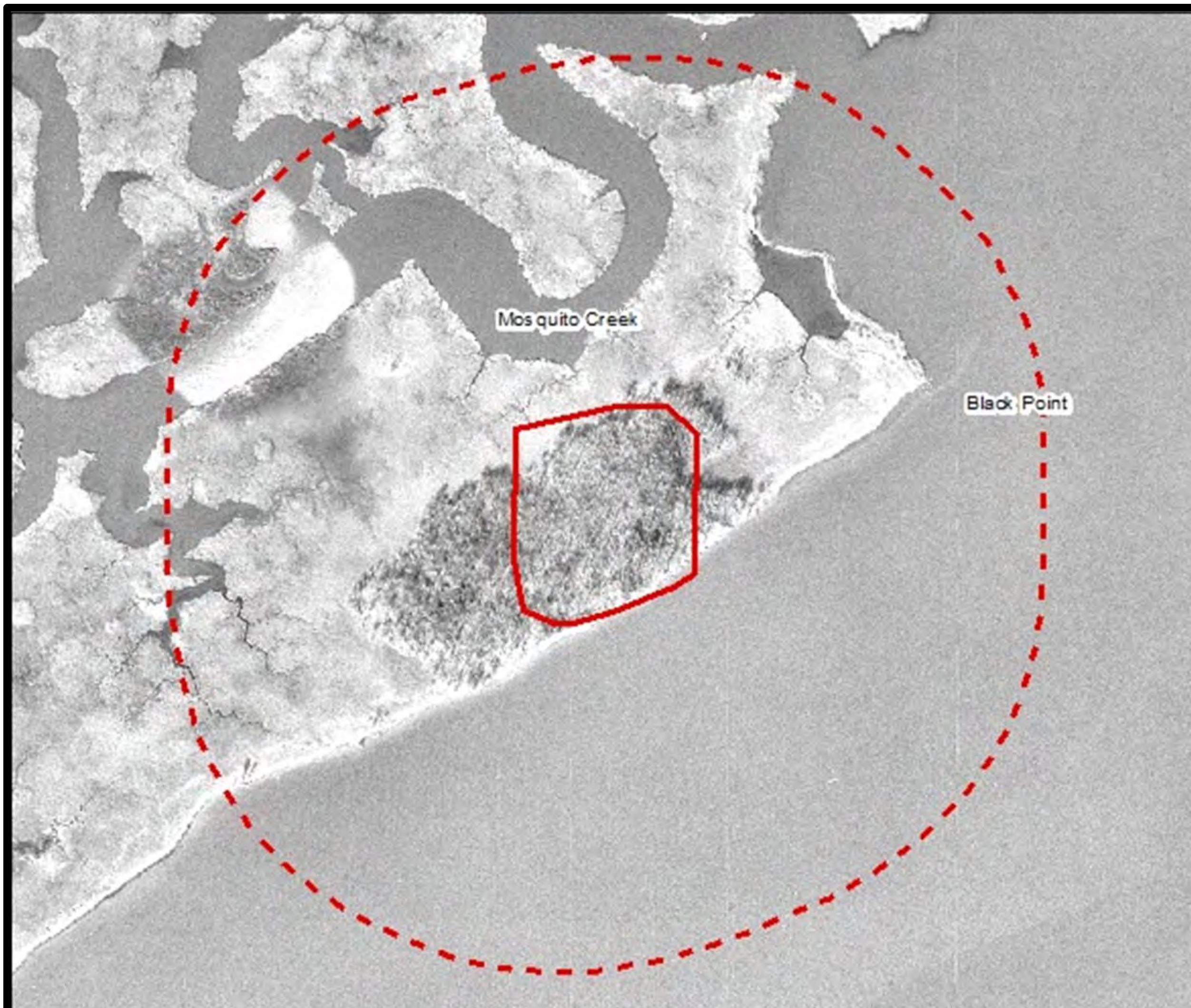
Roost No. 6
Roost Name: Range 8
Predominant Season: Summer

No. Midnight Locations: 186
No. Total Locations: 703
No. Transmittered Eagles: 17

Roost Boundary 500m Buffer

0 70 140 280 Meters N

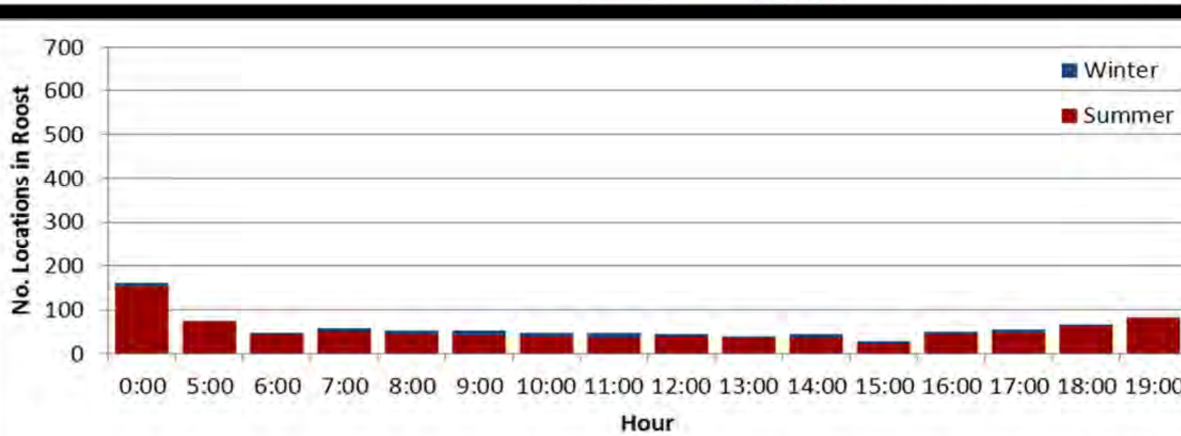


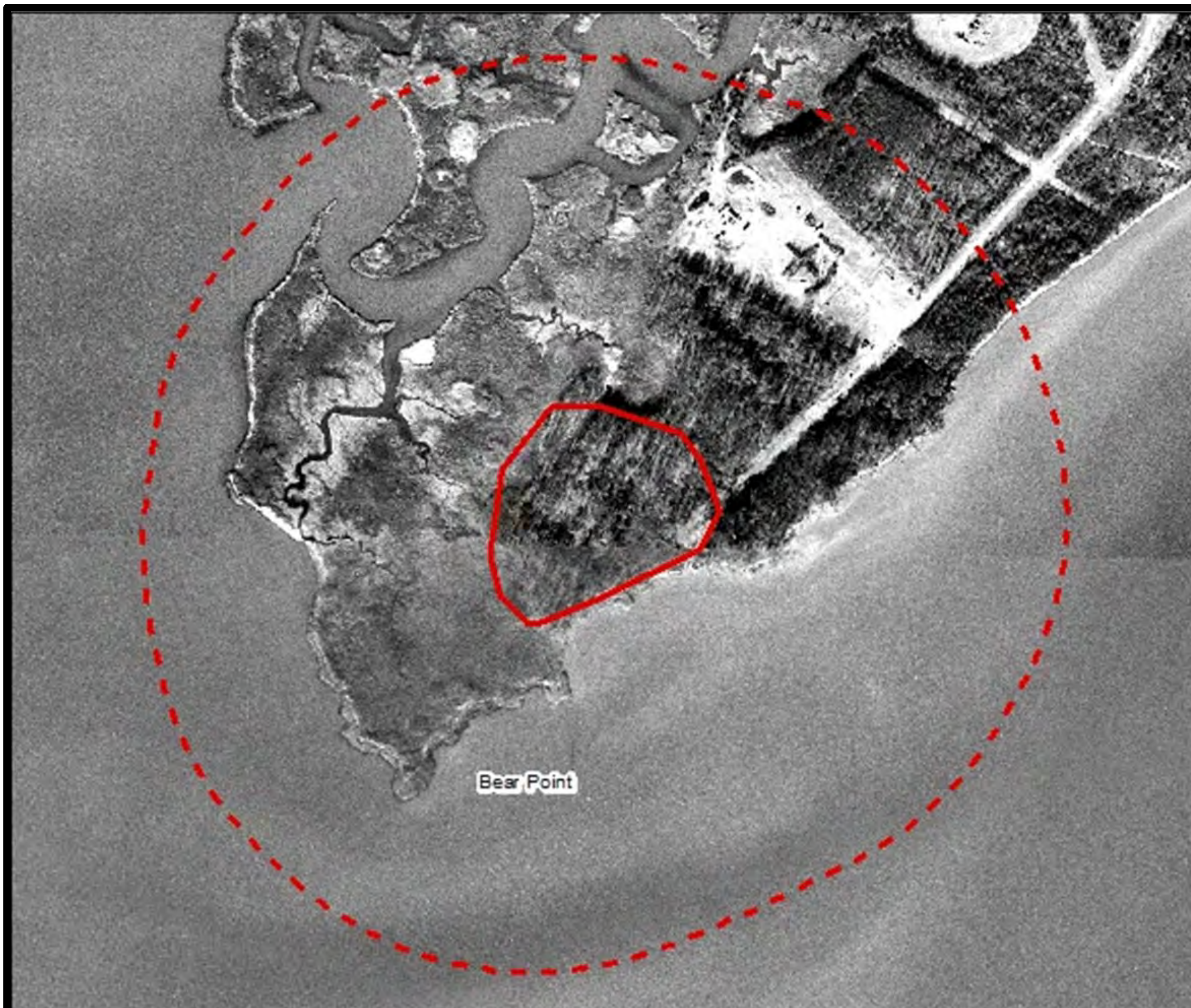


Roost No. 7
Roost Name: Black Point
Predominant Season: Summer

No. Midnight Locations: 175
No. Total Locations: 1,019
No. Transmittered Eagles: 29

Roost Boundary
500m Buffer
0 65 130 260 Meters
N



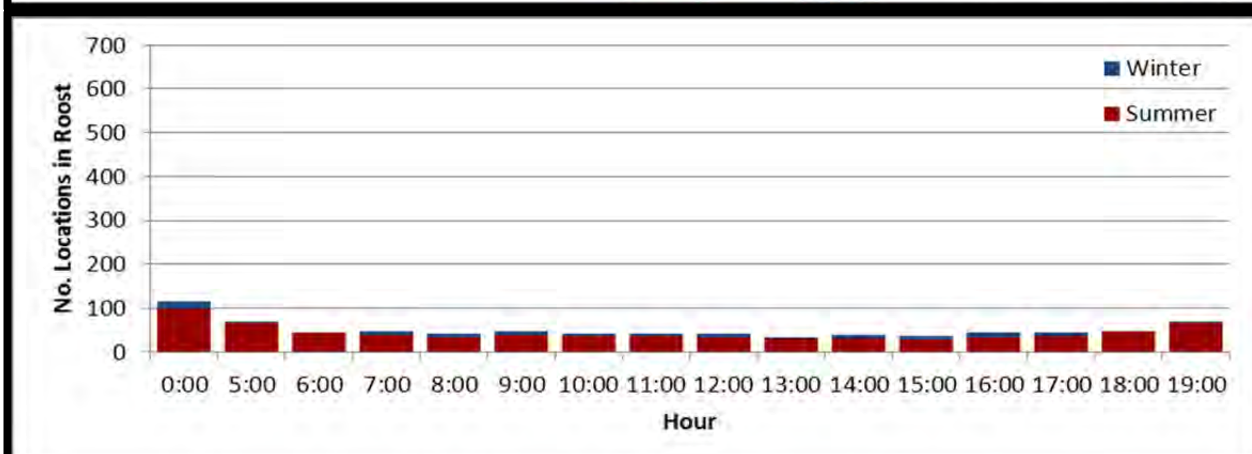


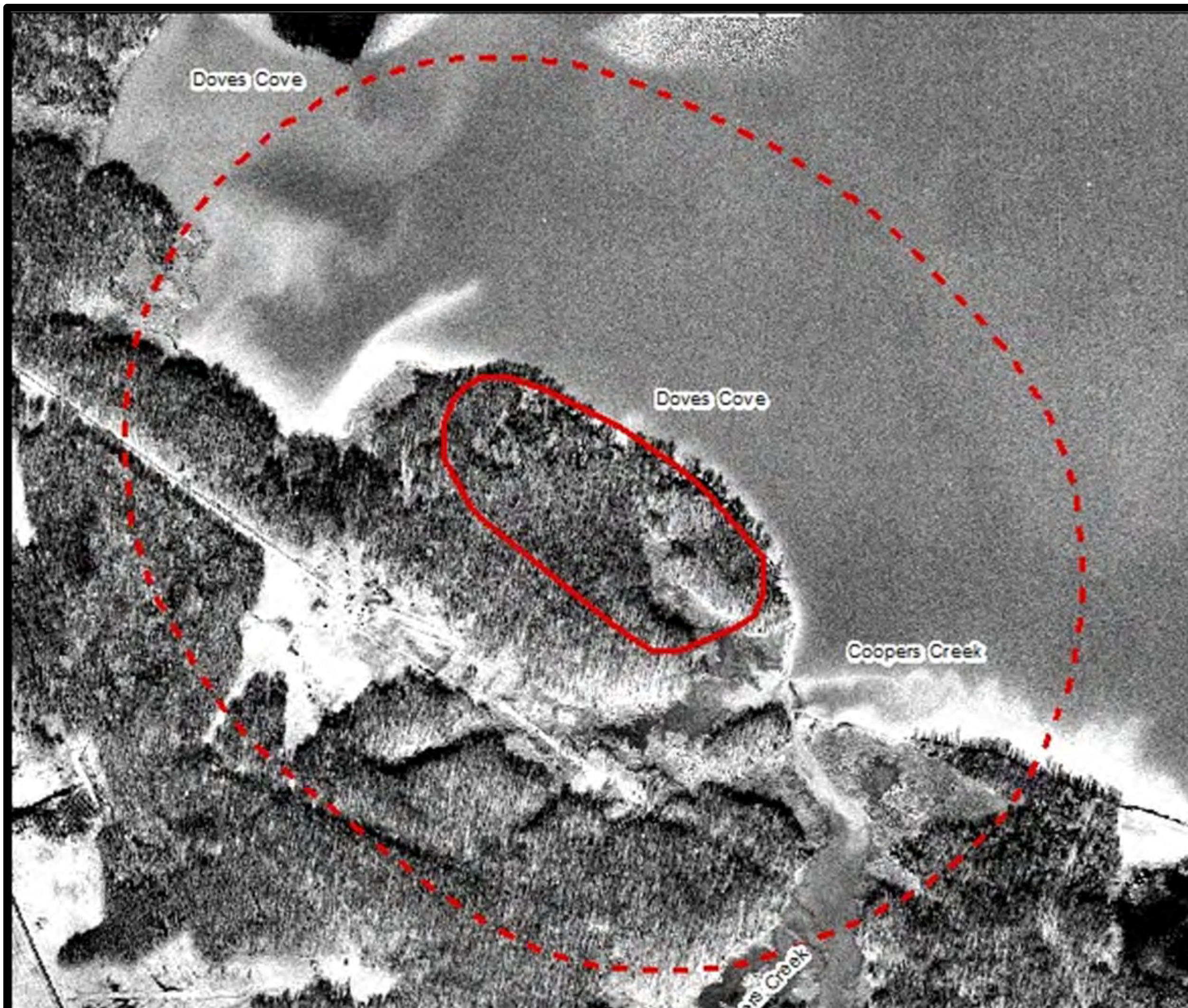
Roost No. 8
Roost Name: Bear Point - A
Predominant Season: Summer and Winter

No. Midnight Locations: 132
No. Total Locations: 883
No. Transmittered Eagles: 26

Roost Boundary 500m Buffer

0 65 130 260 Meters N





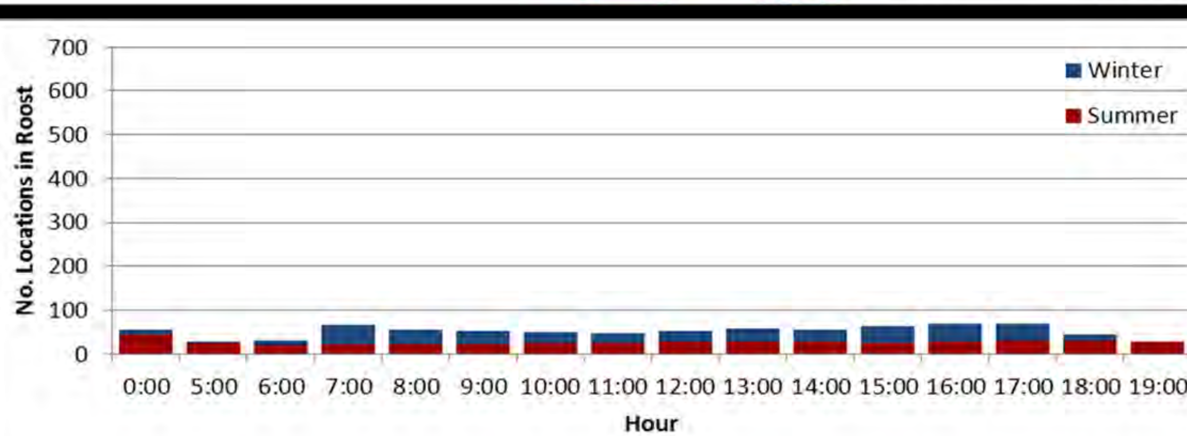
Roost No. 9
Roost Name: Doves Cove Cliff
Predominant Season: Summer and Winter

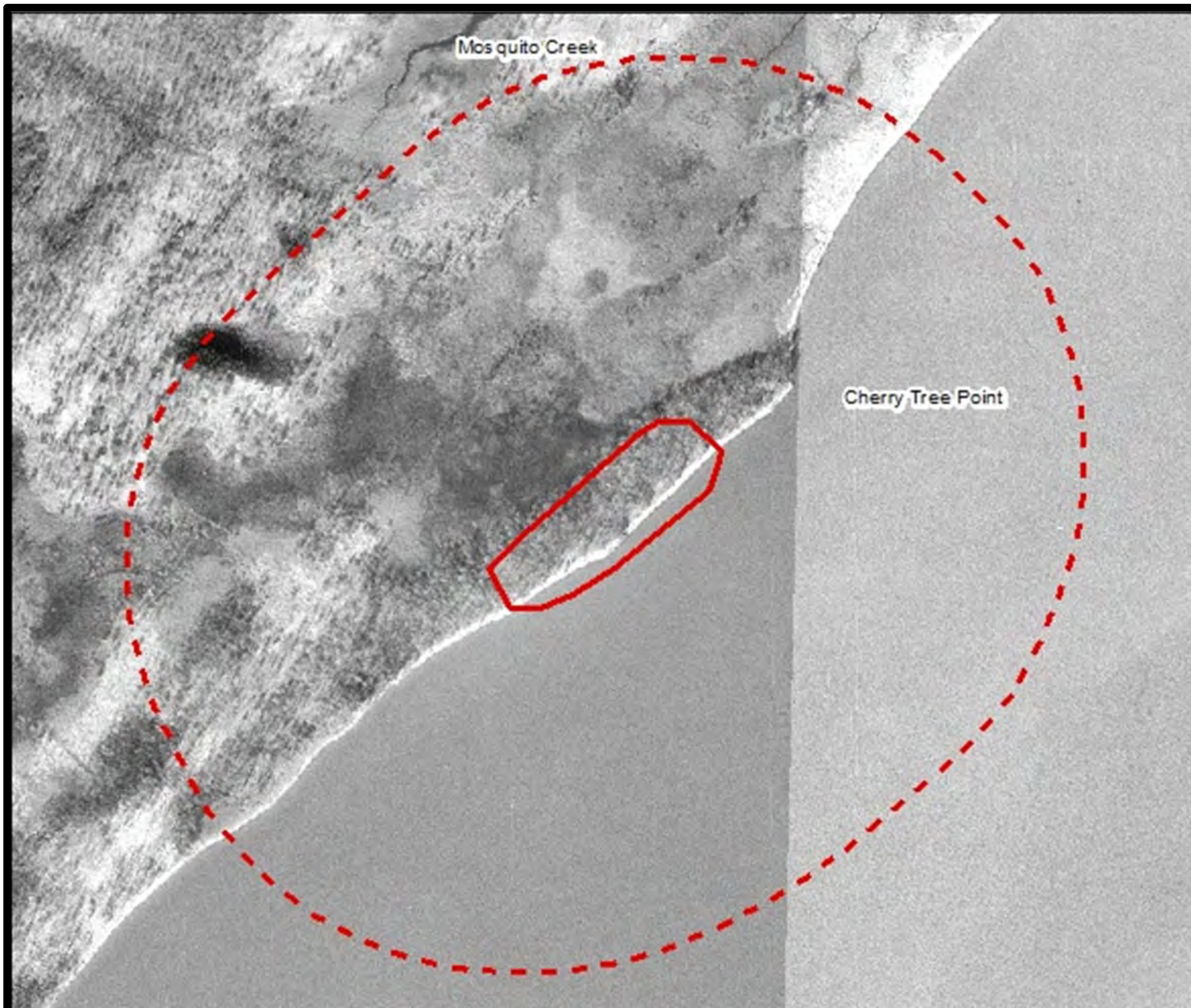
No. Midnight Locations: 74
No. Total Locations: 1,370
No. Transmittered Eagles: 35

Roost Boundary 500m Buffer

0 70 140 280 Meters

N

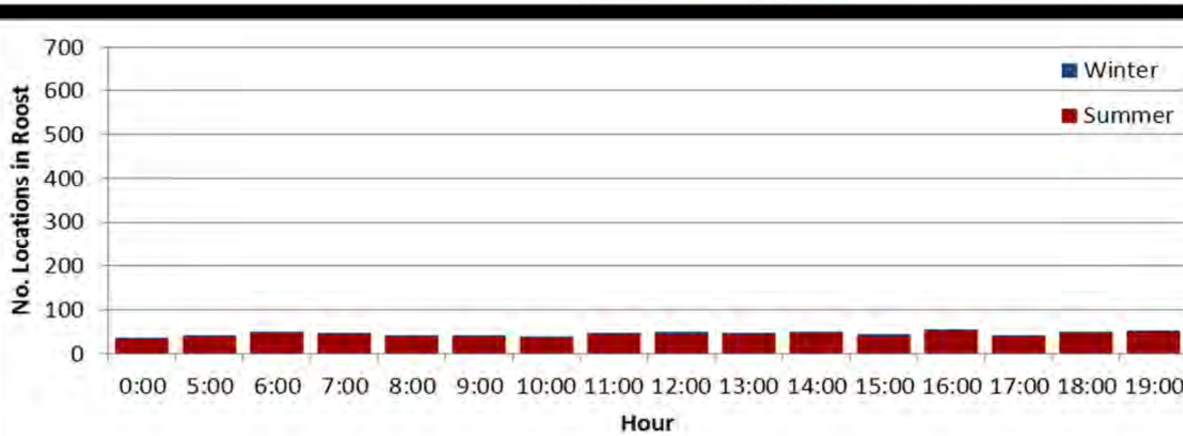


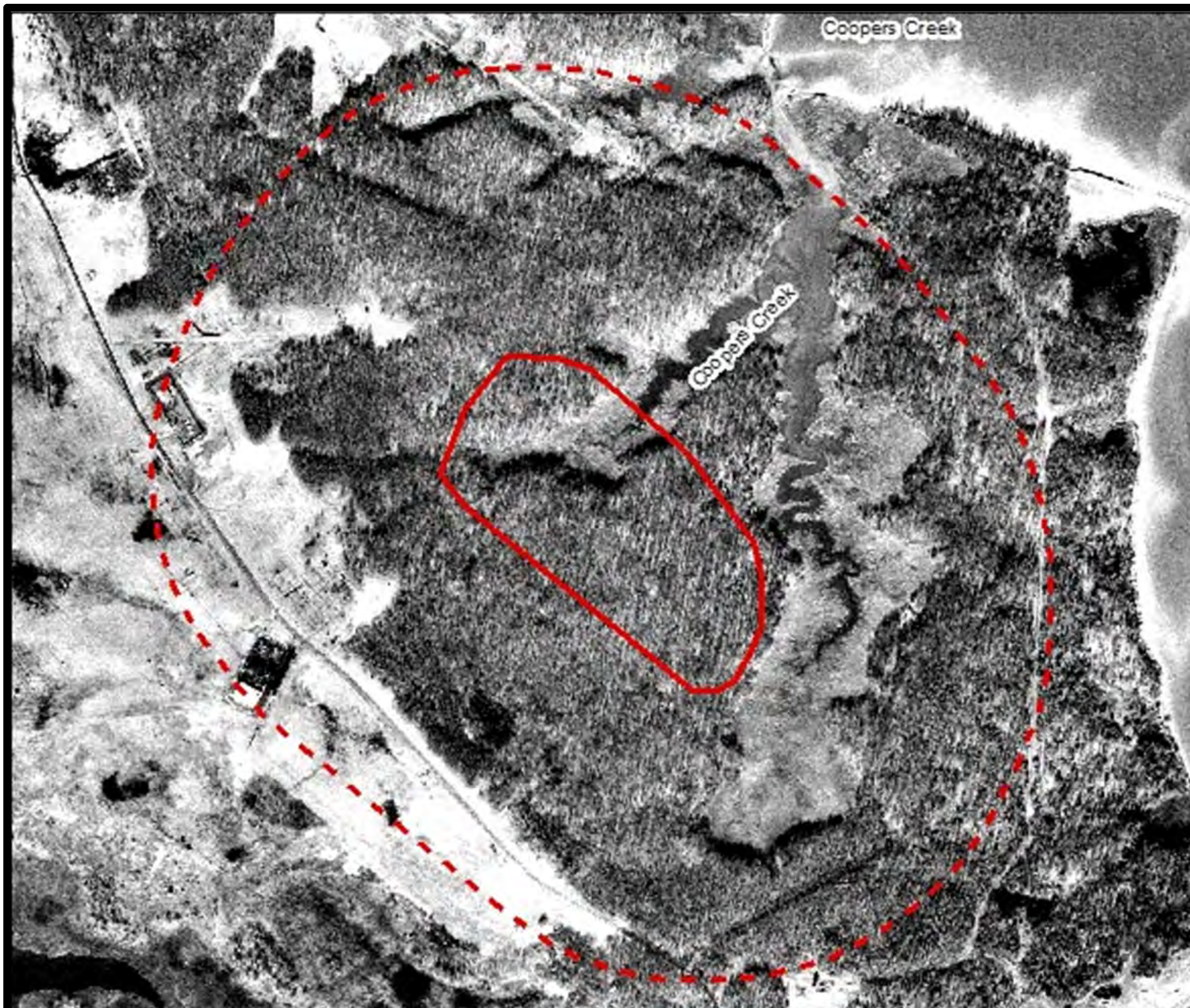


Roost No. 10
Roost Name: Cherry Tree Pt - A
Predominant Season: Summer

No. Midnight Locations: 39
No. Total Locations: 798
No. Transmittered Eagles: 28

Roost Boundary 500m Buffer 0 62.5 125 250 Meters N



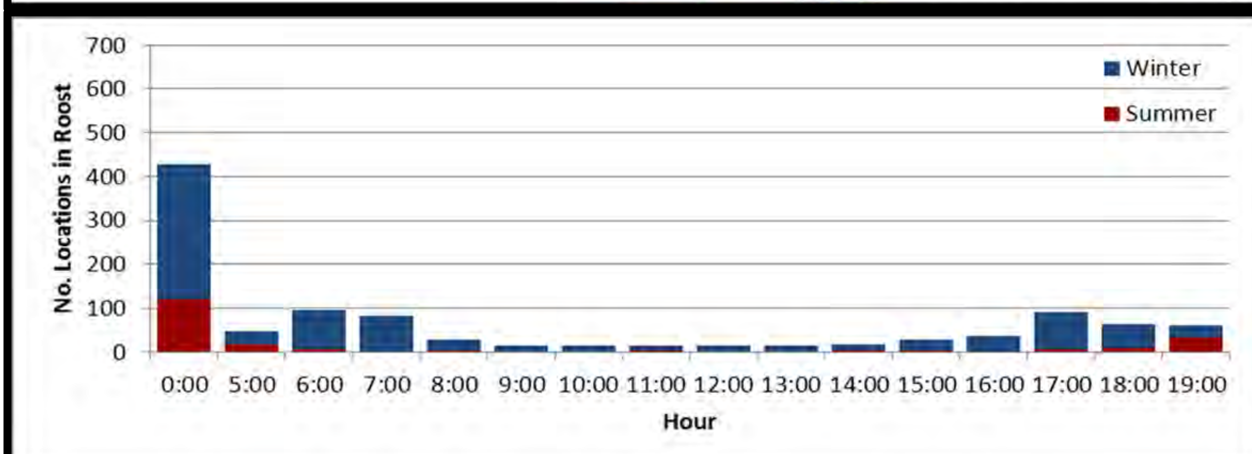


Roost No. 11
Roost Name: Coopers Creek
Predominant Season: Summer and Winter

No. Midnight Locations: 599
No. Total Locations: 1,599
No. Transmittered Eagles: 40

Roost Boundary **500m Buffer**

0 80 160 320 Meters N



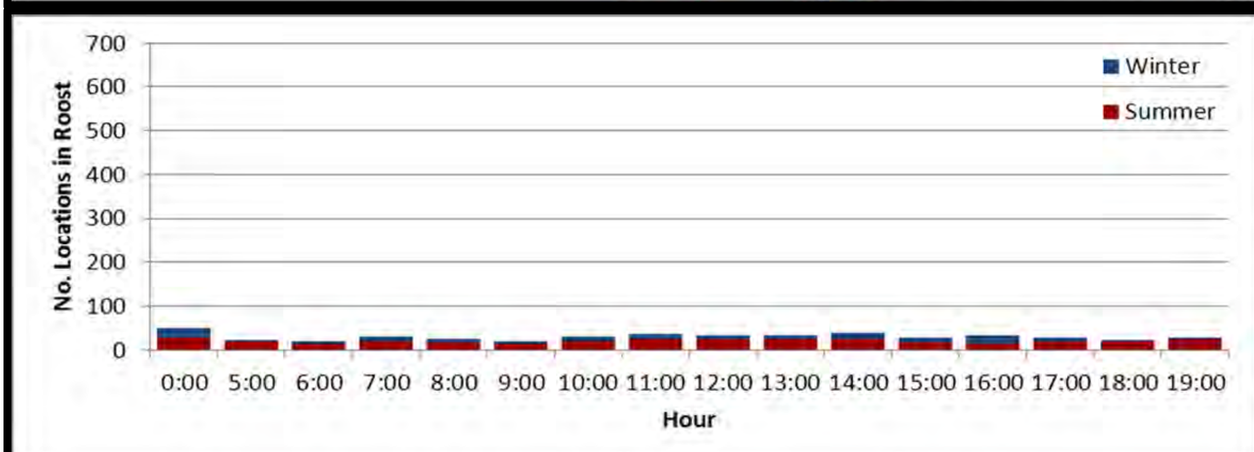
Roost No. 12
Roost Name: Sandy Point
Predominant Season: Summer and Winter

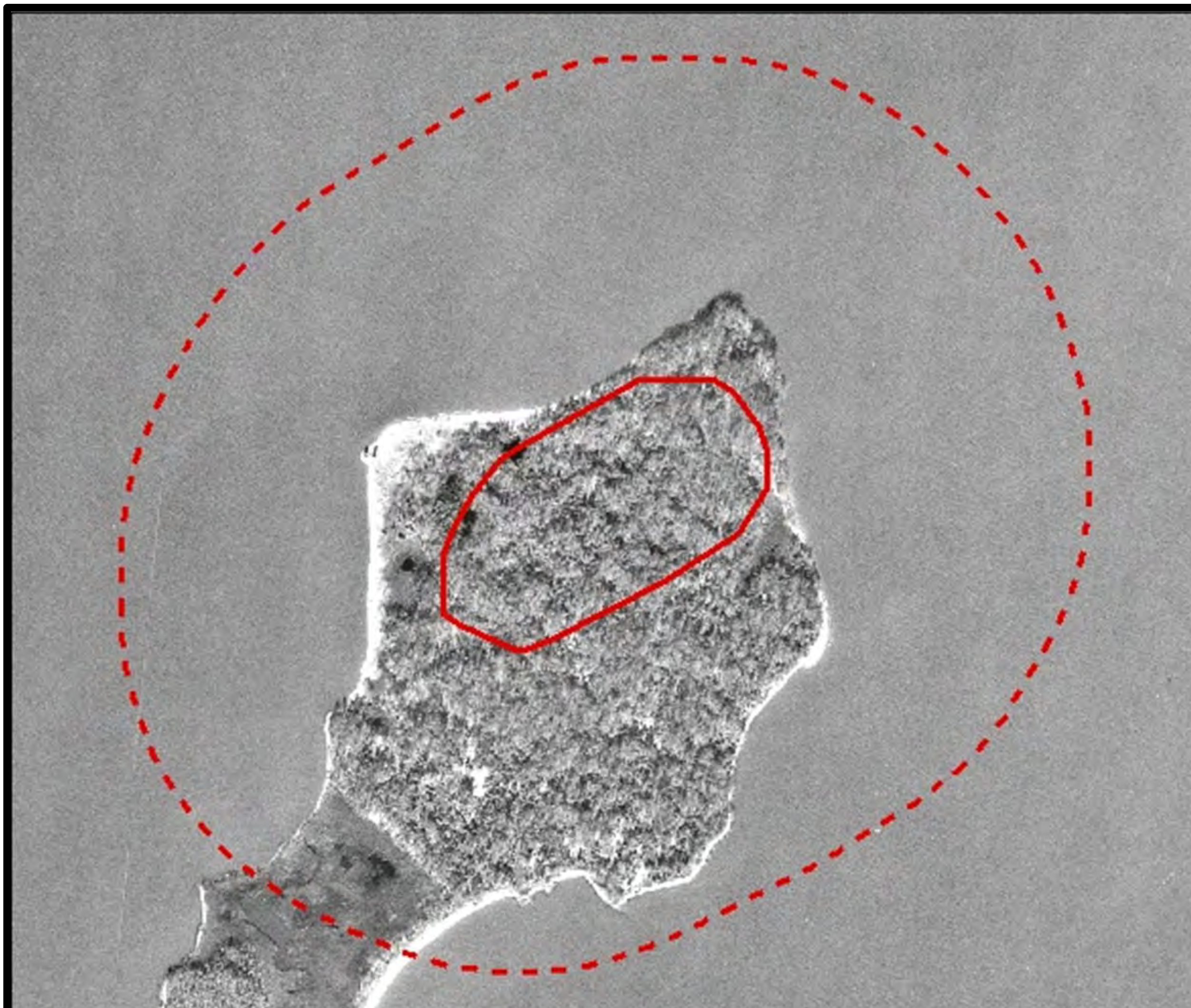
No. Midnight Locations: 52
No. Total Locations: 563
No. Transmittered Eagles: 18

Roost Boundary 500m Buffer

0 65 130 260 Meters

N





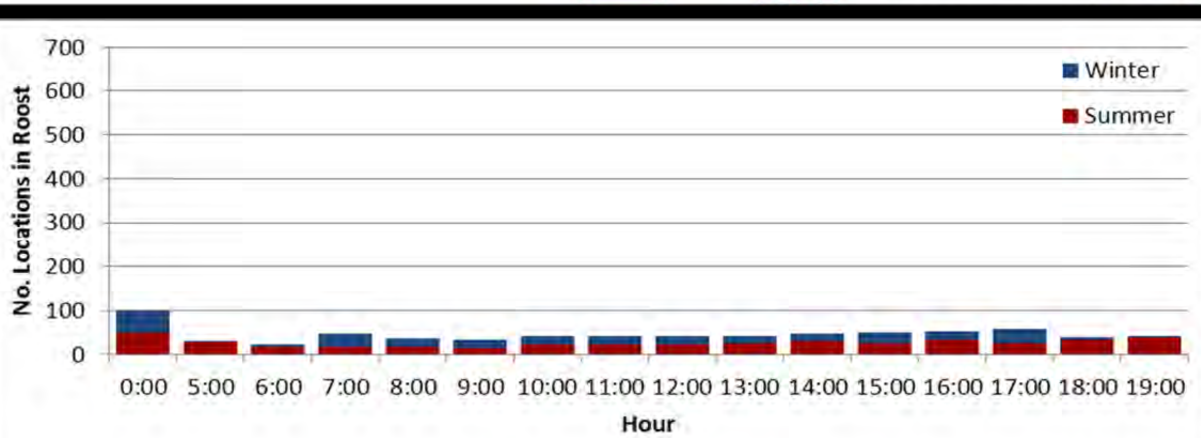
Roost No. 13
Roost Name: Pooles Island North
Predominant Season: Summer and Winter

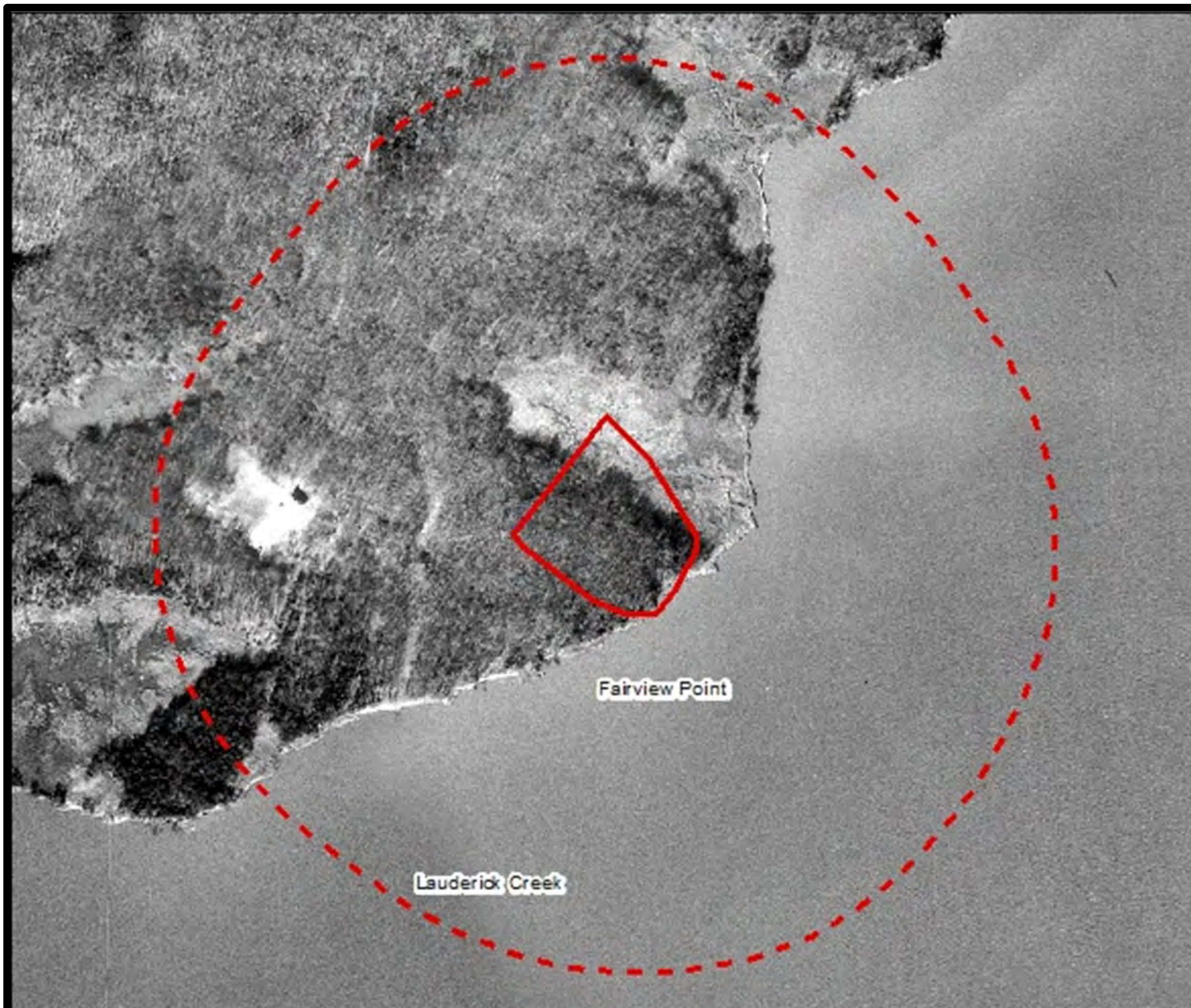
No. Midnight Locations: 127
No. Total Locations: 918
No. Transmittered Eagles: 26

Roost Boundary 500m Buffer

0 70 140 280 Meters

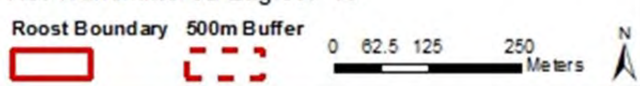
N

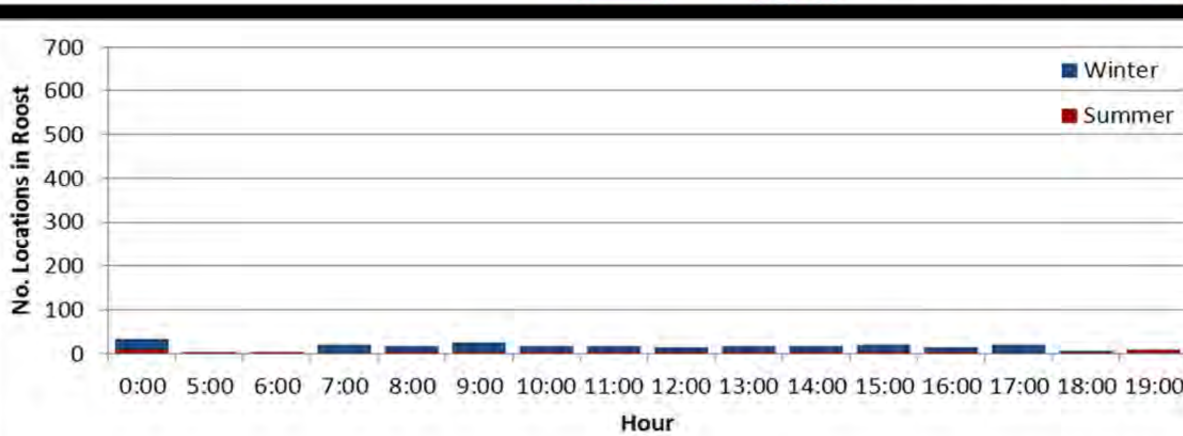




Roost No. 14
Roost Name: Fairview Point - A
Predominant Season: Summer and Winter

No. Midnight Locations: 58
No. Total Locations: 458
No. Transmittered Eagles: 16



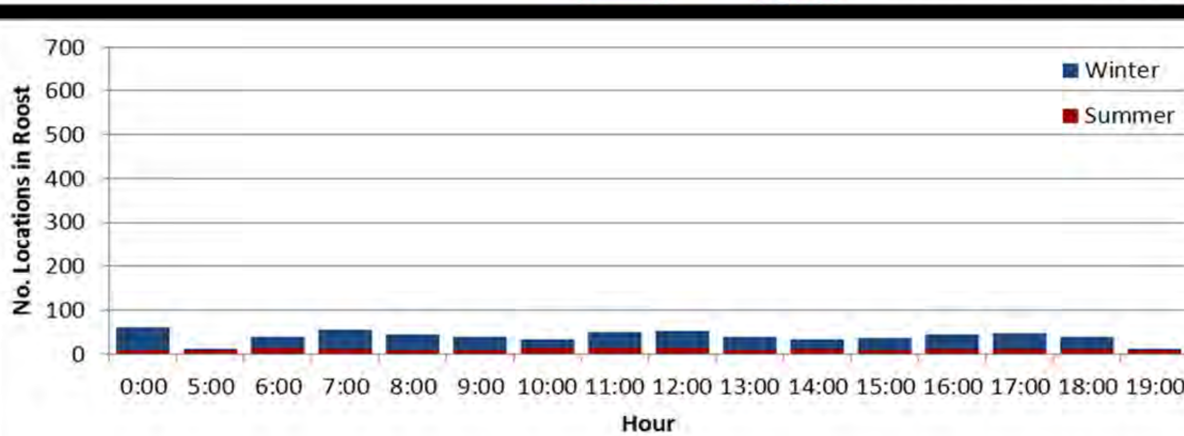


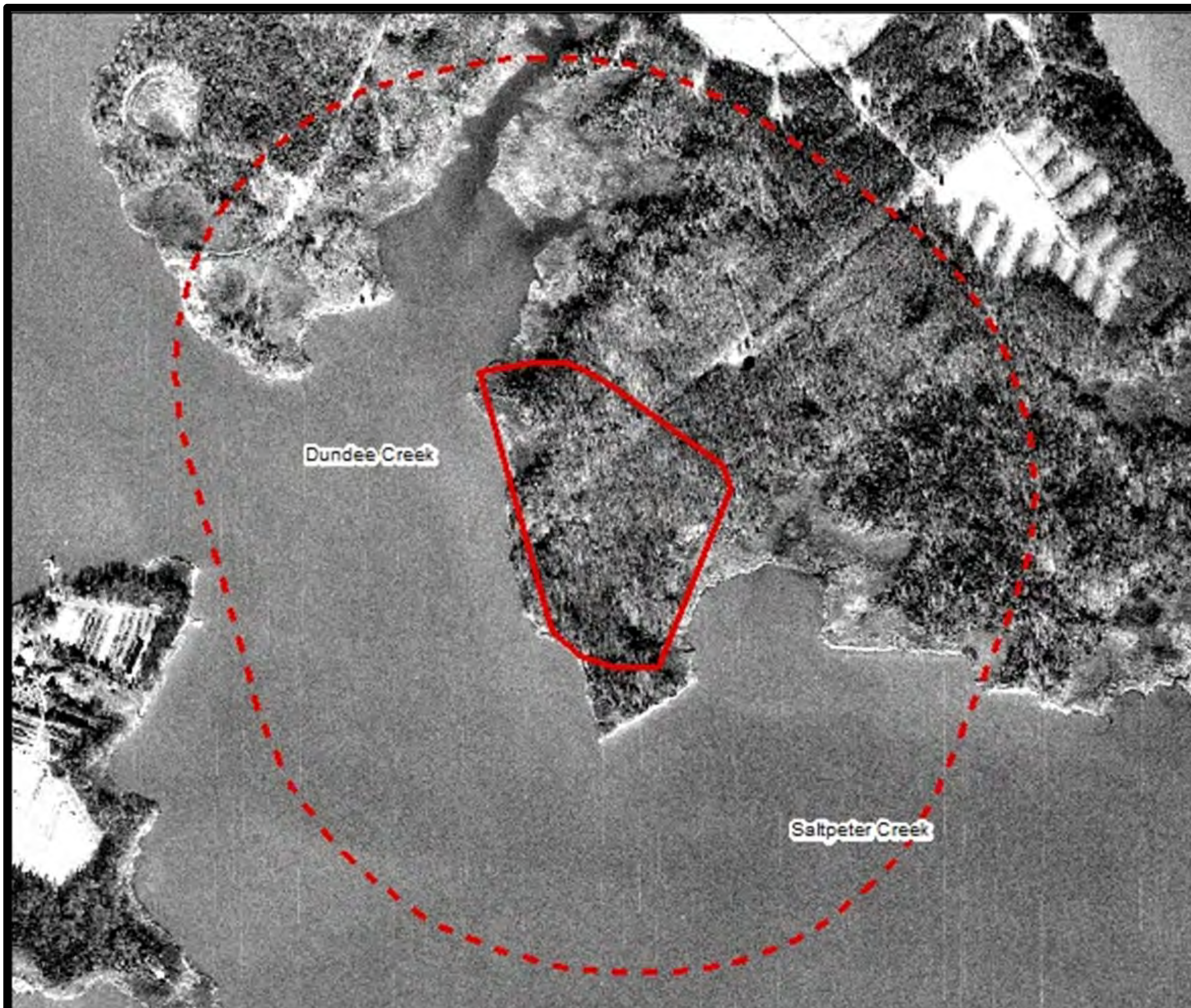
Roost No. 15
Roost Name: Locust Point - A
Predominant Season: Summer and Winter

No. Midnight Locations: 64
No. Total Locations: 694
No. Transmittered Eagles: 29

Roost Boundary   500m Buffer

0 65 130 260 Meters   N





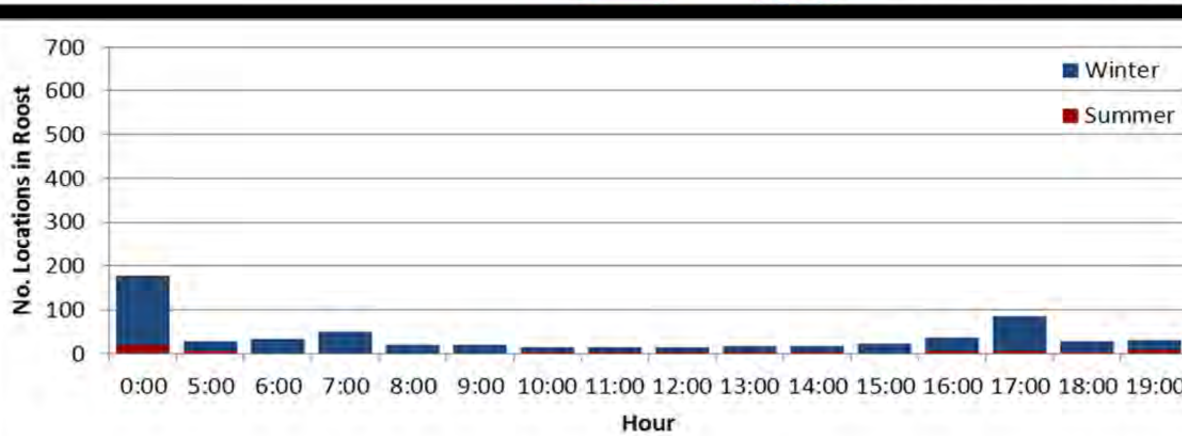
Roost No. 16
Roost Name: Graces Quarters
Predominant Season: Winter

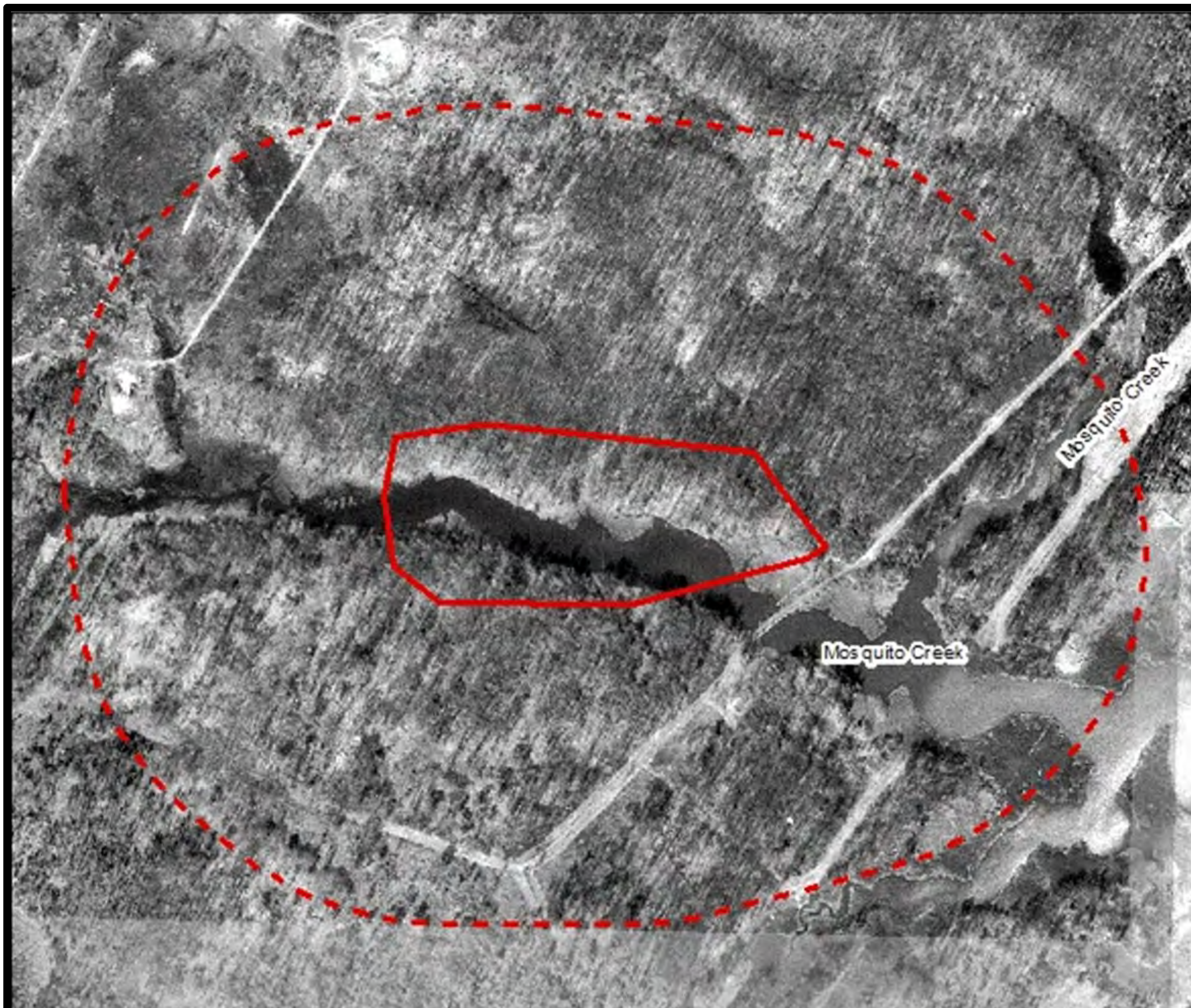
No. Midnight Locations: 252
No. Total Locations: 903
No. Transmittered Eagles: 22

Roost Boundary   500m Buffer

0 75 150 300 Meters

N





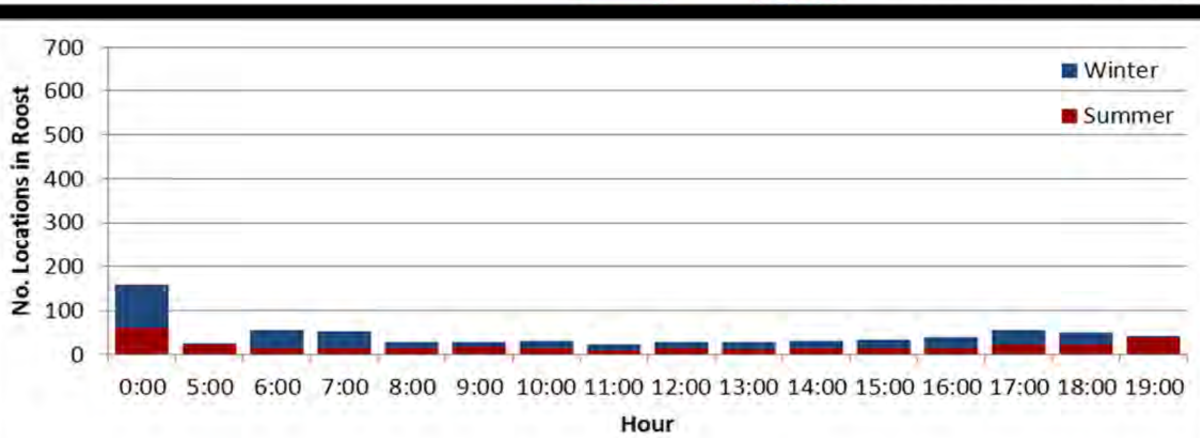
Roost No. 17
Roost Name: Mosquito Creek - A
Predominant Season: Summer and Winter

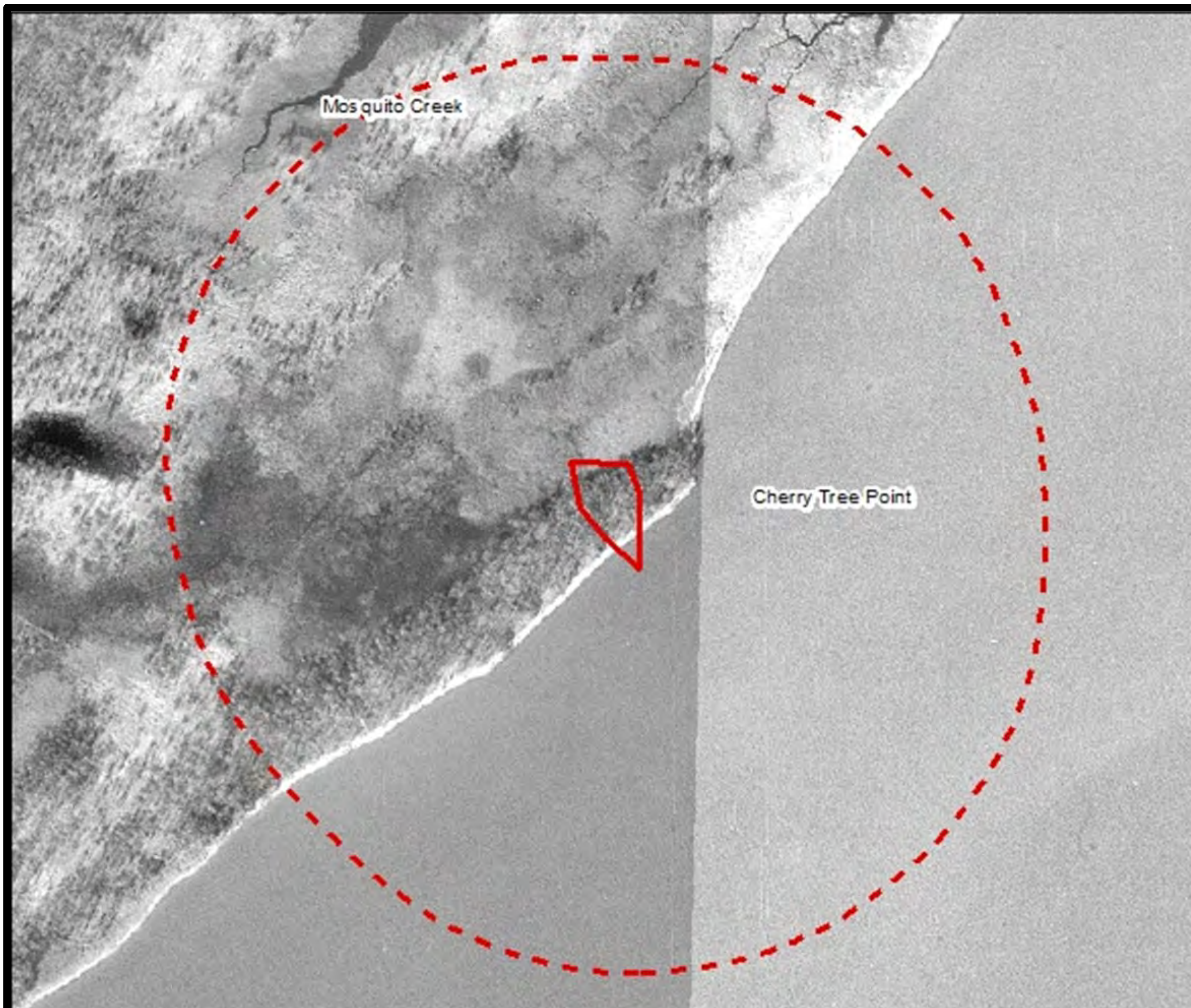
No. Midnight Locations: 190
No. Total Locations: 825
No. Transmittered Eagles: 35

Roost Boundary 500m Buffer

0 70 140 280 Meters

N





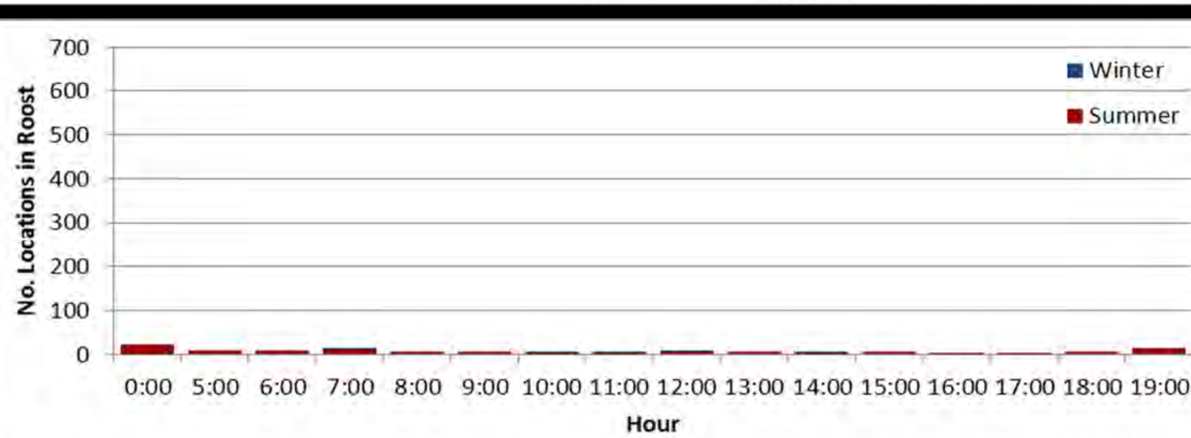
Roost No. 18
Roost Name: Cherry Tree Pt - B
Predominant Season: Summer

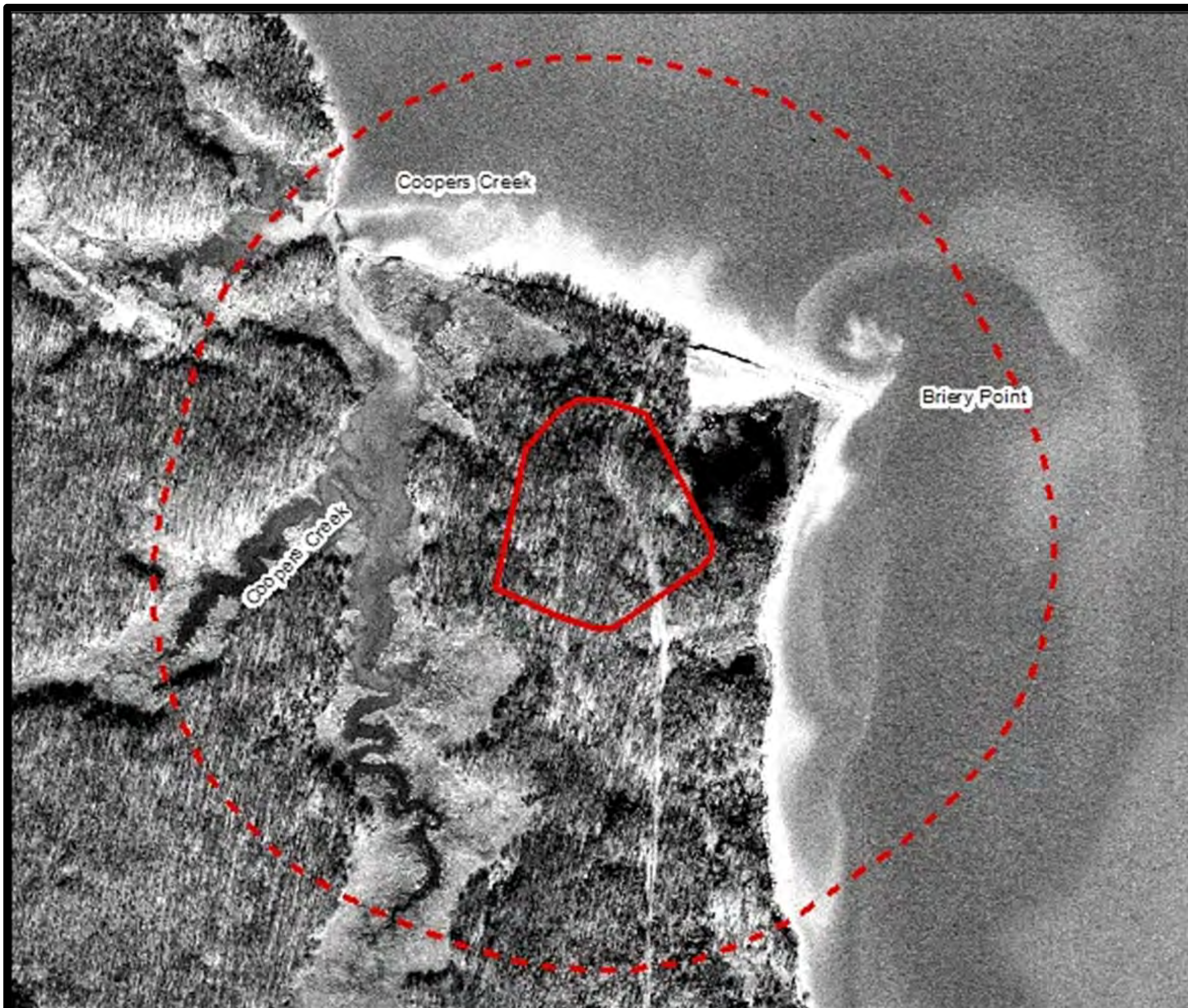
No. Midnight Locations: 18
No. Total Locations: 142
No. Transmittered Eagles: 18

Roost Boundary 500m Buffer

0 55 110 220 Meters

N

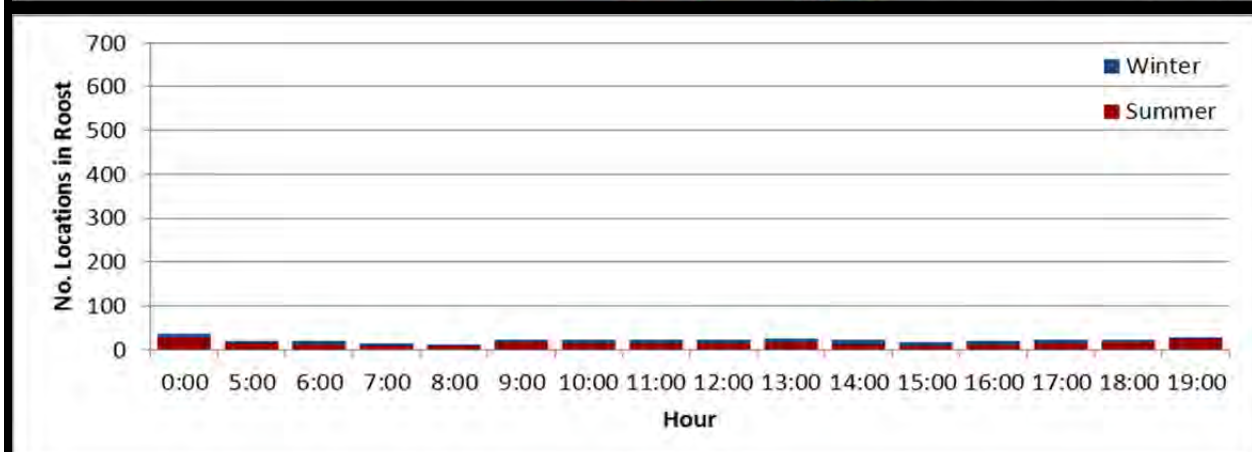


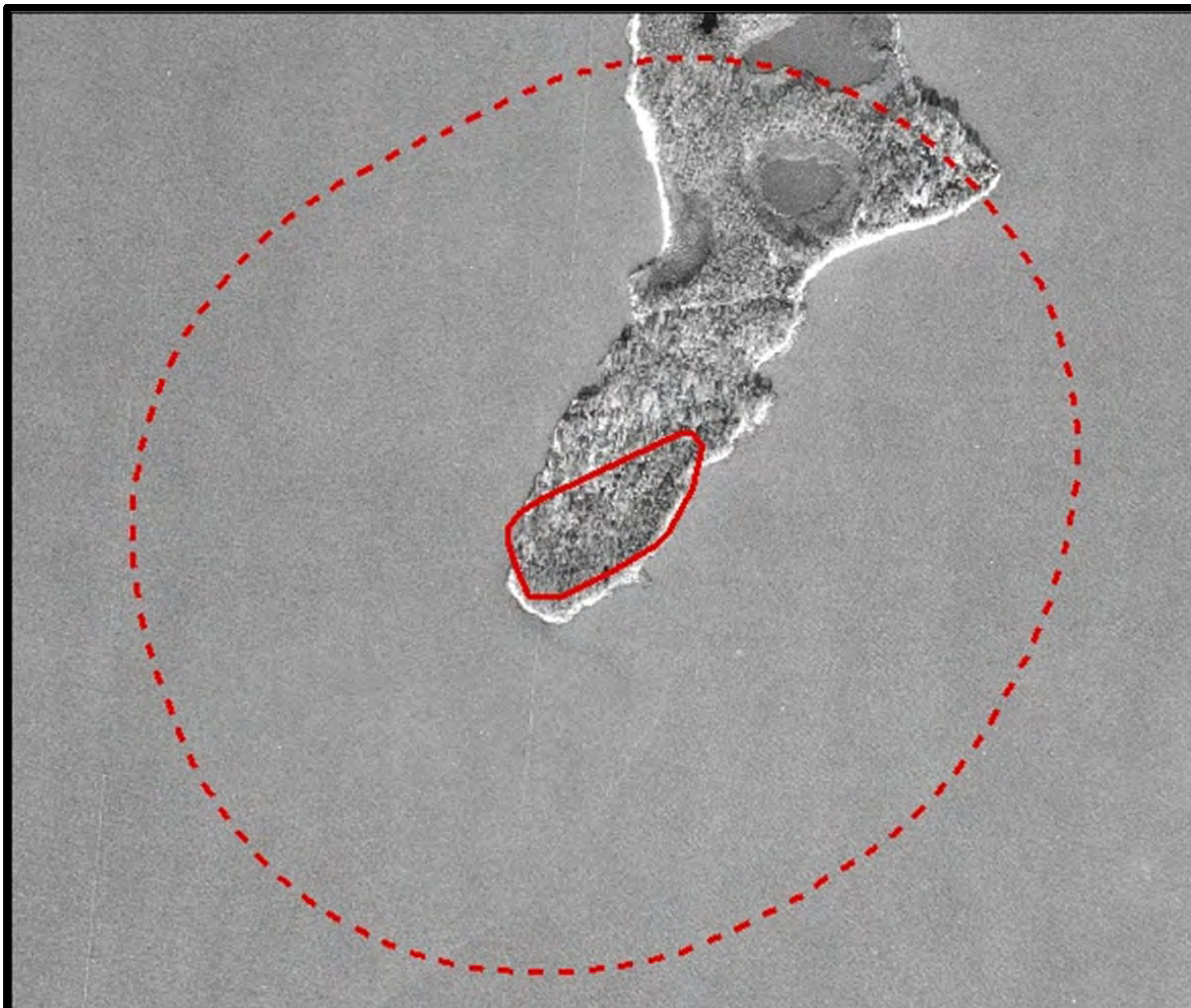


Roost No. 19
Roost Name: Briery Point
Predominant Season: Summer and Winter

No. Midnight Locations: 51
No. Total Locations: 542
No. Transmittered Eagles: 27

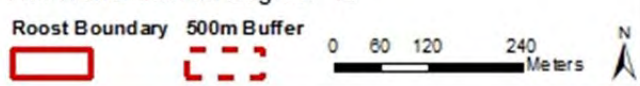
Roost Boundary
500m Buffer
0 70 140 280 Meters
N

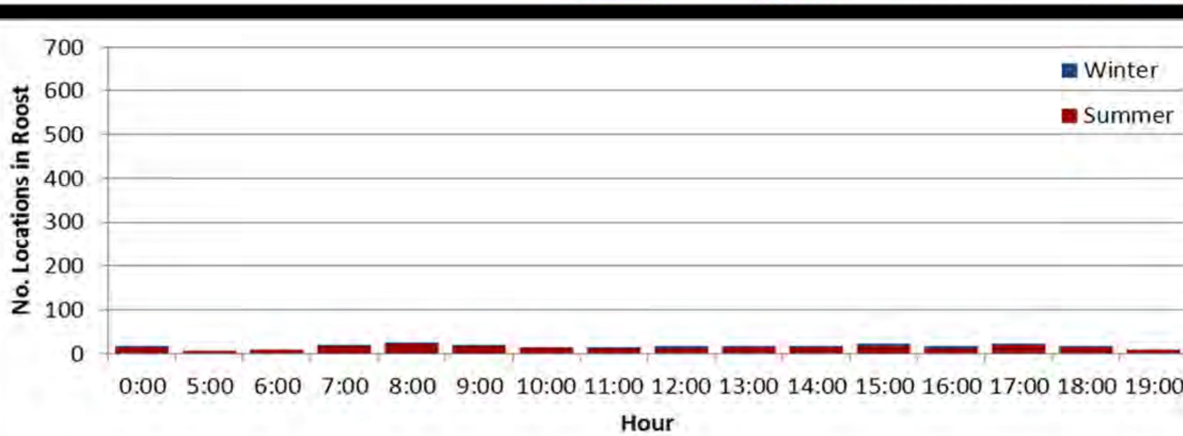


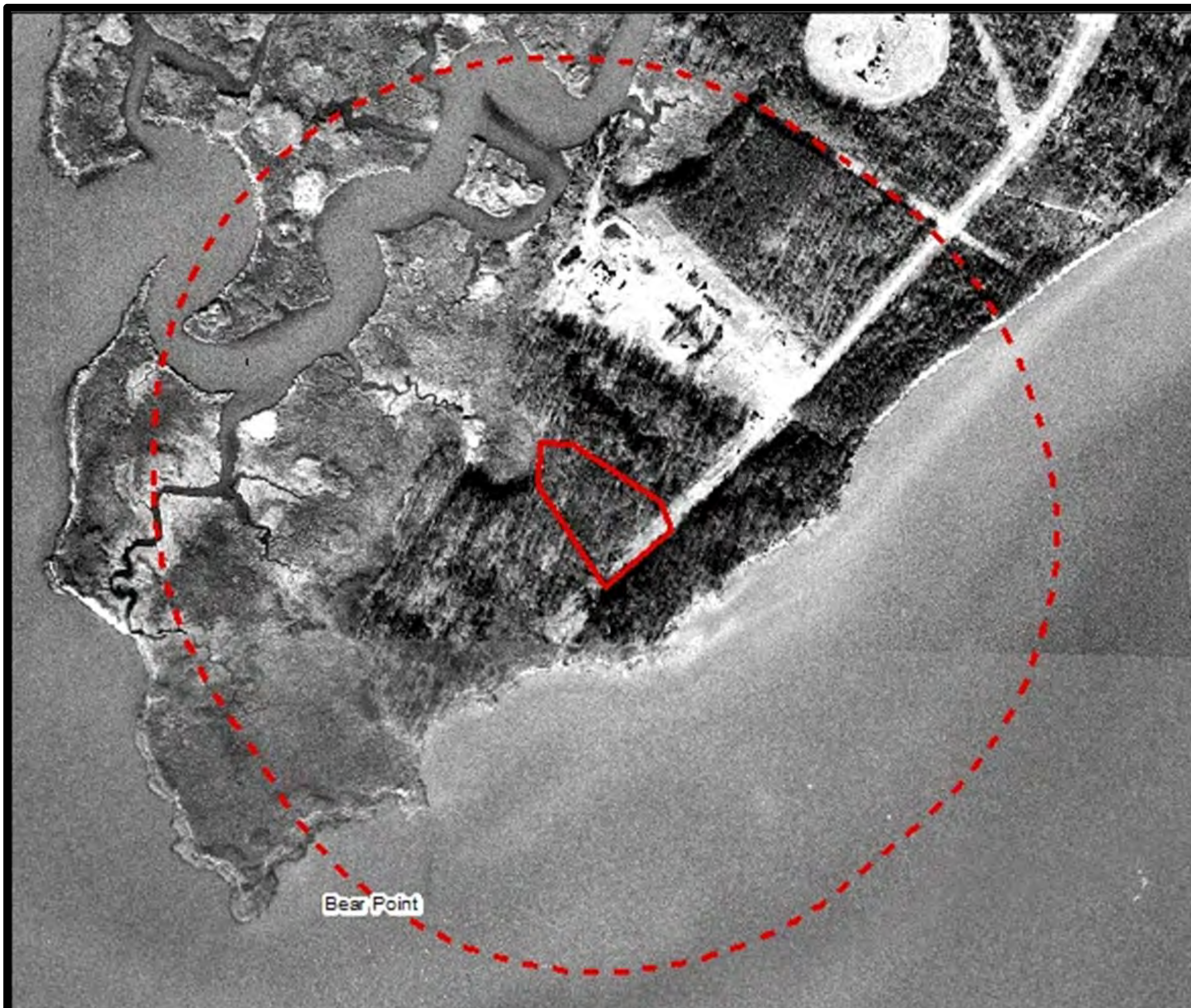


Roost No. 20
Roost Name: Pooles Island South
Predominant Season: Summer and Winter

No. Midnight Locations: 16
No. Total Locations: 276
No. Transmittered Eagles: 16

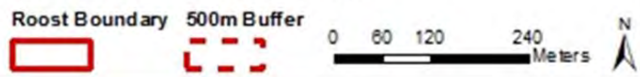


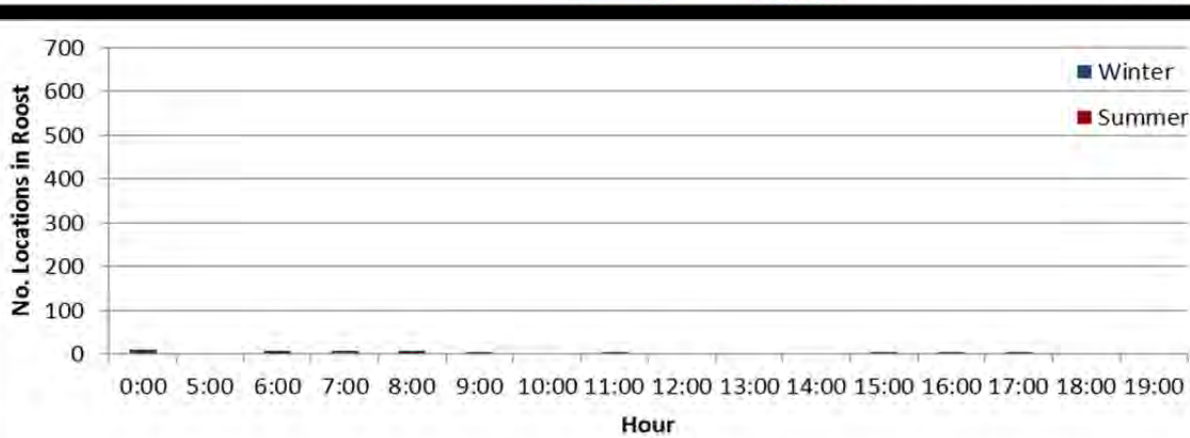




Roost No. 21
Roost Name: Bear Point - B
Predominant Season: Summer and Winter

No. Midnight Locations: 20
No. Total Locations: 56
No. Transmittered Eagles: 15

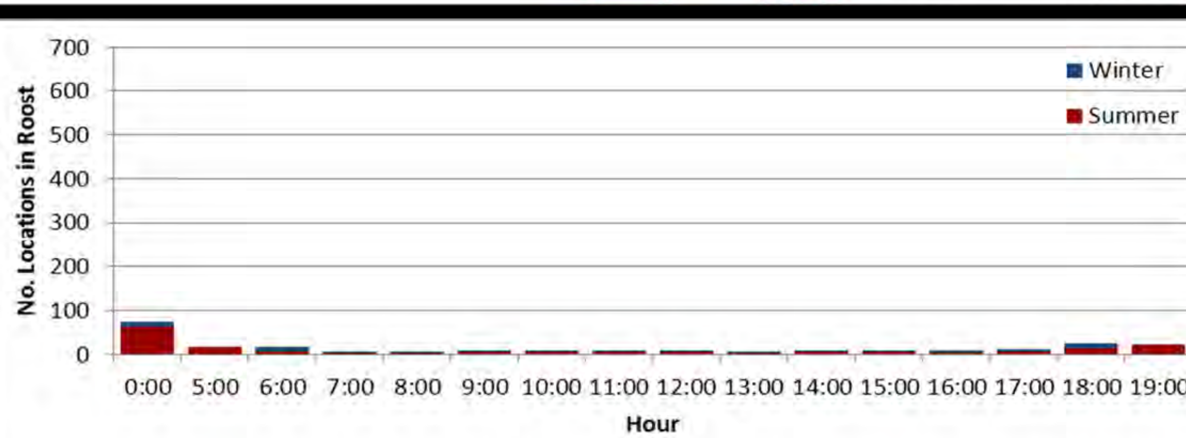


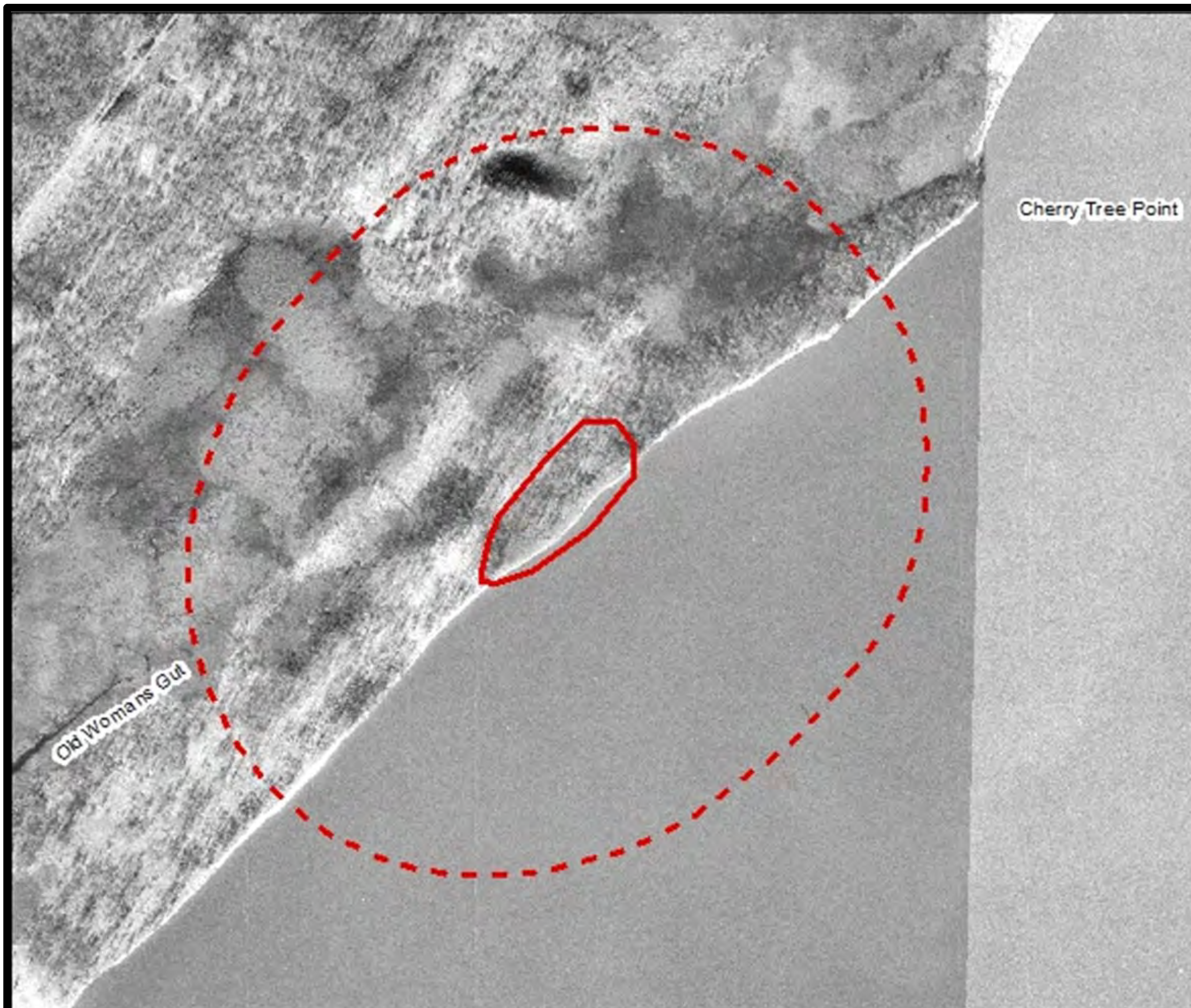


Roost No. 22
Roost Name: Swan Creek - A
Predominant Season: Summer and Winter

No. Midnight Locations: 83
No. Total Locations: 299
No. Transmittered Eagles: 17

Roost Boundary 500m Buffer
0 65 130 260 Meters
N

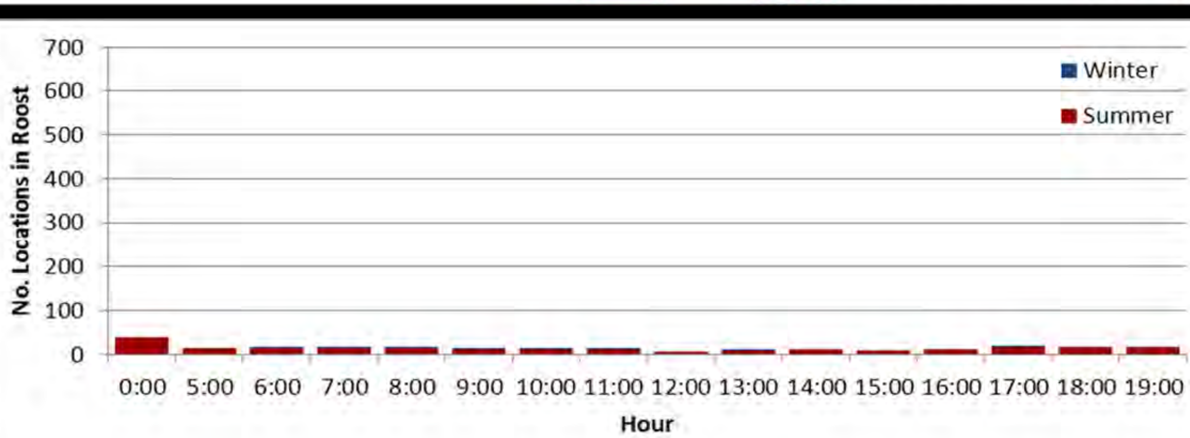




Roost No. 23
Roost Name: Cherry Tree Pt - C
Predominant Season: Summer

No. Midnight Locations: 43
No. Total Locations: 297
No. Transmittered Eagles: 23

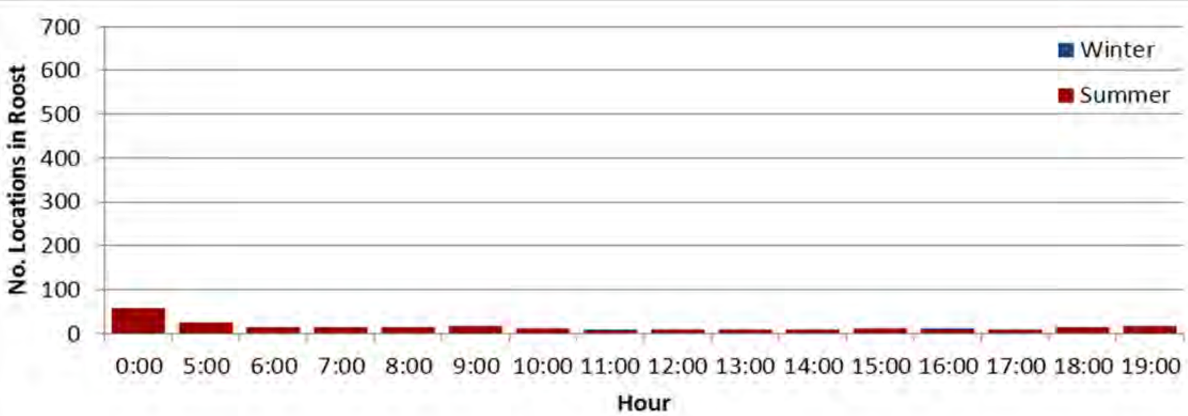
Roost Boundary 500m Buffer 0 75 150 300 Meters N

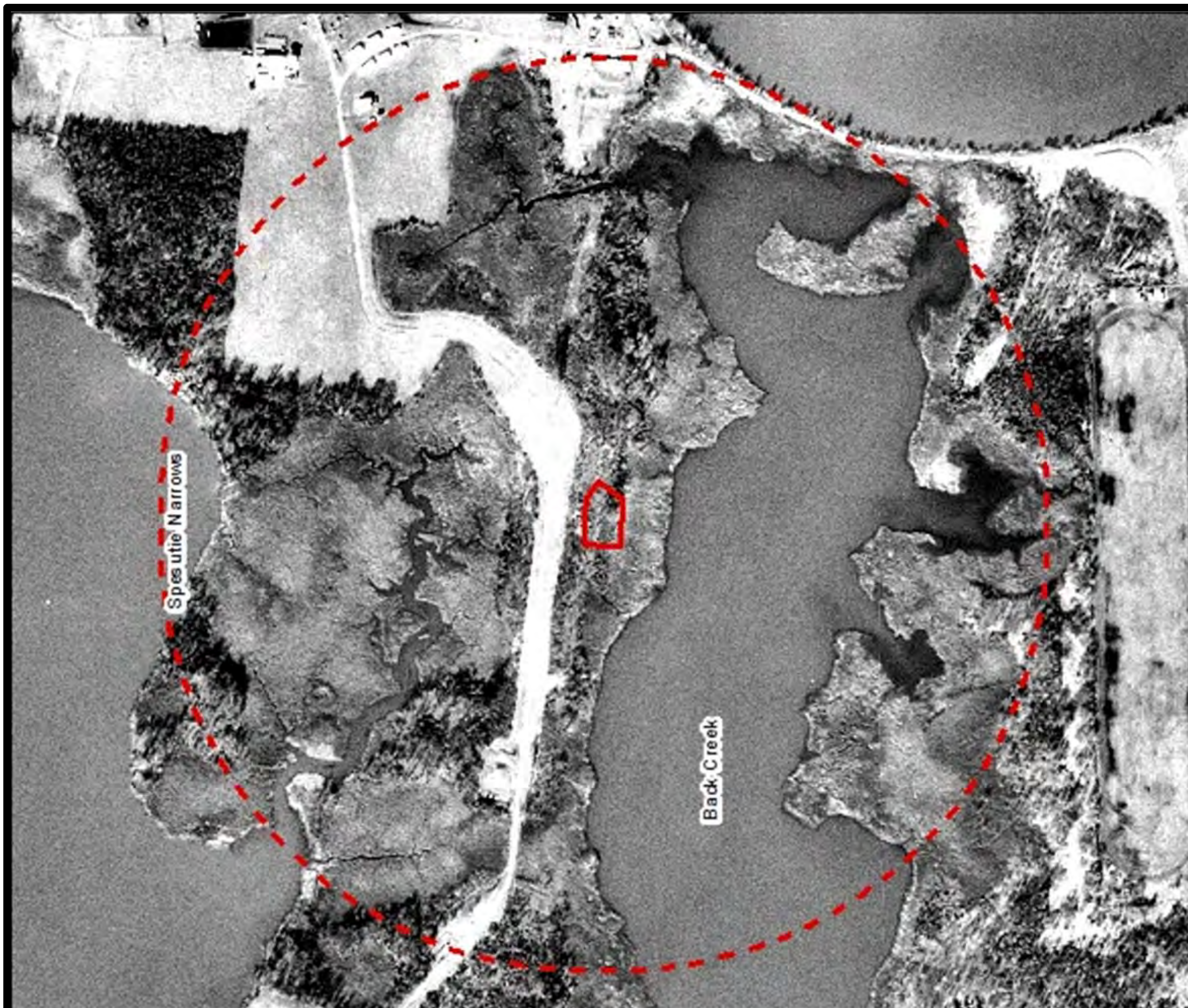


Roost No. 24
Roost Name: Range 7a - A
Predominant Season: Summer

No. Midnight Locations: 60
No. Total Locations: 259
No. Transmittered Eagles: 10

Roost Boundary
500m Buffer
0 55 110 220 Meters
N

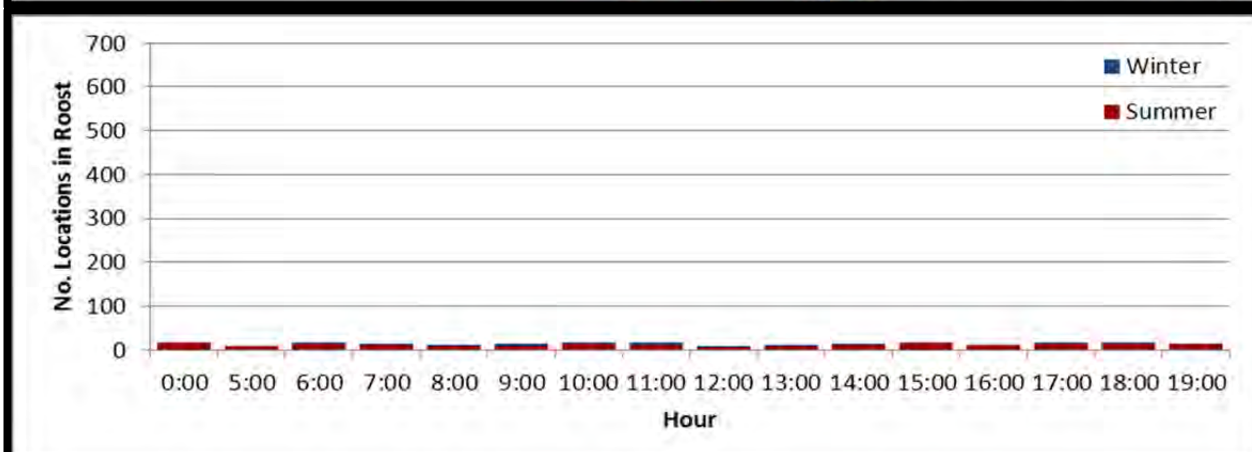


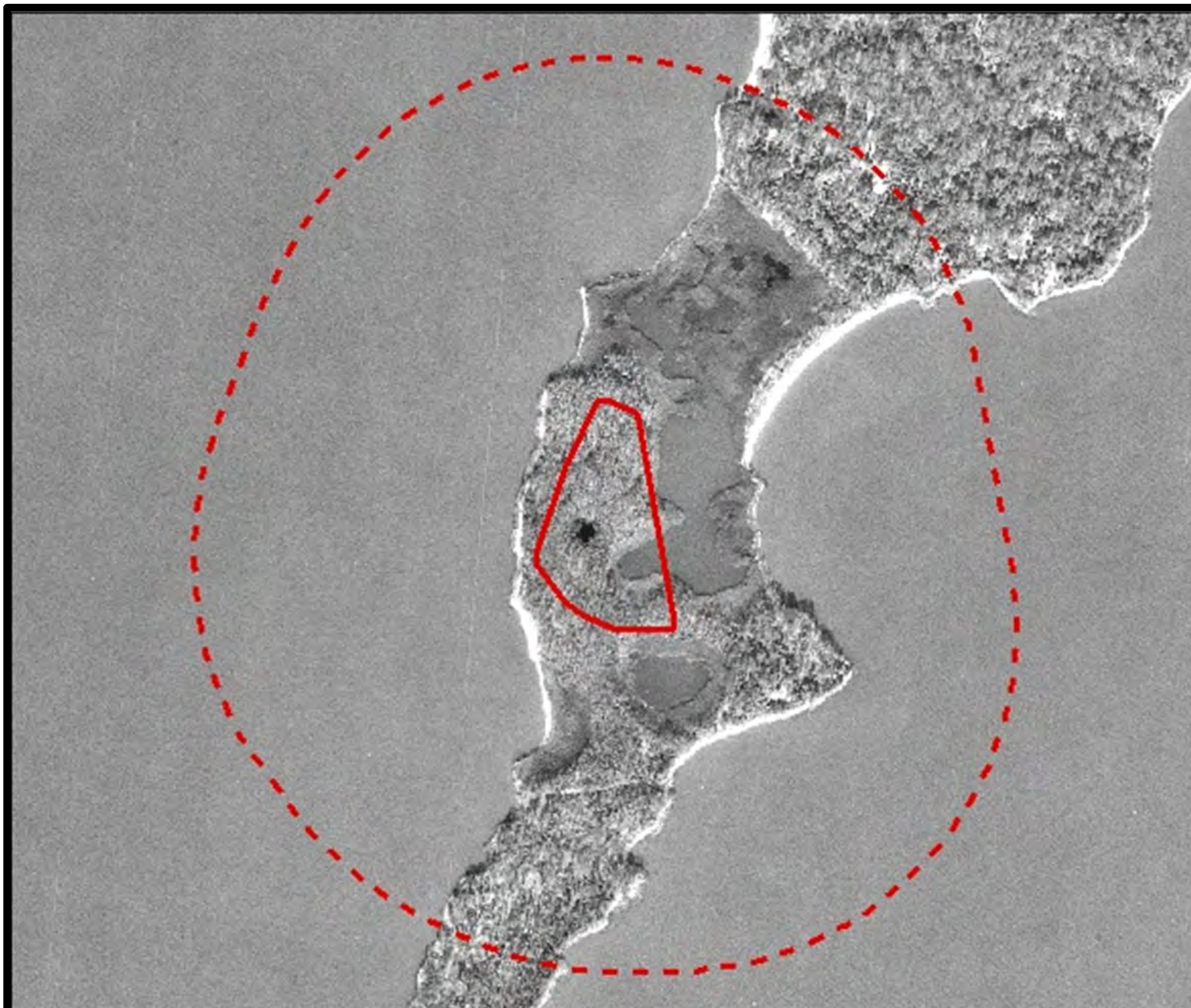


Roost No. 25
Roost Name: Back Creek
Predominant Season: Summer and Winter

No. Midnight Locations: 16
No. Total Locations: 231
No. Transmittered Eagles: 15

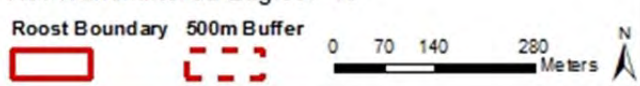
Roost Boundary 500m Buffer
0 55 110 220 Meters
N

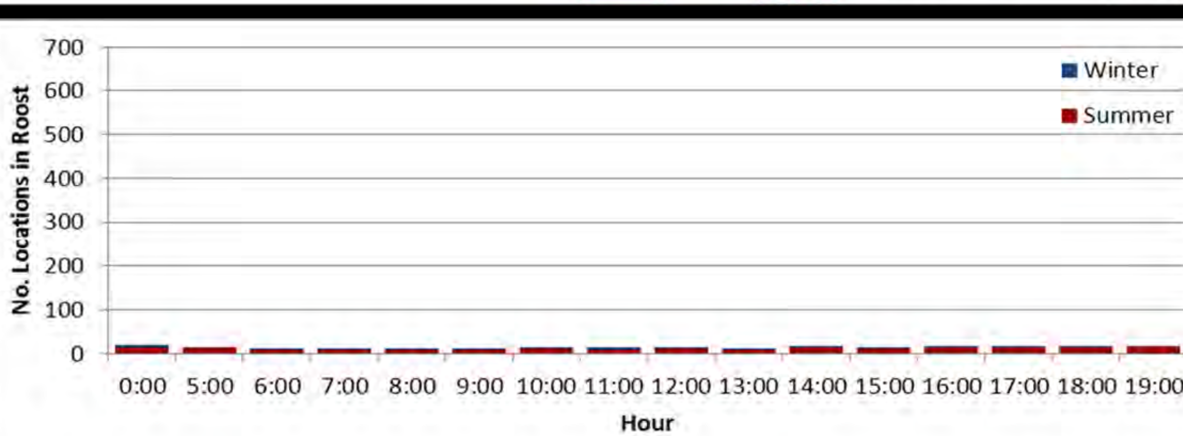




Roost No. 26
Roost Name: Pooles Island Pothole
Predominant Season: Summer and Winter

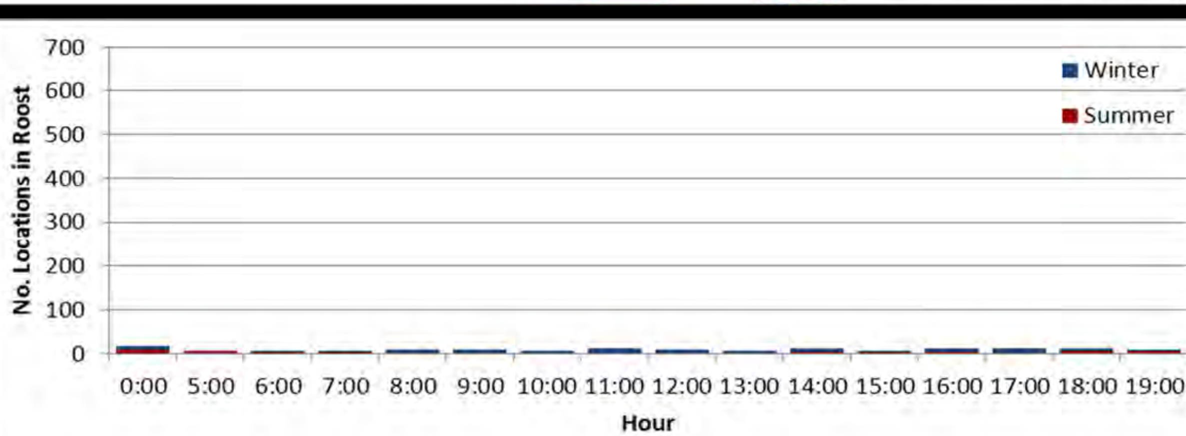
No. Midnight Locations: 23
No. Total Locations: 290
No. Transmittered Eagles: 18

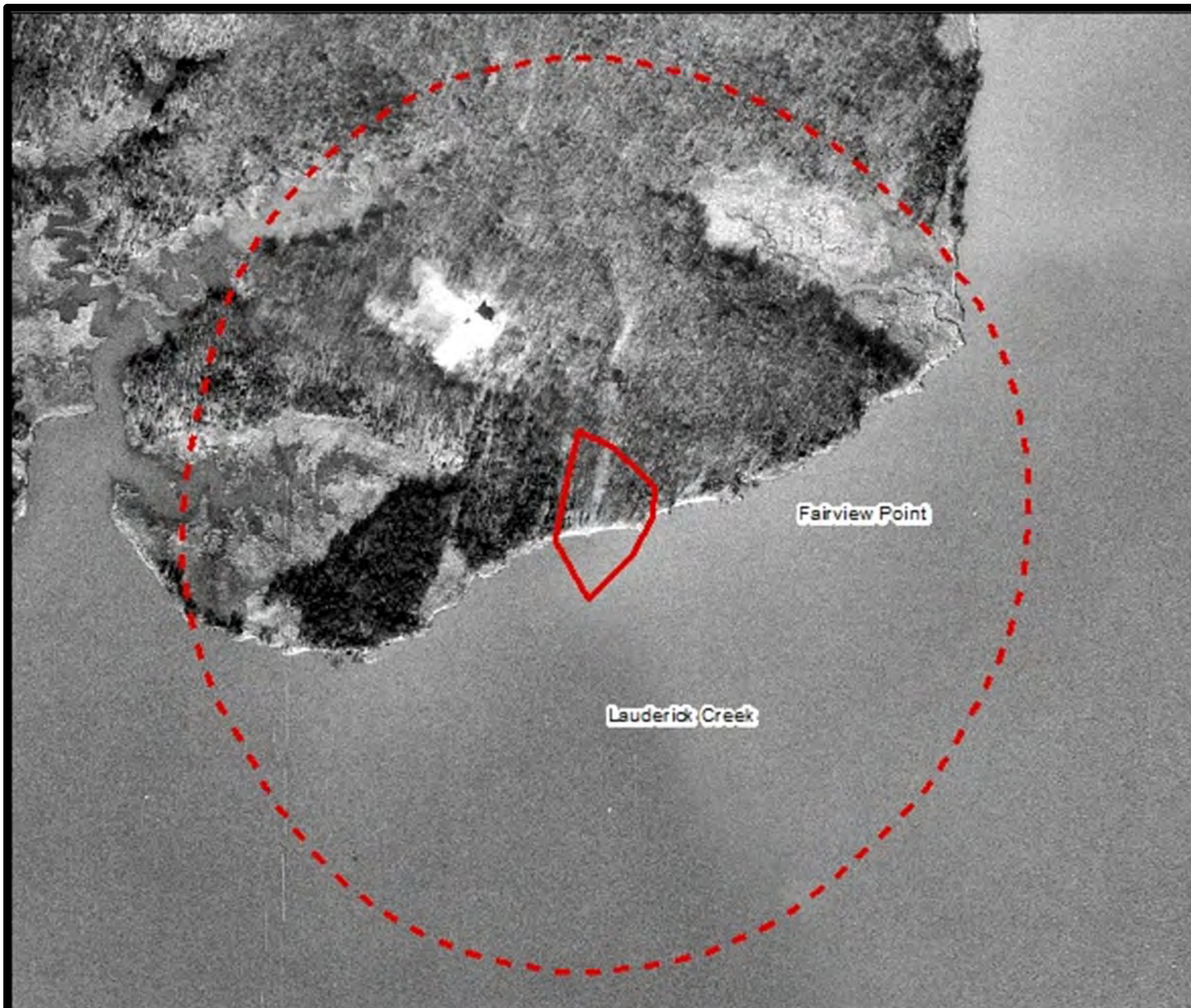




Roost No. 27
Roost Name: Carroll Island
Predominant Season: Summer and Winter

No. Midnight Locations: 32
No. Total Locations: 289
No. Transmittered Eagles: 11





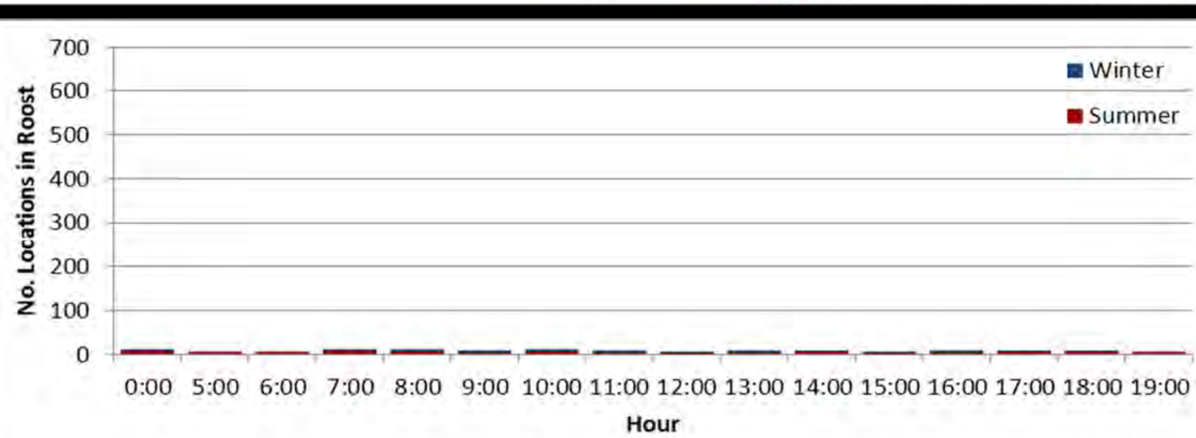
Roost No. 28
Roost Name: Fairview Point - B
Predominant Season: Summer and Winter

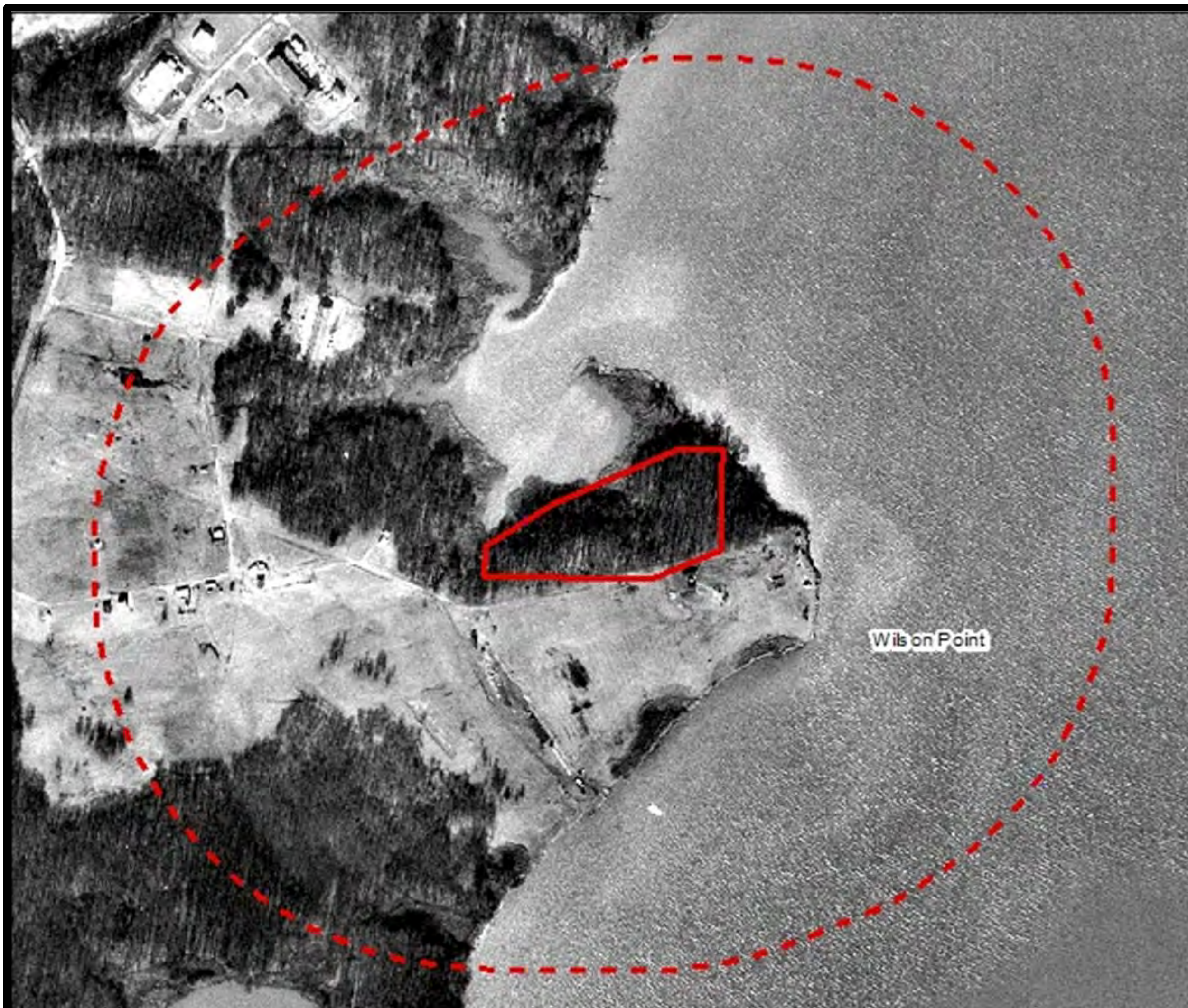
No. Midnight Locations: 15
No. Total Locations: 234
No. Transmittered Eagles: 18

Roost Boundary 500m Buffer

0 60 120 240 Meters

N

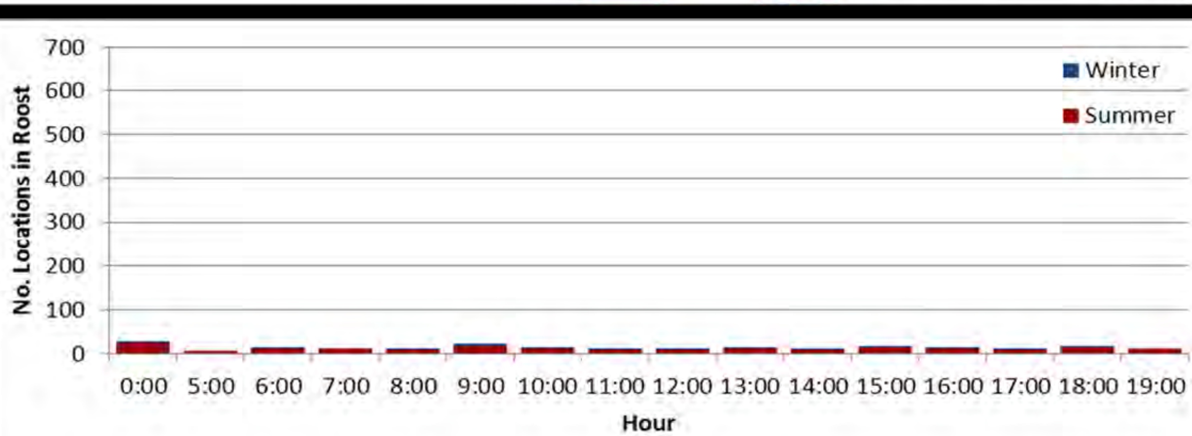


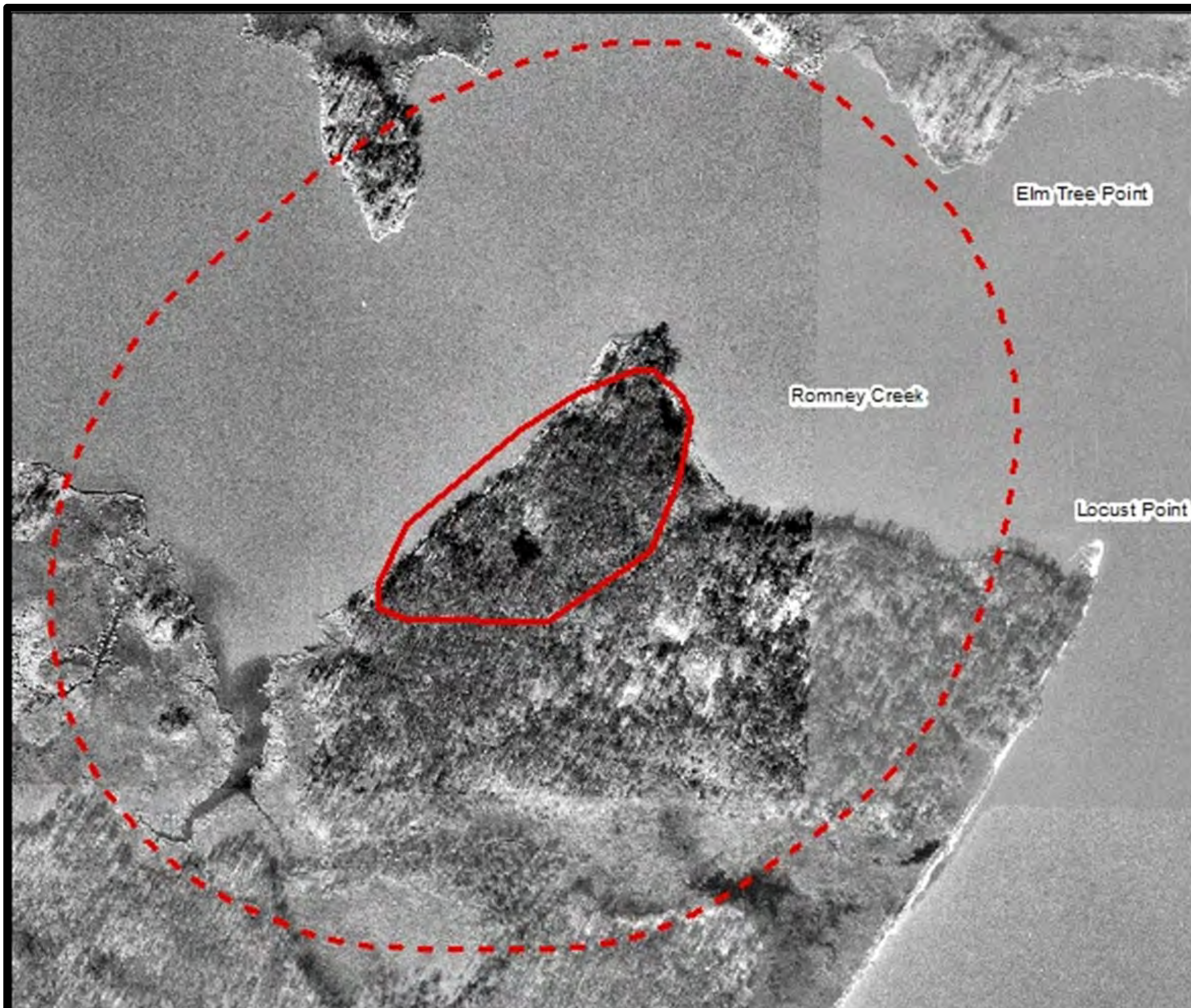


Roost No. 29
Roost Name: Wilson Point
Predominant Season: Summer and Winter

No. Midnight Locations: 27
No. Total Locations: 238
No. Transmittered Eagles: 14

Roost Boundary | 500m Buffer | 0 60 120 240 Meters | N



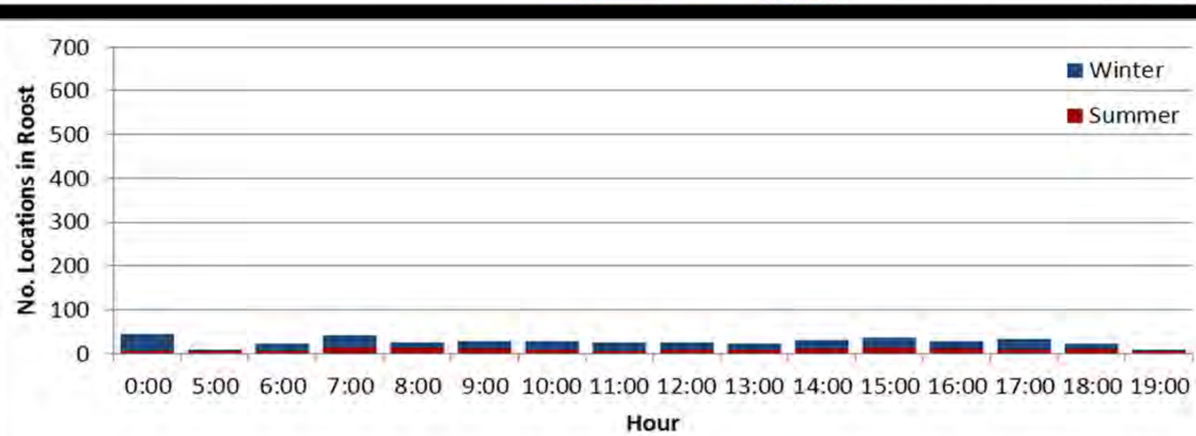


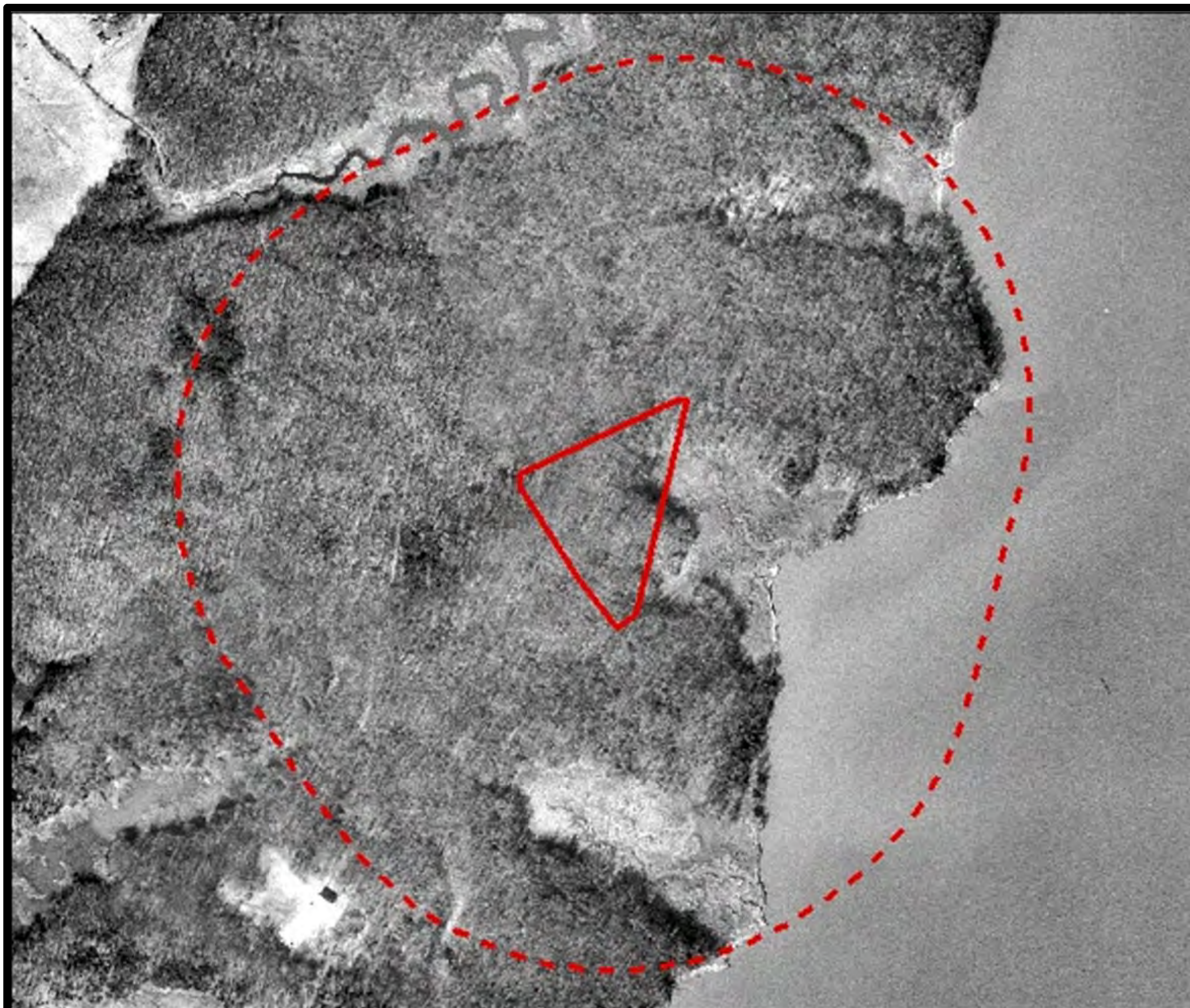
Roost No. 30
Roost Name: Locust Point - B
Predominant Season: Summer and Winter

No. Midnight Locations: 54
No. Total Locations: 583
No. Transmittered Eagles: 35

Roost Boundary **500m Buffer**

0 70 140 280 Meters N

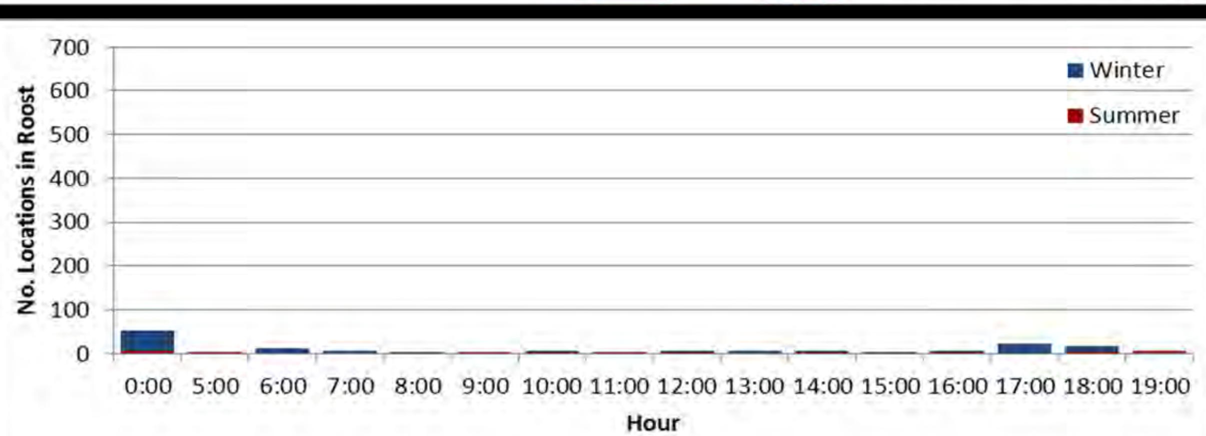


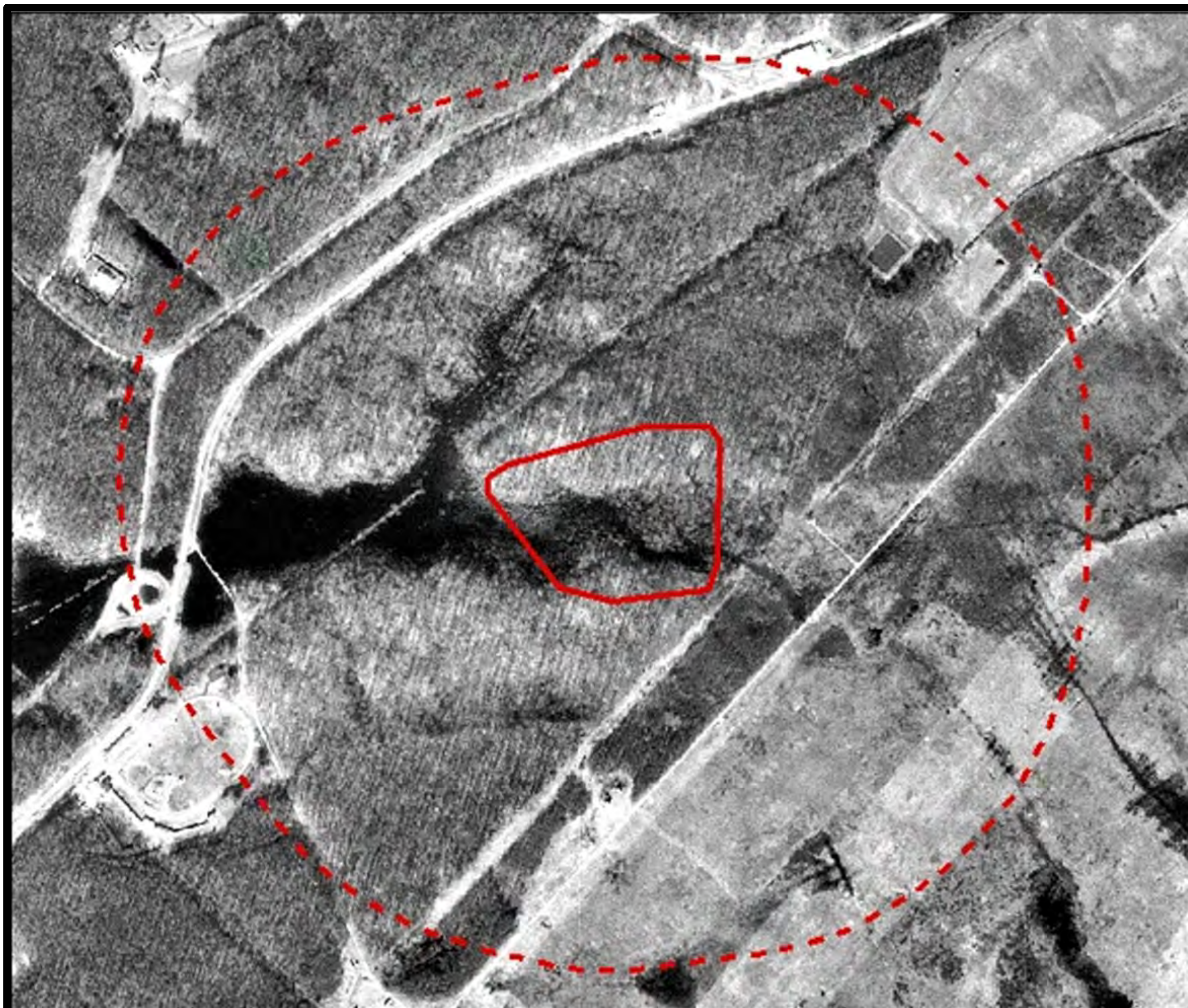


Roost No. 31
Roost Name: Fairview Point - C
Predominant Season: Summer and Winter

No. Midnight Locations: 70
No. Total Locations: 211
No. Transmittered Eagles: 9

Roost Boundary
500m Buffer
0 65 130 260 Meters
N

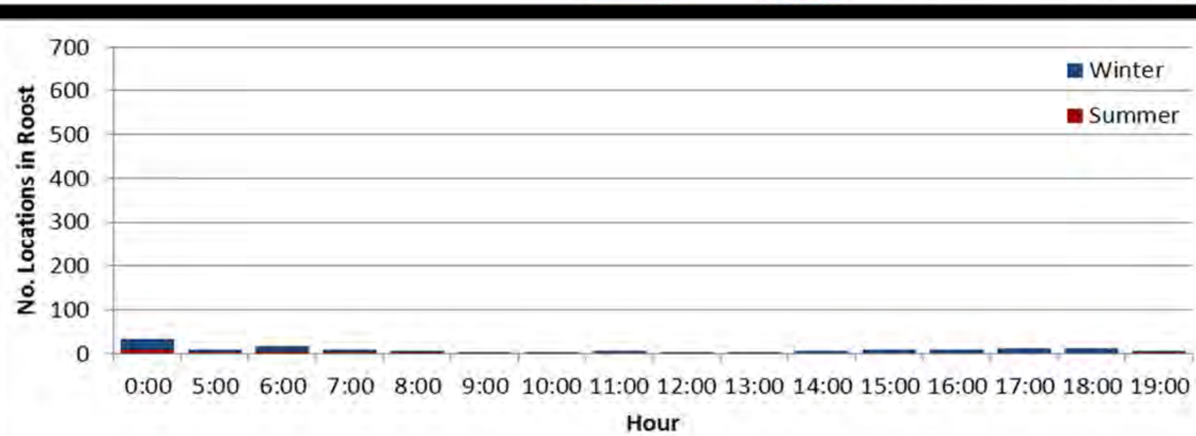


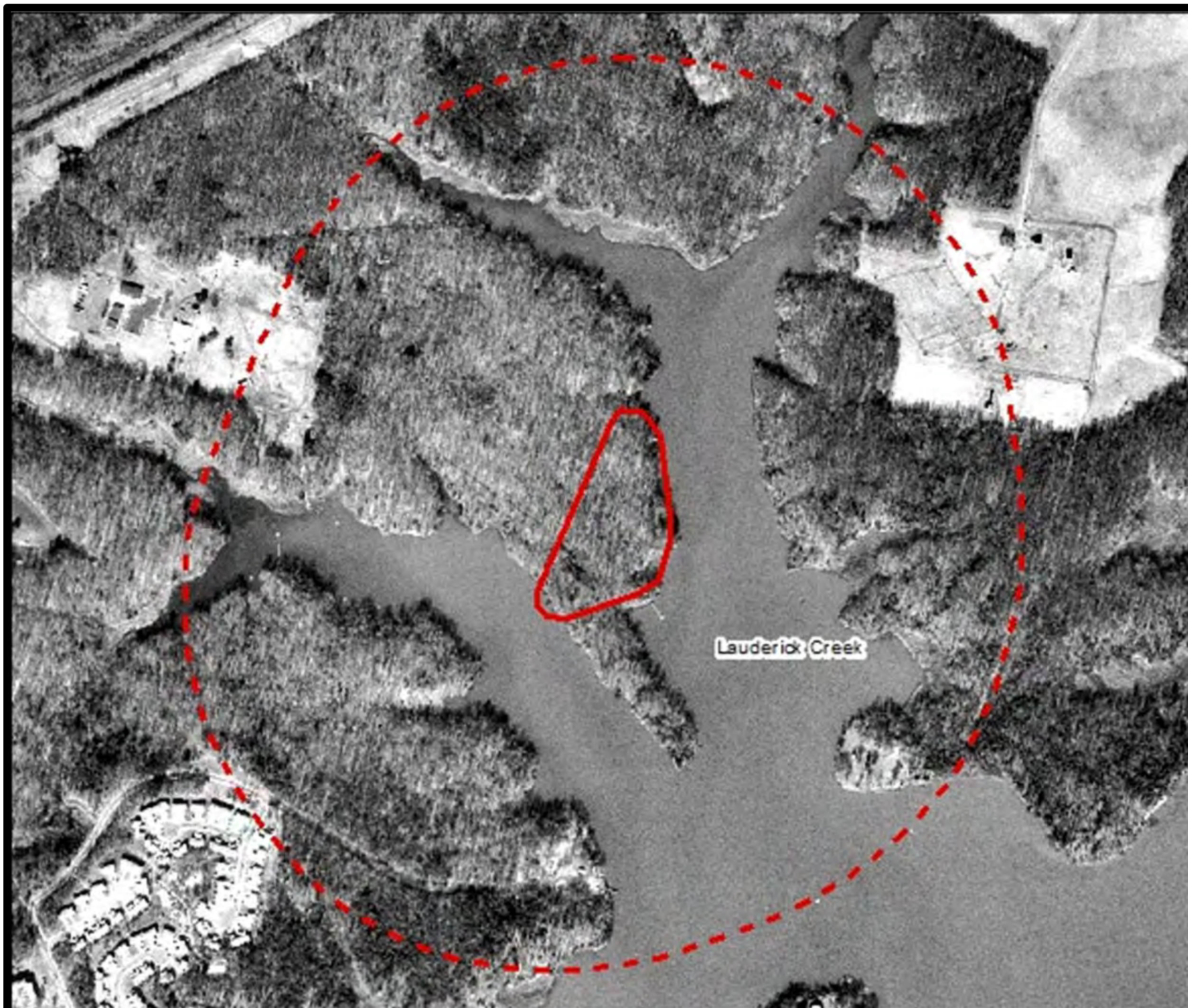


Roost No. 32
Roost Name: Dynomometer
Predominant Season: Summer and Winter

No. Midnight Locations: 53
No. Total Locations: 255
No. Transmittered Eagles: 17

Roost Boundary 500m Buffer
0 62.5 125 250 Meters
N

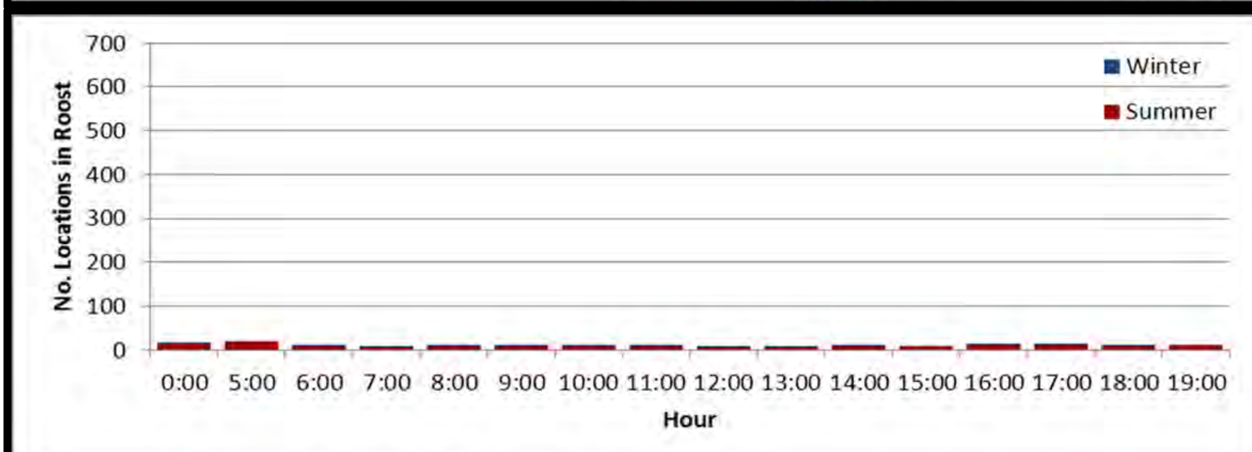


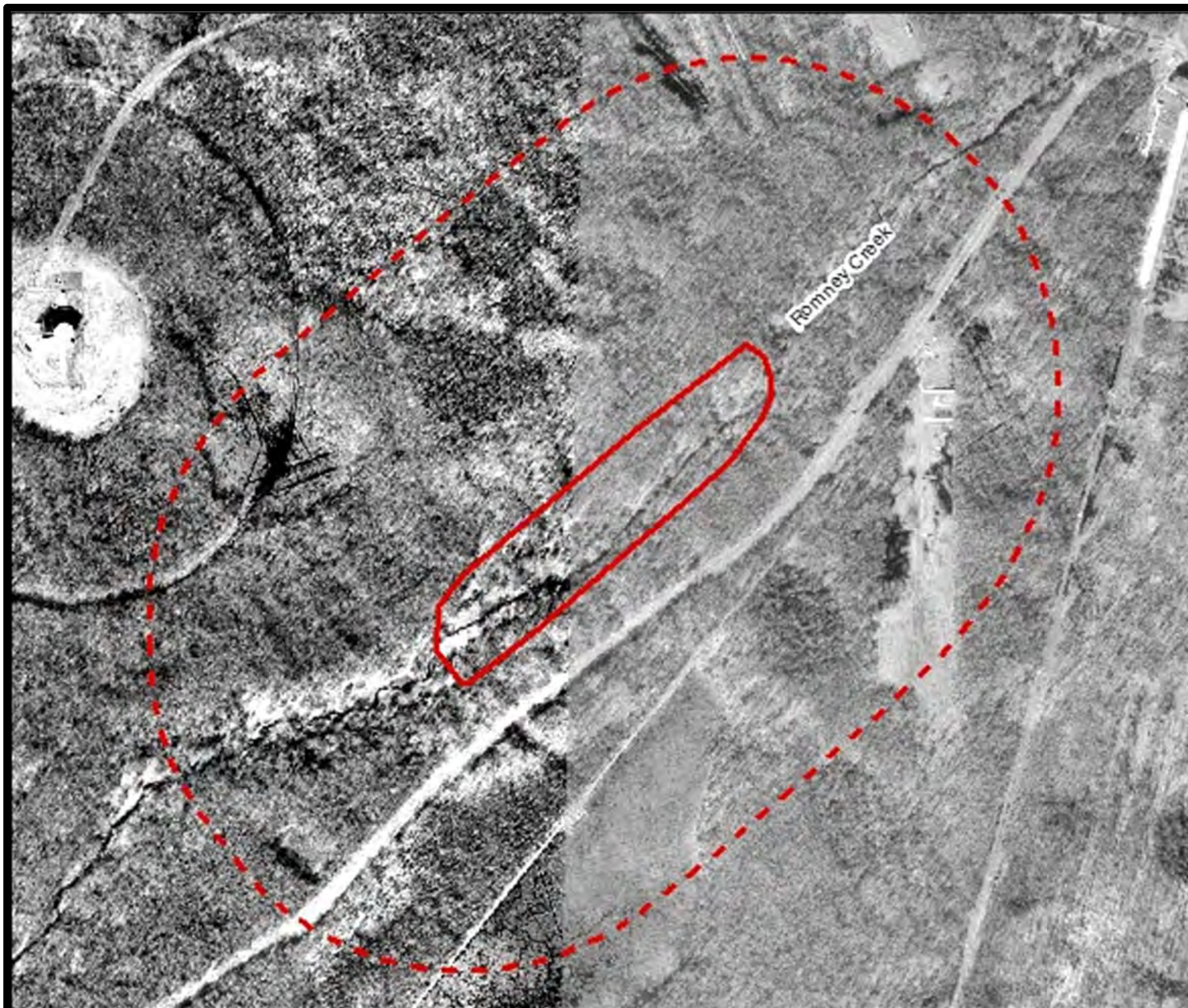


Roost No. 33
Roost Name: Lauderick Creek - A
Predominant Season: Summer

No. Midnight Locations: 26
No. Total Locations: 260
No. Transmittered Eagles: 13

Roost Boundary
500m Buffer
0 65 130 260 Meters
N





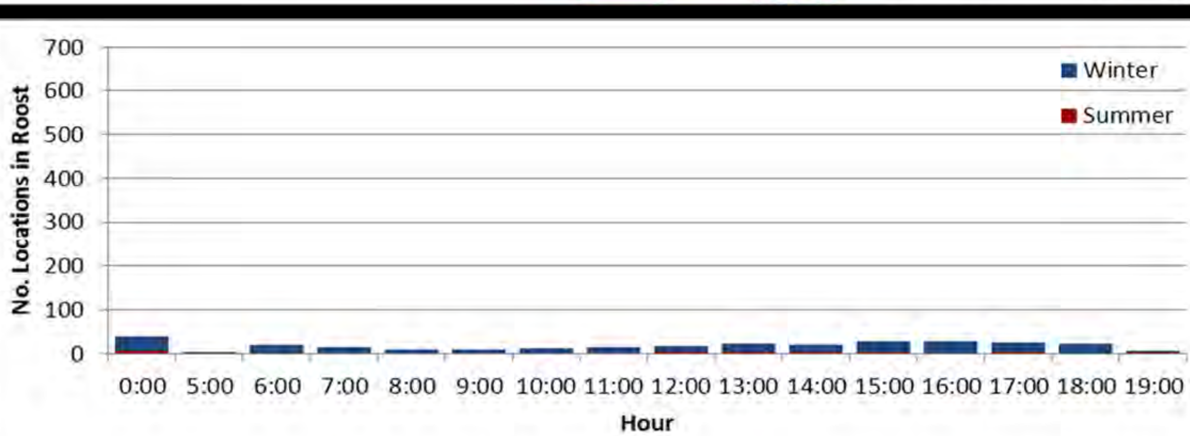
Roost No. 34
Roost Name: Romney Creek - Upper
Predominant Season: Winter

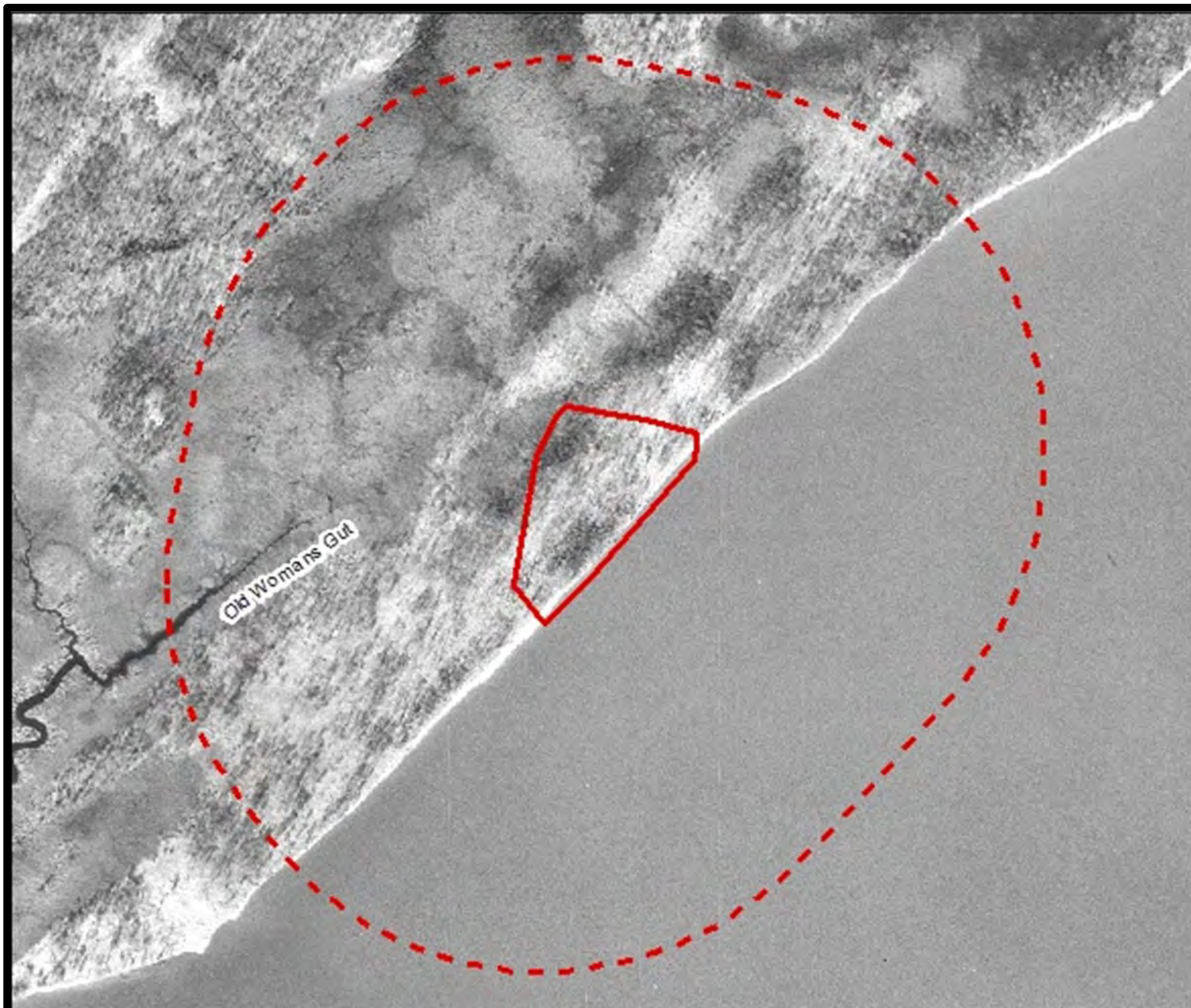
No. Midnight Locations: 50
No. Total Locations: 391
No. Transmittered Eagles: 27

Roost Boundary
500m Buffer

0 80 160 320 Meters

N

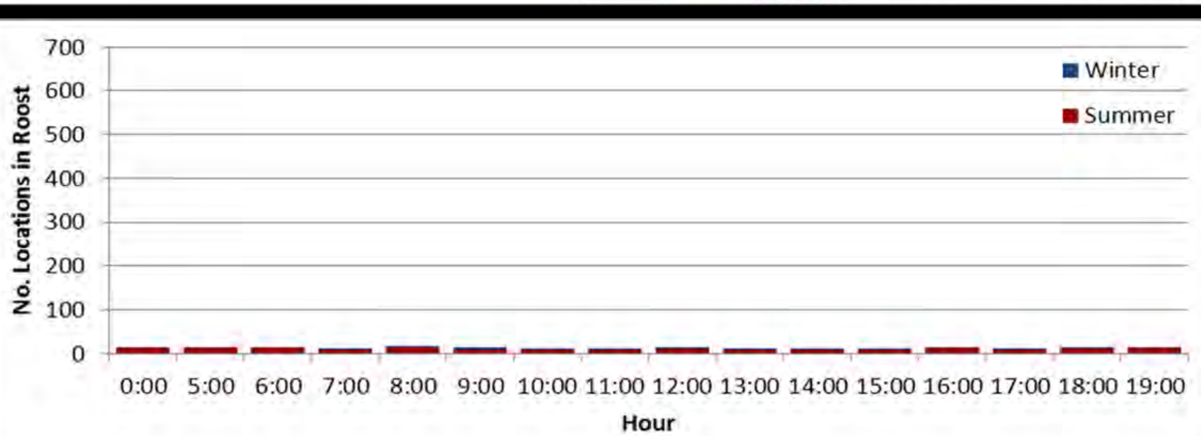


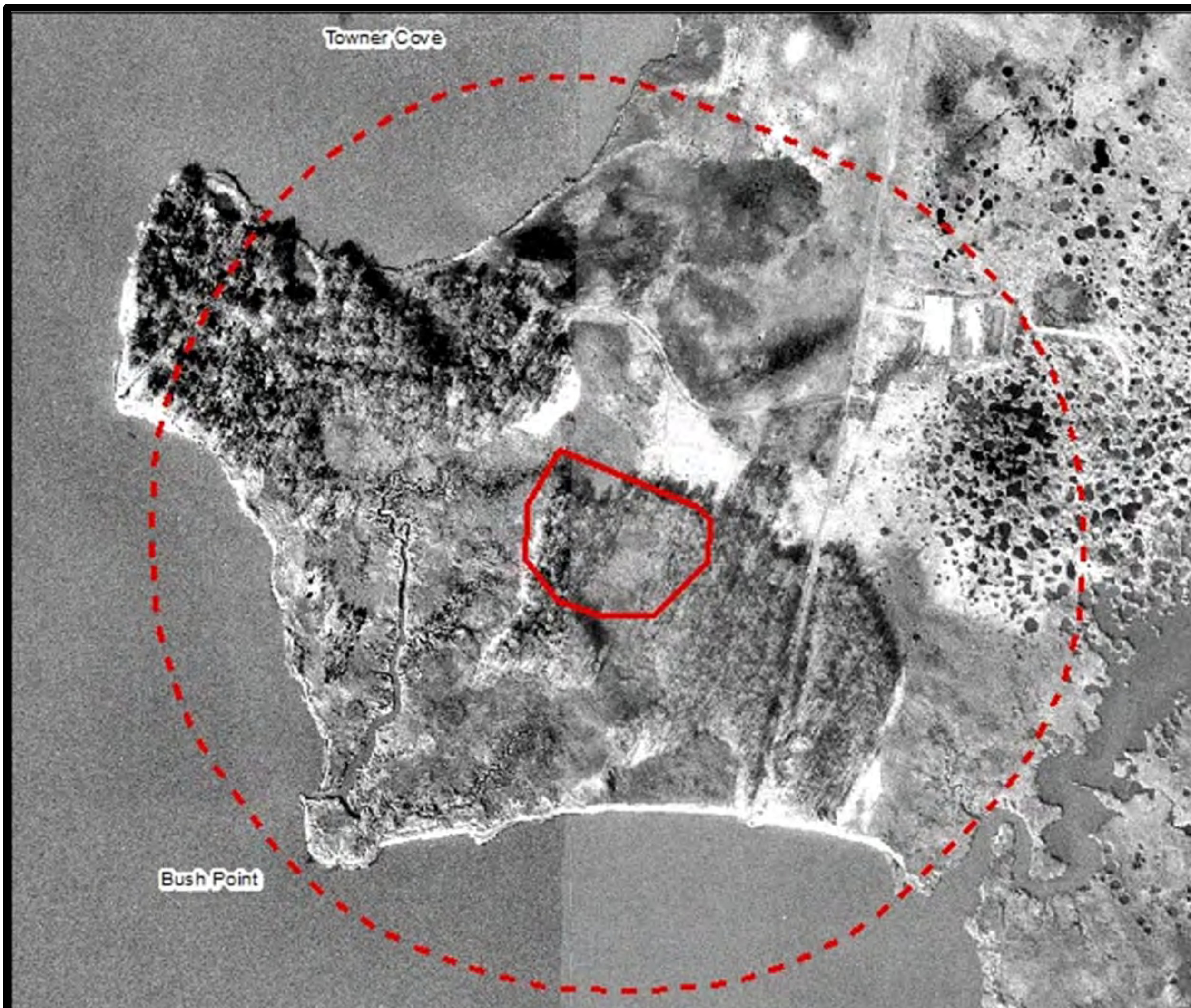


Roost No. 35
Roost Name: Cherry Tree Pt - D
Predominant Season: Summer

No. Midnight Locations: 13
No. Total Locations: 223
No. Transmittered Eagles: 24

Roost Boundary 500m Buffer 0 65 130 260 Meters N

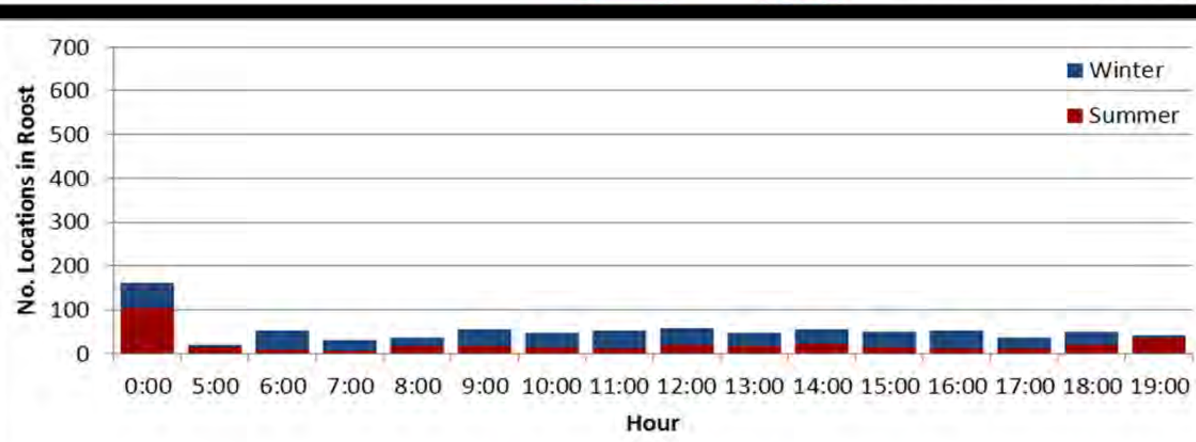


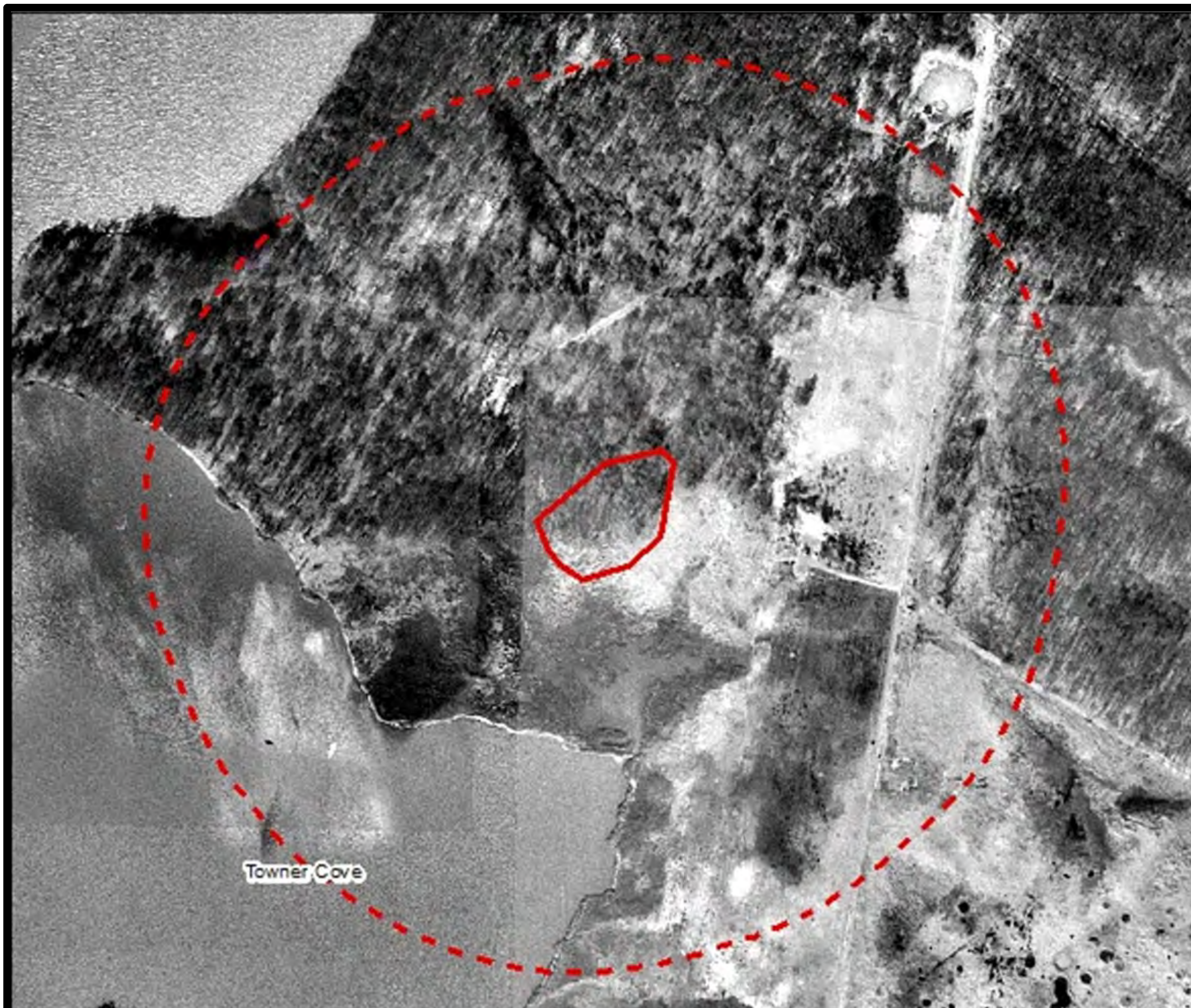


Roost No. 36
Roost Name: Cod Creek Rd - A
Predominant Season: Summer and Winter

No. Midnight Locations: 211
No. Total Locations: 1,212
No. Transmittered Eagles: 15

Roost Boundary
500m Buffer
0 60 120 240 Meters
N



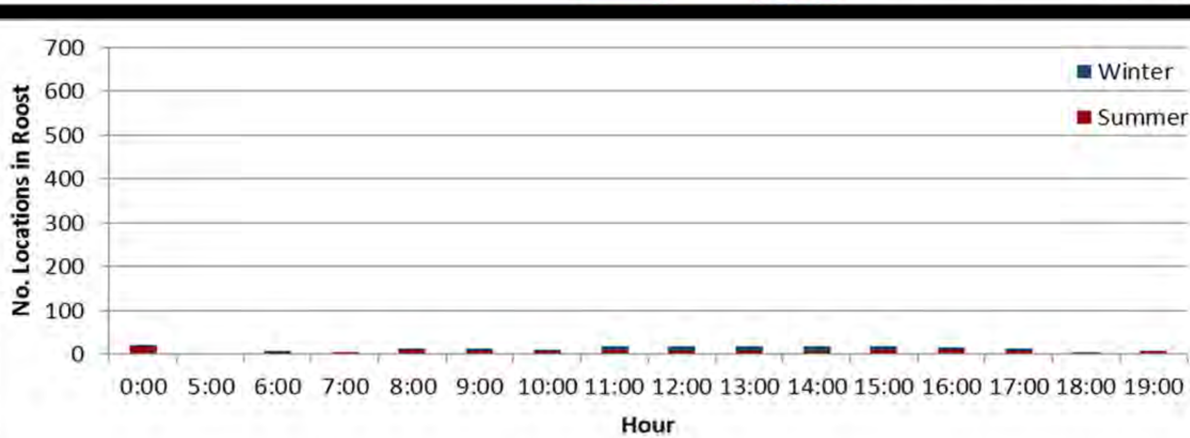


Roost No. 37
Roost Name: Cod Creek Rd - B
Predominant Season: Summer and Winter

No. Midnight Locations: 33
No. Total Locations: 245
No. Transmittered Eagles: 11

Roost Boundary
500m Buffer

0 60 120 240 Meters
N

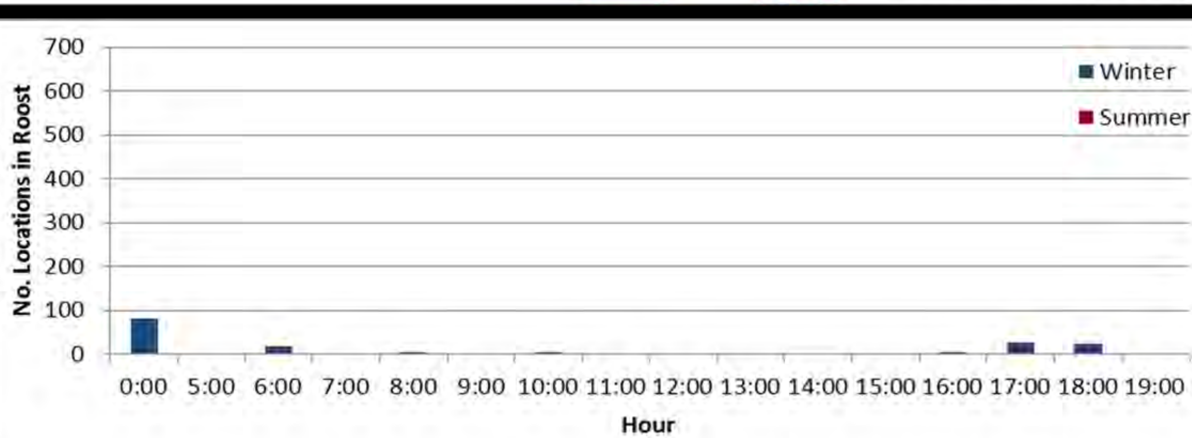


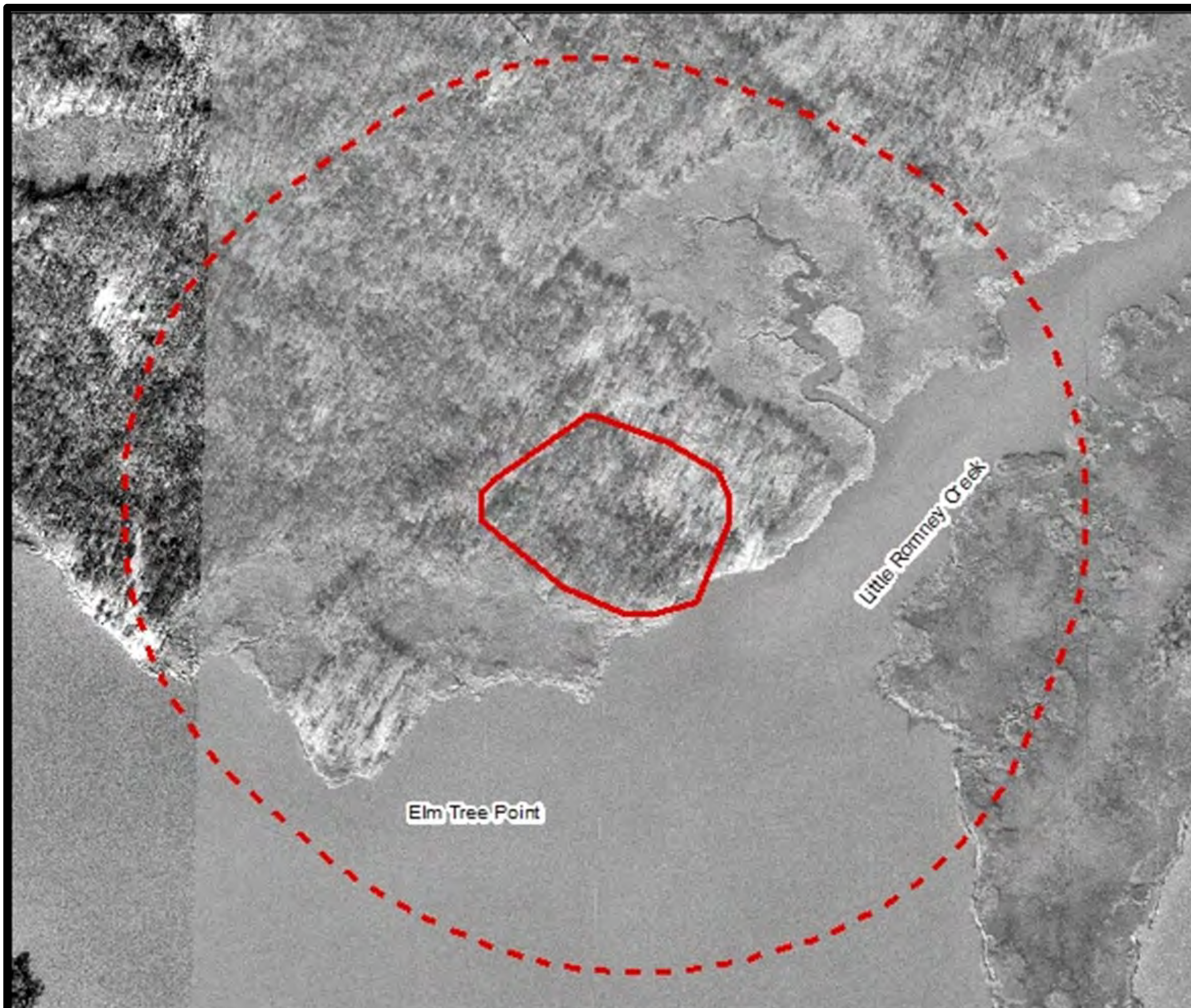
Roost No. 38
Roost Name: Cod Creek Rd - C
Predominant Season: Winter

No. Midnight Locations: 106
No. Total Locations: 239
No. Transmittered Eagles: 8

Roost Boundary
500m Buffer

0 60 120 240 Meters
N



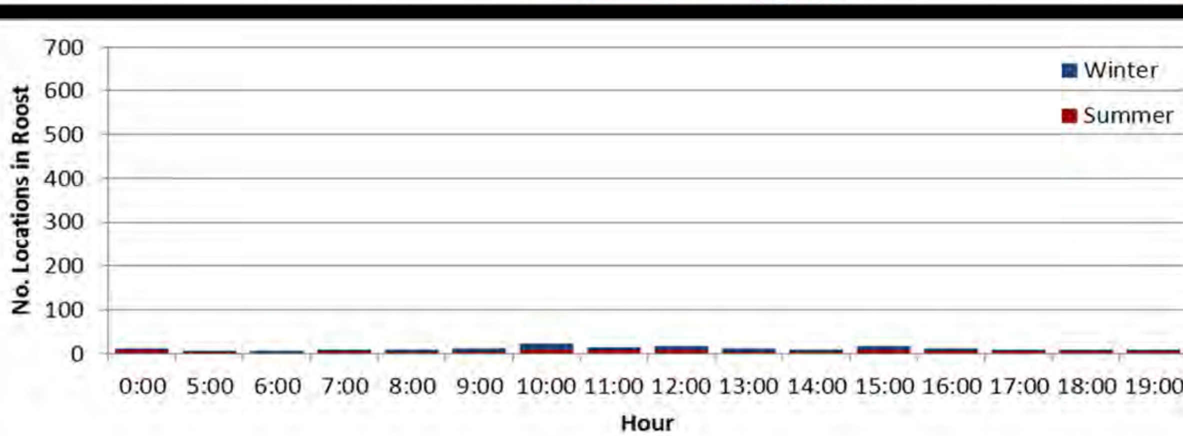


Roost No. 39
Roost Name: Elm Tree Point
Predominant Season: Summer and Winter

No. Midnight Locations: 17
No. Total Locations: 218
No. Transmittered Eagles: 23

Roost Boundary 500m Buffer

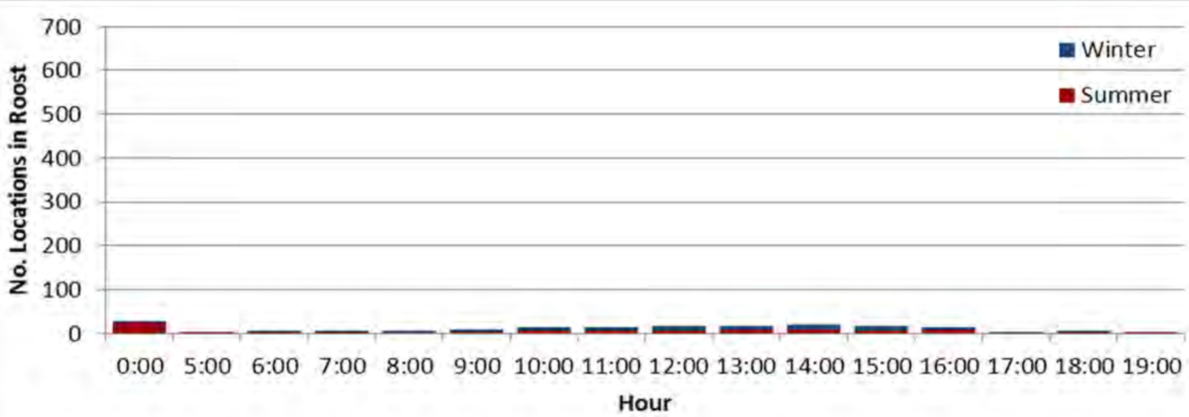
0 62.5 125 250 Meters N

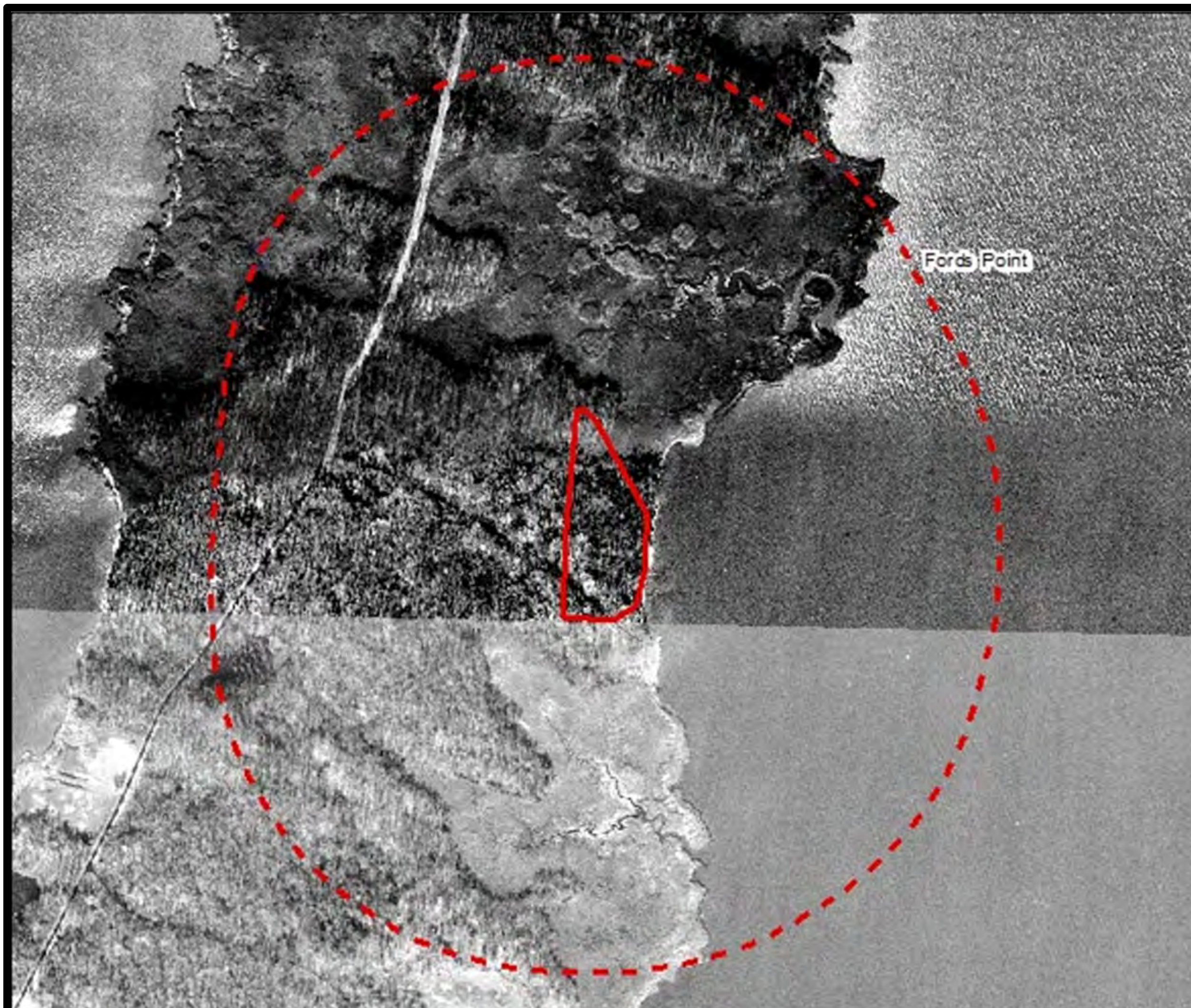


Roost No. 40
Roost Name: Doves Cove
Predominant Season: Summer and Winter

No. Midnight Locations: 29
No. Total Locations: 247
No. Transmittered Eagles: 19

Roost Boundary 500m Buffer
0 55 110 220 Meters
N



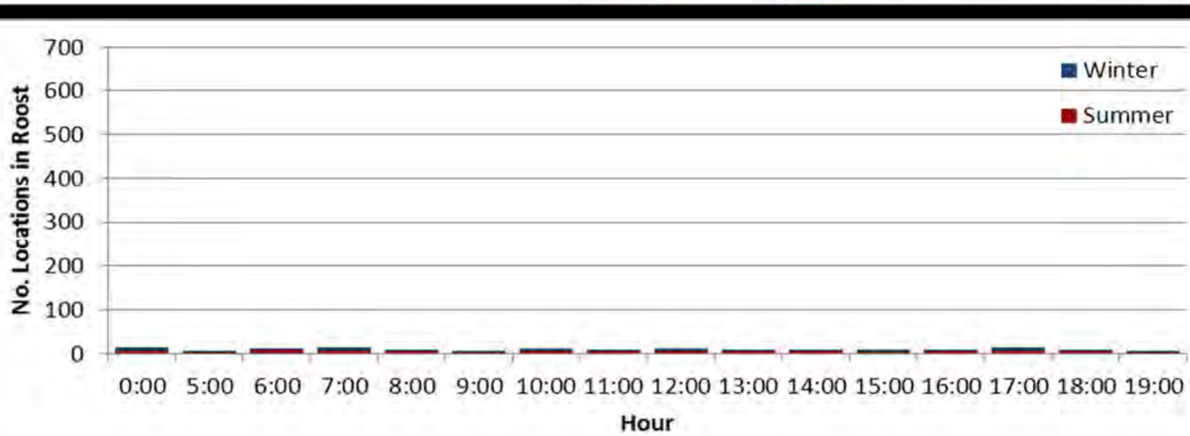


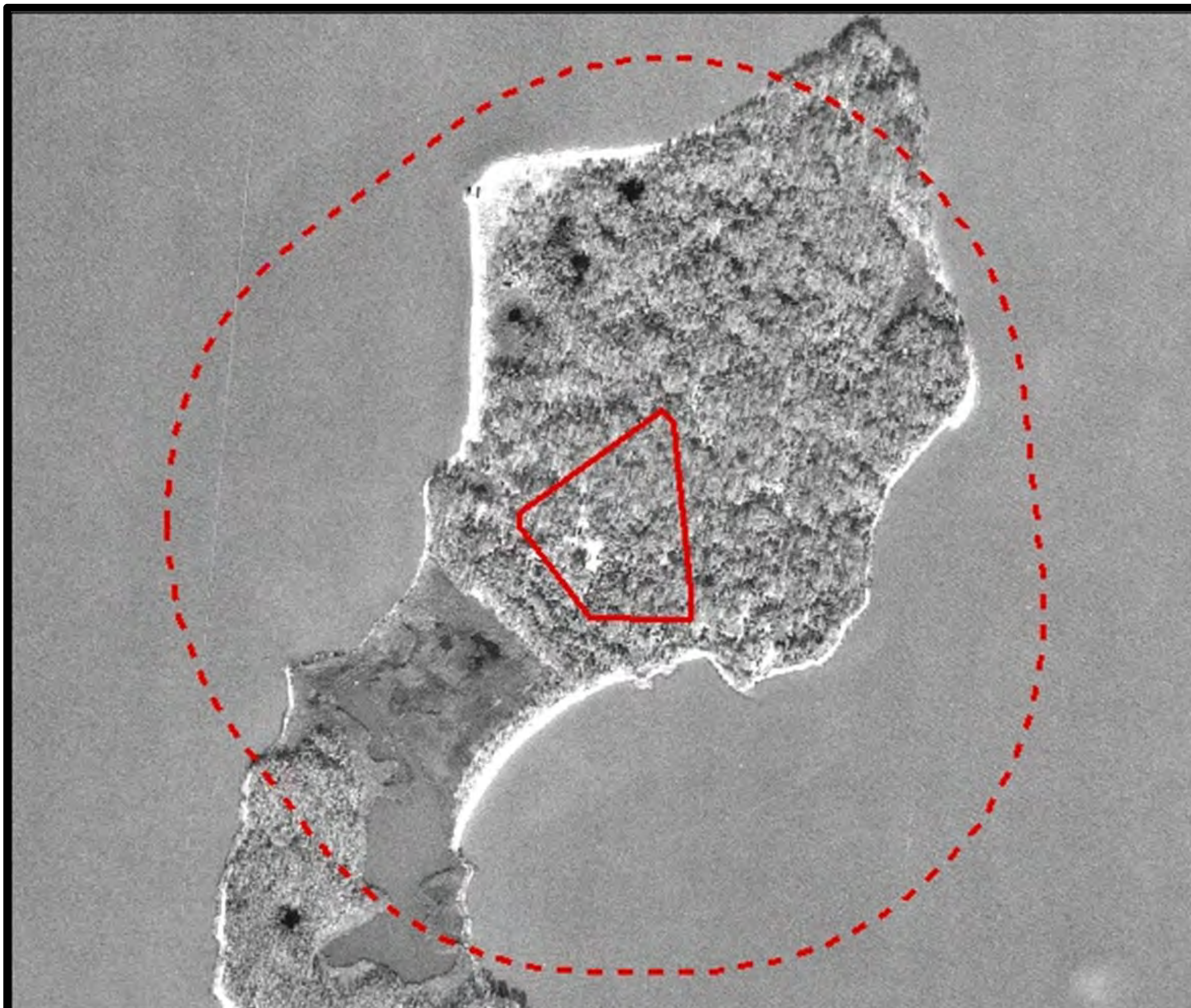
Roost No. 41
Roost Name: Fords Point - A
Predominant Season: Summer and Winter

No. Midnight Locations: 15
No. Total Locations: 241
No. Transmittered Eagles: 21

Roost Boundary 500m Buffer

0 65 130 260 Meters N

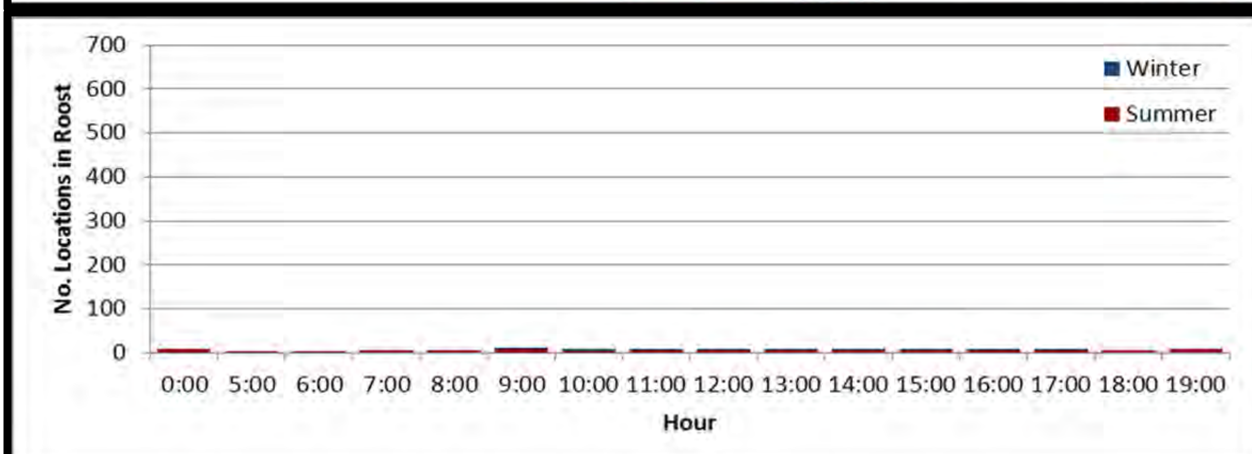


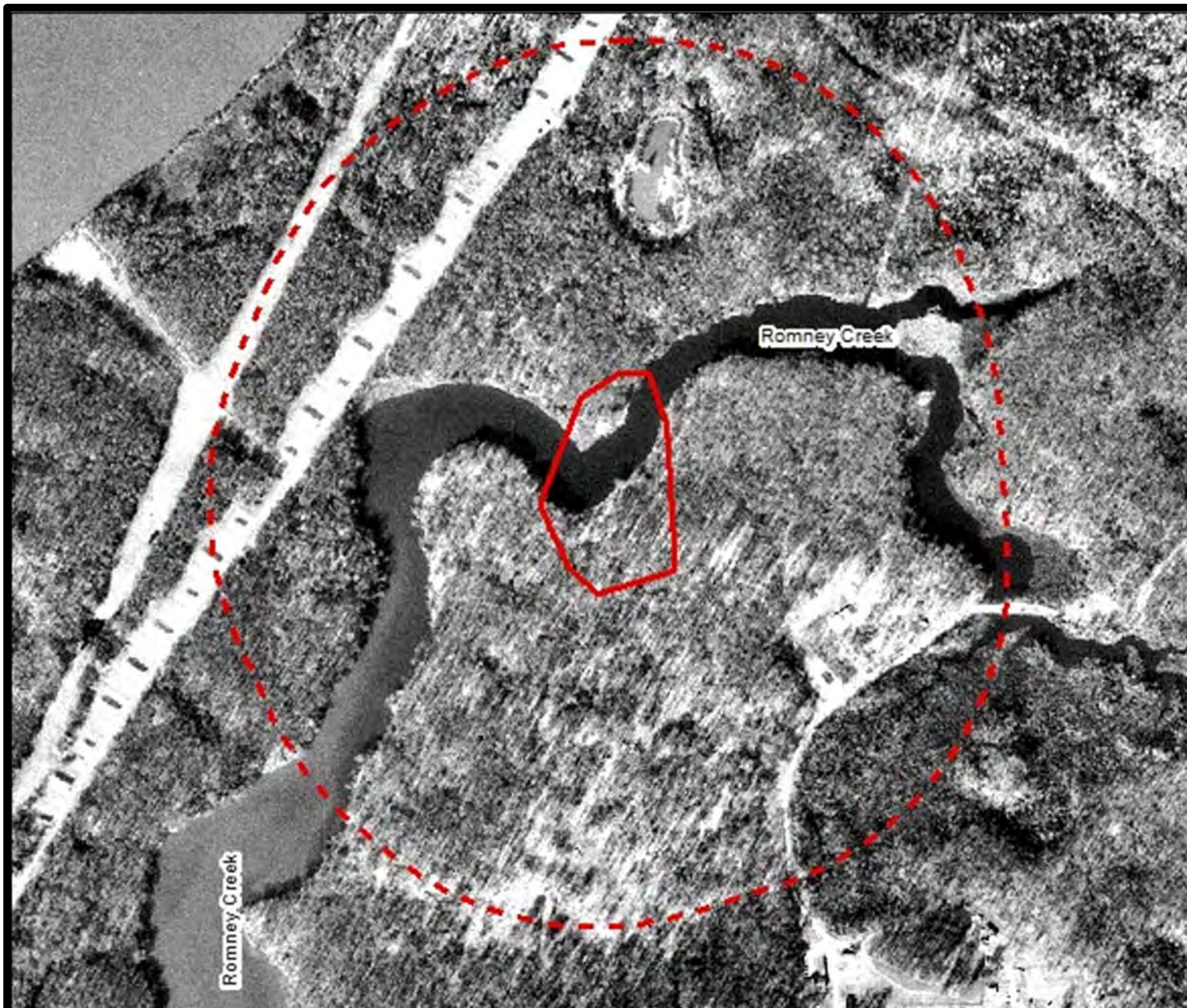


Roost No. 42
Roost Name: Pooles Island Peach Orchard
Predominant Season: Summer and Winter

No. Midnight Locations: 13
No. Total Locations: 135
No. Transmittered Eagles: 14

Roost Boundary 500m Buffer
0 65 130 260 Meters
N

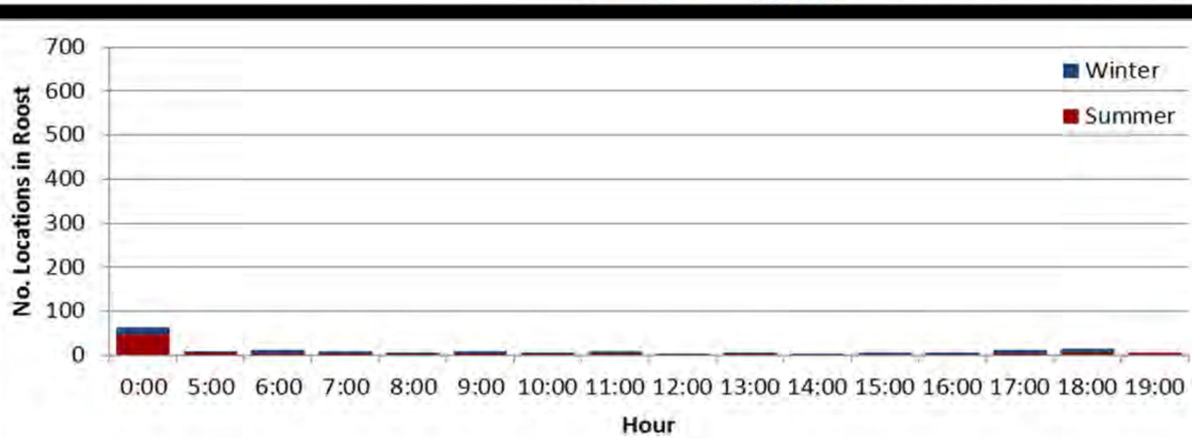


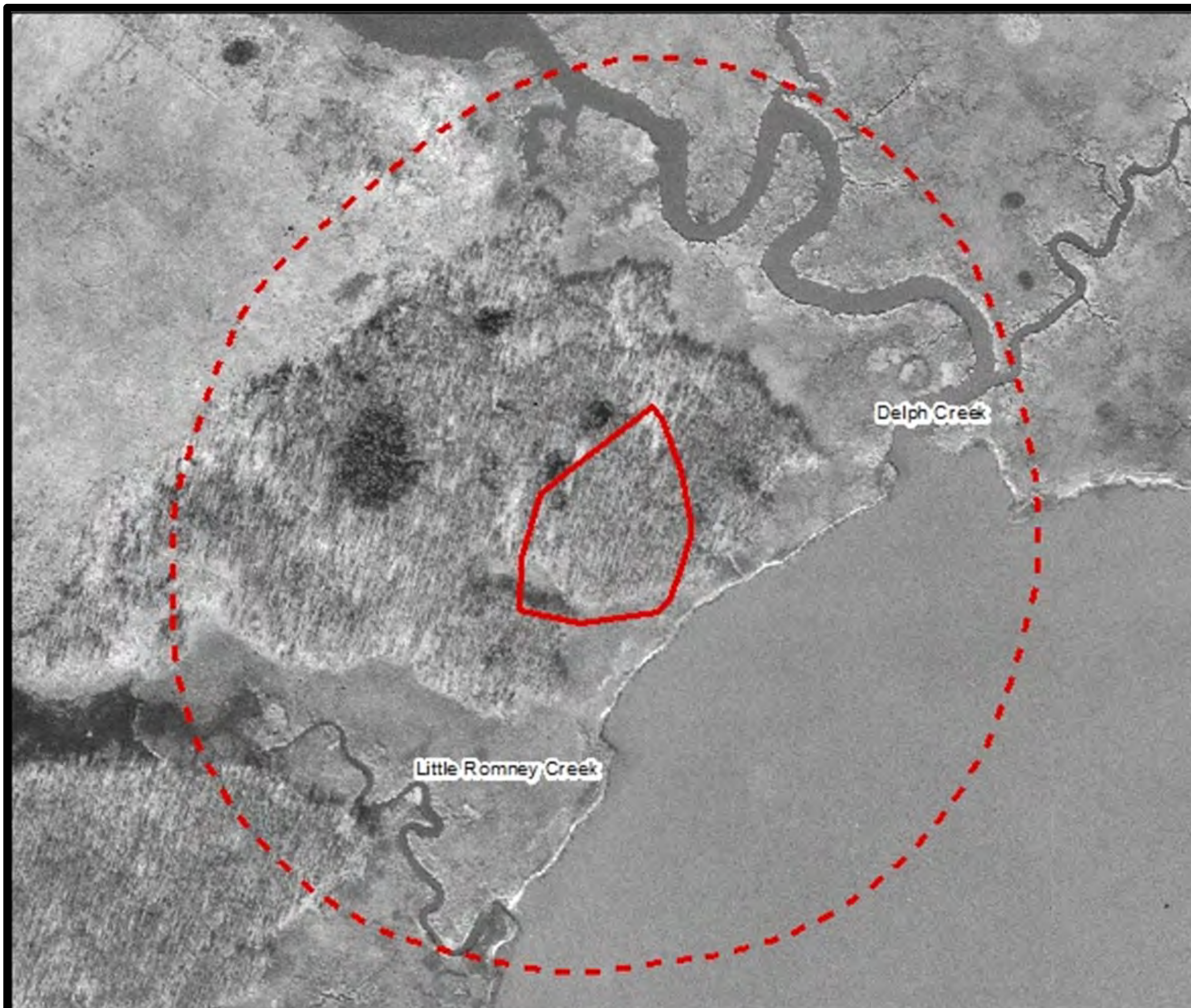


Roost No. 43
Roost Name: Romney Creek - A
Predominant Season: Summer and Winter

No. Midnight Locations: 71
No. Total Locations: 212
No. Transmittered Eagles: 33

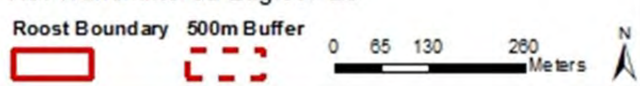
Roost Boundary 500m Buffer
0 70 140 280 Meters N

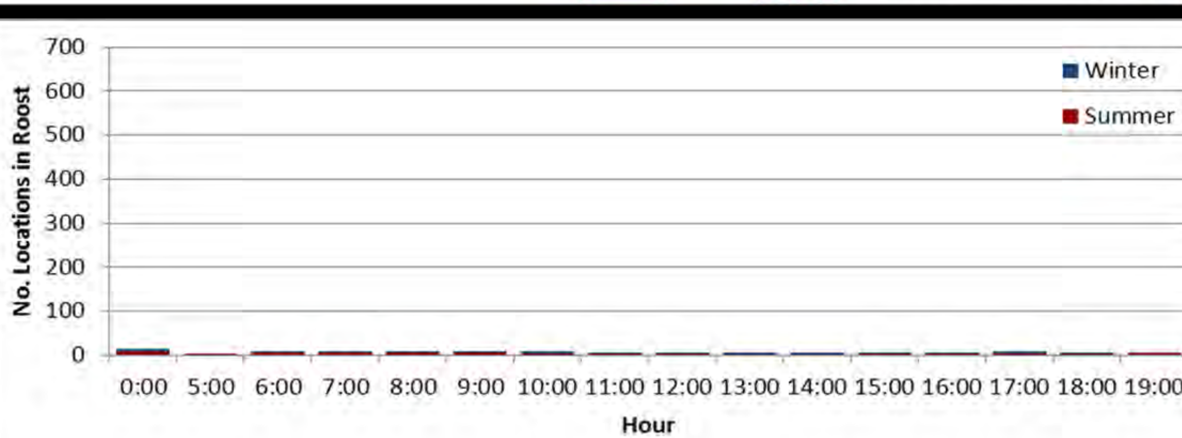




Roost No. 44
Roost Name: Little Romney Creek - A
Predominant Season: Summer and Winter

No. Midnight Locations: 16
No. Total Locations: 140
No. Transmittered Eagles: 23



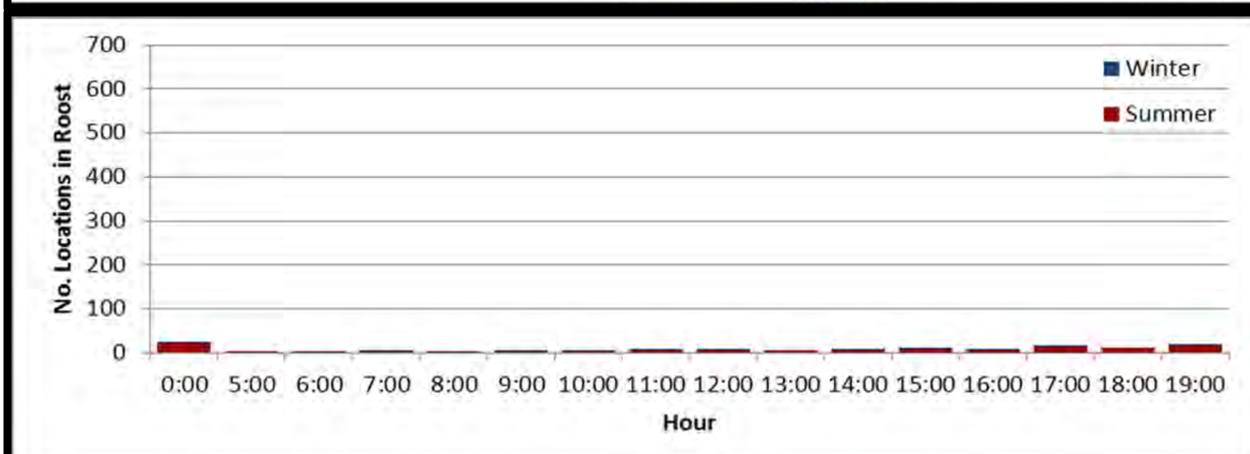


Roost No. 45
Roost Name: Lauderick Creek - B
Predominant Season: Summer

No. Midnight Locations: 33
No. Total Locations: 185
No. Transmittered Eagles: 10

Roost Boundary 500m Buffer

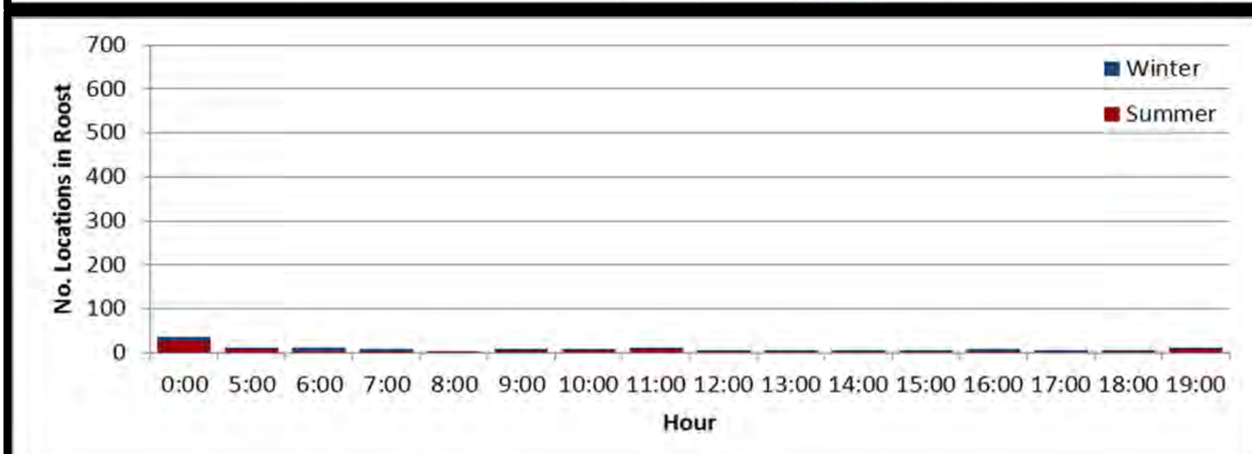
0 65 130 260 Meters N



Roost No. 46
Roost Name: Mosquito Creek - B
Predominant Season: Summer and Winter

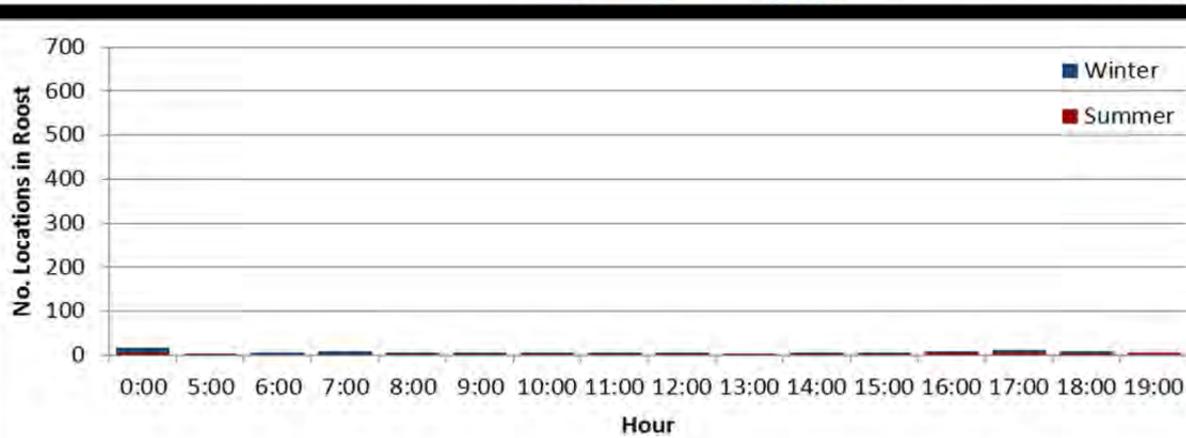
No. Midnight Locations: 43
No. Total Locations: 178
No. Transmittered Eagles: 21

Roost Boundary
500m Buffer
0 60 120 240 Meters
N



Roost No. 47
Roost Name: H-field
Predominant Season: Summer and Winter

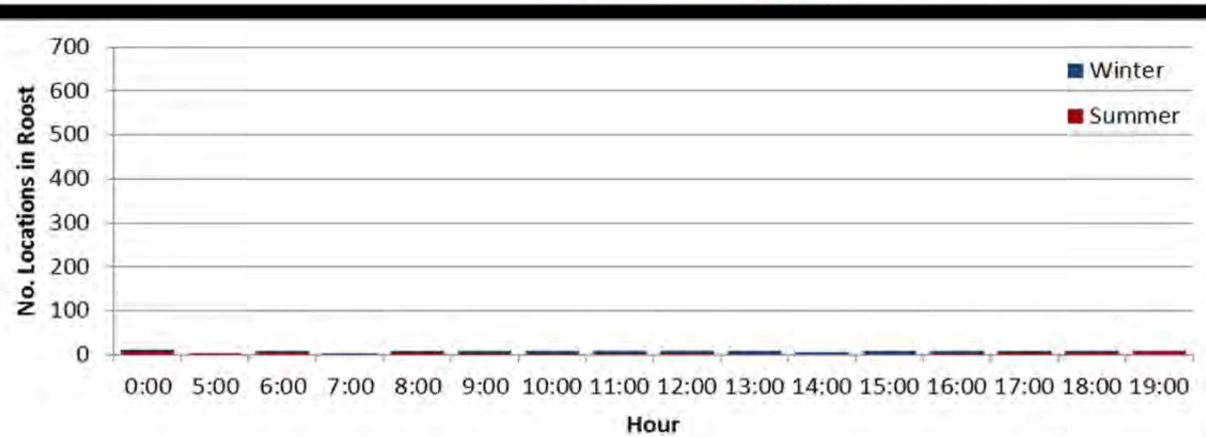
No. Midnight Locations: 30
No. Total Locations: 177
No. Transmittered Eagles: 22

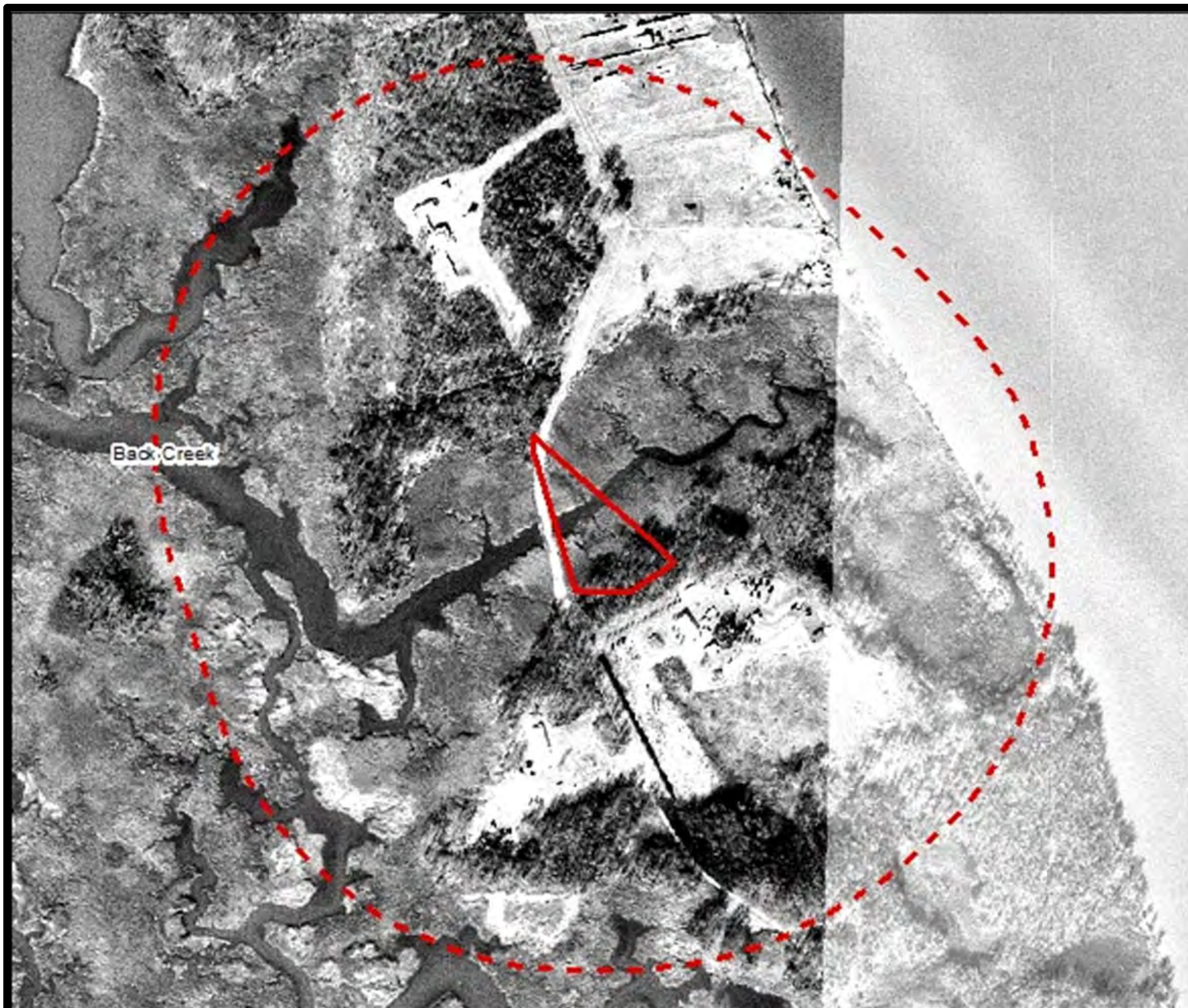


Roost No. 48
Roost Name: Palmer House
Predominant Season: Summer and Winter

No. Midnight Locations: 12
No. Total Locations: 158
No. Transmittered Eagles: 17

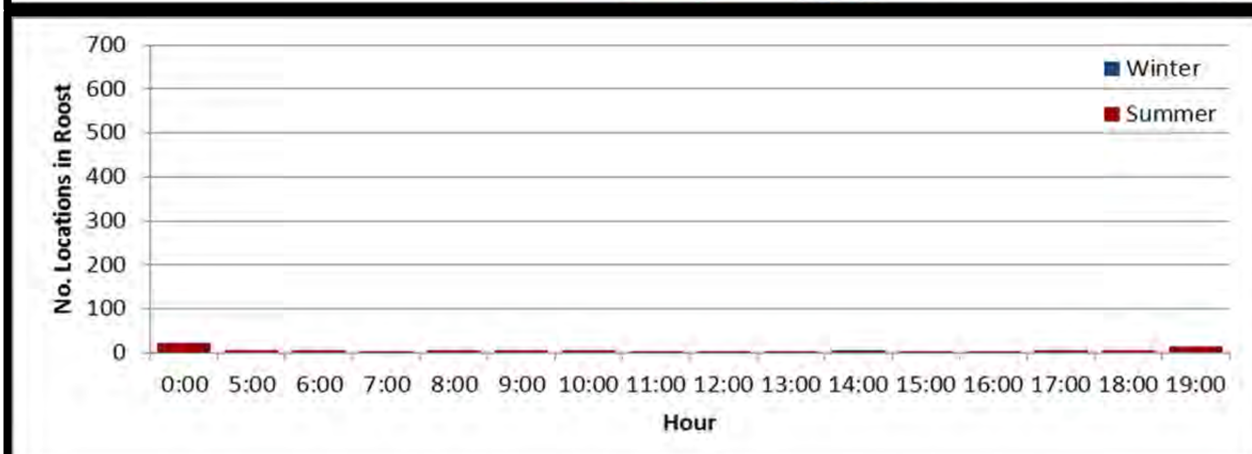
Roost Boundary
500m Buffer
0 60 120 240 Meters
N

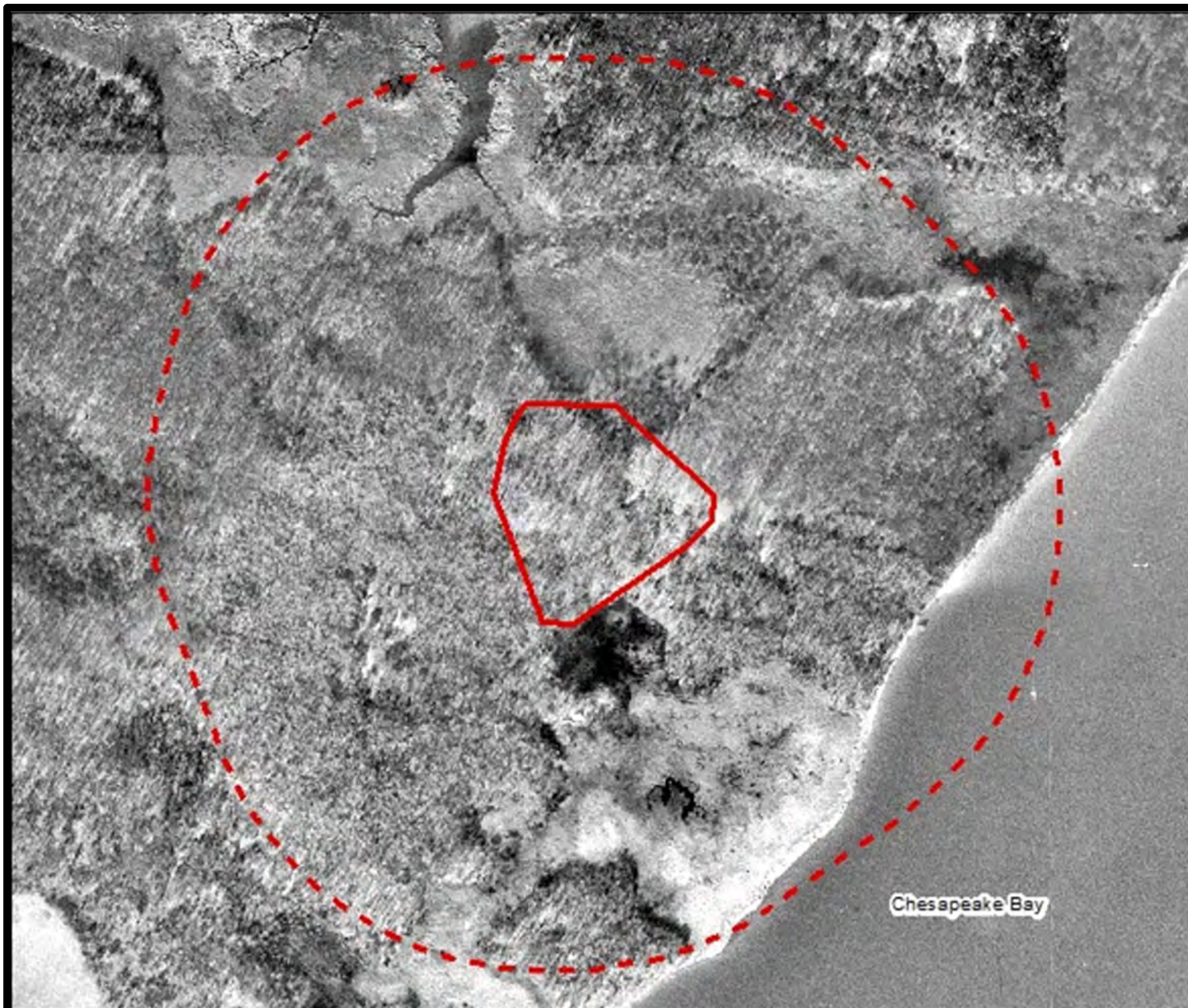




Roost No. 49
Roost Name: Range 7a - B
Predominant Season: Summer

No. Midnight Locations: 25
No. Total Locations: 141
No. Transmittered Eagles: 7





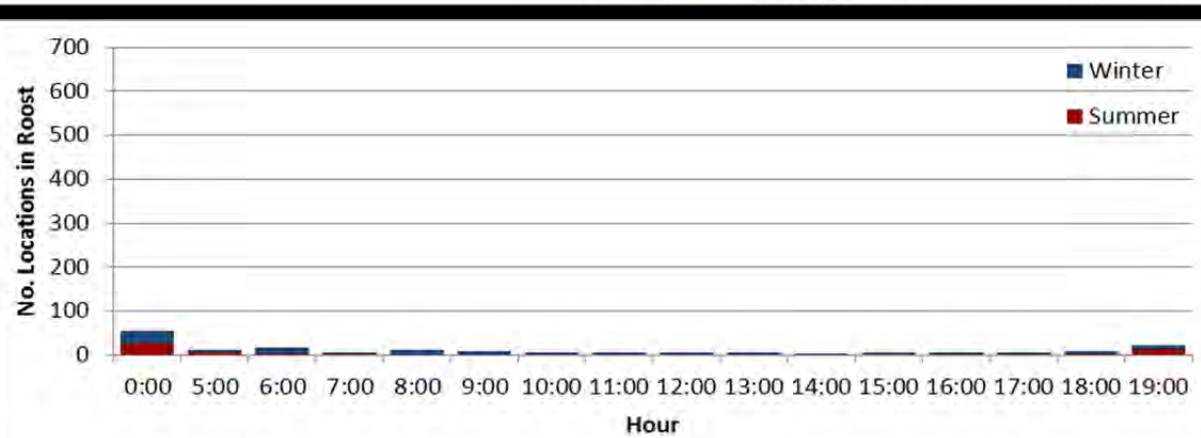
Roost No. 50
Roost Name: Locust Point - C
Predominant Season: Summer and Winter

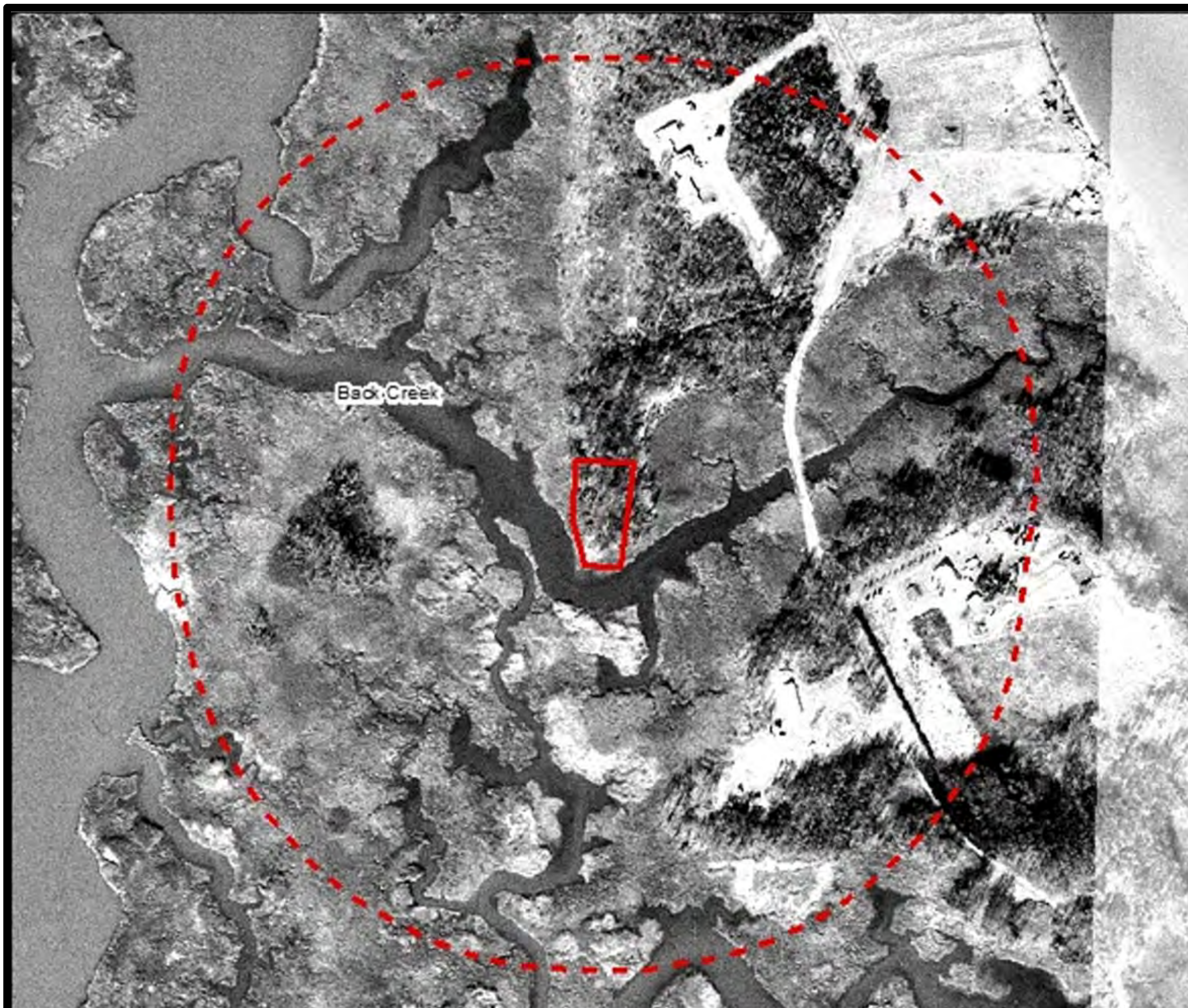
No. Midnight Locations: 78
No. Total Locations: 272
No. Transmittered Eagles: 19

Roost Boundary 500m Buffer

0 65 130 260 Meters

N

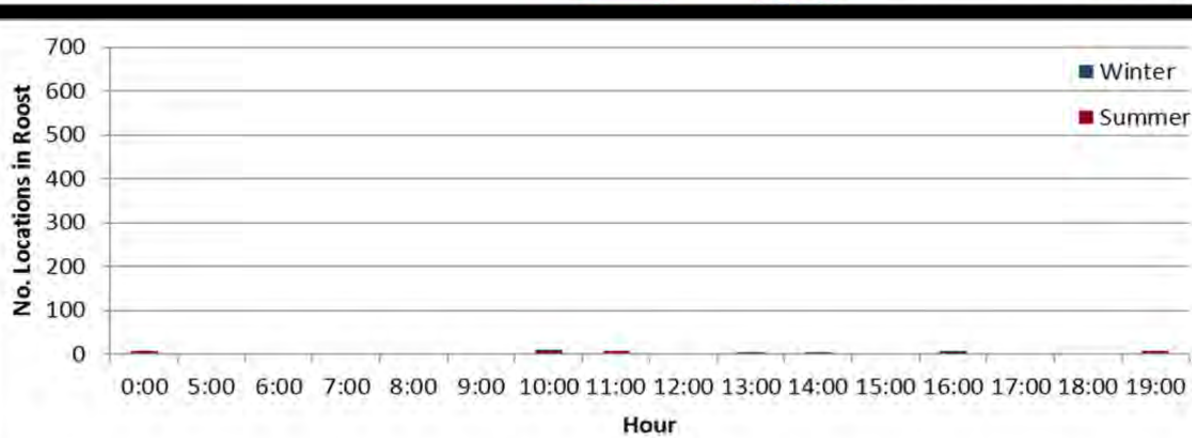


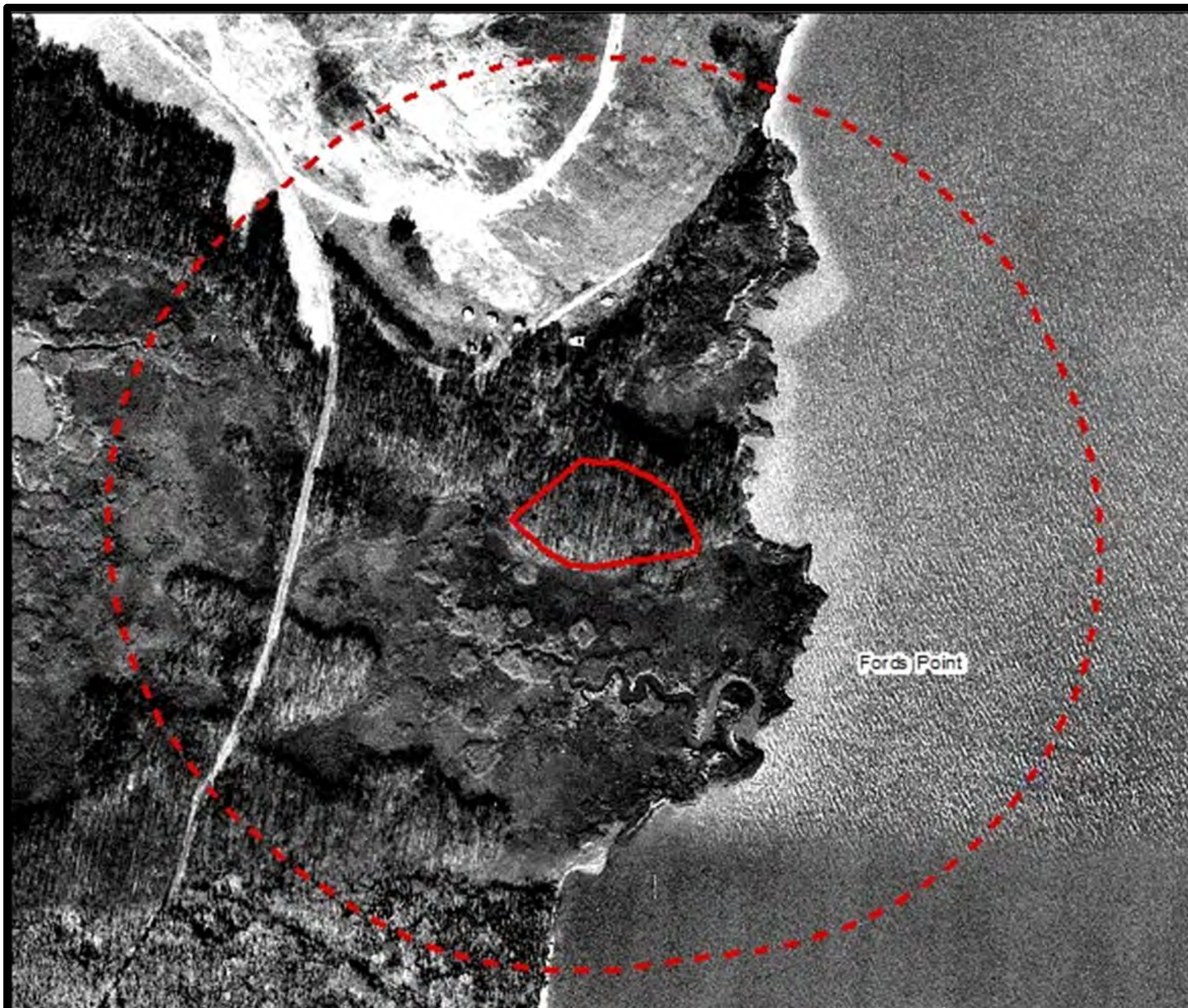


Roost No. 51
Roost Name: Range 7a - C
Predominant Season: Summer

No. Midnight Locations: 11
No. Total Locations: 93
No. Transmittered Eagles: 10

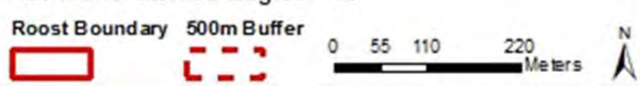
Roost Boundary
500m Buffer
0 55 110 220 Meters
N

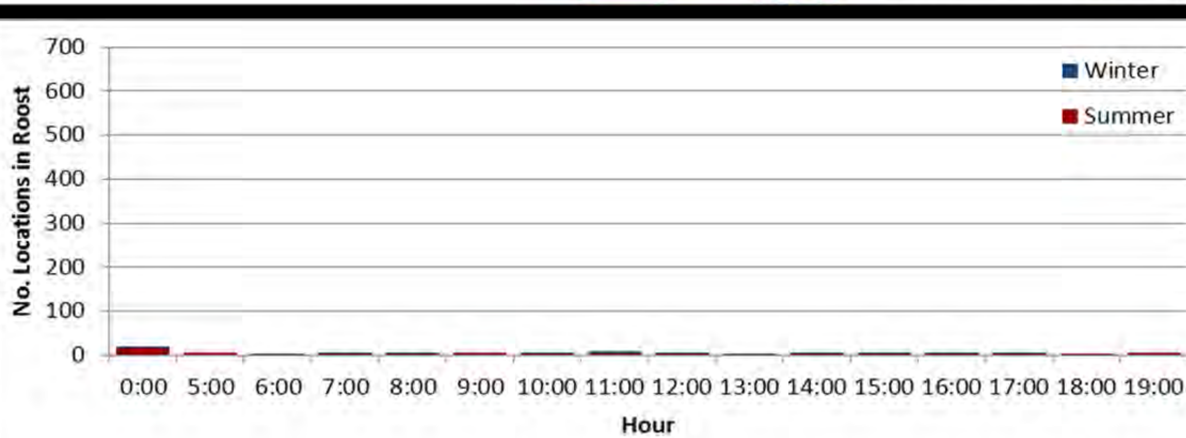




Roost No. 52
Roost Name: Fords Point - B
Predominant Season: Summer and Winter

No. Midnight Locations: 28
No. Total Locations: 146
No. Transmittered Eagles: 15

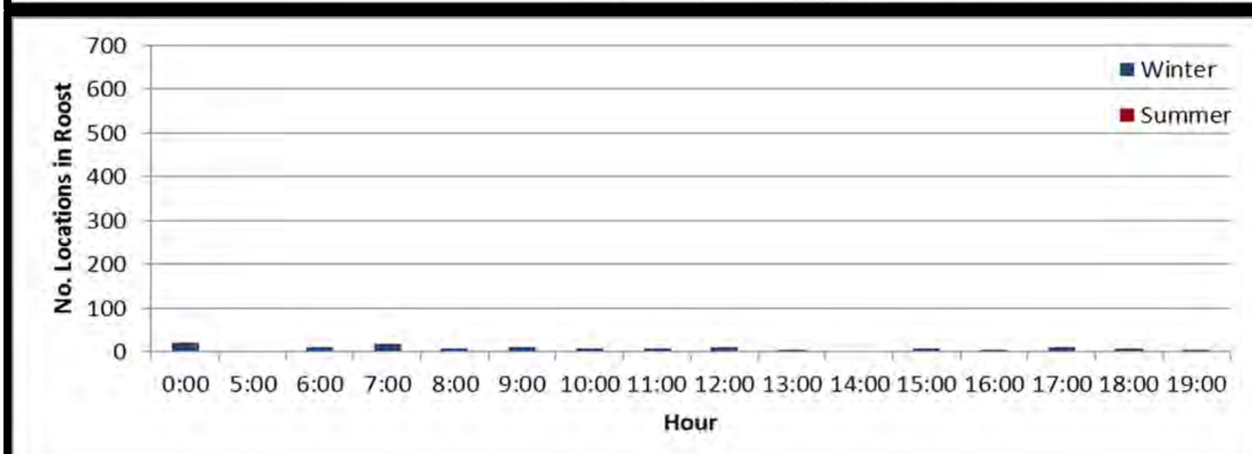


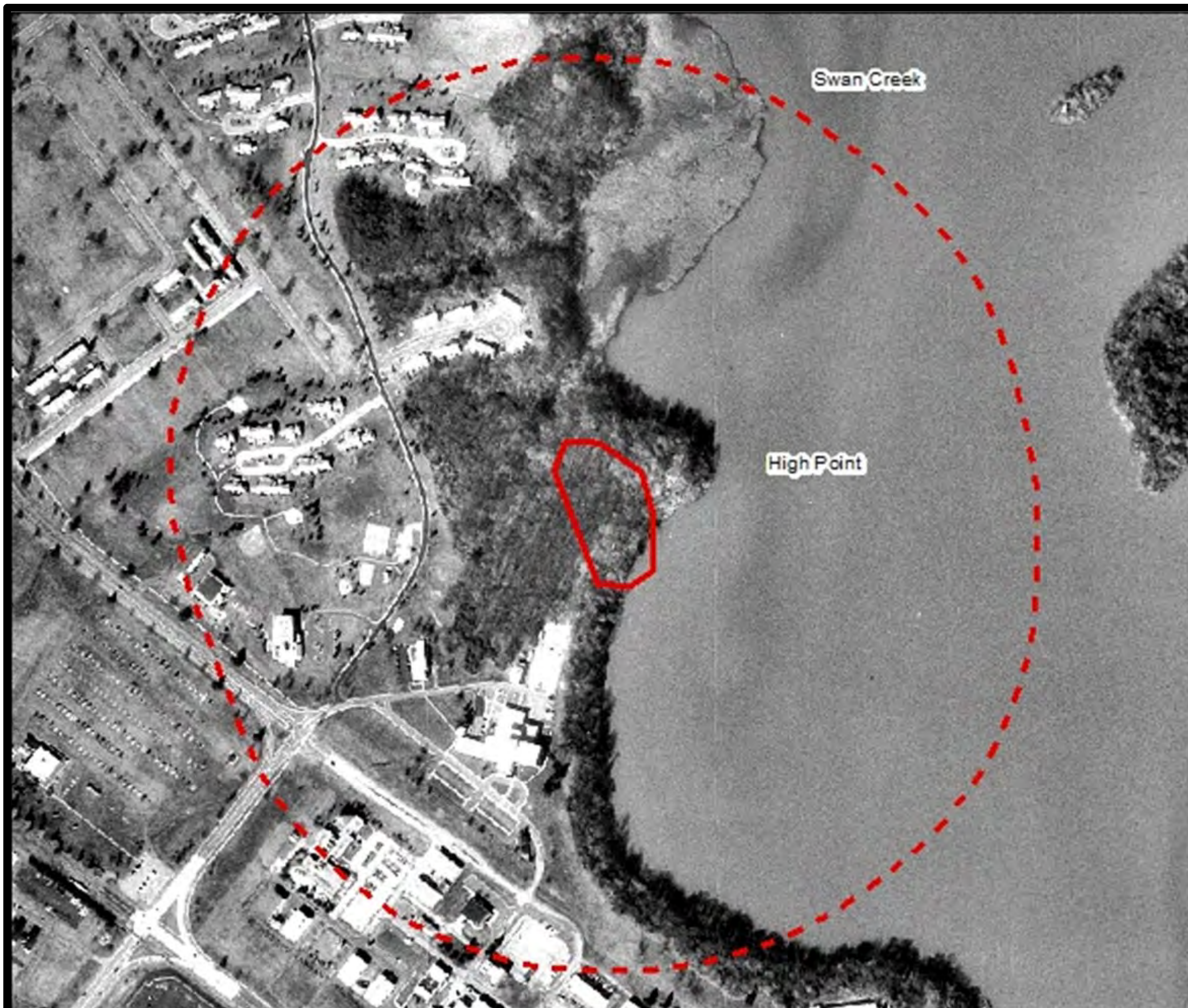


Roost No. 53
Roost Name: Poverty Island
Predominant Season: Winter

No. Midnight Locations: 24
No. Total Locations: 141
No. Transmittered Eagles: 19

Roost Boundary
500m Buffer
0 65 130 260 Meters
N

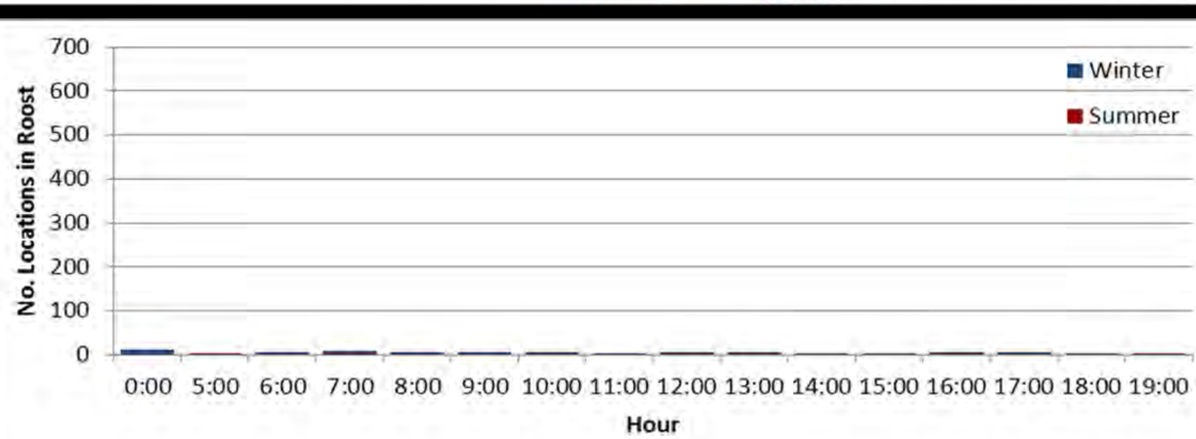


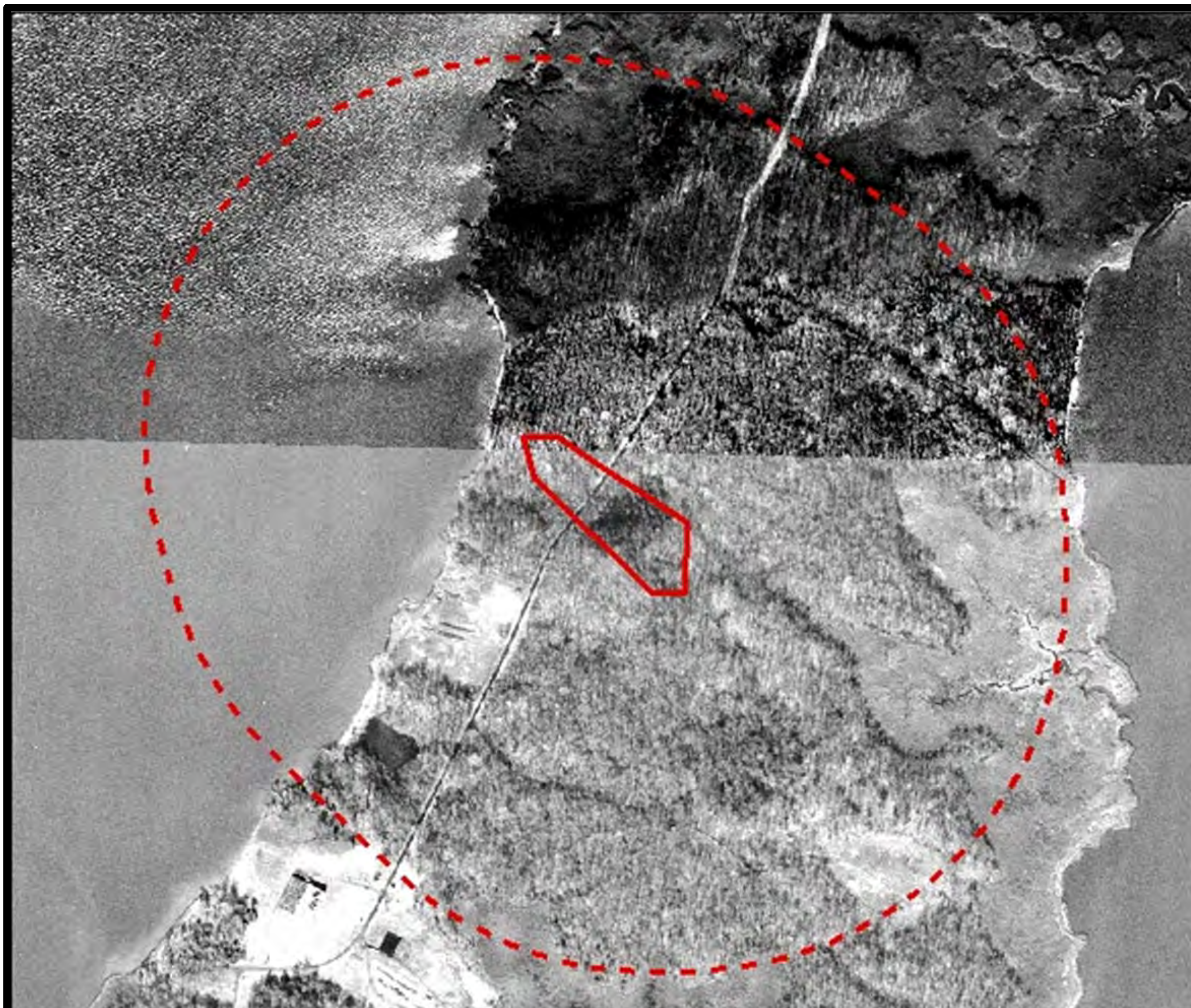


Roost No. 54
Roost Name: Swan Creek - B
Predominant Season: Summer and Winter

No. Midnight Locations: 12
No. Total Locations: 85
No. Transmittered Eagles: 15

Roost Boundary 500m Buffer
0 60 120 240 Meters
N



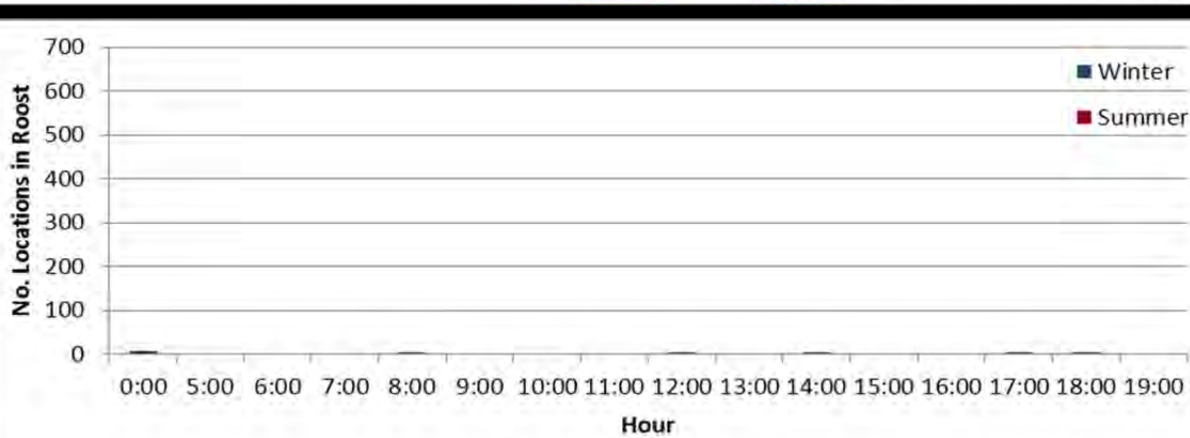


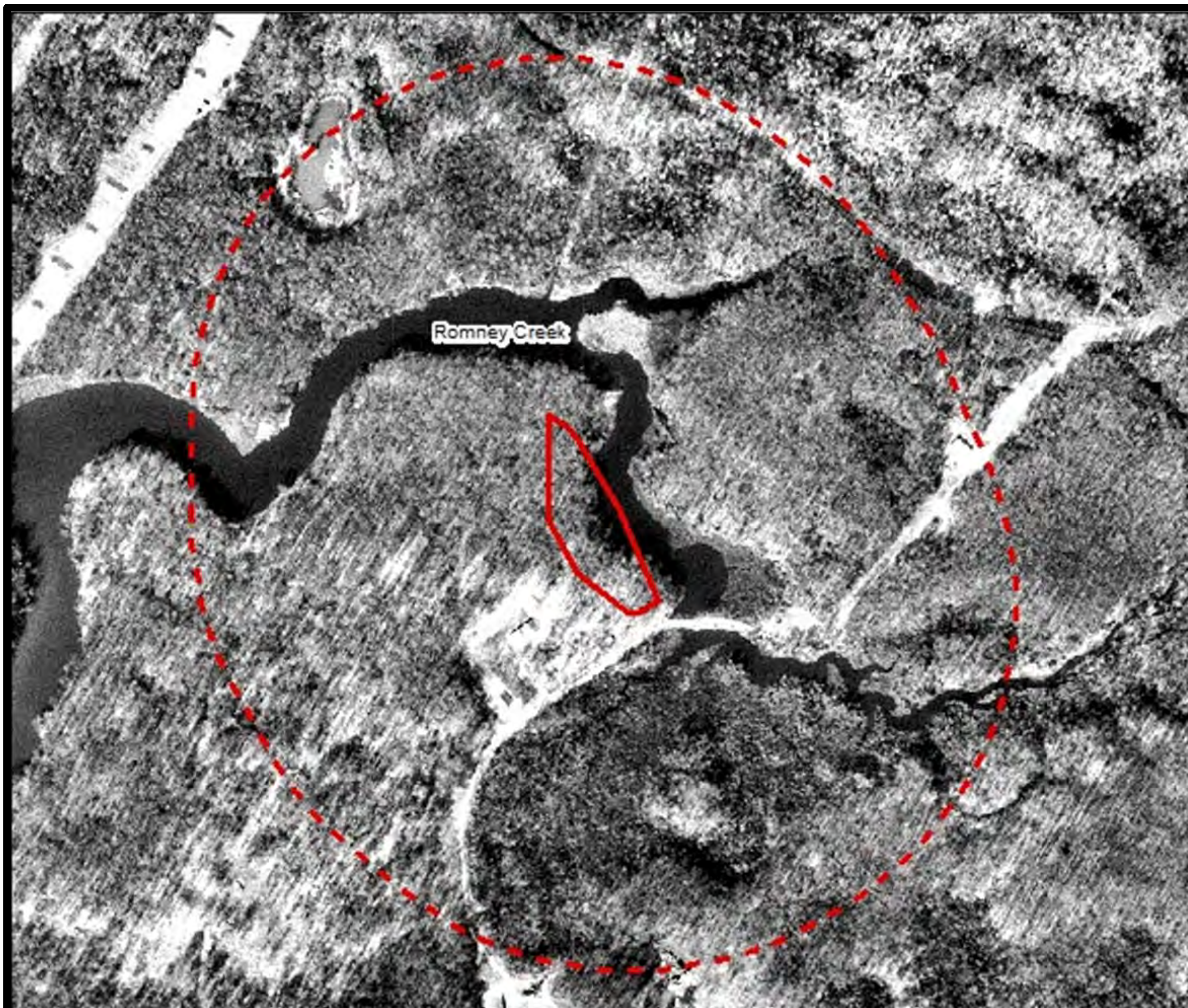
Roost No. 55
Roost Name: J-field
Predominant Season: Summer and Winter

No. Midnight Locations: 17
No. Total Locations: 90
No. Transmittered Eagles: 10

Roost Boundary   500m Buffer

0 60 120 240 Meters   N

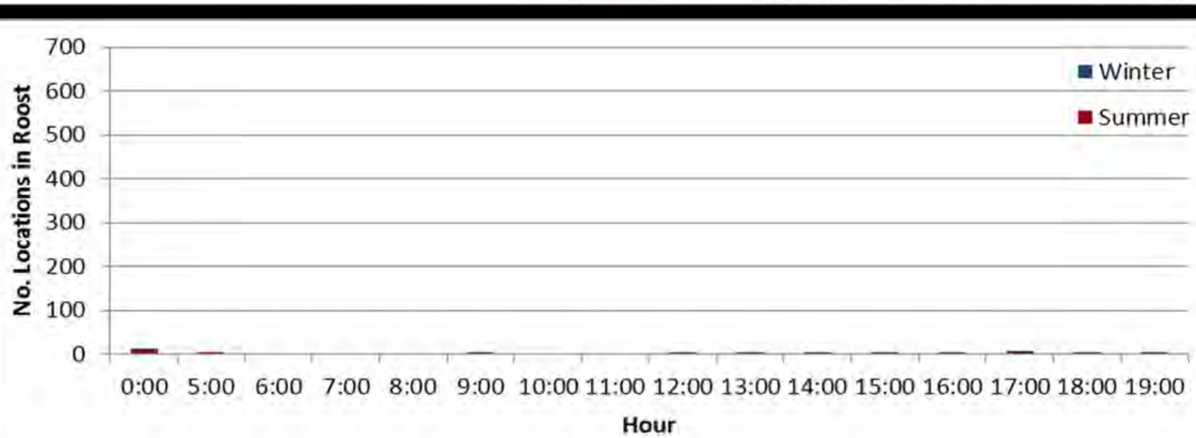


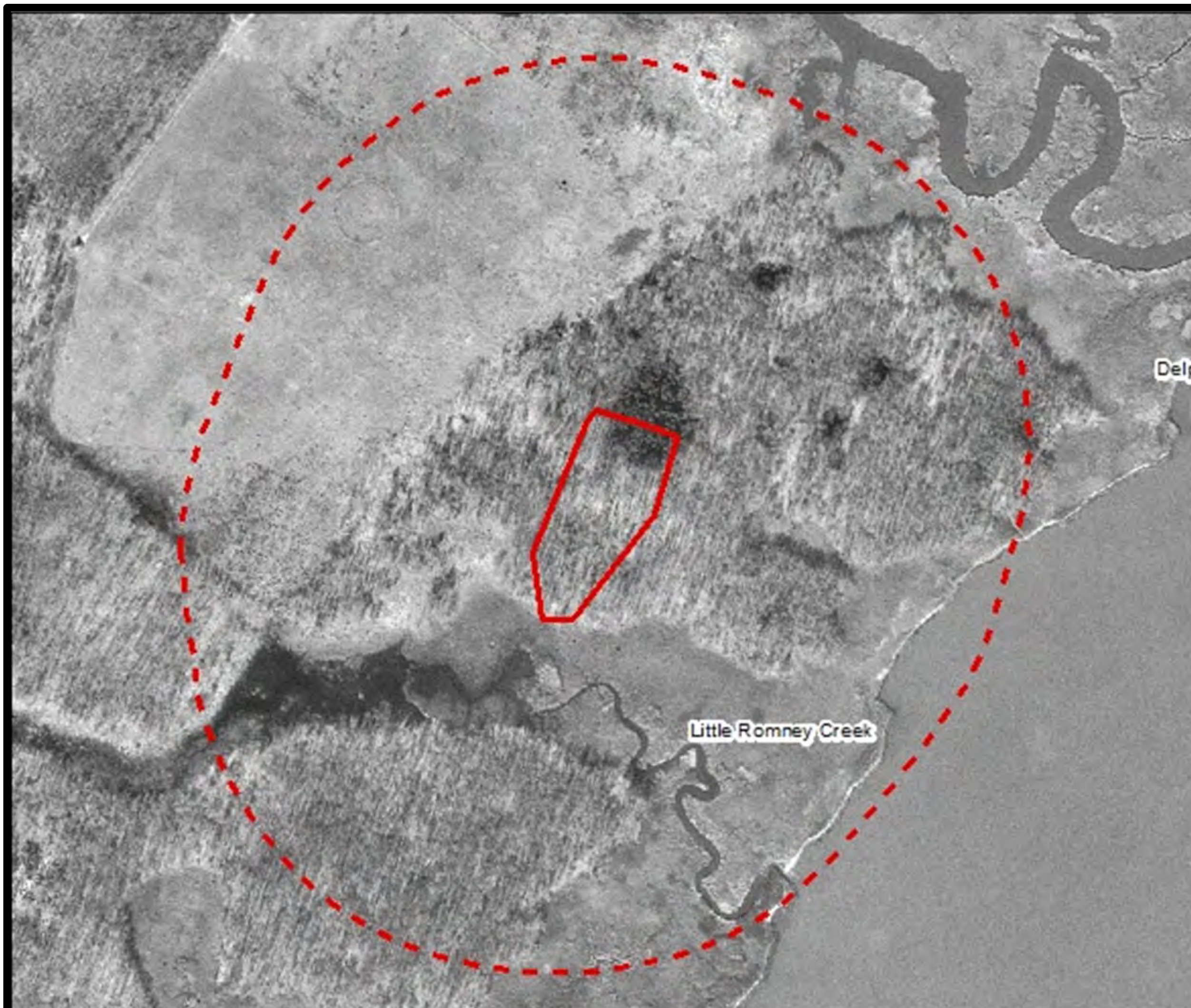


Roost No. 56
Roost Name: Romney Creek - B
Predominant Season: Summer and Winter

No. Midnight Locations: 11
No. Total Locations: 57
No. Transmittered Eagles: 15

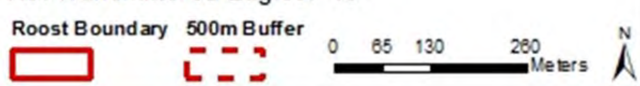
Roost Boundary 500m Buffer
0 62.5 125 250 Meters
N

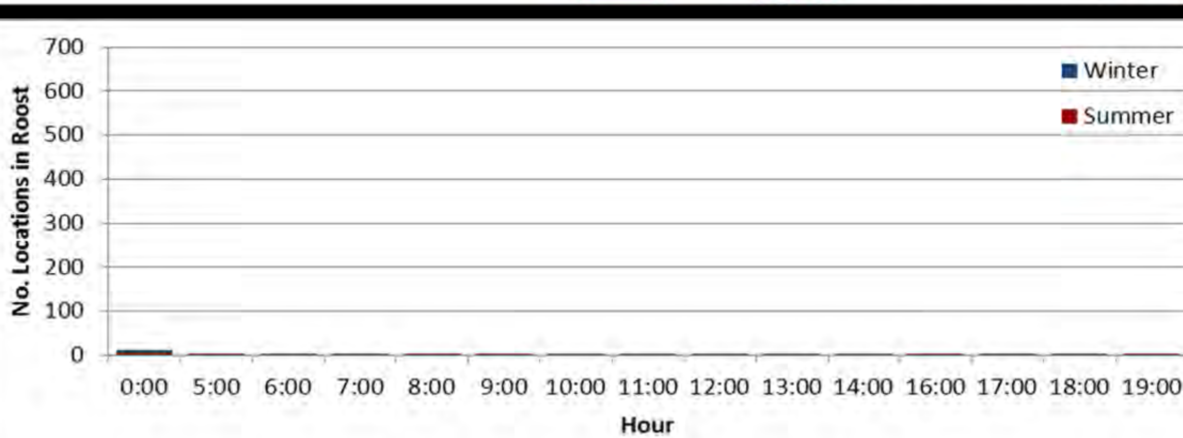


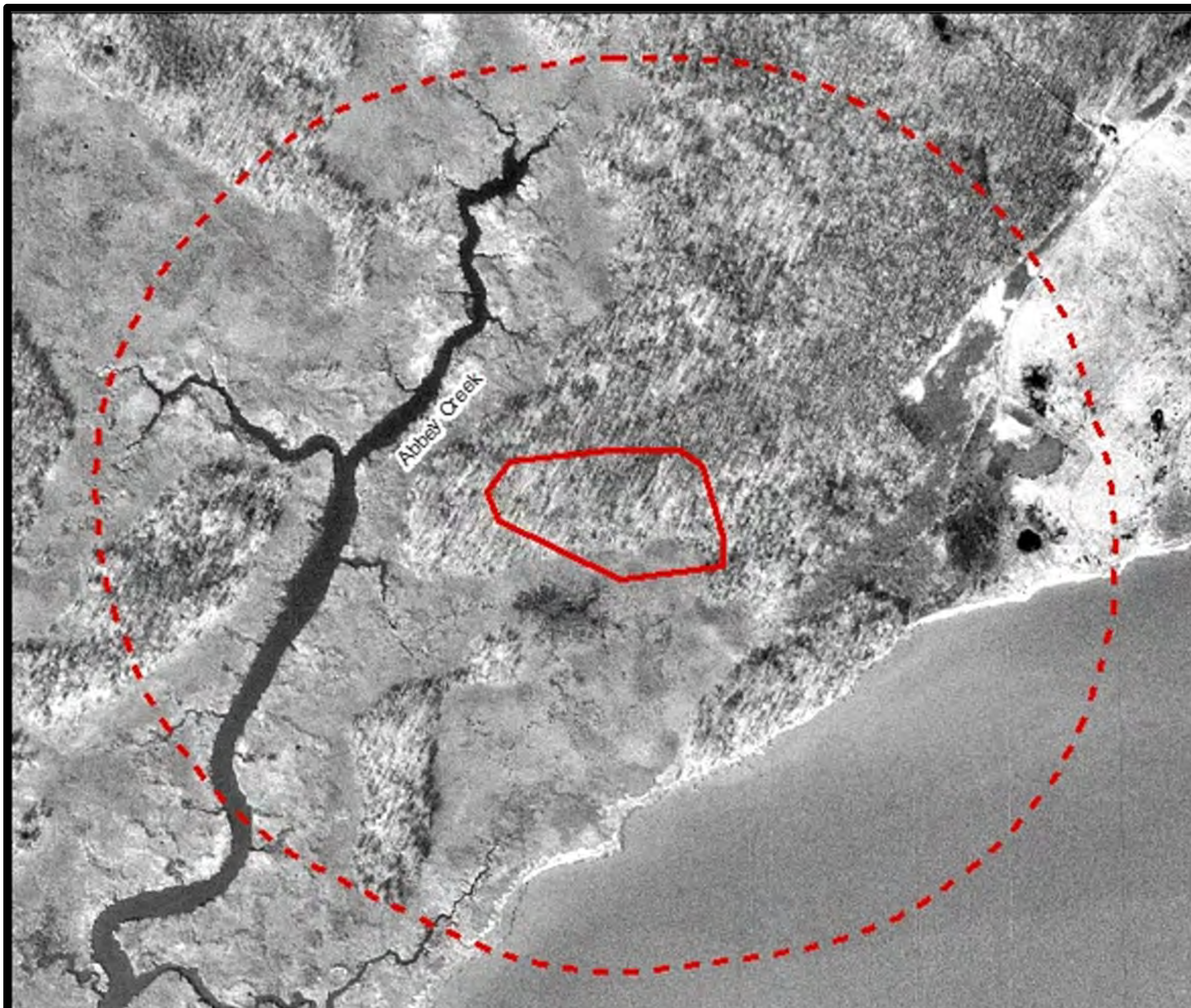


Roost No. 57
Roost Name: Little Romney Creek - B
Predominant Season: Summer and Winter

No. Midnight Locations: 17
No. Total Locations: 60
No. Transmittered Eagles: 15

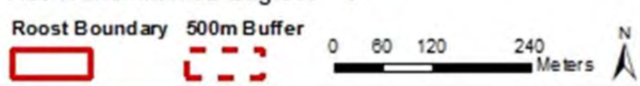


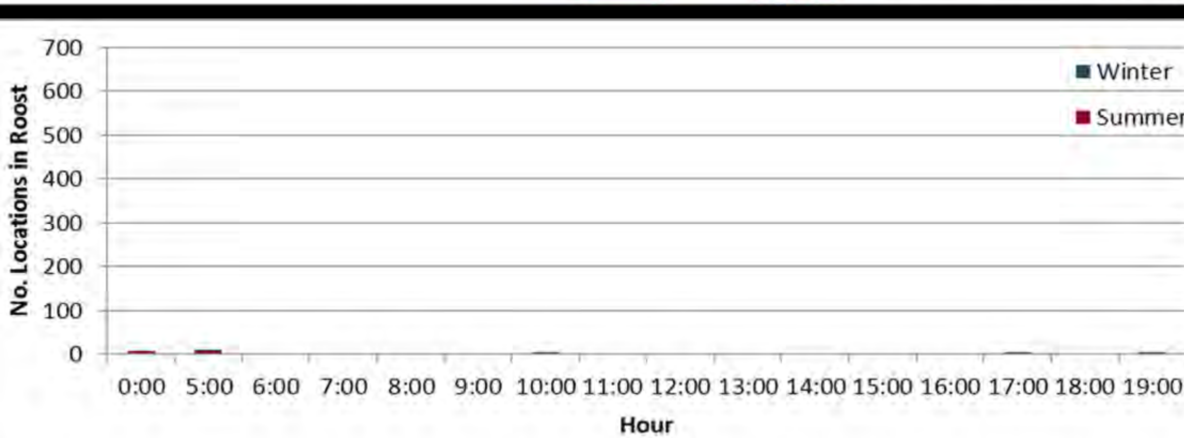


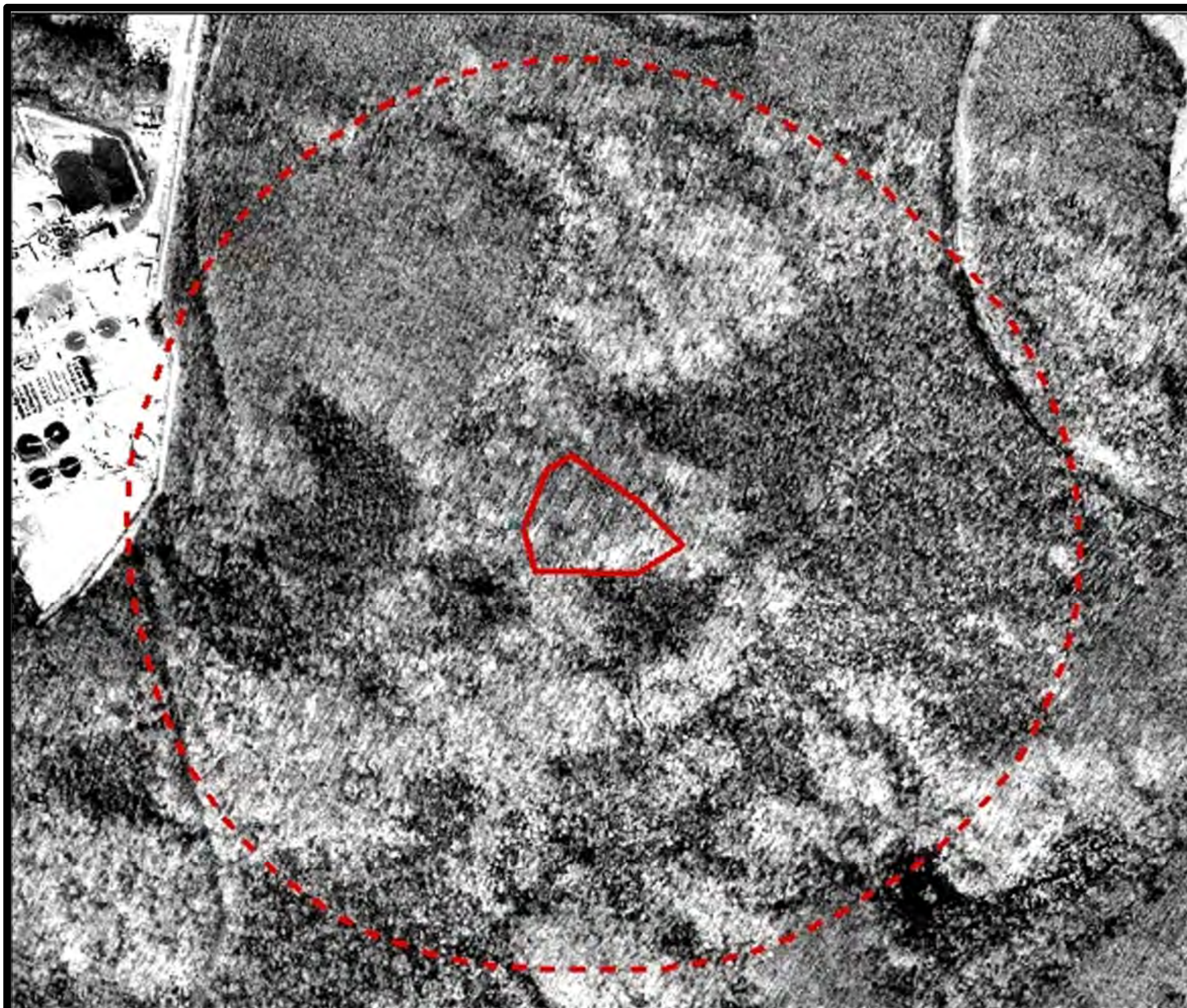


Roost No. 58
Roost Name: Abbey Point
Predominant Season: Summer and Winter

No. Midnight Locations: 20
No. Total Locations: 44
No. Transmittered Eagles: 8

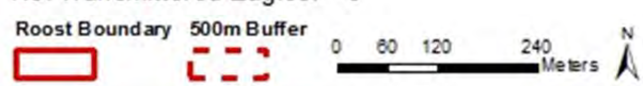


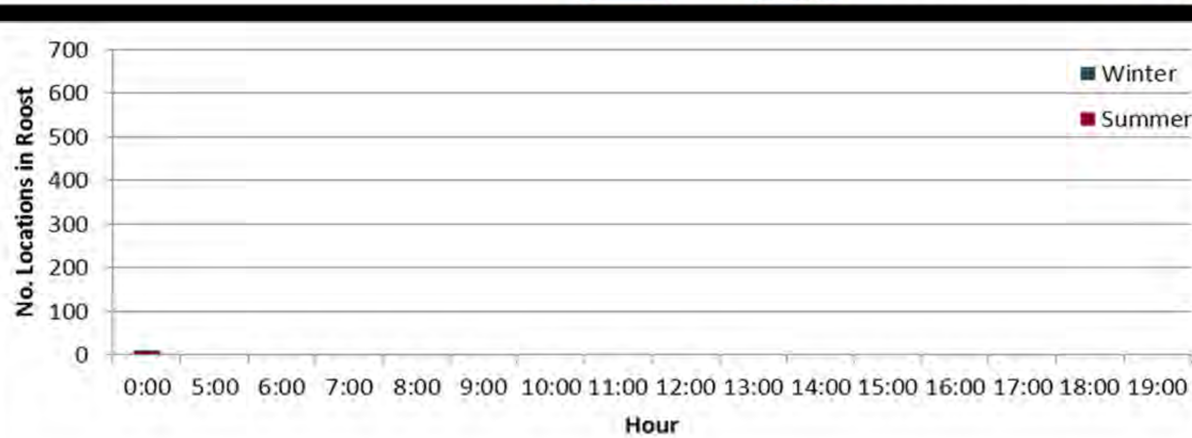




Roost No. 59
Roost Name: Water Treatment Plant
Predominant Season: Summer and Winter

No. Midnight Locations: 10
No. Total Locations: 22
No. Transmittered Eagles: 8





Appendix 10. Dead or injured bald eagles documented on Aberdeen Proving Ground May 1985 – May 2012. From 2007 to 2012 an Army veterinarian necropsied carcasses and determined cause of death. Injured birds were sent to Tri-state Animal Hospital in DE. Data collected and maintained by the APG Department of Public Works Environmental Management Division.

Date	Location	Age	Cause	Status
5/24/1985	C-Field near a telephone pole transformer	Immature	Electrocution	Dead
11/15/1989	Whorton Point Tower	Subadult	Electrocution	Dead
3/19/1990	Range 14 on Spesutie Island	Immature	Electrocution	Dead
7/30/1990	Range 7 near powerline pole	Immature	Electrocution	Dead
7/27/1992	Range 10 on Spesutie Island	Adult	Line strike	Dead
7/22/1993	Range 18 on Spesutie Island near base of powerline pole next to Building 1146B	Immature	Electrocution	Dead
8/7/1995	Range 10 on Spesutie Island near a powerline pole	Unknown	Electrocution	Dead
4/22/1996	Poverty Island	Unknown	Electrocution	Dead
5/1/1996	Super Pond	Immature	Electrocution	Dead
7/18/1997	Gunpowder Marina	Immature	Undetermined	Injured
4/13/1998	Maryland National Guard area near Nike Site	Adult	Bacterial Infection	Dead
2/23/1999	Locust Point area on Spesutie Island	Adult	Electrocution	Dead
4/20/1999	Building 910 in Ford's Farm area	Unknown	Line strike	Dead
10/20/1999	Trench Warfare Range	Immature	Undetermined	Injured
7/30/2000	Building 1161 on Spesutie Island near a powerline pole	Unknown	Line strike	Dead
8/1/2000	Locust Point area on Spesutie Island	Immature	Electrocution	Dead
8/23/2000	Locust Point area on Spesutie Island near a powerline pole	Immature	Line strike	Dead
8/29/2000	Amphibious landing area next to powerline pole	Immature	Electrocution	Dead
11/8/2001	100 yards south of AA5 range entrance in the woods	Immature	Undetermined	Injured
1/27/2002	Michaelsville area near a powerline pole	Immature	Range Fire	Dead
2/9/2002	Skipper's Point Campground	Adult	Undetermined	Injured
5/14/2002	Range 7A on Spesutie Island near Building 1139	Immature	Natural causes	Dead
5/14/2002	Range 7A on Spesutie Island near Building 1139	Immature	Natural causes	Injured
6/6/2002	Graces Quarters next to old FEMA bunker	Immature	Line strike	Dead
6/17/2002	Range 16 on Spesutie Island near a powerline pole near Building 1199	Immature	Line strike	Dead
7/8/2002	Ricketts Point Road near Building E1476 in the Watson Creek area	Adult	Undetermined	Dead
8/21/2002	Locust Point area on Spesutie Island near a powerline pole	Immature	Line strike	Injured
8/24/2002	Mulberry Point near Building 634	Subadult	Line strike	Dead

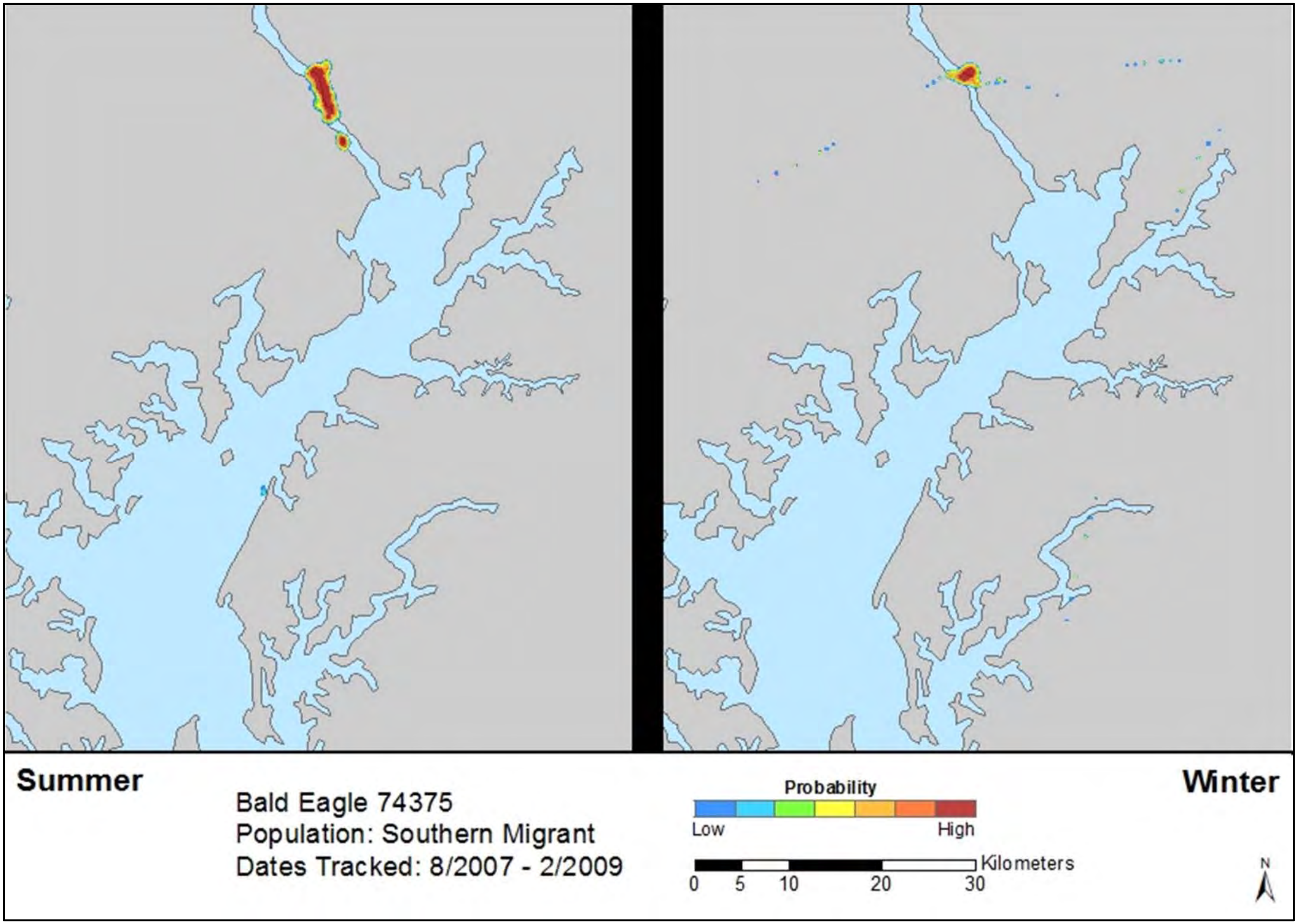
Date	Location	Age	Cause	Status
8/25/2002	Locust Point area on Spesutie Island below a telephone pole near Building 1134A	Subadult	Line strike	Dead
1/4/2003	Spesutie Island in the middle of Spesutie Island Road by the Guard Shack	Adult	Line strike	Dead
2/22/2003	Michaelsville Road under a powerline pole near Building 742	Adult	Line strike	Dead
2/25/2003	Area 389 near Building 762 on Old Baltimore Road	Adult	Undetermined	Dead
3/13/2003	Test Course A of Perryman Test Track	Adult	Mating Flight	Injured
3/18/2003	Spesutie Island near Building 1181	Adult	Line strike	Dead
4/29/2003	East side of Watson Creek Road near powerline pole	Immature	Line strike	Dead
5/2/2003	Along Watson Creek Road adjacent to Watson Creek near powerline pole	Adult	Electrocution	Dead
5/12/2003	Fords Farm Road	Adult	Undetermined	Injured
5/27/2003	M-Field area near Watson Creek	Subadult	Line strike	Dead
6/15/2003	J-Field area along Ricketts Point Road	Adult	Electrocution	Dead
6/21/2003	Middle of Range 7 on Spesutie Island	Immature	Line strike	Dead
8/19/2003	Near a shed on L-Field	Adult	Viral Infection	Dead
8/25/2003	C-Field beneath a powerline pole adjacent to Building 1428	Immature	Electrocution	Dead
11/12/2003	Mulberry Point boat dock	Adult	Undetermined	Dead
12/7/2003	B-1 Range at the 2000M location	Immature	Electrocution	Dead
12/26/2003	Palmer Road	Immature	Electrocution	Dead
12/26/2003	Palmer Road	Immature	Electrocution	Dead
1/17/2004	Grace's Quarters	Immature	Electrocution	Dead
2/27/2004	Building E1423	Immature	Undetermined	Dead
3/17/2004	300 yards west of Poverty Island Road and 20 yards east of Romney Creek shoreline	Adult	Undetermined	Dead
3/20/2004	Towner cove nest	Adult	Intraspecies aggression	Dead
4/18/2004	East leg Spesutie Island	Adult	Electrocution	Dead
5/28/2004	Bldg 1146B Spesutie island	Subadult	Line strike	Dead
6/14/2004	M Field	Subadult	Undetermined	Dead
6/15/2004	East leg - Spesutie Island	Adult	Undetermined	Dead
6/15/2004	Spesutie Island	Subadult	Undetermined	Dead
7/1/2004	Maxwell Point	Subadult	Undetermined	Dead
7/20/2004	Spesutie Island	Adult	Line strike	Dead
8/23/2004	East leg Spesutie Island	Immature	Line strike	Dead
9/4/2004	Spesutie Island	Immature	Line strike	Dead

Date	Location	Age	Cause	Status
10/11/2004	Spesutie Island	Immature	Line strike	Dead
10/14/2004	L Field	Immature	Electrocution	Dead
1/18/2005	Michaelsville Area	Subadult	Electrocution	Dead
4/5/2005	Poverty Island	Subadult	Electrocution	Dead
4/14/2005	Poverty Island Range 3	Unknown	Line strike	Dead
5/2/2005	Poverty Island Range 3	Immature	Electrocution	Dead
5/2/2005	I Field	Immature	Line strike	Dead
8/19/2005	Spesutie Island	Immature	Undetermined	Dead
9/5/2005	Spesuite Island	Adult	Electrocution	Dead
1/27/2006	H Field	Adult	Undetermined	Dead
2/10/2006	Air Base range 9	Adult	Undetermined	Dead
6/20/2006	Trench Warfare	Unknown	Undetermined	Dead
7/9/2006	J Field	Subadult	Undetermined	Dead
8/20/2006	Spesutie Island, adjacent to Bldg #1155	Unknown	Undetermined	Dead
9/29/2006	East Leg of Spesutie Island adjacent to range 18	Unknown	Undetermined	Dead
1/18/2007	Off-Post bridge near Carroll Island Power Plant	Adult	Intraspecies aggression	Dead
3/30/2007	PAAF	Unknown	Undetermined	Dead
4/3/2007	Spesutie Island, Range 14	Subadult	Undetermined	Dead
6/14/2007	Spesutie Island, Fuse Range	Subadult	Natural causes	Dead
6/22/2007	Spesutie Island	Subadult	Line strike	Dead
6/27/2007	L-field	Unknown	Drowning	Dead
3/18/2008	Sod Run roost buffer	Adult	Natural causes (lightning strike)	Dead
6/25/2008	Maxwell Point	Adult	Natural causes	Dead
1/20/2009	CAPA Field	Adult	Likely natural causes (striking tree limb in flight or territorial fight with another bird)	Injured
8/7/2009	I-Field	Hatchling	Possibly natural causes (predation)	Dead
8/29/2009	Spesutie Island	Subadult	Line strike and electrocution	Dead
8/31/2009	Spesutie Island	Subadult	Electrocution	Dead
9/13/2009	Woodpecker Point	Immature	Line strike	Dead

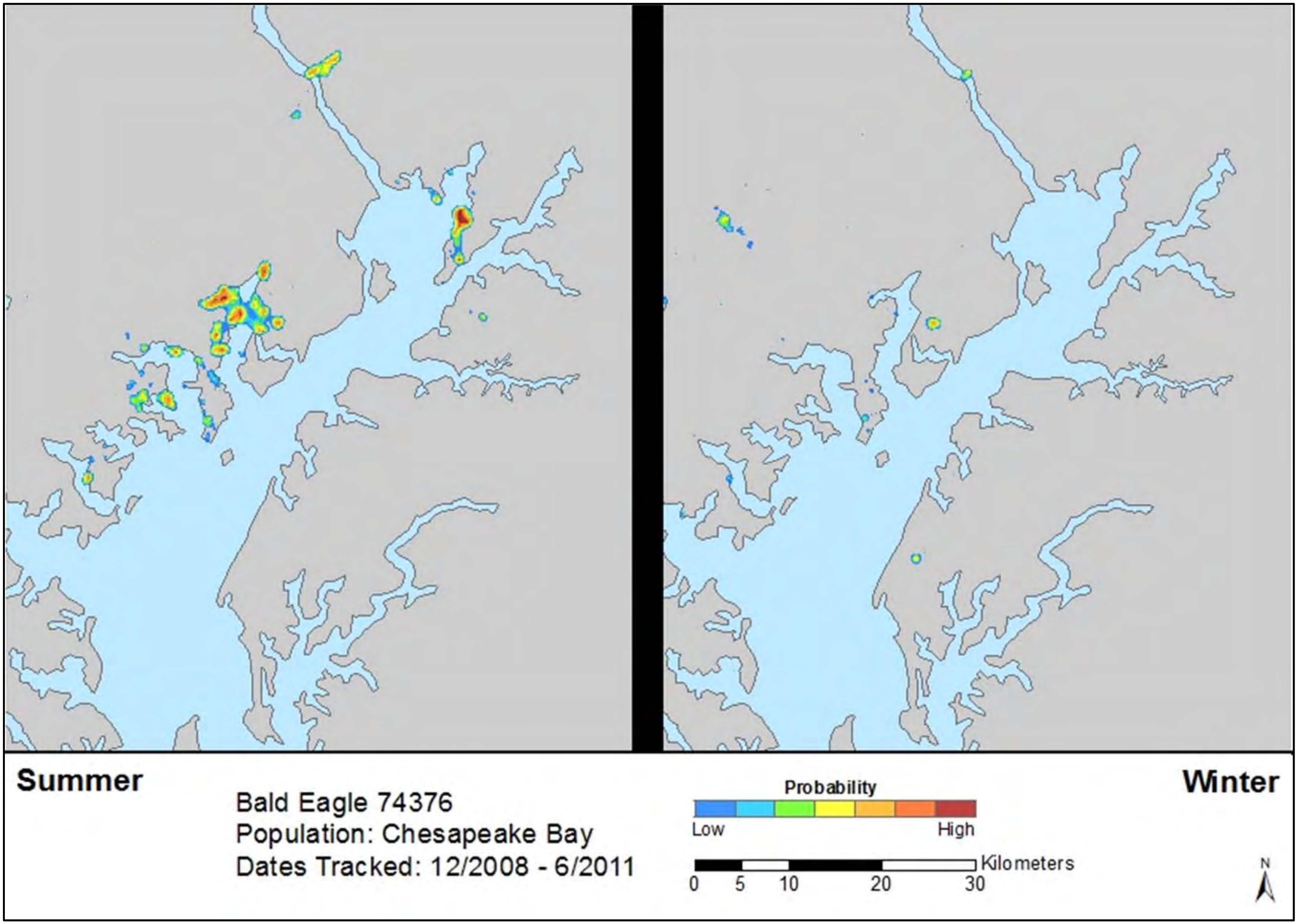
Date	Location	Age	Cause	Status
1/5/2010	New Bombing Field	Subadult	Electrocution	Dead
3/3/2010	Dipper Creek marsh	Adult	Undetermined	Injured
3/13/2010	Off-Post Perryman north of Sod Run Treatment Plant	Subadult	Undetermined	Dead
3/15/2010	Old Baltimore Road south of Vertical Camera	Adult	Line strike and electrocution	Dead
4/2/2010	Building 449	Adult	Undetermined	Injured
4/15/2010	Perryman Test Area	Adult	Undetermined	Injured
4/26/2010	Spesutie Island near Bldg 1196	Adult	Line strike and electrocution	Dead
6/21/2010	C-Field	Subadult	Undetermined	Dead
7/21/2010	J-Field	Adult	Line strike	Dead
7/29/2010	Spesutie Island near Bldg 1122	Subadult	Line strike	Dead
8/12/2010	Spesutie Island near Magazine 1181	Subadult	Electrocution	Dead
9/19/2010	Spesutie Island Bldg 1188	Adult	Impaled on lightning rod	Injured
1/3/2011	Fords Farm Road	Subadult	Line strike	Dead
1/25/2011	Spesutie Island Range 14	Adult	Line strike and electrocution	Dead
2/4/2011	Old Baltimore Road	Subadult	Intraspecies aggression followed by line strike with electrocution	Dead
2/9/2011	Swan Creek	Adult	Likely electrocution off-Post	Dead
2/16/2011	Ricketts Point Road north of I-Field	Adult	Natural causes (intraspecies aggression)	Injured
3/22/2011	Michaelsville Road	Subadult	Line strike	Dead
4/9/2011	Spesutie Island near Bldg 1131	Subadult	Line strike and electrocution	Dead
4/10/2011	Stoney Point	Adult	Natural causes (intraspecies aggression)	Dead
6/9/2011	Woodpecker Point	Adult	Line strike	Dead
9/13/2011	Spesutie Island near EF9	Subadult	Line strike and electrocution	Dead
10/1/2011	Carroll Island	Subadult	Lead toxicity	Dead
11/20/2011	Old Baltimore Road	Adult	Line strike and	Injured

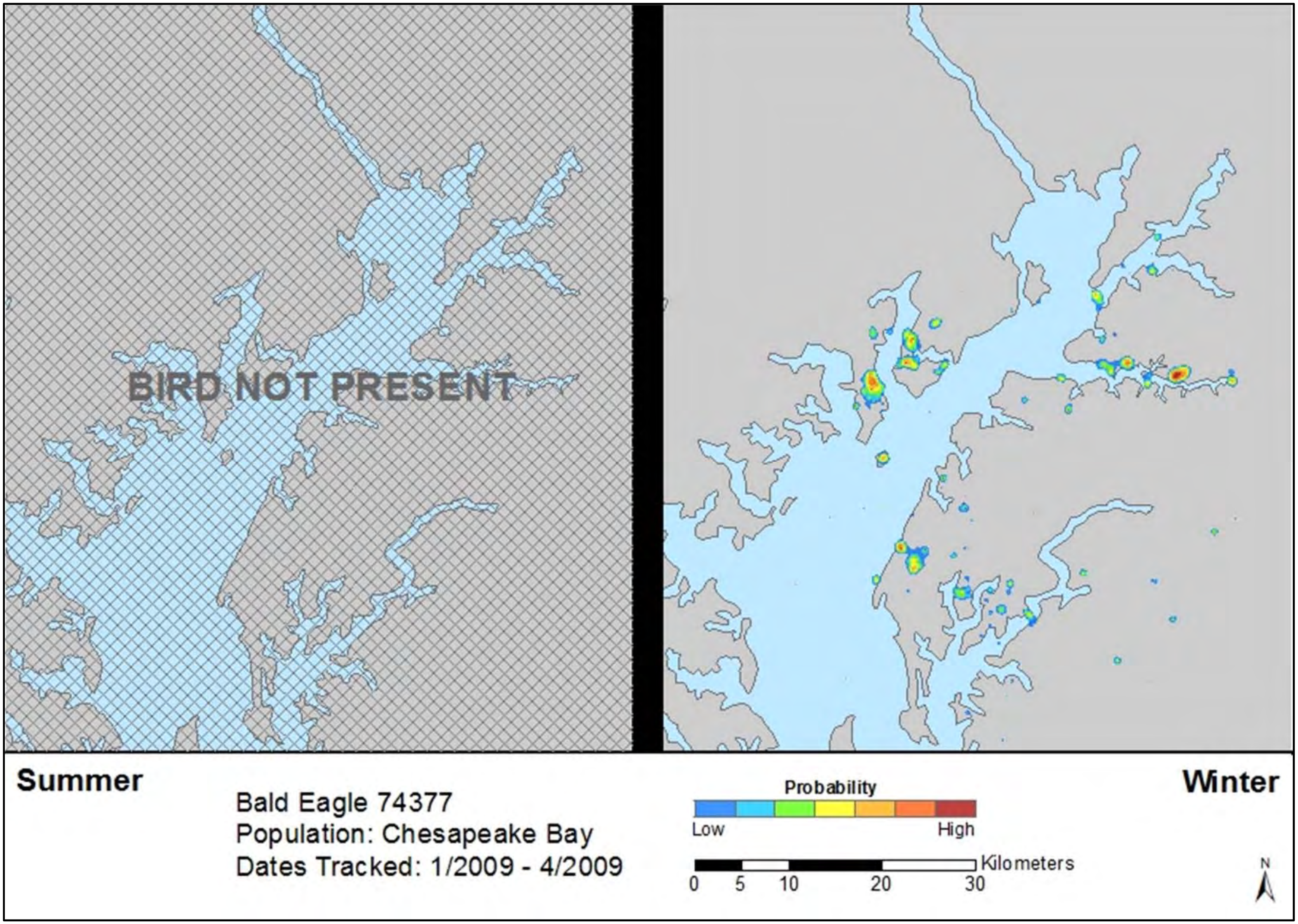
Date	Location	Age	Cause	Status
			electrocution (likely lead toxicity)	
12/27/2011	Maxwell Point	Subadult	Line strike	Dead
2/6/2012	Michaelsville Road	Adult	Inconclusive, possibly vehicular collision (per Tri-State) or collision with telephone pole (per USFWS) possibly due to impairment from lead toxicity	Injured

Appendix 11. Results of Brownian bridge movement modeling for individual eagles showing utilization distribution for tracking data within the upper Chesapeake Bay study area. Warmer colors reflect areas with higher utilization density. If a bird migrated out of the study area during a winter (November – March) or summer (May-August) the map notes the bird was not present.

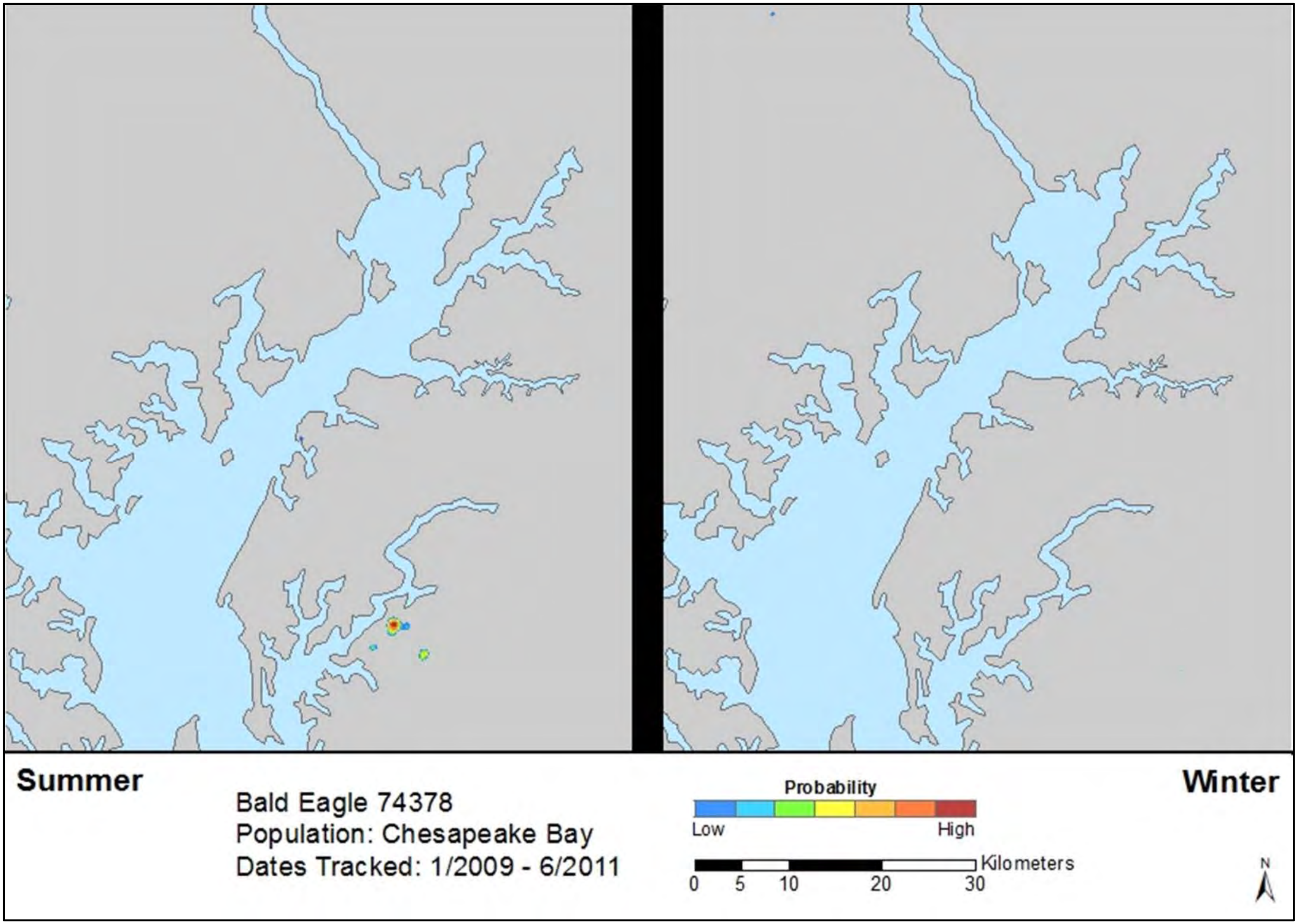


Summer
Bald Eagle 74375
Population: Southern Migrant
Dates Tracked: 8/2007 - 2/2009
Probability
Low
High
0
5
10
20
30
Kilometers
Winter
N

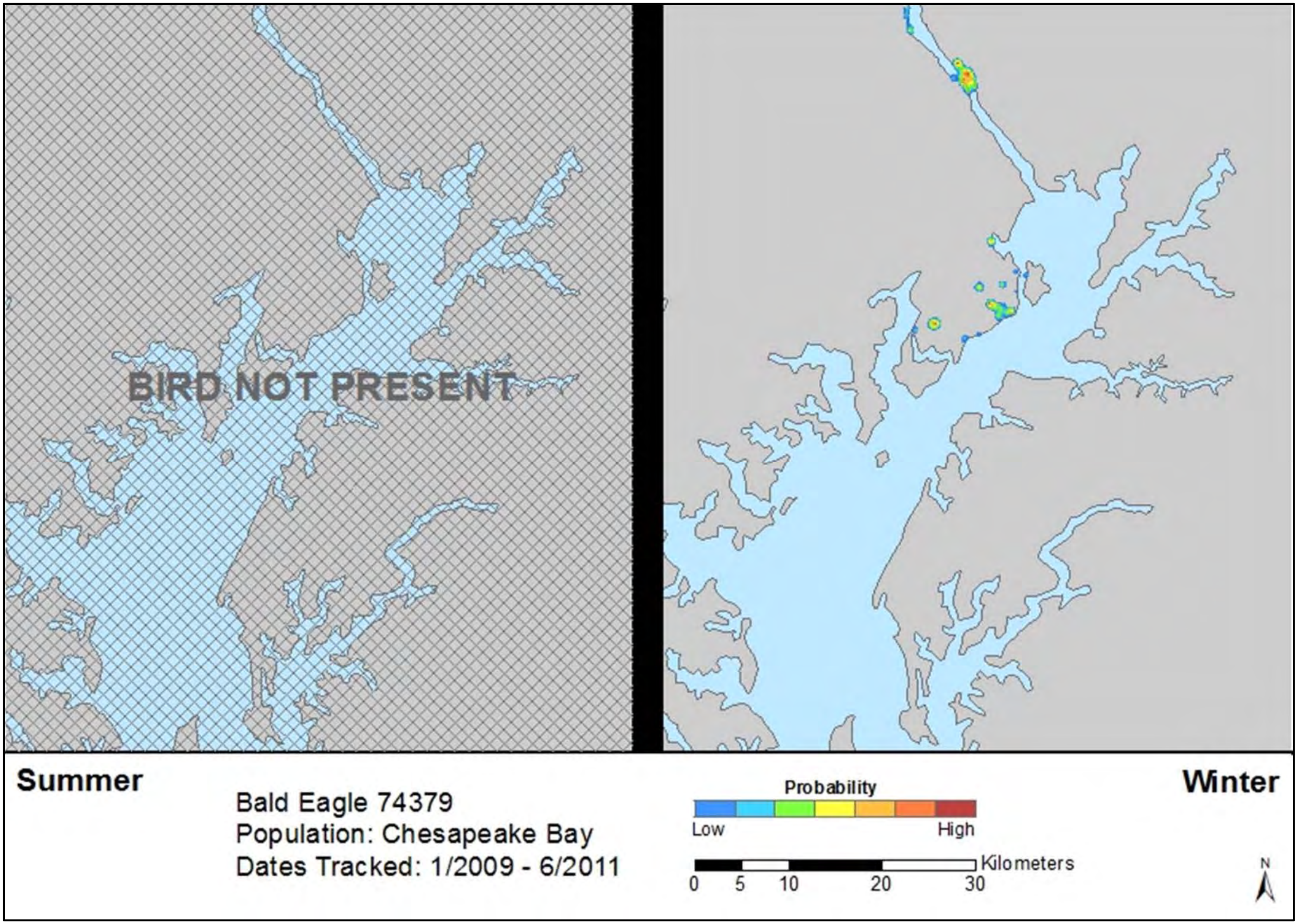

Summer
Bald Eagle 74376
Population: Chesapeake Bay
Dates Tracked: 12/2008 - 6/2011
Probability
Low
High
0 5 10 20 30 Kilometers
N
Winter

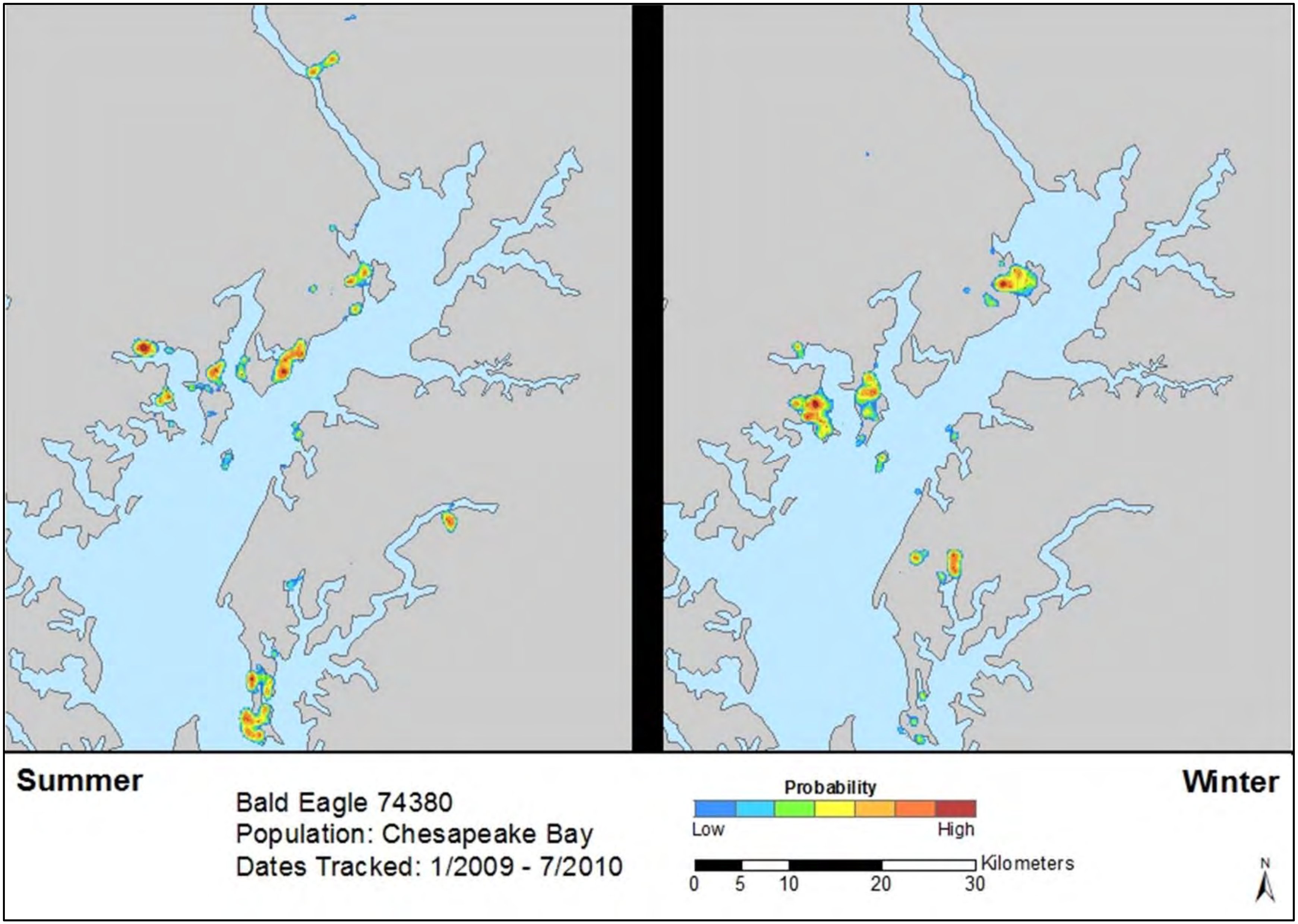


BIRD NOT PRESENT
Summer
Bald Eagle 74377
Population: Chesapeake Bay
Dates Tracked: 1/2009 - 4/2009
Probability
Low
High
0
5
10
20
30
Kilometers
N
Winter

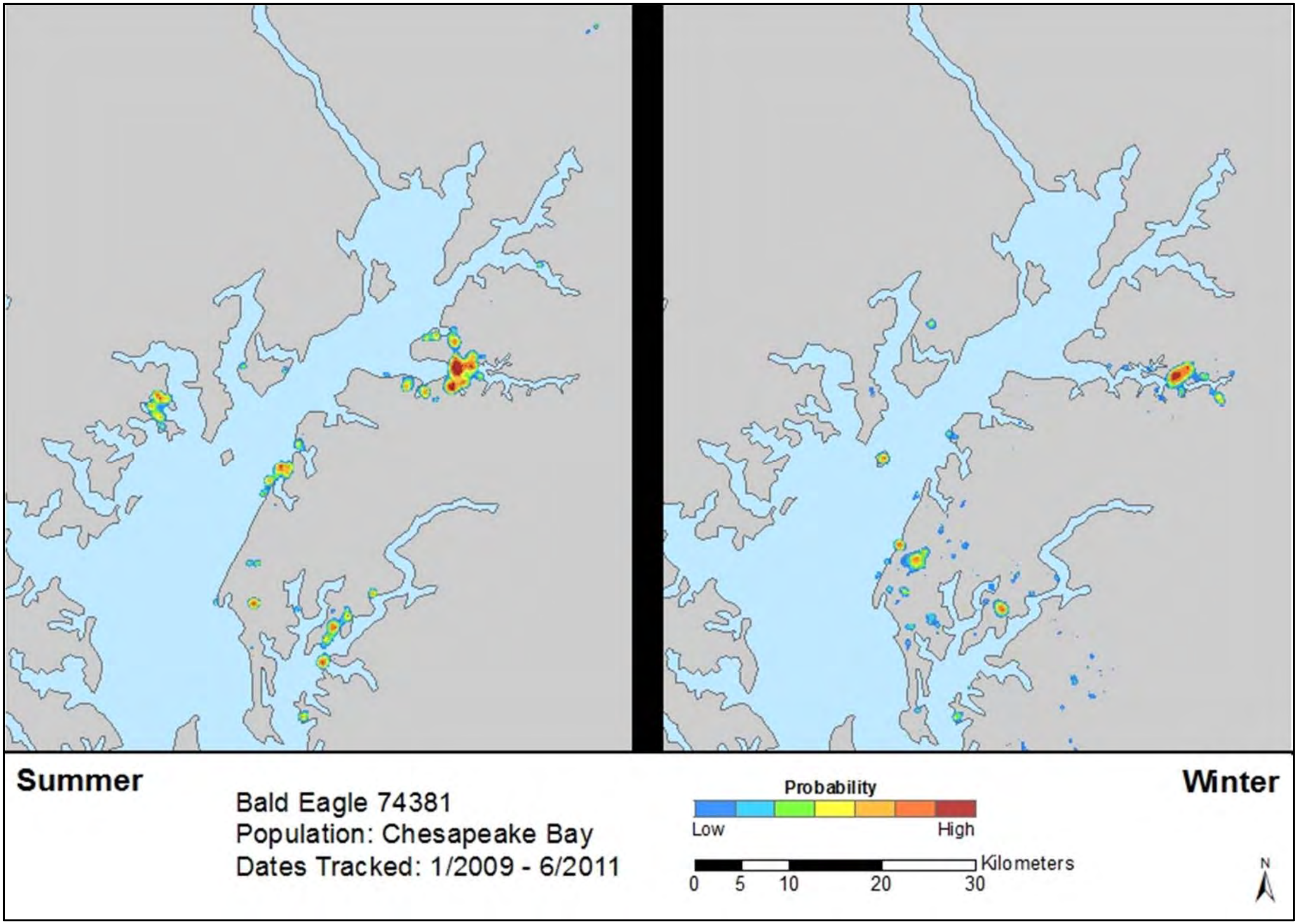


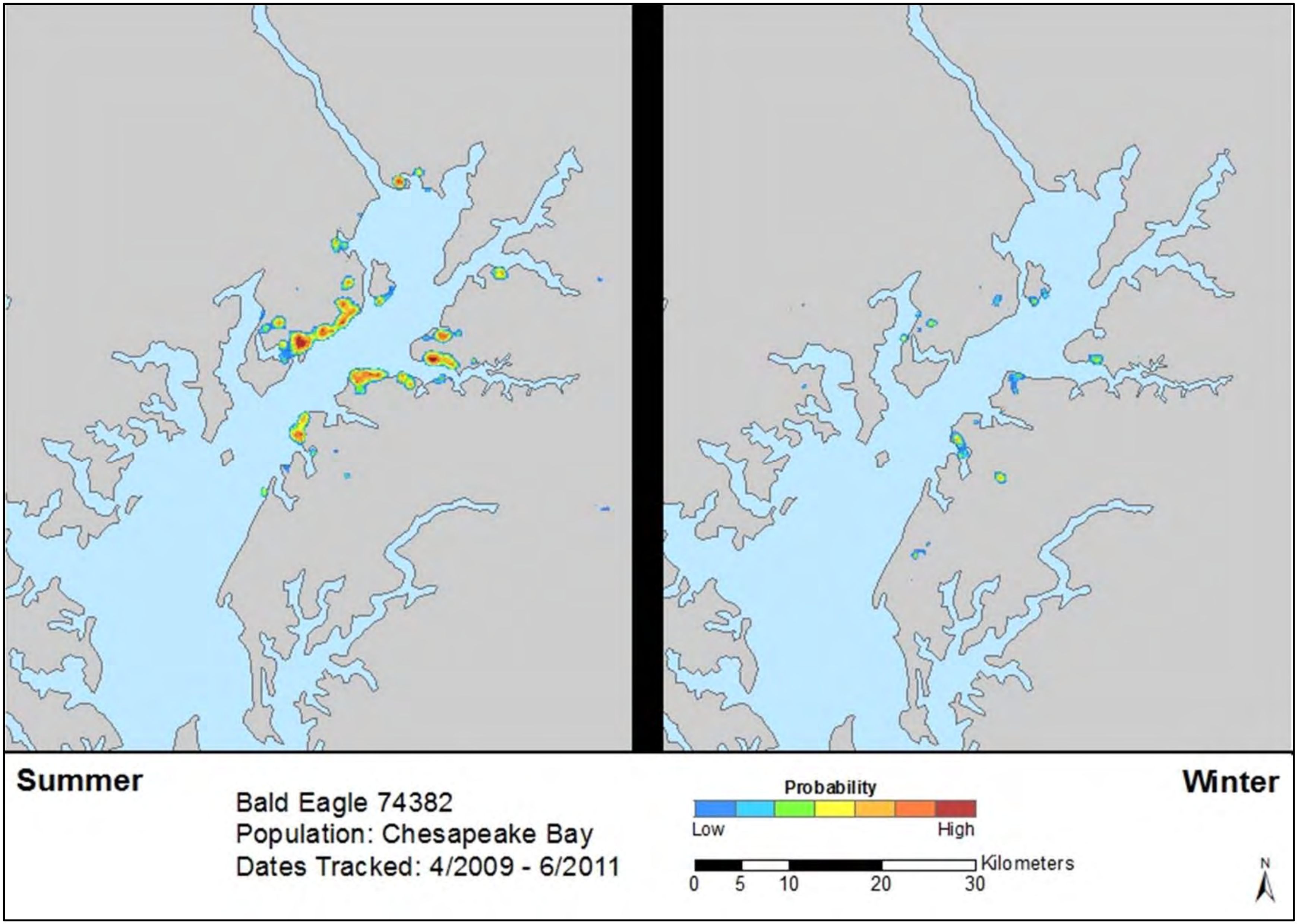
Summer
Bald Eagle 74378
Population: Chesapeake Bay
Dates Tracked: 1/2009 - 6/2011
Probability
Low
High
Kilometers
0
5
10
20
30
N
Winter

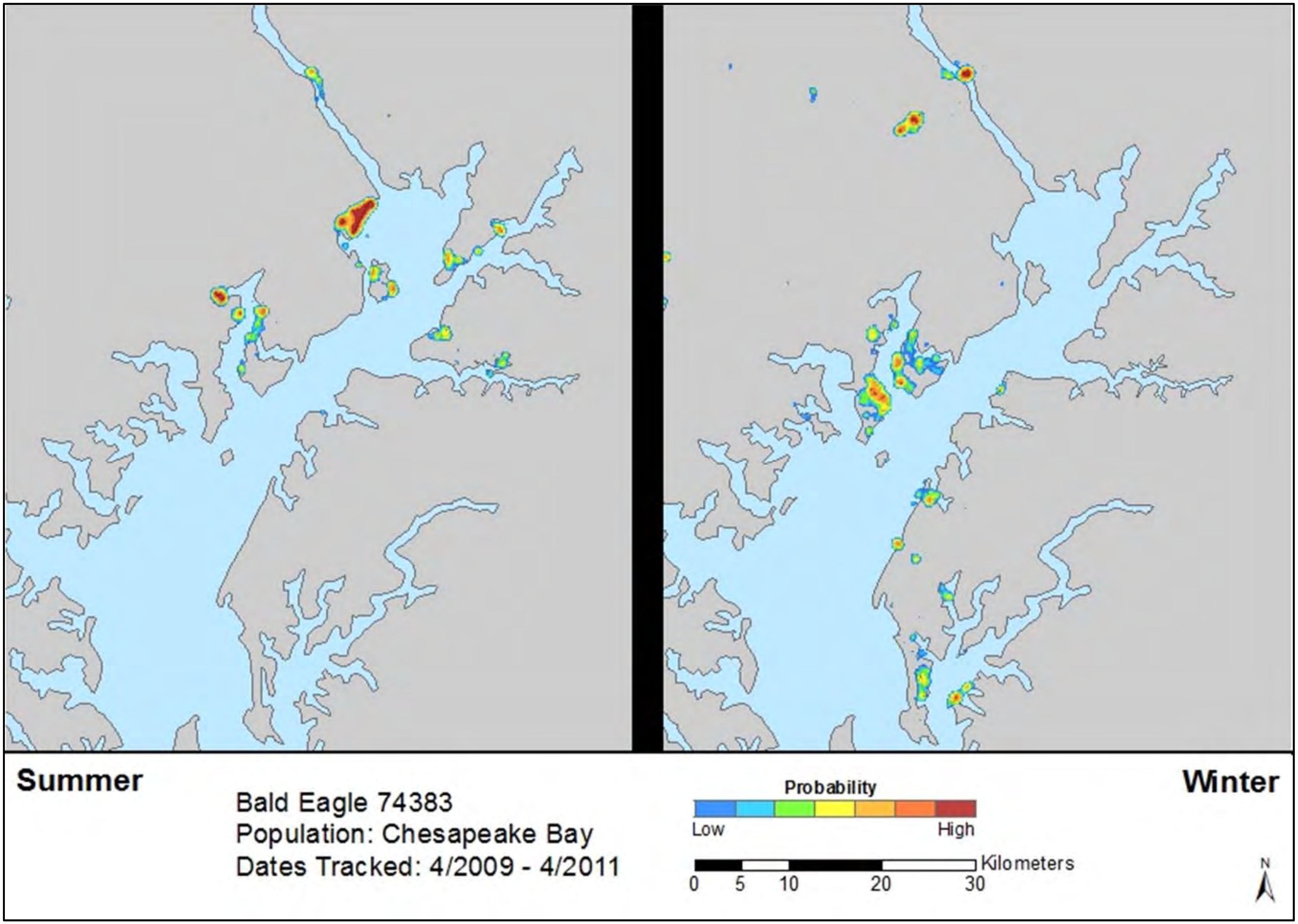

BIRD NOT PRESENT
Summer
Winter
Bald Eagle 74379
Population: Chesapeake Bay
Dates Tracked: 1/2009 - 6/2011
Probability
Low
High
0
5
10
20
30
Kilometers
N

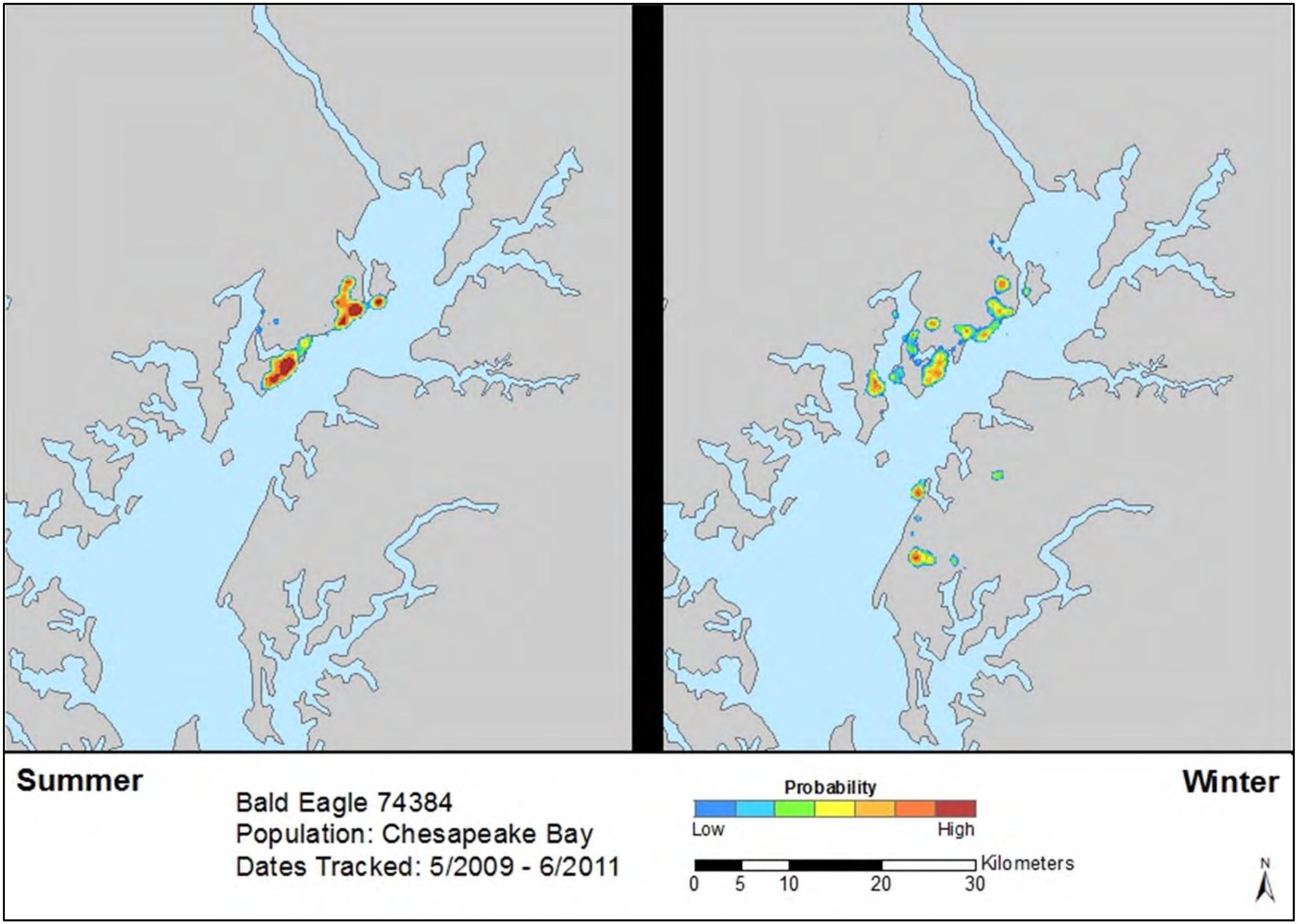


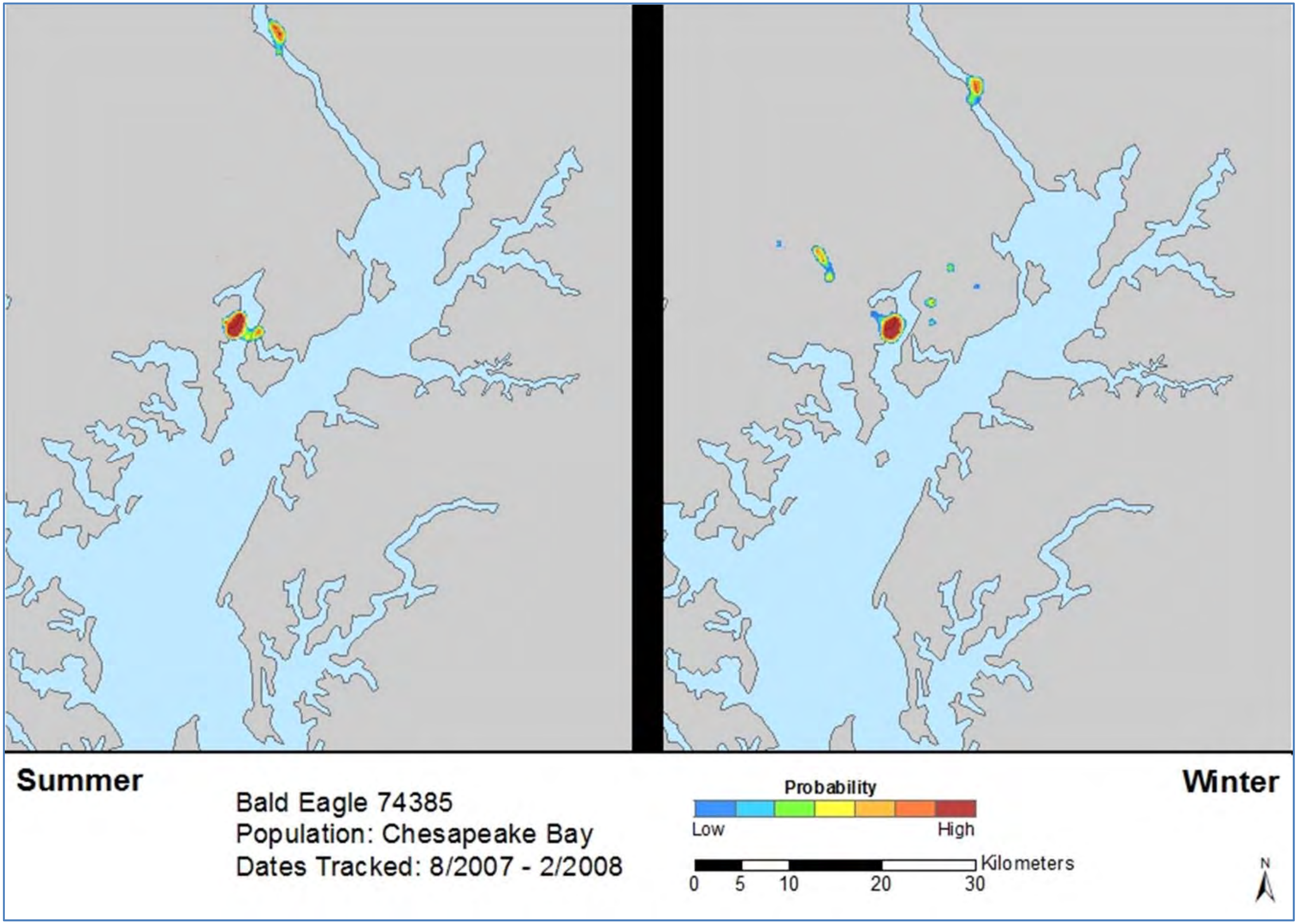
Summer
Bald Eagle 74380
Population: Chesapeake Bay
Dates Tracked: 1/2009 - 7/2010
Probability
Low
High
Kilometers
0
5
10
20
30
Winter
N

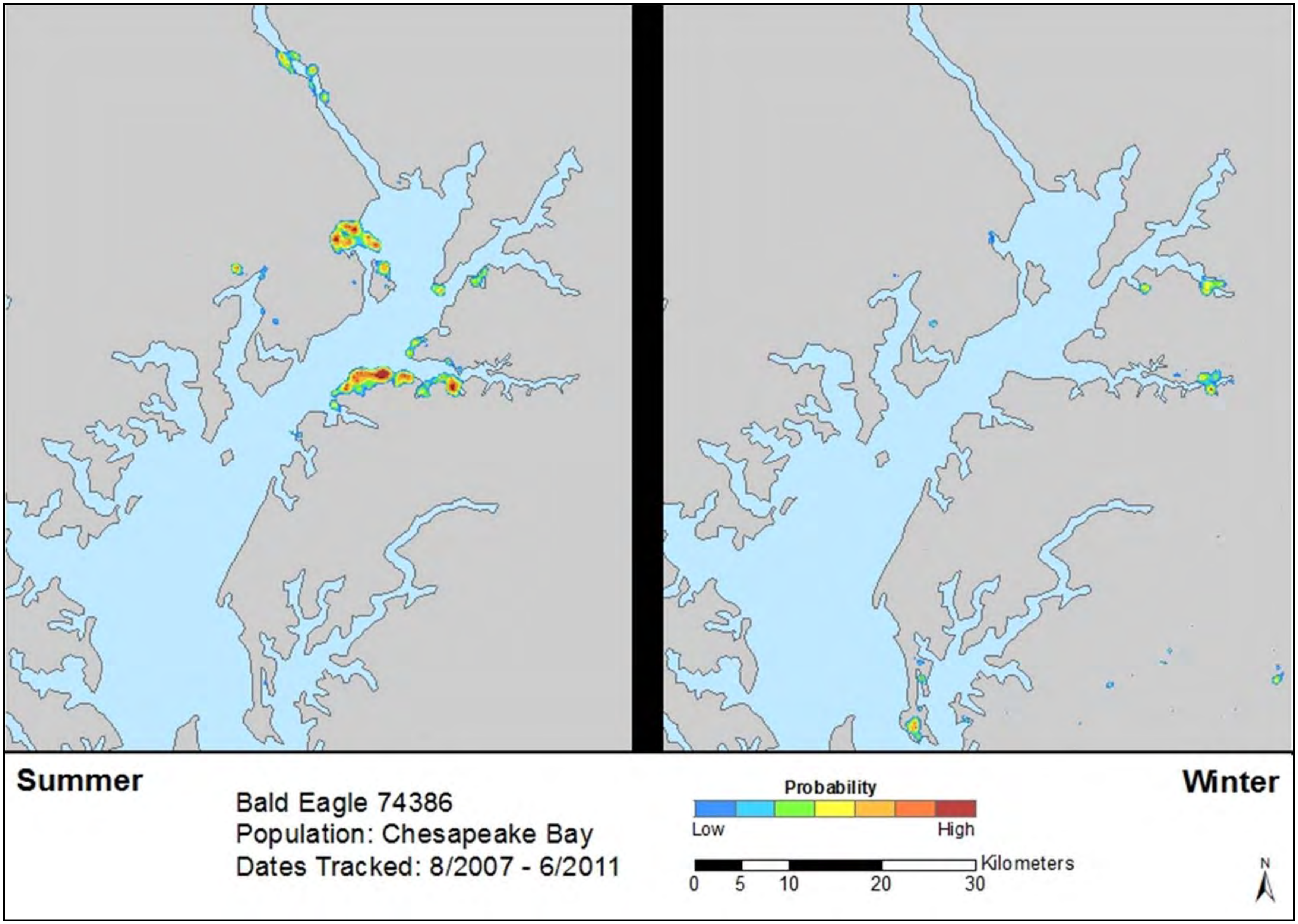

Summer
Bald Eagle 74381
Population: Chesapeake Bay
Dates Tracked: 1/2009 - 6/2011
Probability
Low
High
0 5 10 20 30 Kilometers
N
Winter

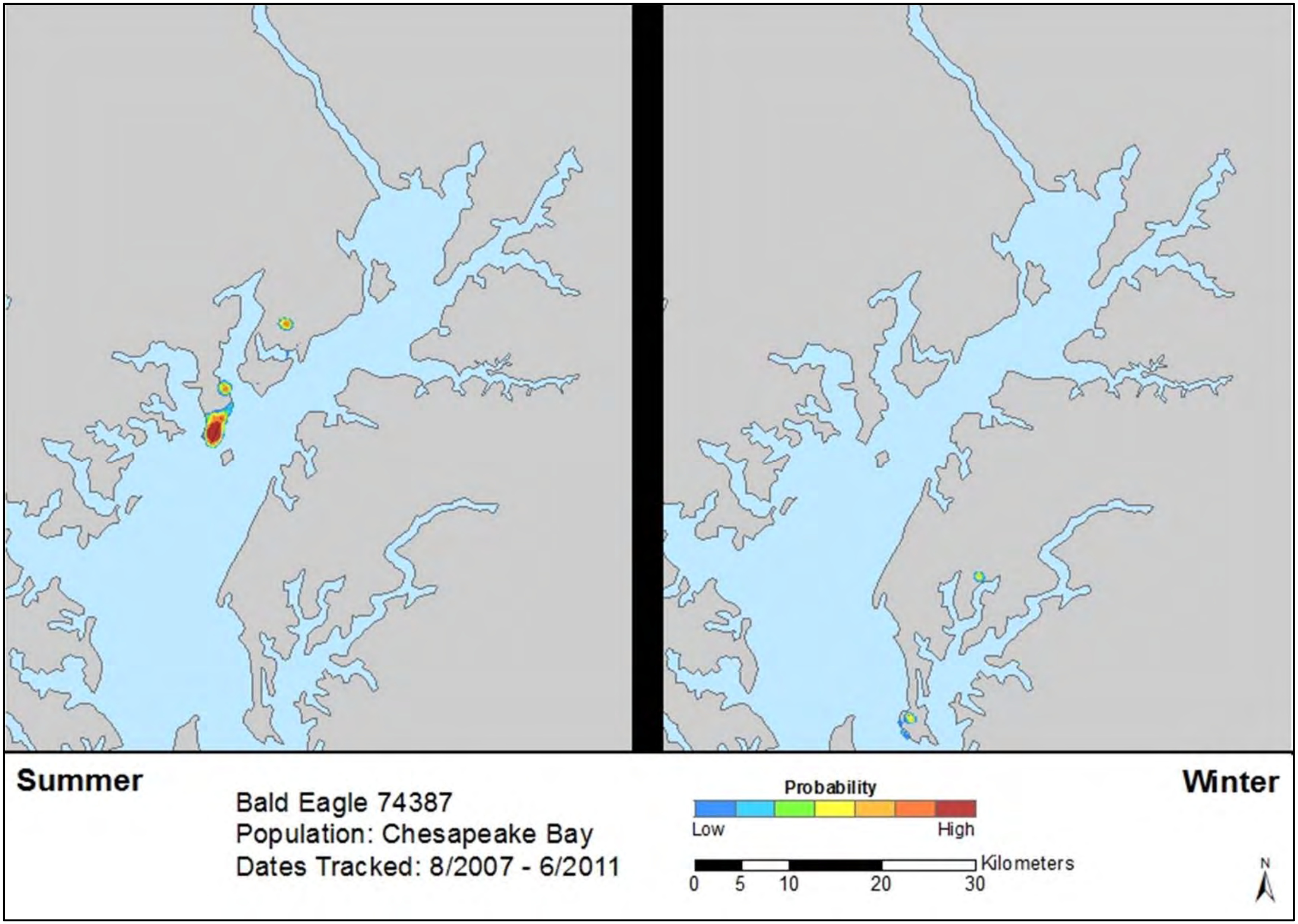

Summer
Winter
Bald Eagle 74382
Population: Chesapeake Bay
Dates Tracked: 4/2009 - 6/2011
Probability
Low
High
0
5
10
20
30
Kilometers
N


Summer
Winter
Bald Eagle 74383
Population: Chesapeake Bay
Dates Tracked: 4/2009 - 4/2011
Probability
Low
High
Kilometers
0 5 10 20 30
N

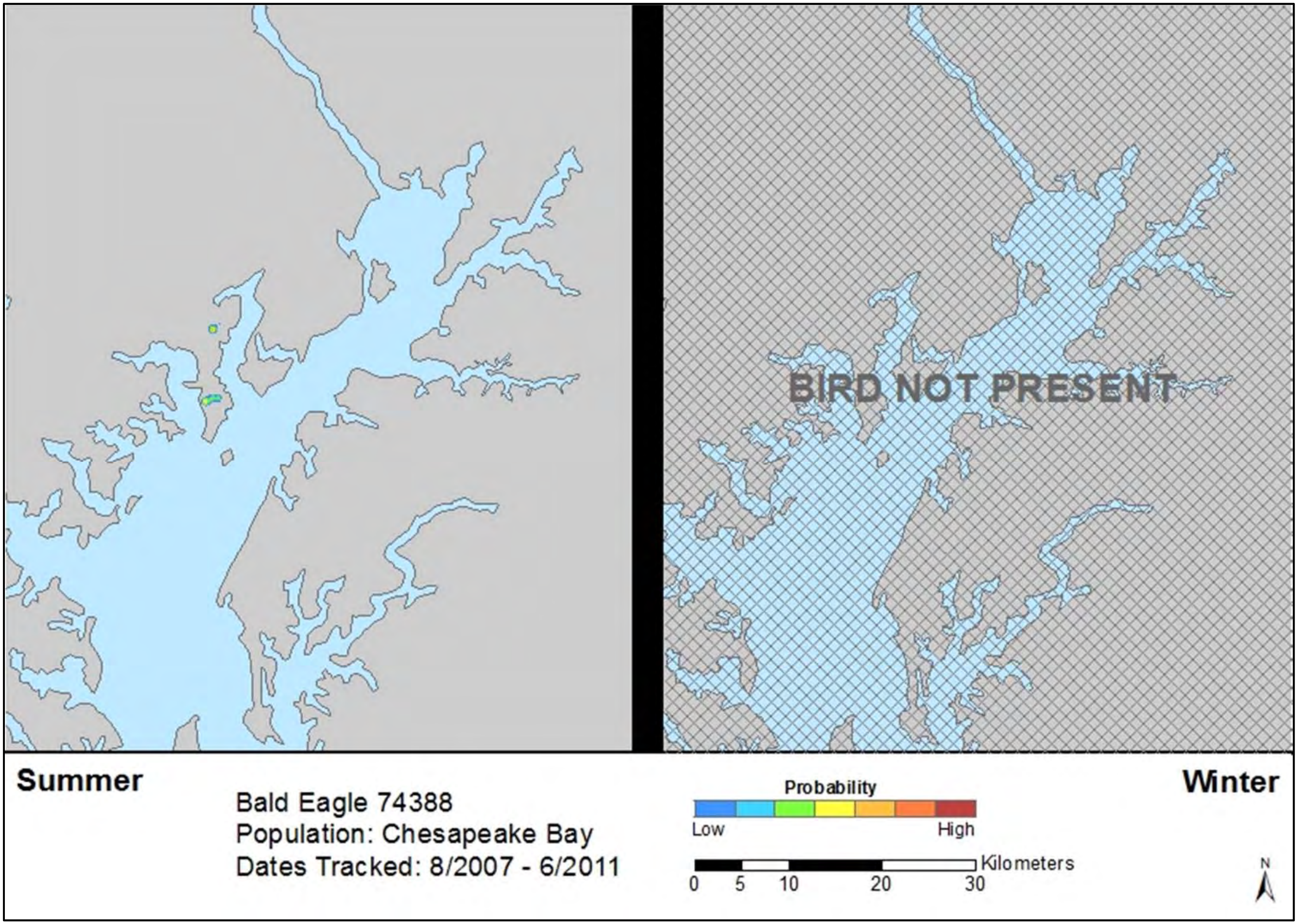

Summer
Bald Eagle 74384
Population: Chesapeake Bay
Dates Tracked: 5/2009 - 6/2011
Probability
Low
High
Kilometers
0
5
10
20
30
N
Winter

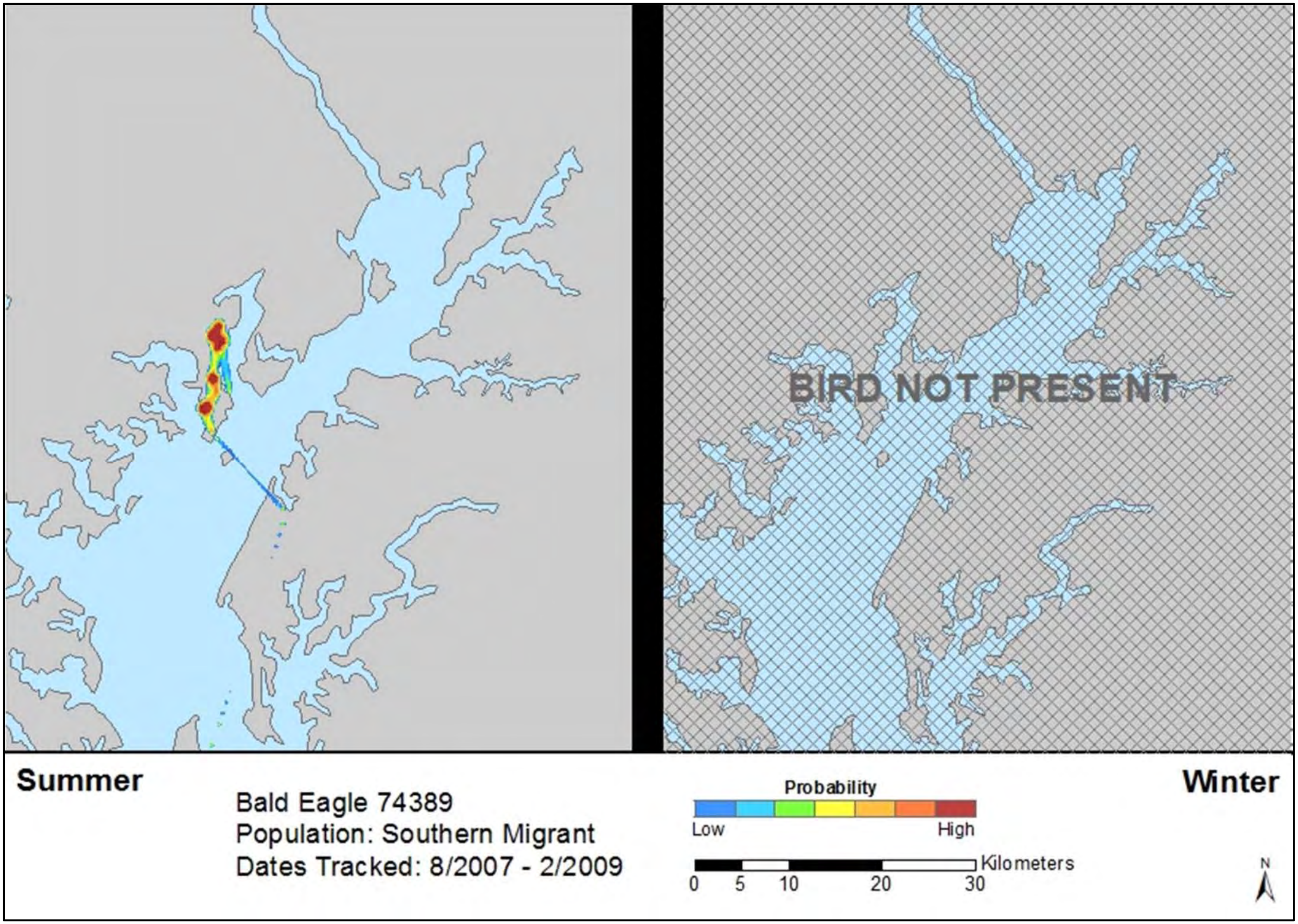

Summer
Bald Eagle 74385
Population: Chesapeake Bay
Dates Tracked: 8/2007 - 2/2008
Probability
Low
High
0 5 10 20 30 Kilometers
N
Winter

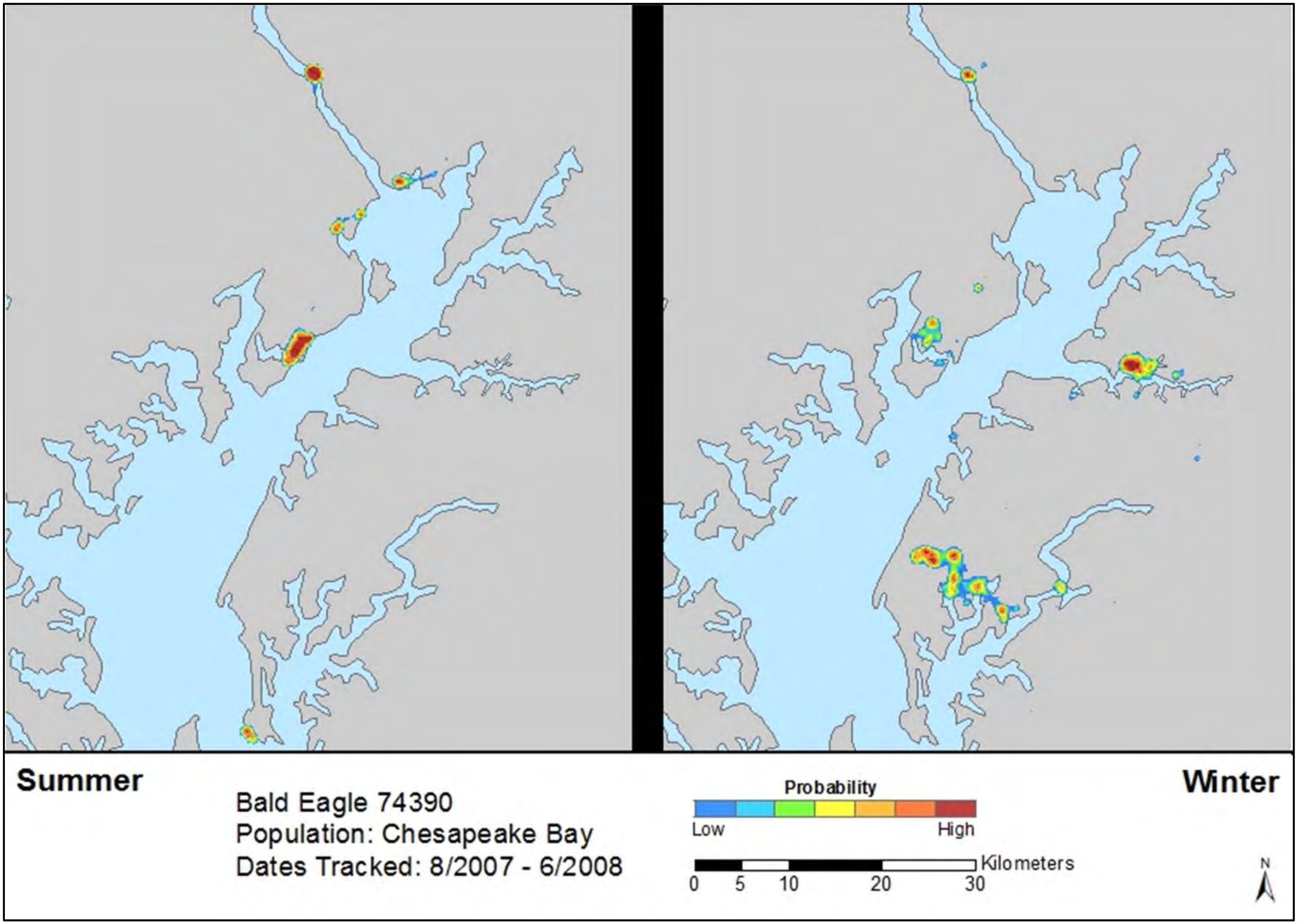

Summer
Winter
Bald Eagle 74386
Population: Chesapeake Bay
Dates Tracked: 8/2007 - 6/2011
Probability
Low
High
Kilometers
0
5
10
20
30
N

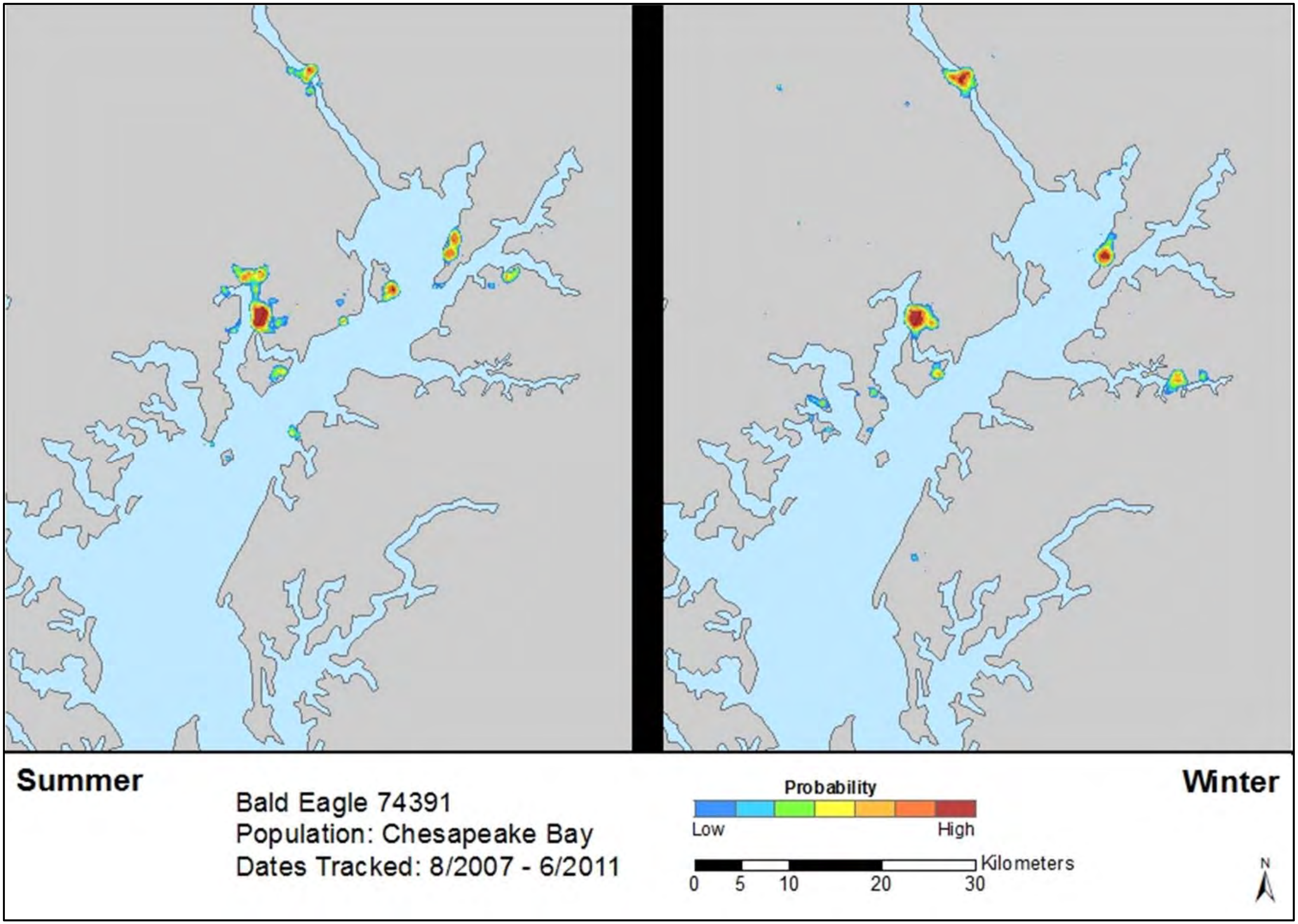


Bald Eagle 74387
Population: Chesapeake Bay
Dates Tracked: 8/2007 - 6/2011

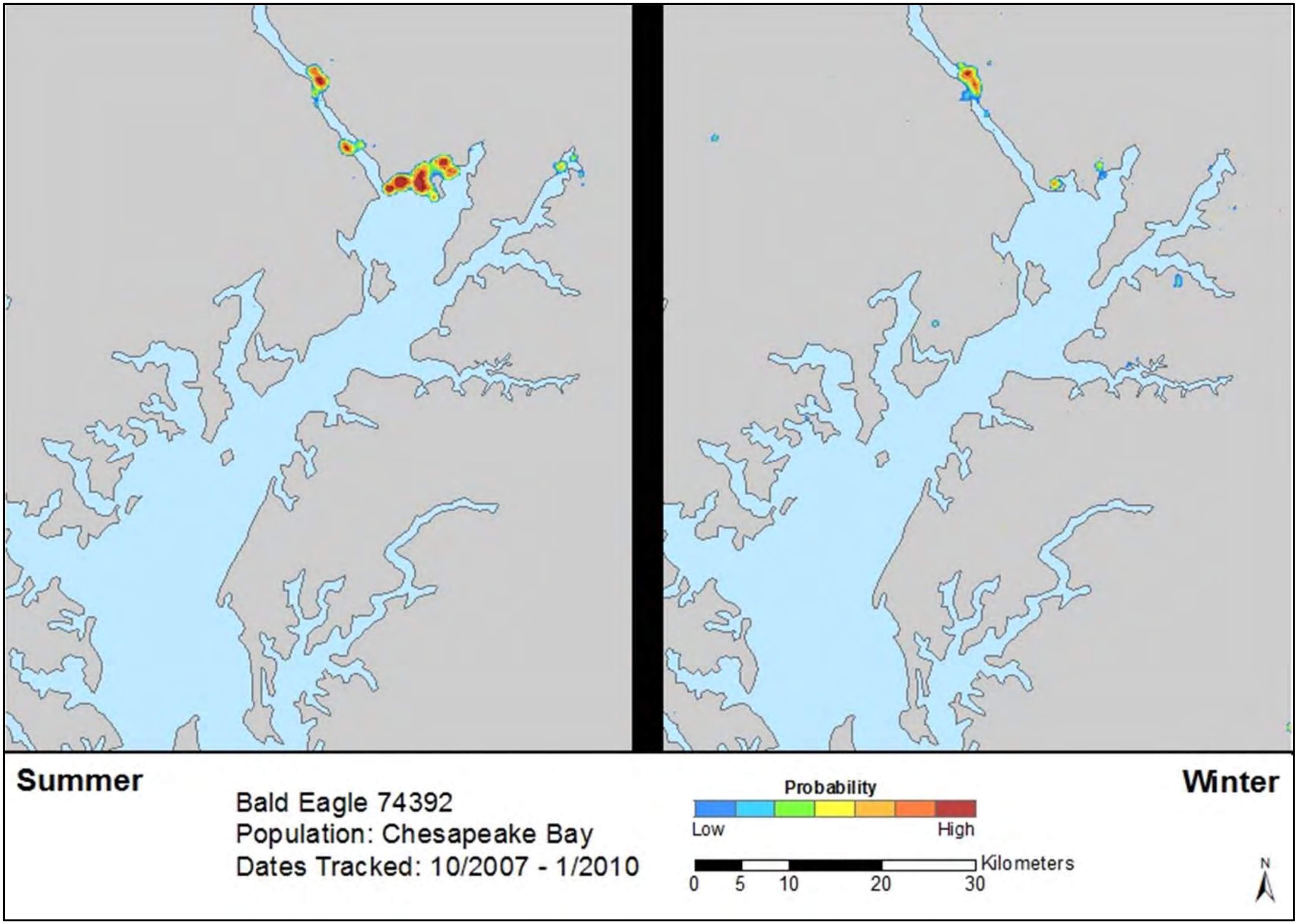

BIRD NOT PRESENT
Summer
Winter
Bald Eagle 74388
Population: Chesapeake Bay
Dates Tracked: 8/2007 - 6/2011
Probability
Low
High
0 5 10 20 30 Kilometers
N


BIRD NOT PRESENT
Summer
Bald Eagle 74389
Population: Southern Migrant
Dates Tracked: 8/2007 - 2/2009
Probability
Low
High
Kilometers
0
5
10
20
30
N
Winter

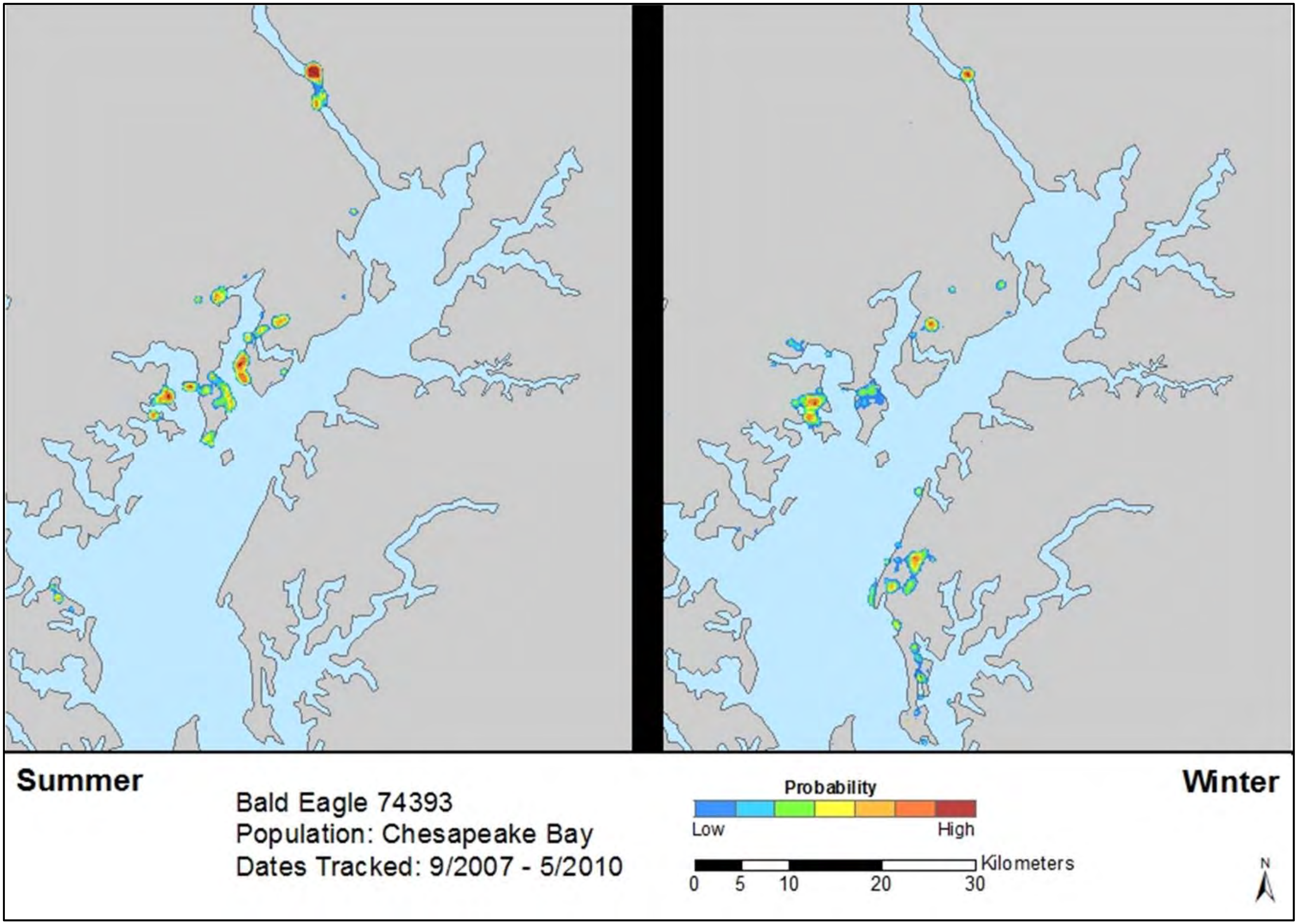

Summer
Winter
Bald Eagle 74390
Population: Chesapeake Bay
Dates Tracked: 8/2007 - 6/2008
Probability
Low
High
Kilometers
0
5
10
20
30
N

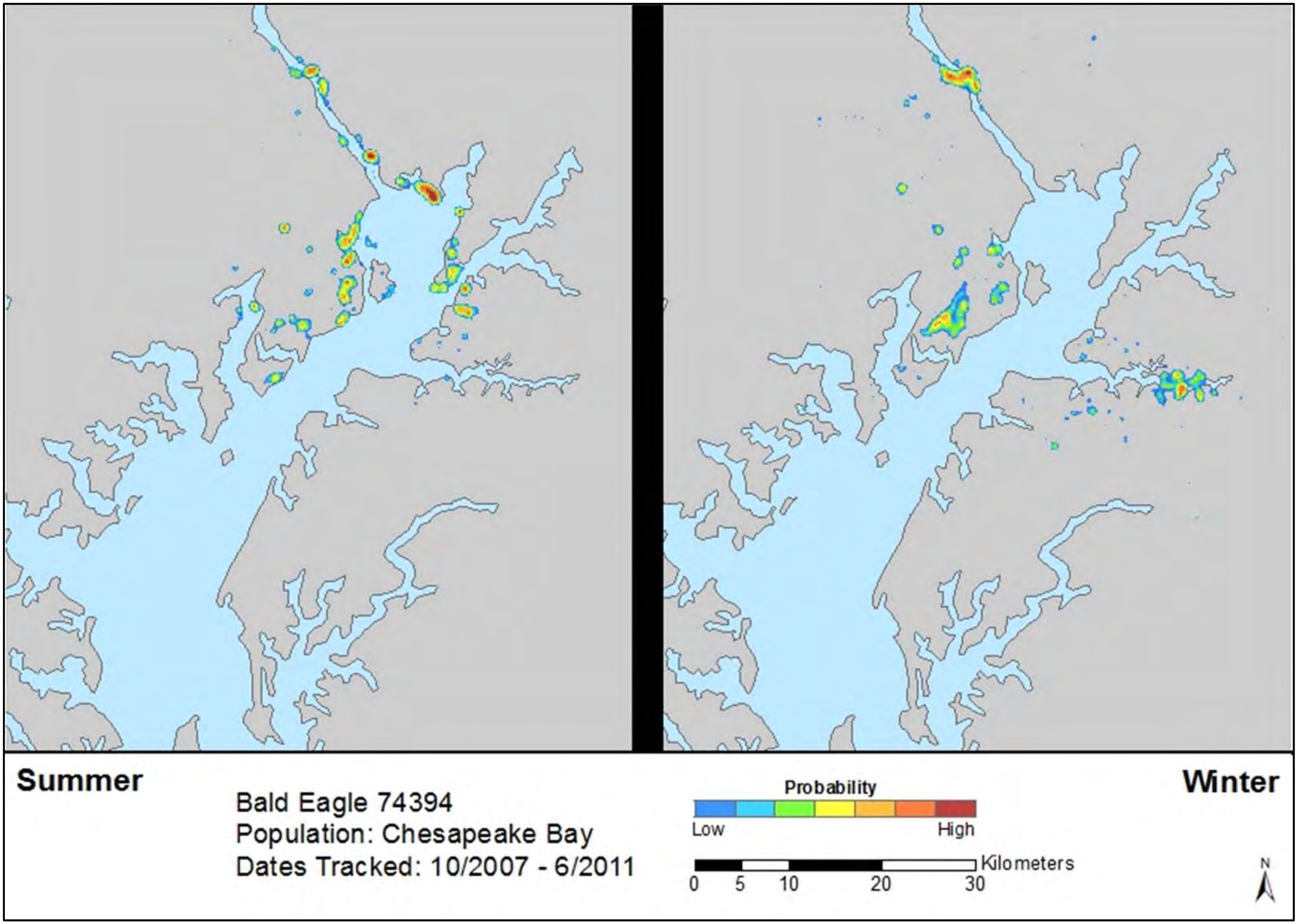


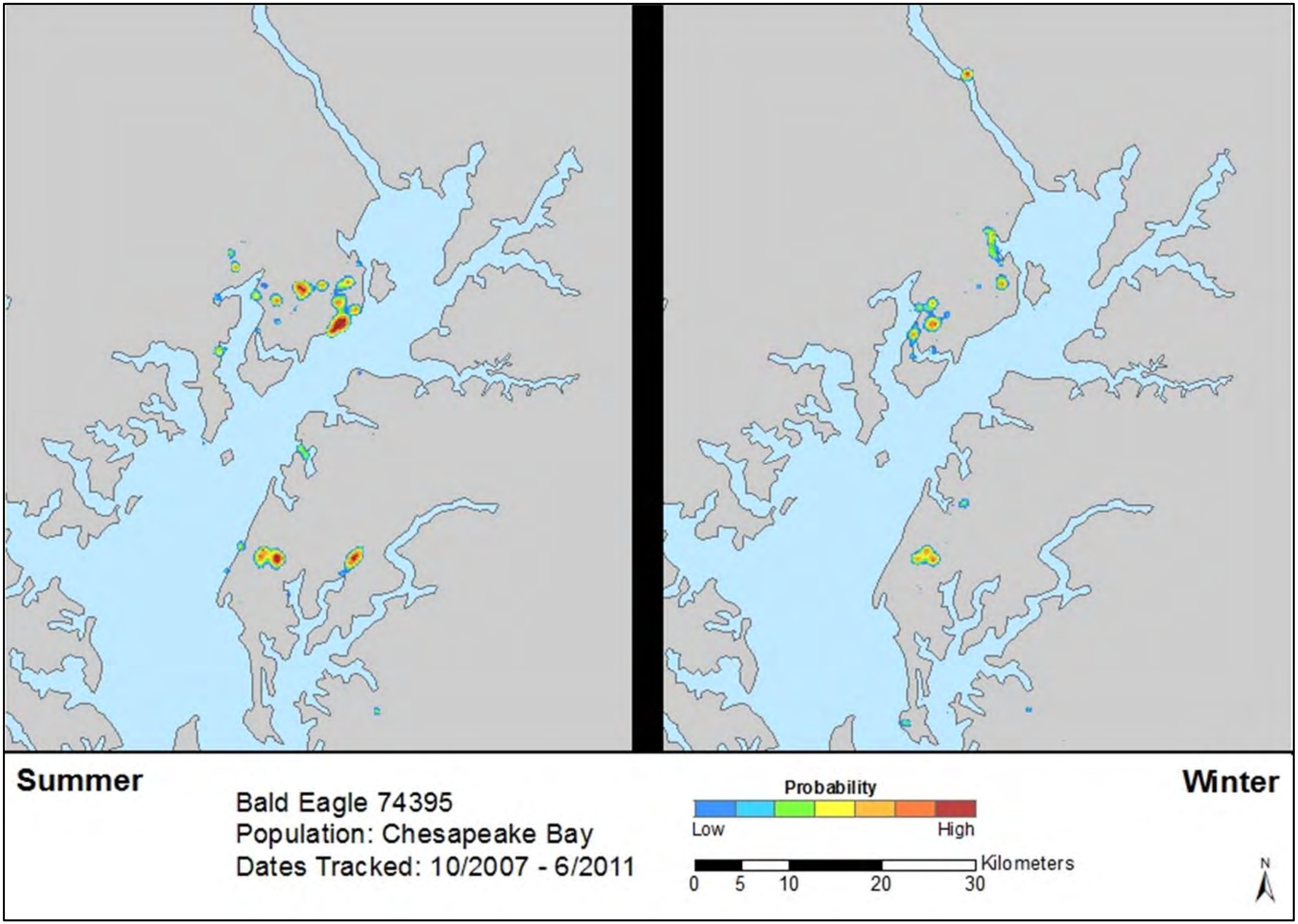
Summer
Winter
Bald Eagle 74391
Population: Chesapeake Bay
Dates Tracked: 8/2007 - 6/2011
Probability
Low
High
0 5 10 20 30 Kilometers
N

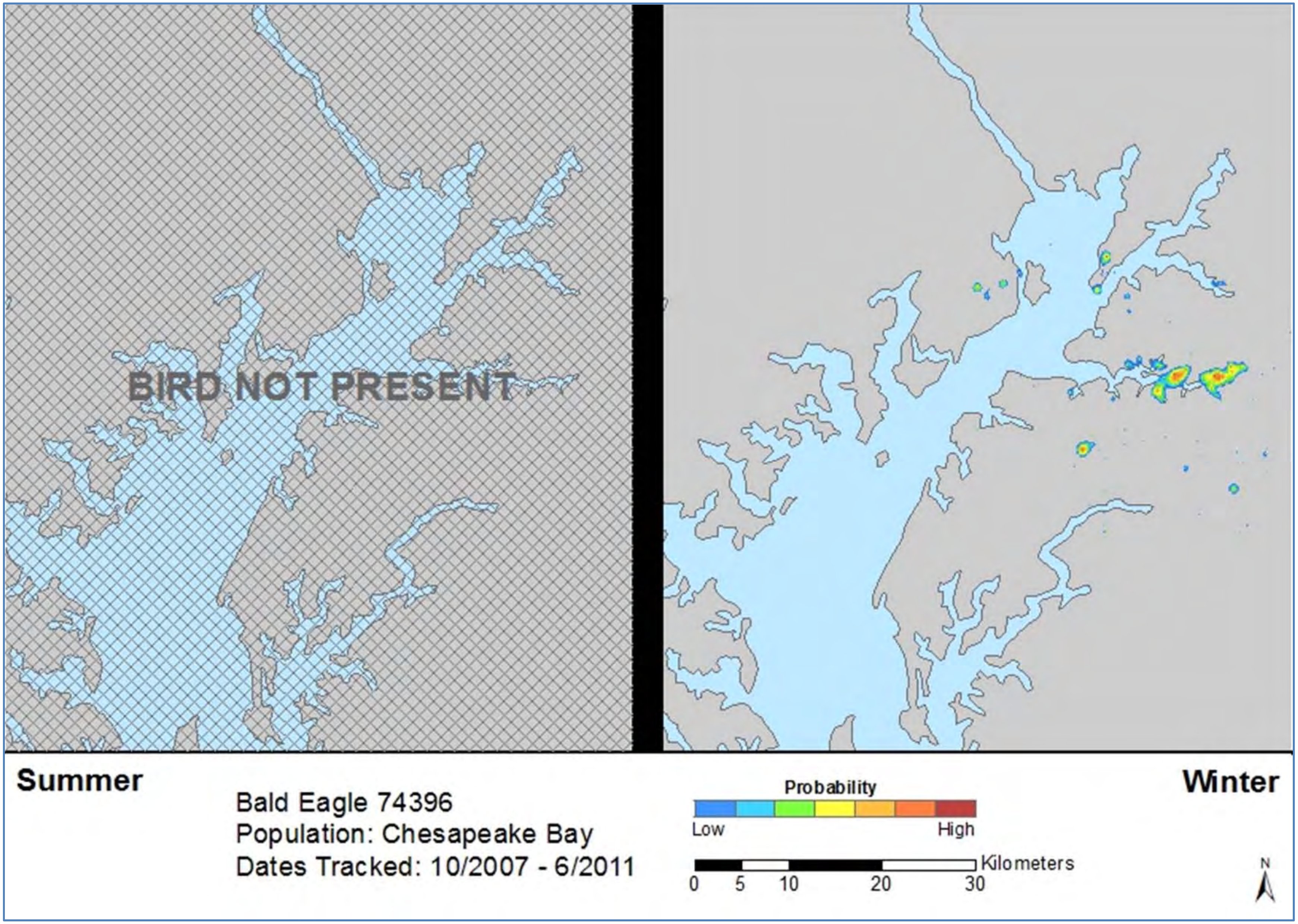


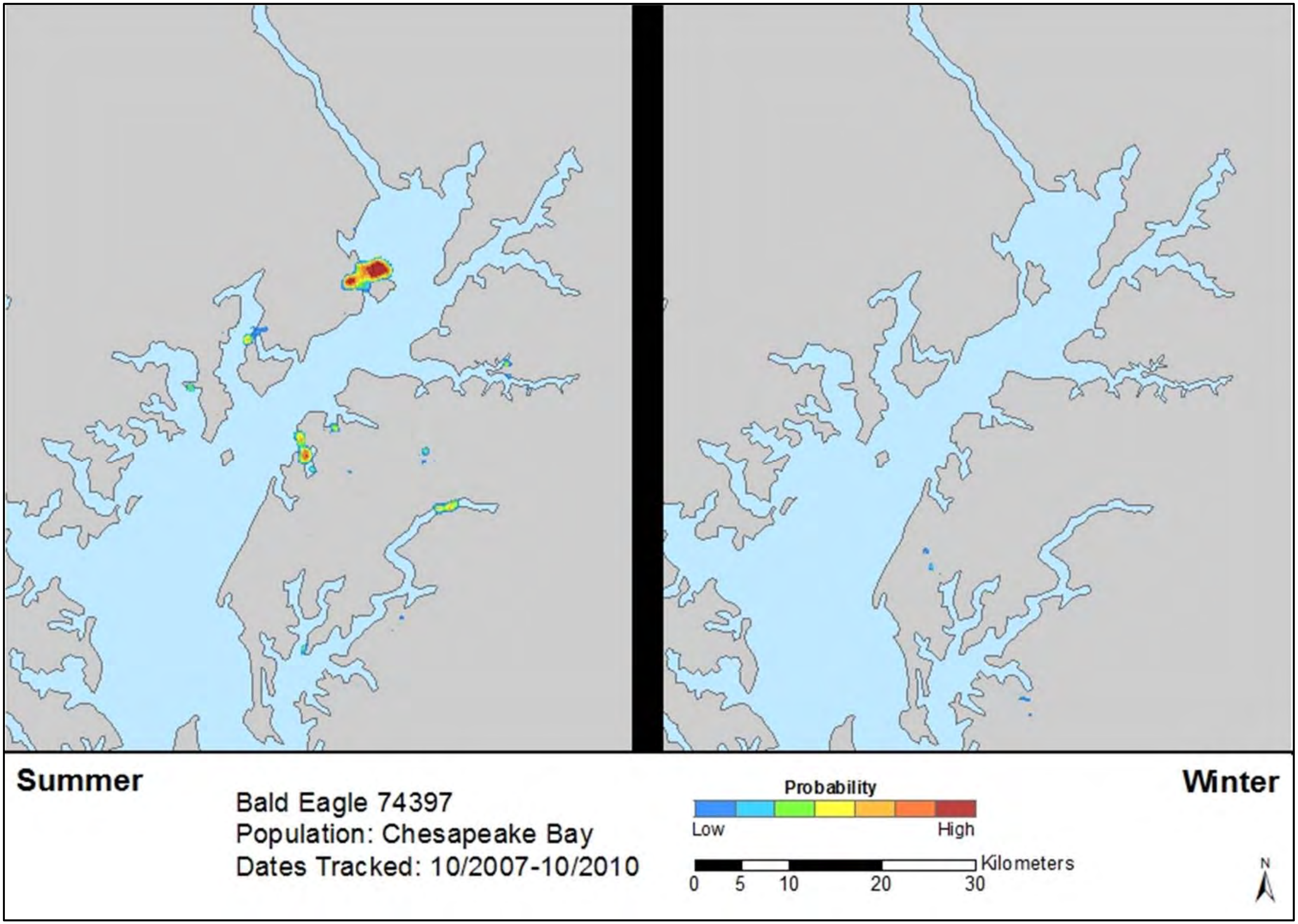
Summer
Bald Eagle 74392
Population: Chesapeake Bay
Dates Tracked: 10/2007 - 1/2010
Probability
Low
High
Kilometers
0
5
10
20
30
N
Winter

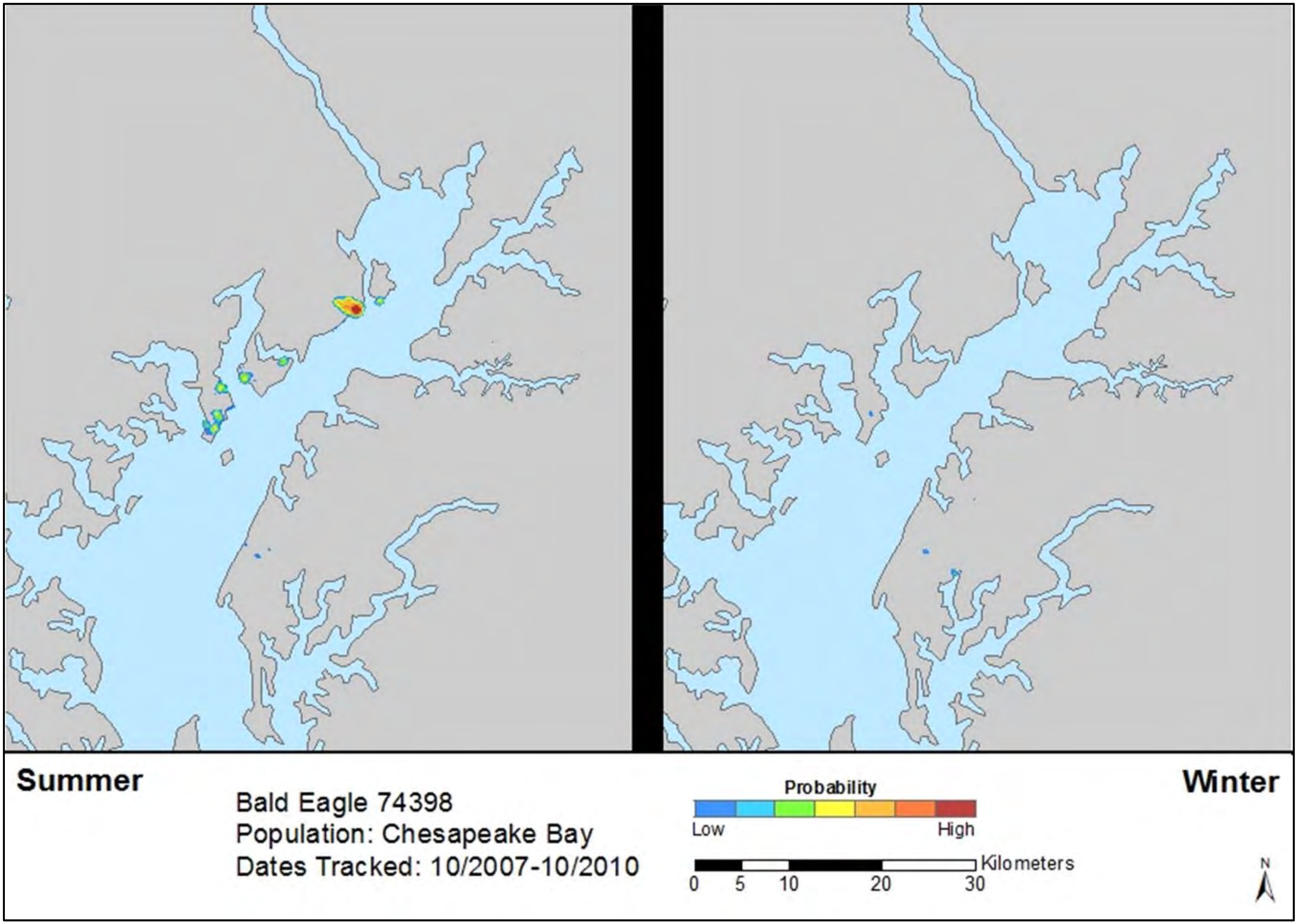

Summer
Bald Eagle 74393
Population: Chesapeake Bay
Dates Tracked: 9/2007 - 5/2010
Probability
Low
High
0 5 10 20 30 Kilometers
N
Winter

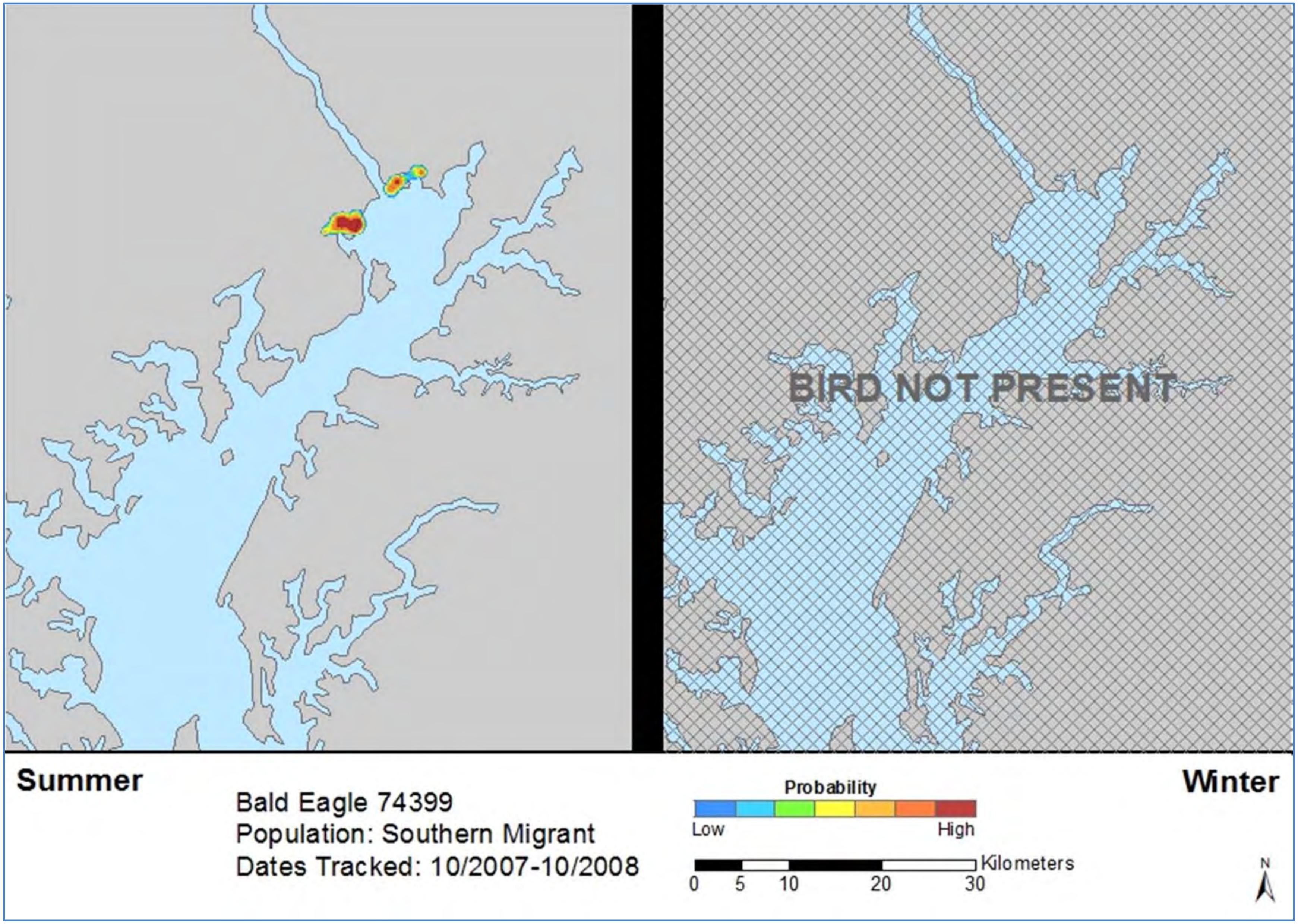

Summer
Winter
Bald Eagle 74394
Population: Chesapeake Bay
Dates Tracked: 10/2007 - 6/2011
Probability
Low
High
Kilometers
0 5 10 20 30
N

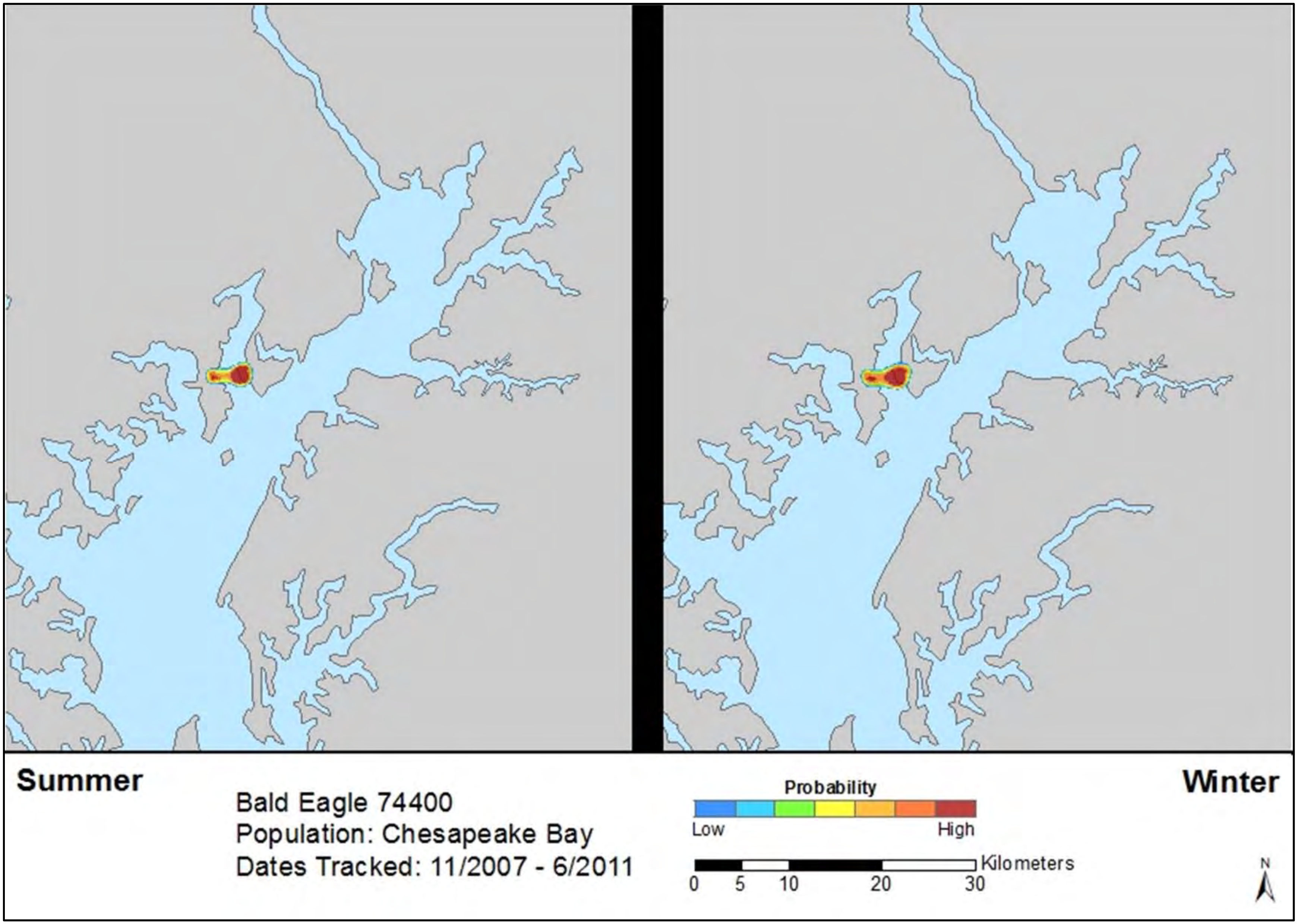

Summer
Bald Eagle 74395
Population: Chesapeake Bay
Dates Tracked: 10/2007 - 6/2011
Probability
Low
High
0
5
10
20
30
Kilometers
Winter
N

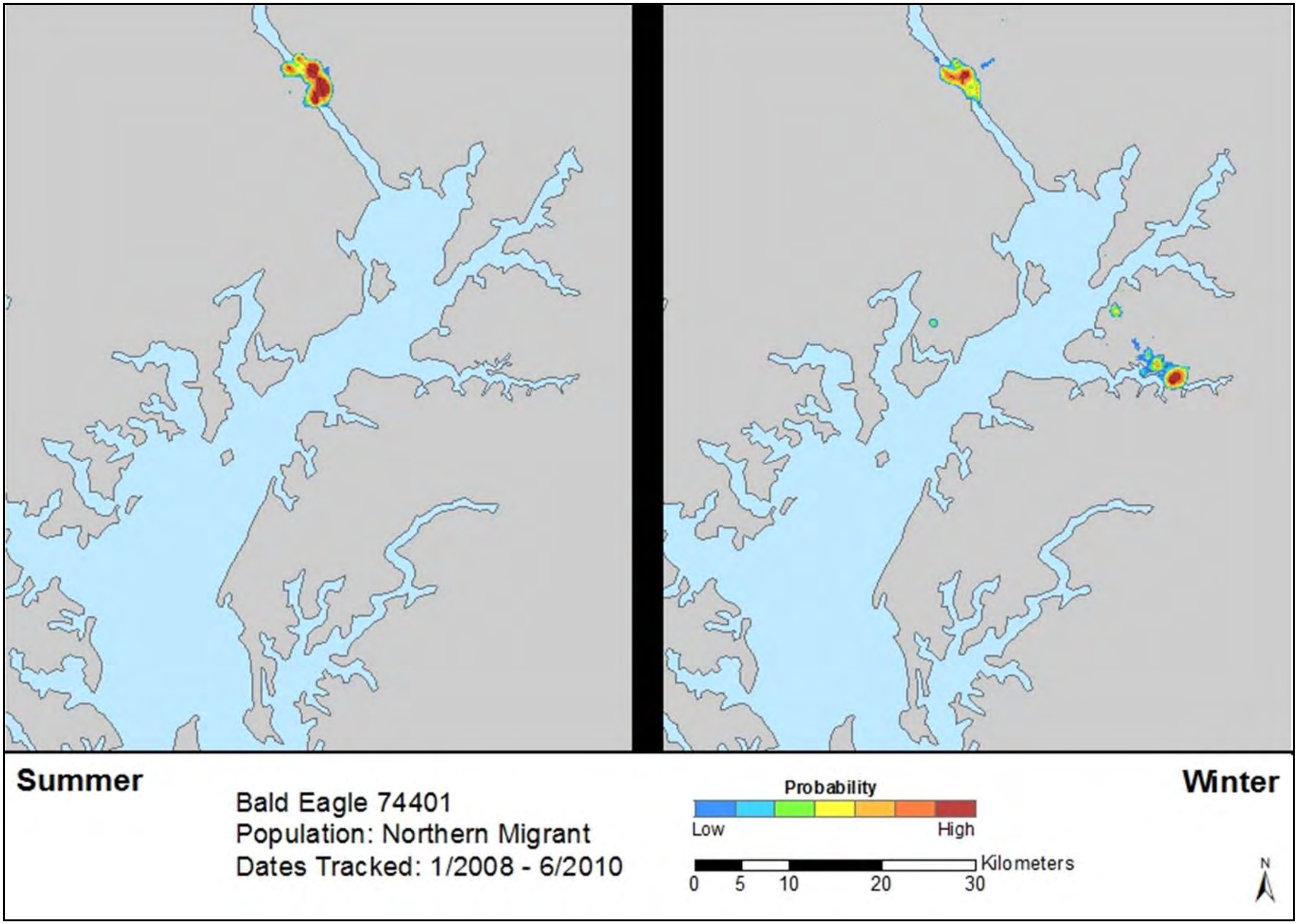

BIRD NOT PRESENT
Summer
Winter
Bald Eagle 74396
Population: Chesapeake Bay
Dates Tracked: 10/2007 - 6/2011
Probability
Low
High
Kilometers
0
5
10
20
30
N

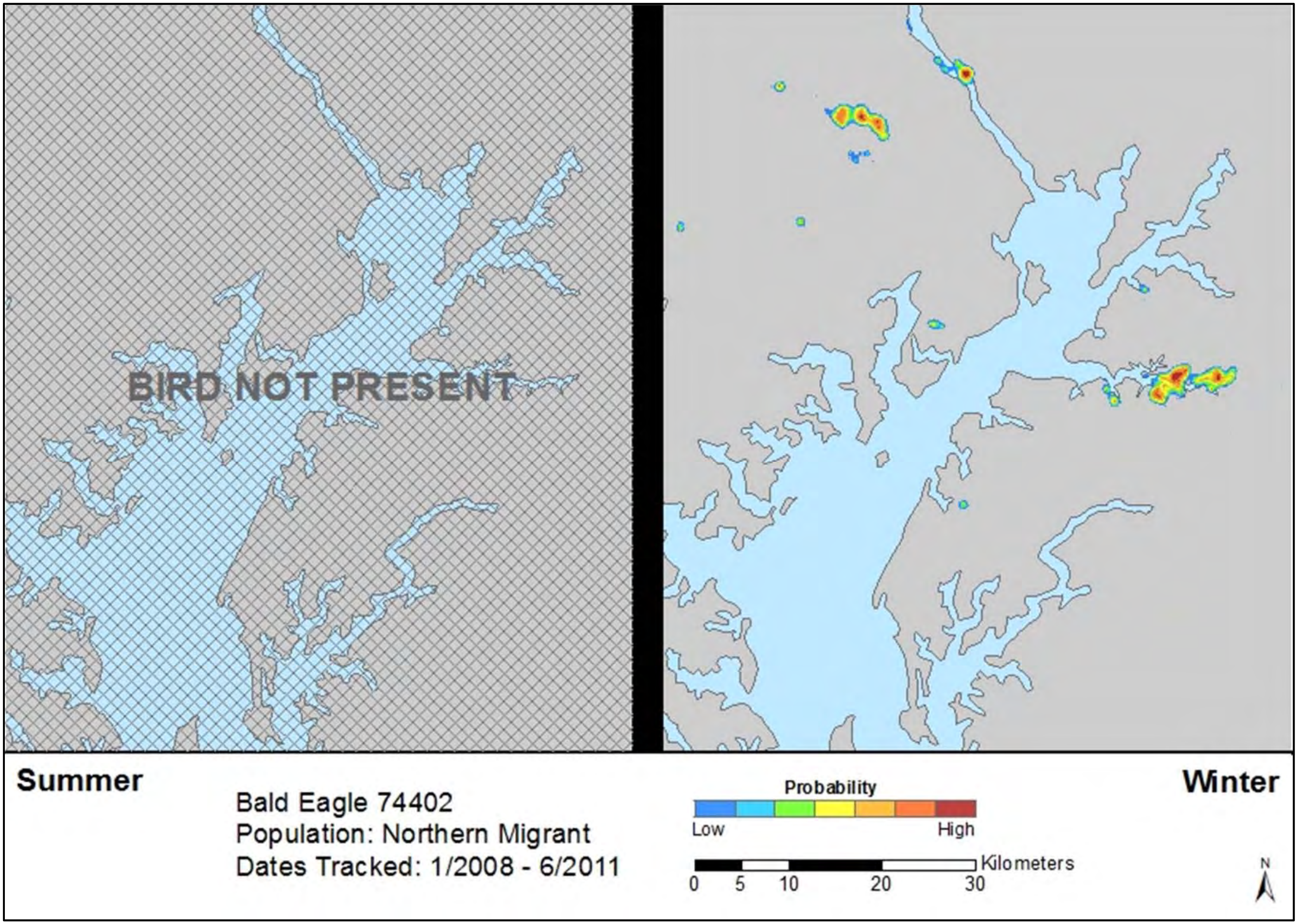

Summer
Winter
Bald Eagle 74397
Population: Chesapeake Bay
Dates Tracked: 10/2007-10/2010
Probability
Low
High
Kilometers
0
5
10
20
30
N

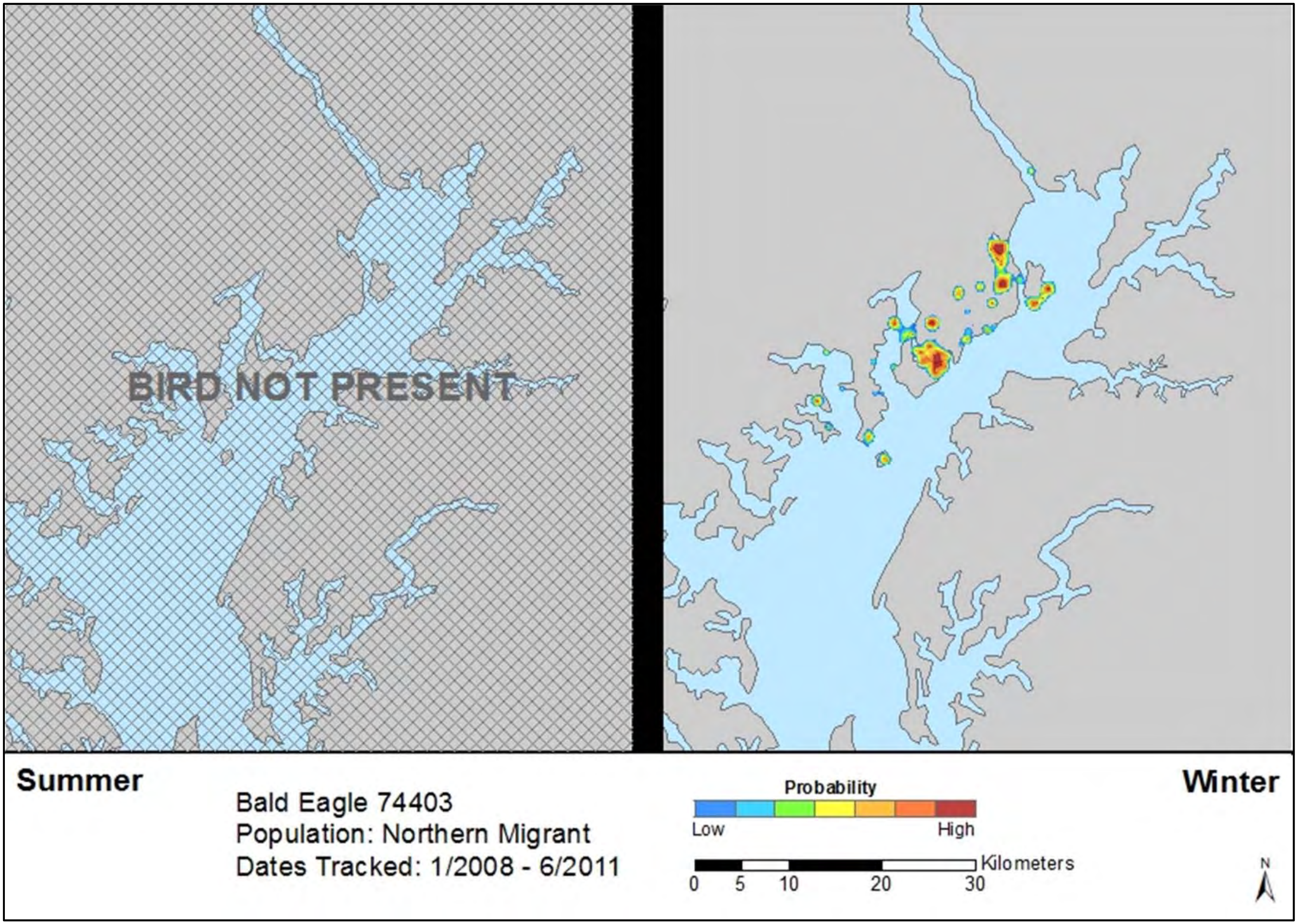

Summer
Winter
Bald Eagle 74398
Population: Chesapeake Bay
Dates Tracked: 10/2007-10/2010
Probability
Low
High
Kilometers
0
5
10
20
30
N

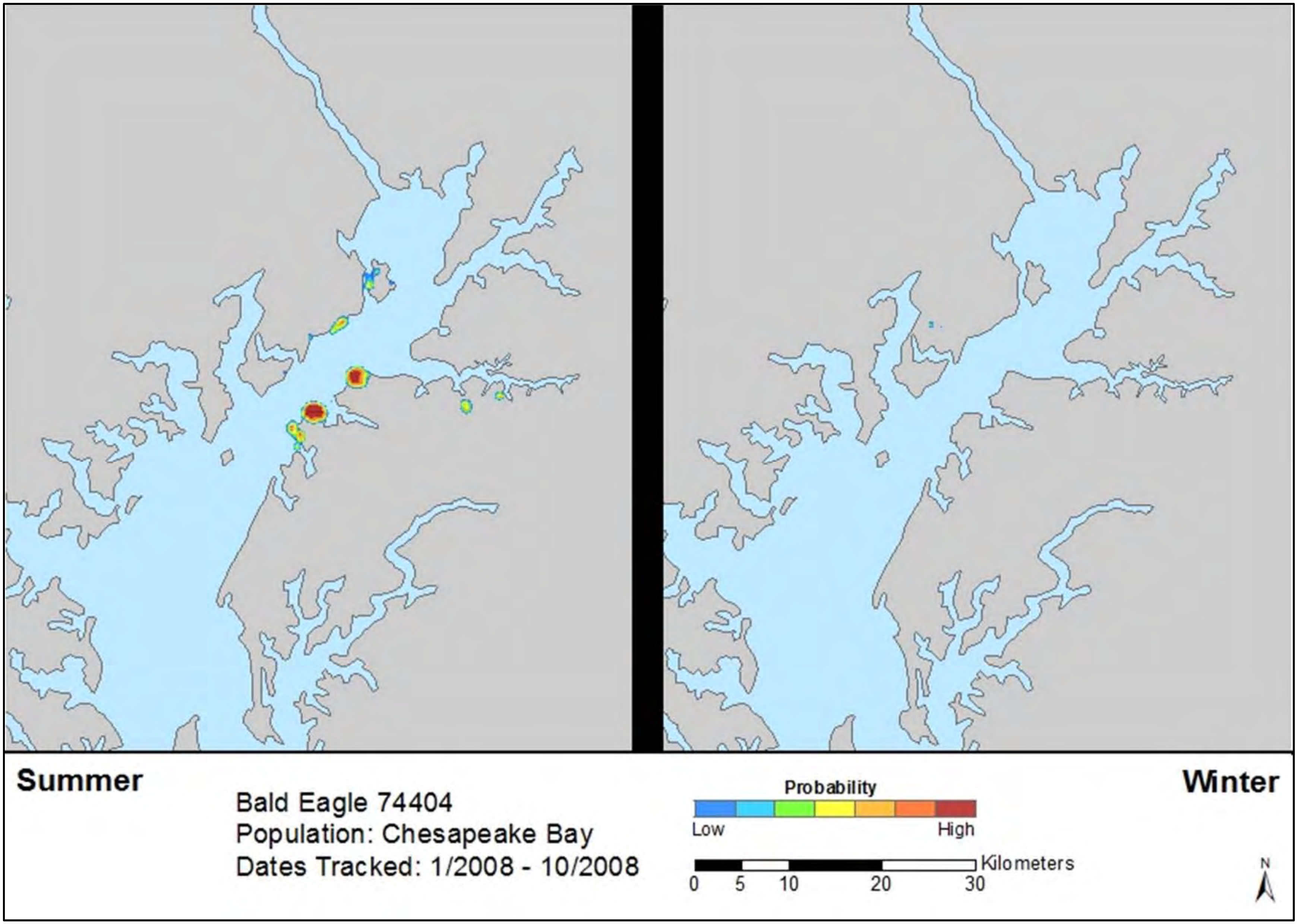

BIRD NOT PRESENT
Summer
Winter
Bald Eagle 74399
Population: Southern Migrant
Dates Tracked: 10/2007-10/2008
Probability
Low
High
Kilometers
0
5
10
20
30
N

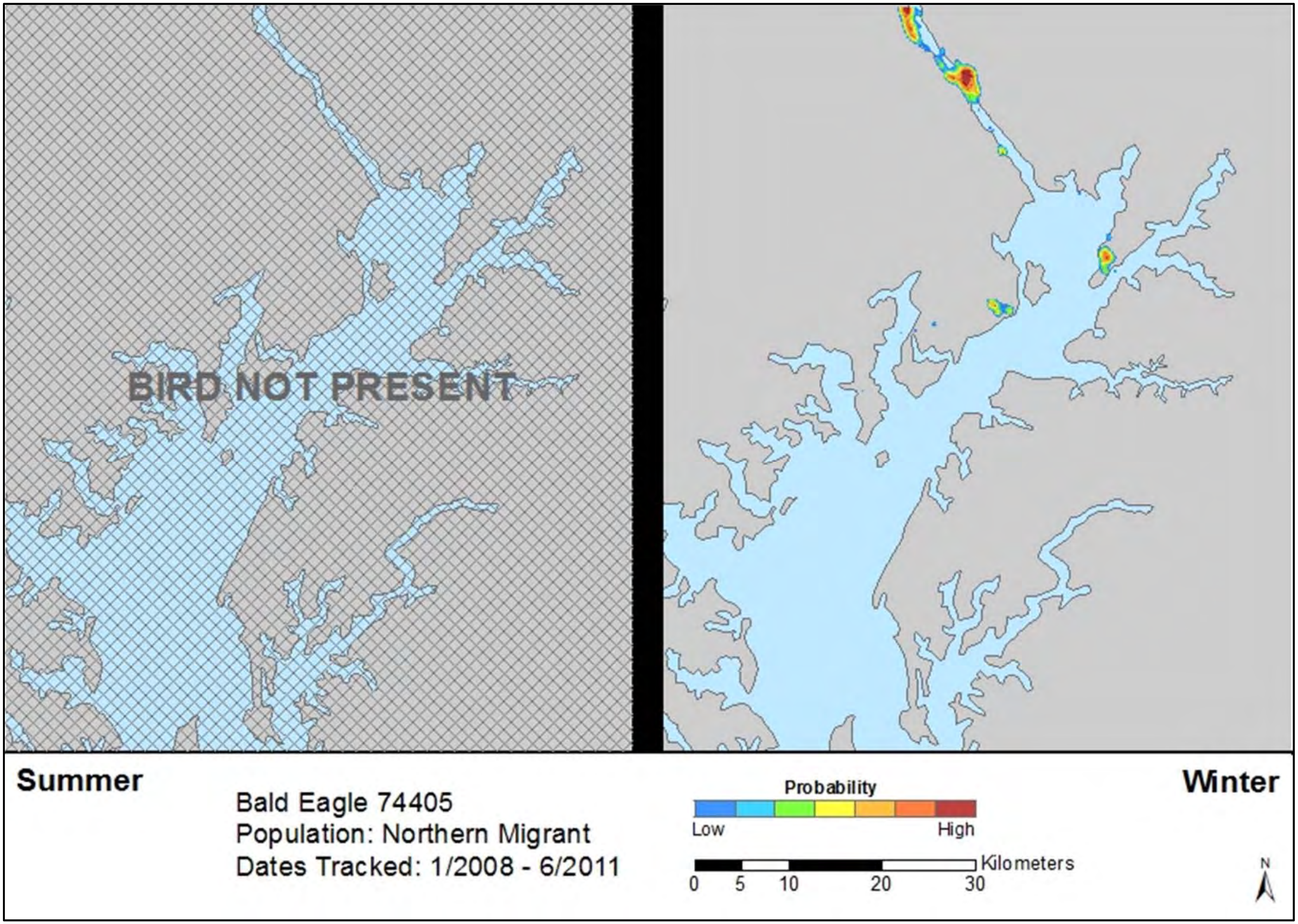

Summer
Bald Eagle 74400
Population: Chesapeake Bay
Dates Tracked: 11/2007 - 6/2011
Probability
Low
High
Kilometers
0
5
10
20
30
N
Winter


Summer
Bald Eagle 74401
Population: Northern Migrant
Dates Tracked: 1/2008 - 6/2010
Probability
Low
High
0
5
10
20
30
Kilometers
Winter
N

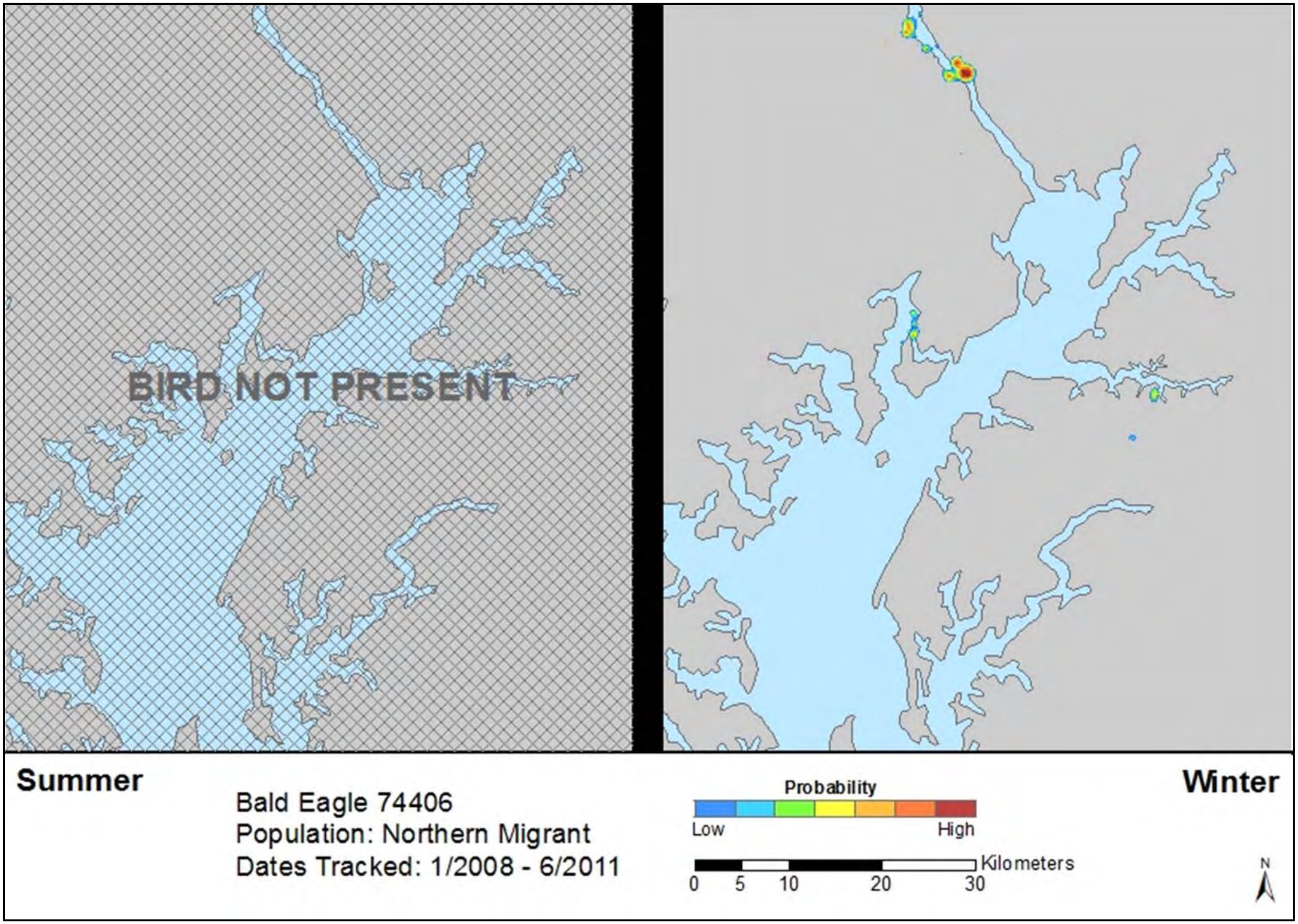

BIRD NOT PRESENT
Summer
Winter
Bald Eagle 74402
Population: Northern Migrant
Dates Tracked: 1/2008 - 6/2011
Probability
Low
High
Kilometers
0
5
10
20
30
N

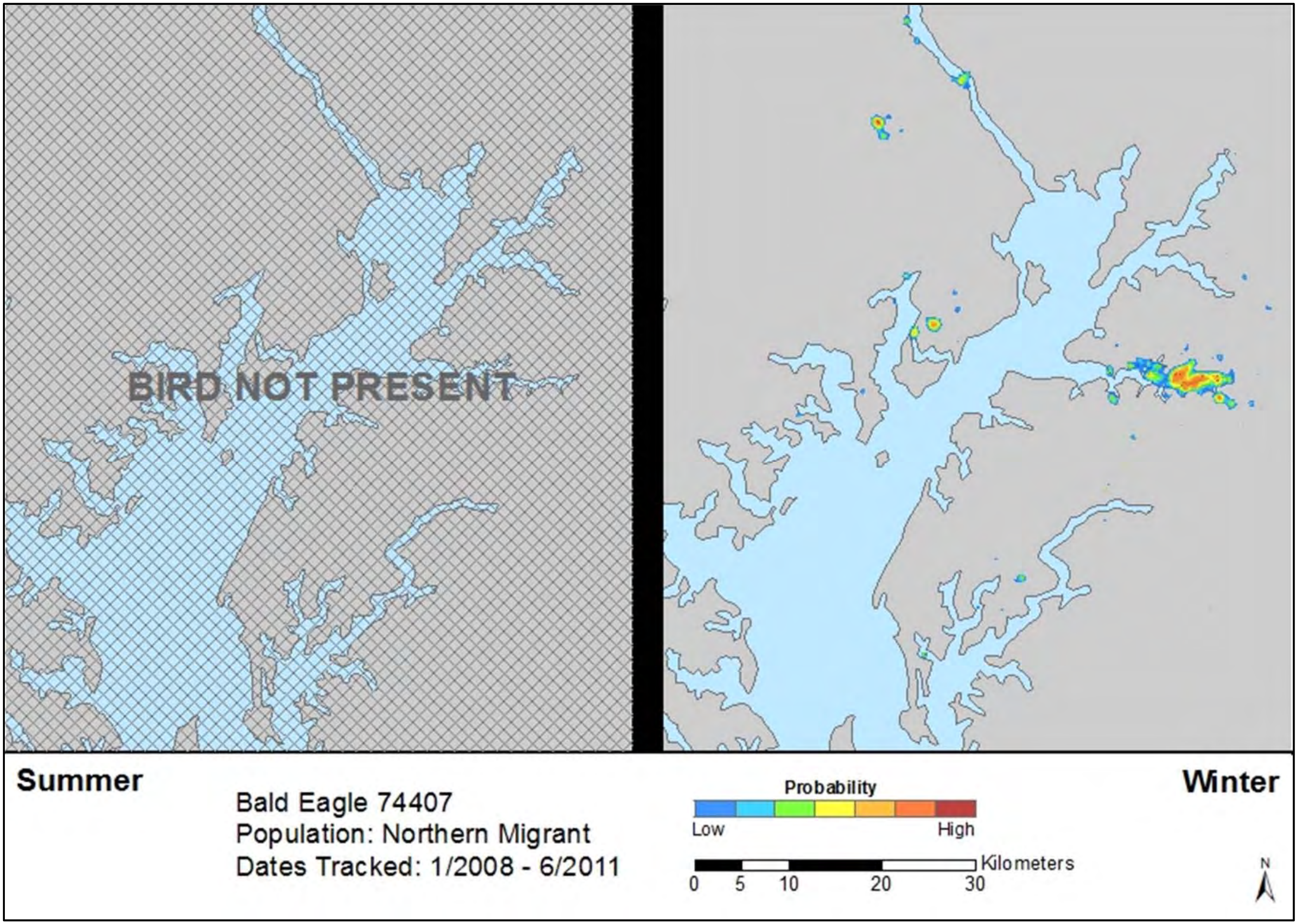

BIRD NOT PRESENT
Summer
Bald Eagle 74403
Population: Northern Migrant
Dates Tracked: 1/2008 - 6/2011
Probability
Low
High
0 5 10 20 30 Kilometers
N
Winter

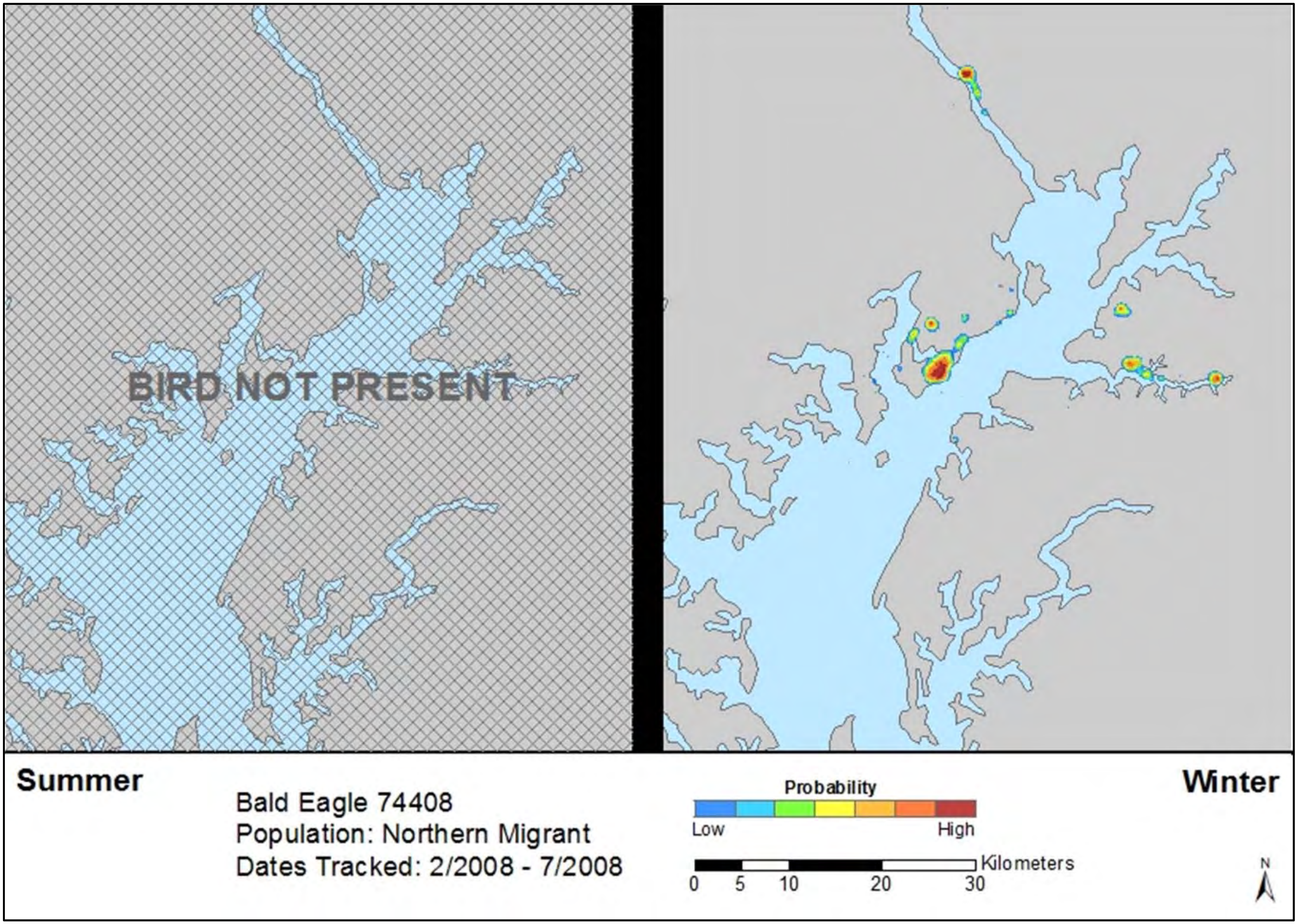

Summer
Winter
Bald Eagle 74404
Population: Chesapeake Bay
Dates Tracked: 1/2008 - 10/2008
Probability
Low
High
Kilometers
0 5 10 20 30
N

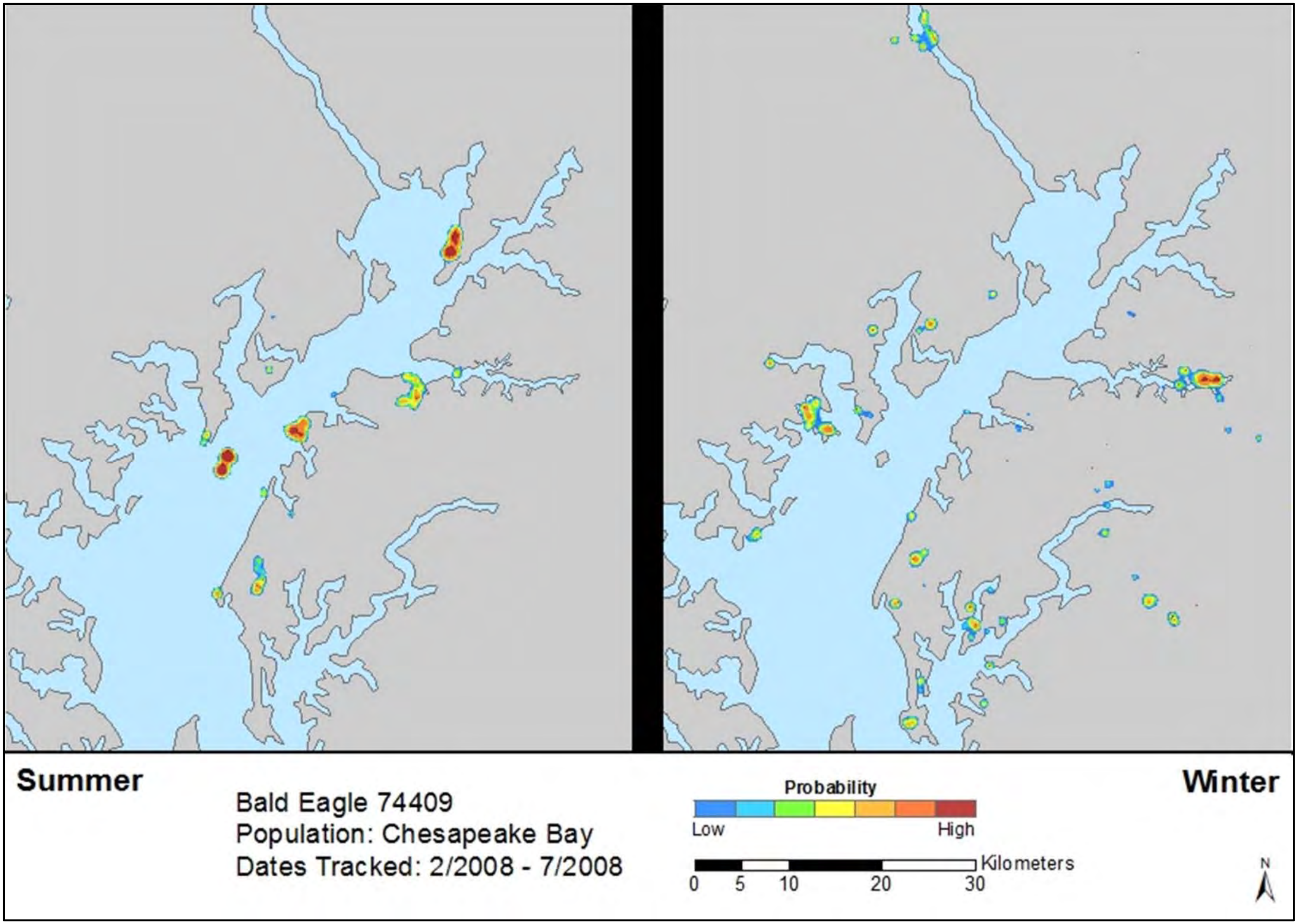


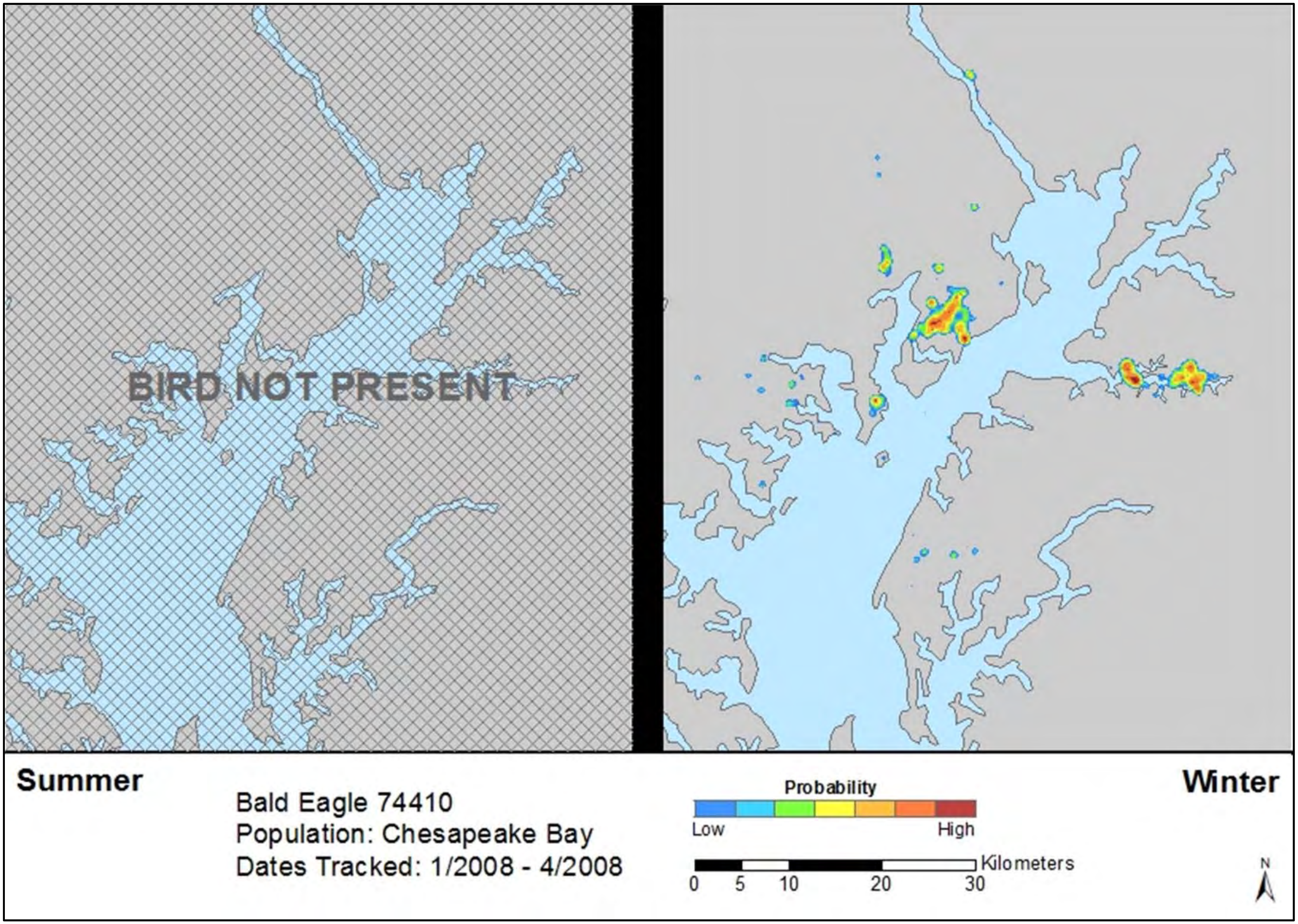
BIRD NOT PRESENT
Summer
Bald Eagle 74405
Population: Northern Migrant
Dates Tracked: 1/2008 - 6/2011
Probability
Low
High
0
5
10
20
30
Kilometers
N
Winter

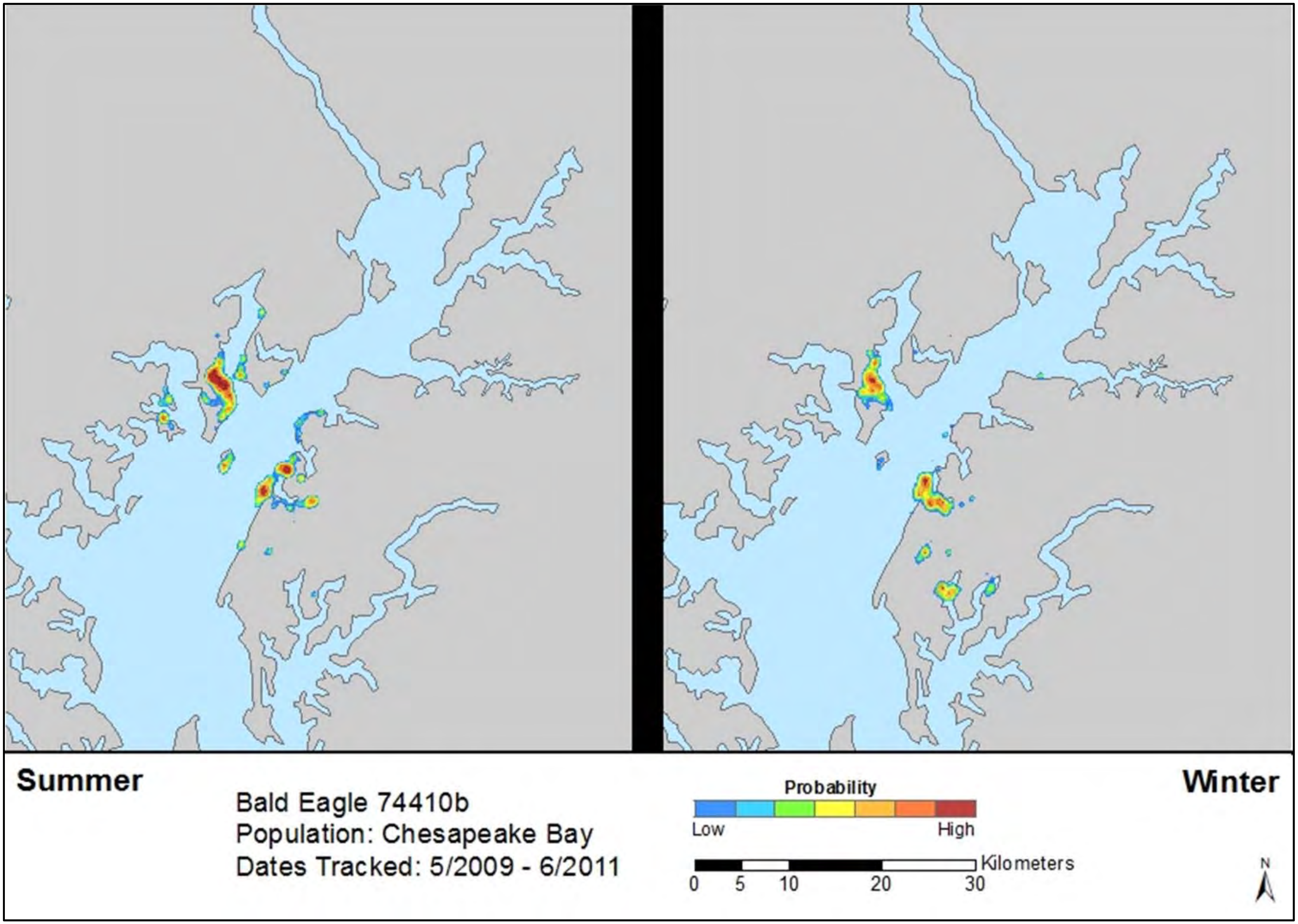

BIRD NOT PRESENT
Summer
Bald Eagle 74406
Population: Northern Migrant
Dates Tracked: 1/2008 - 6/2011
Probability
Low
High
Kilometers
0 5 10 20 30
N
Winter

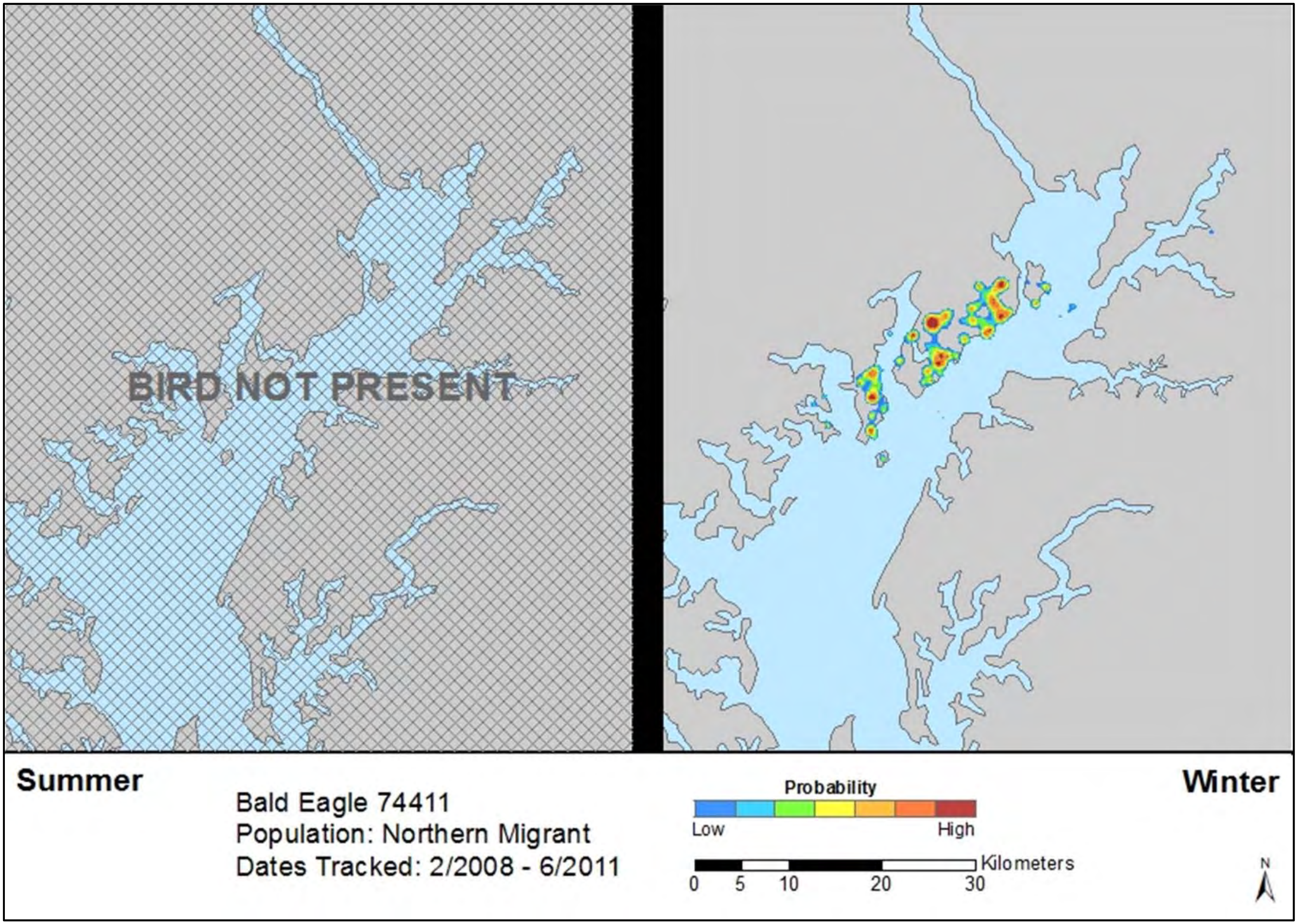

BIRD NOT PRESENT
Summer
Bald Eagle 74407
Population: Northern Migrant
Dates Tracked: 1/2008 - 6/2011
Probability
Low
High
0 5 10 20 30 Kilometers
N
Winter

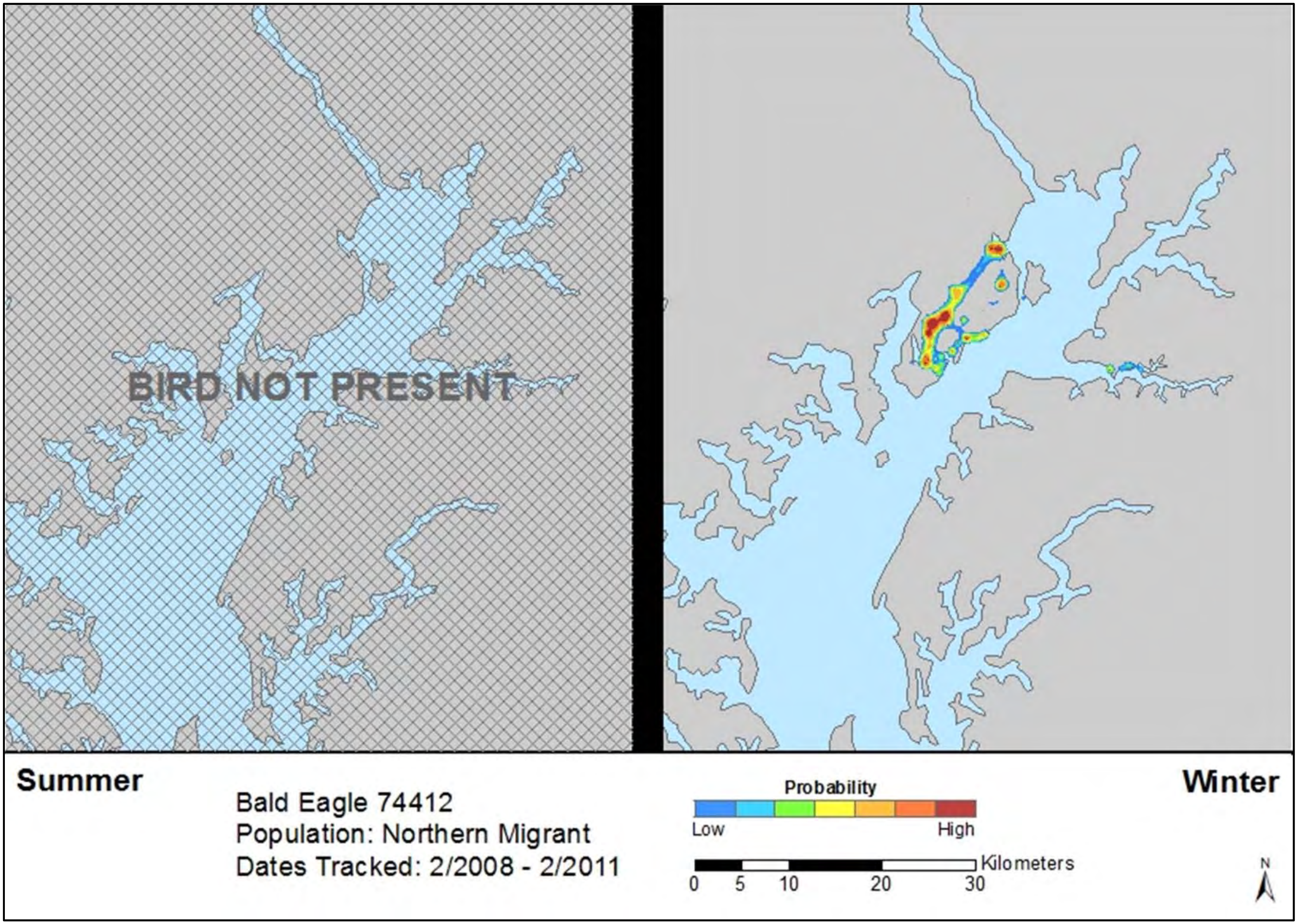

BIRD NOT PRESENT
Summer
Bald Eagle 74408
Population: Northern Migrant
Dates Tracked: 2/2008 - 7/2008
Probability
Low
High
Kilometers
0
5
10
20
30
N
Winter

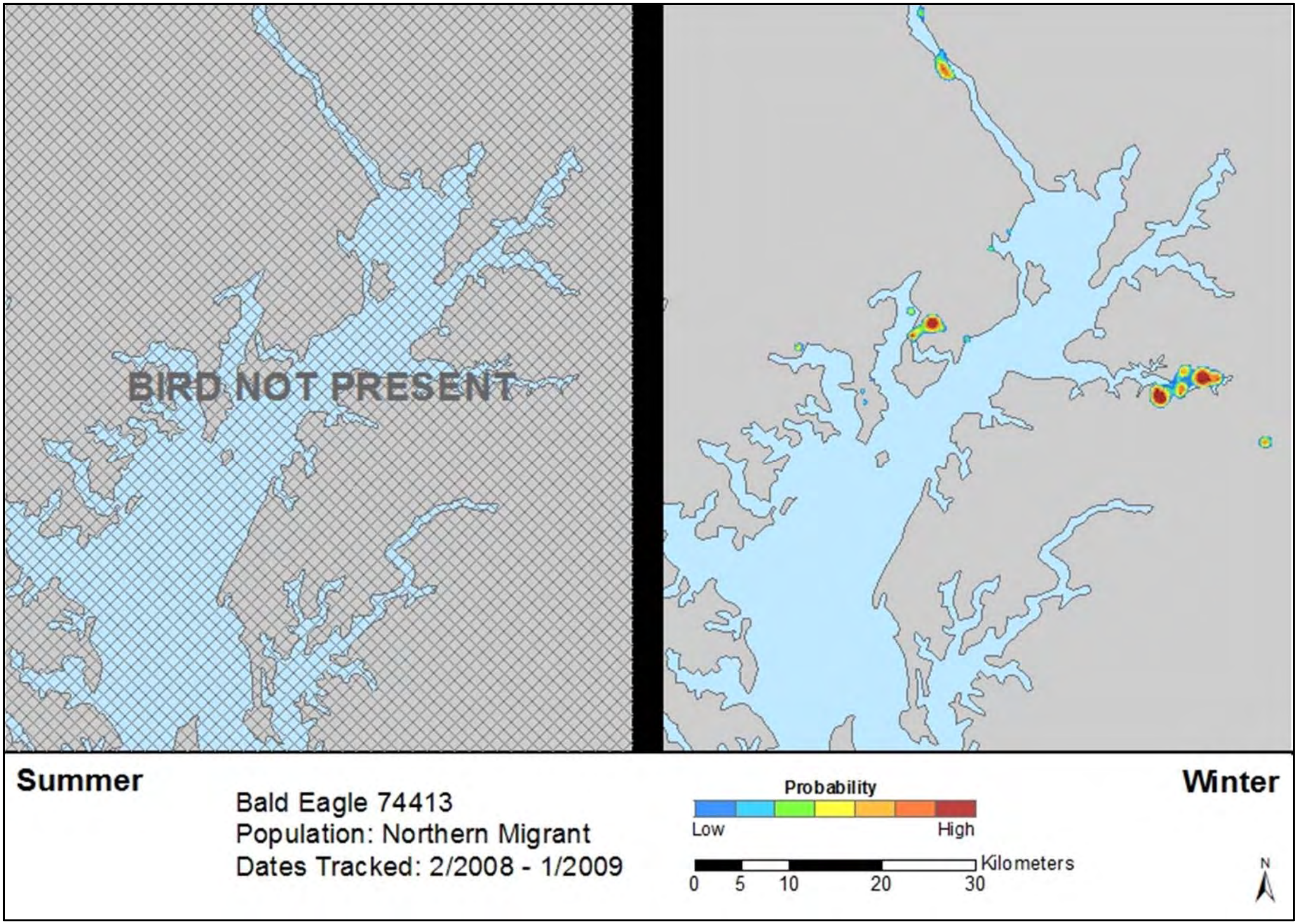

Summer
Bald Eagle 74409
Population: Chesapeake Bay
Dates Tracked: 2/2008 - 7/2008
Probability
Low
High
Kilometers
0
5
10
20
30
N
Winter

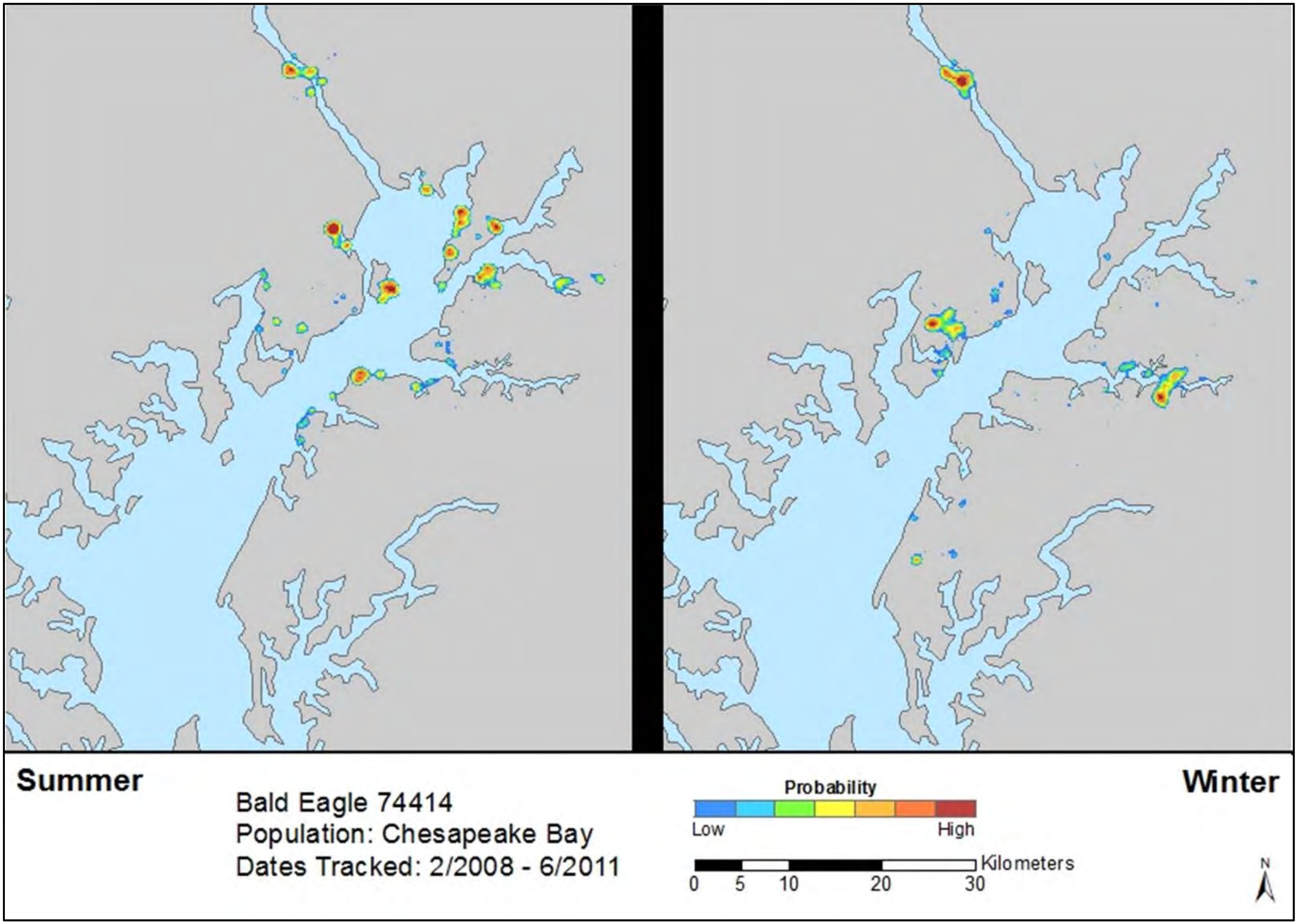

BIRD NOT PRESENT
Summer
Winter
Bald Eagle 74410
Population: Chesapeake Bay
Dates Tracked: 1/2008 - 4/2008
Probability
Low
High
Kilometers
0
5
10
20
30
N

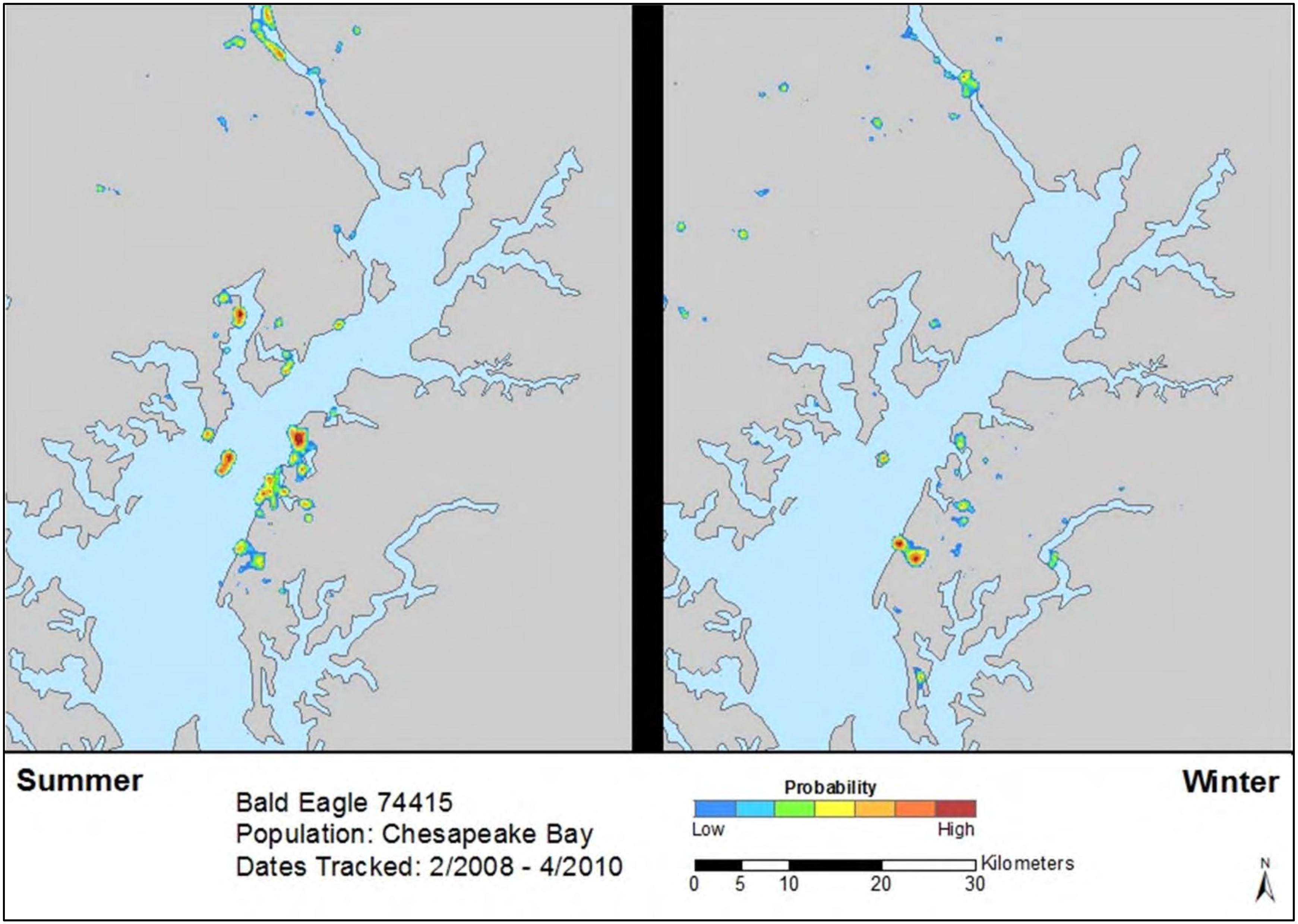

Summer
Winter
Bald Eagle 74410b
Population: Chesapeake Bay
Dates Tracked: 5/2009 - 6/2011
Probability
Low
High
0 5 10 20 30
Kilometers
N

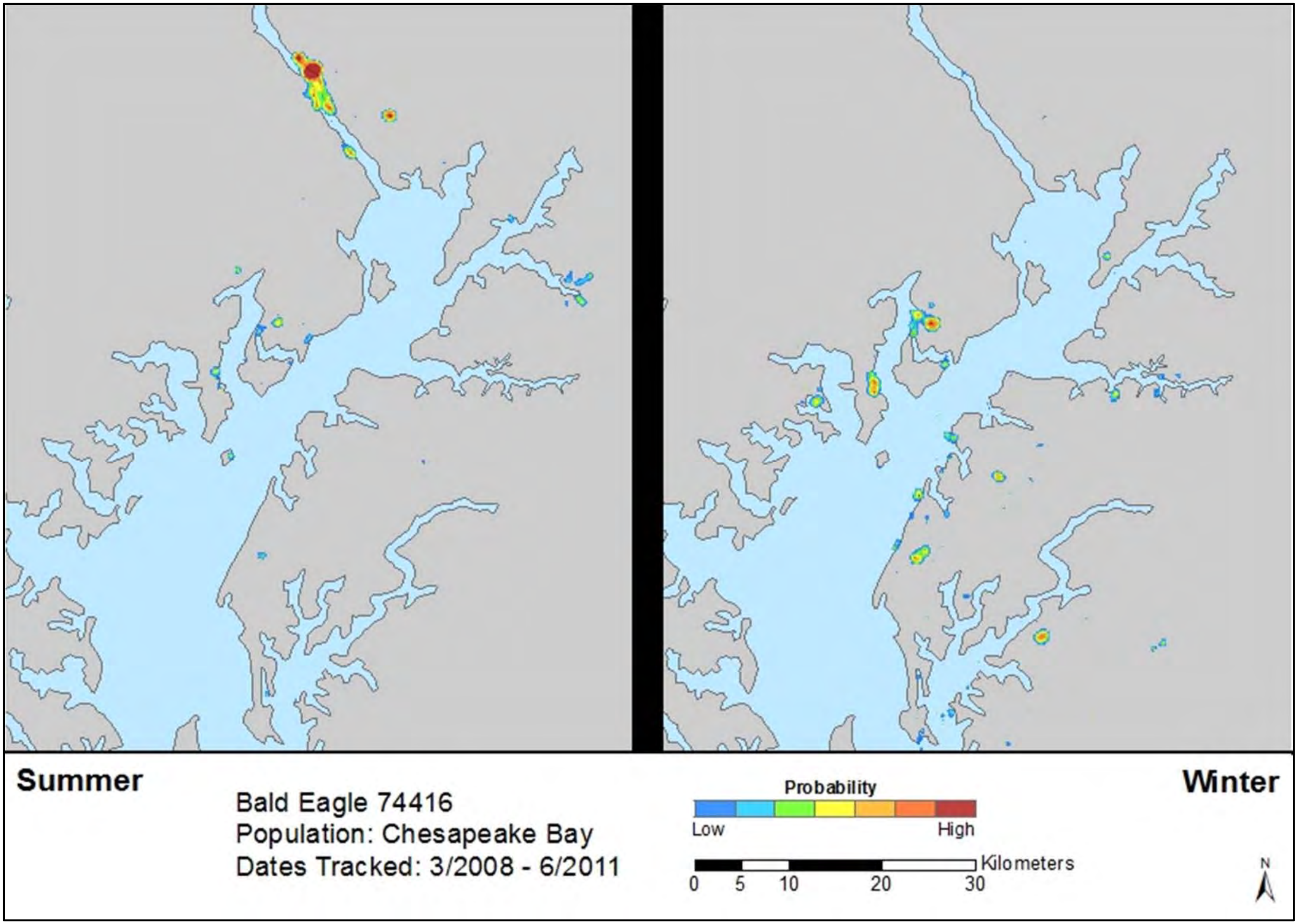

BIRD NOT PRESENT
Summer
Bald Eagle 74411
Population: Northern Migrant
Dates Tracked: 2/2008 - 6/2011
Probability
Low
High
0
5
10
20
30
Kilometers
N
Winter

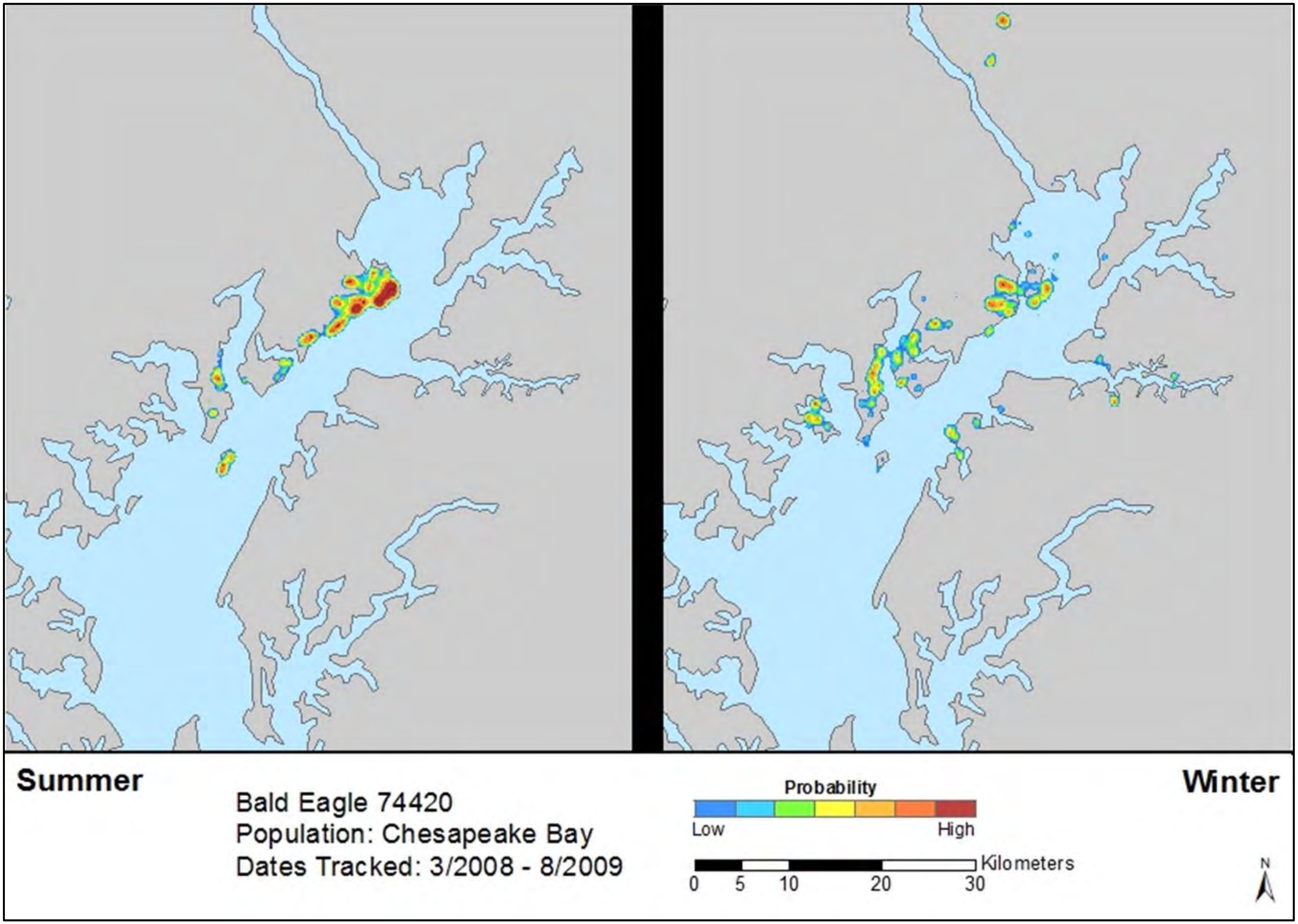

BIRD NOT PRESENT
Summer
Bald Eagle 74412
Population: Northern Migrant
Dates Tracked: 2/2008 - 2/2011
Probability
Low
High
0 5 10 20 30 Kilometers
N
Winter

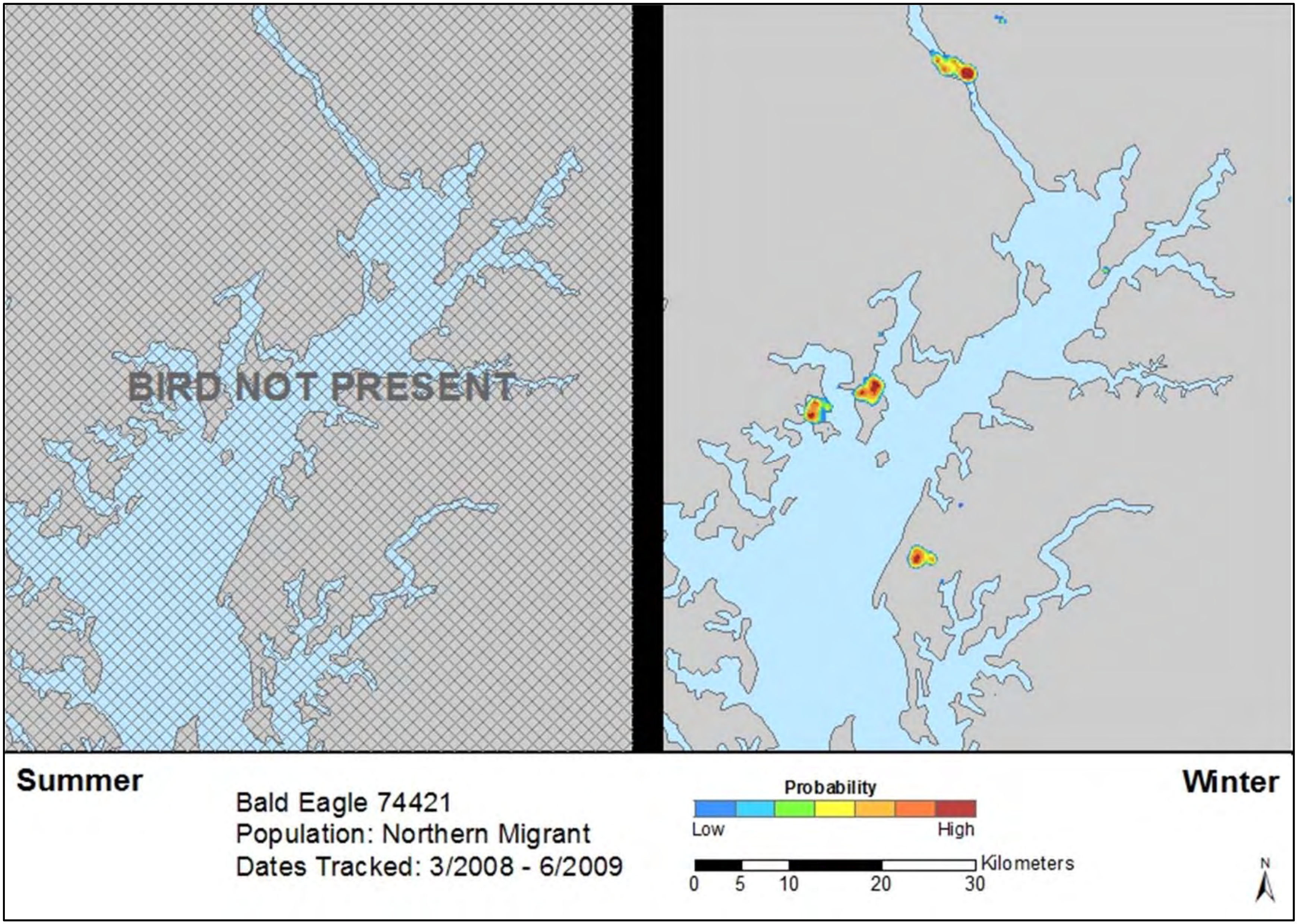

BIRD NOT PRESENT
Summer
Winter
Bald Eagle 74413
Population: Northern Migrant
Dates Tracked: 2/2008 - 1/2009
Probability
Low
High
0
5
10
20
30
Kilometers
N

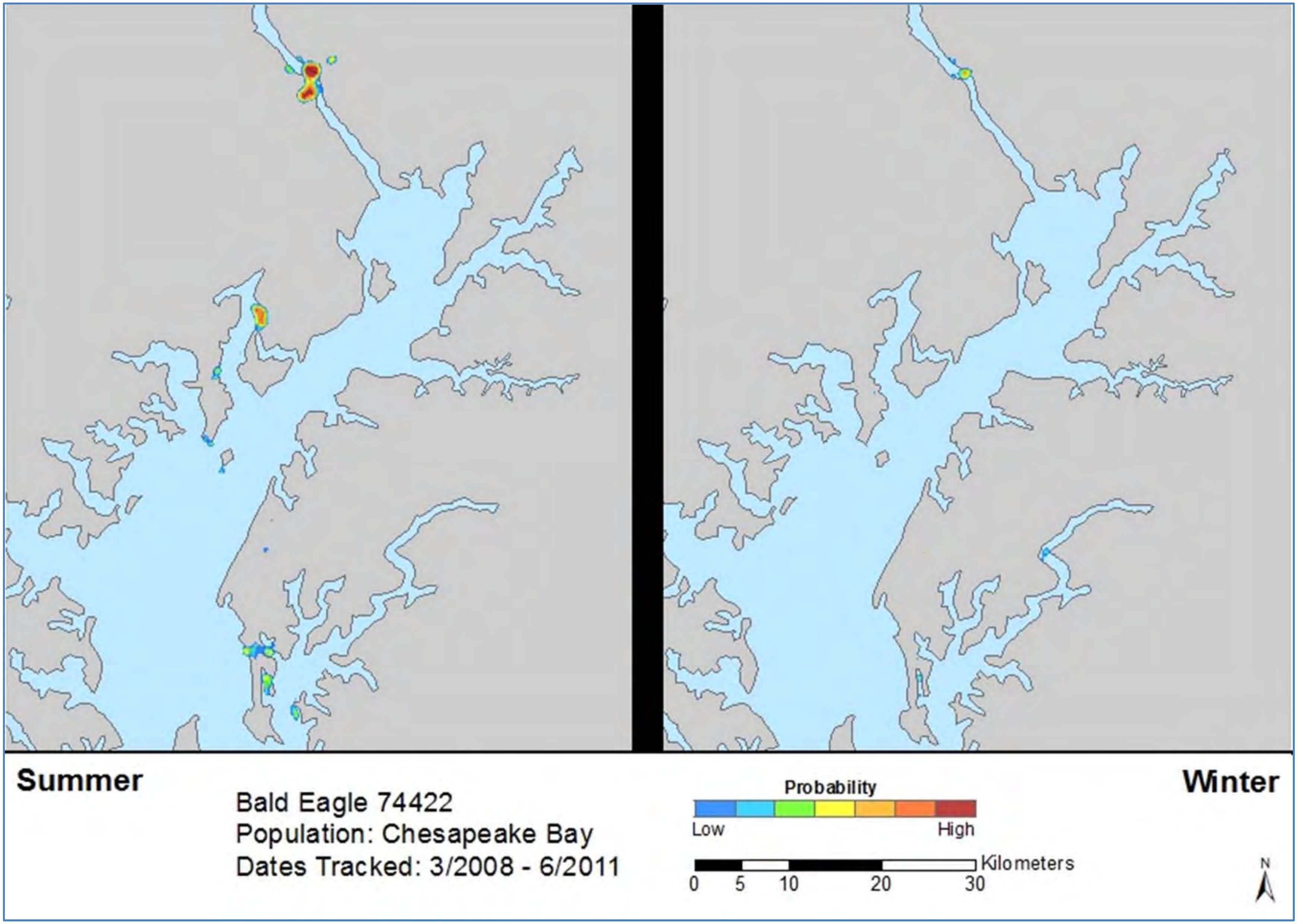

Summer
Bald Eagle 74414
Population: Chesapeake Bay
Dates Tracked: 2/2008 - 6/2011
Probability
Low
High
0 5 10 20 30 Kilometers
N
Winter


Summer
Winter
Bald Eagle 74415
Population: Chesapeake Bay
Dates Tracked: 2/2008 - 4/2010
Probability
Low
High
Kilometers
0 5 10 20 30
N

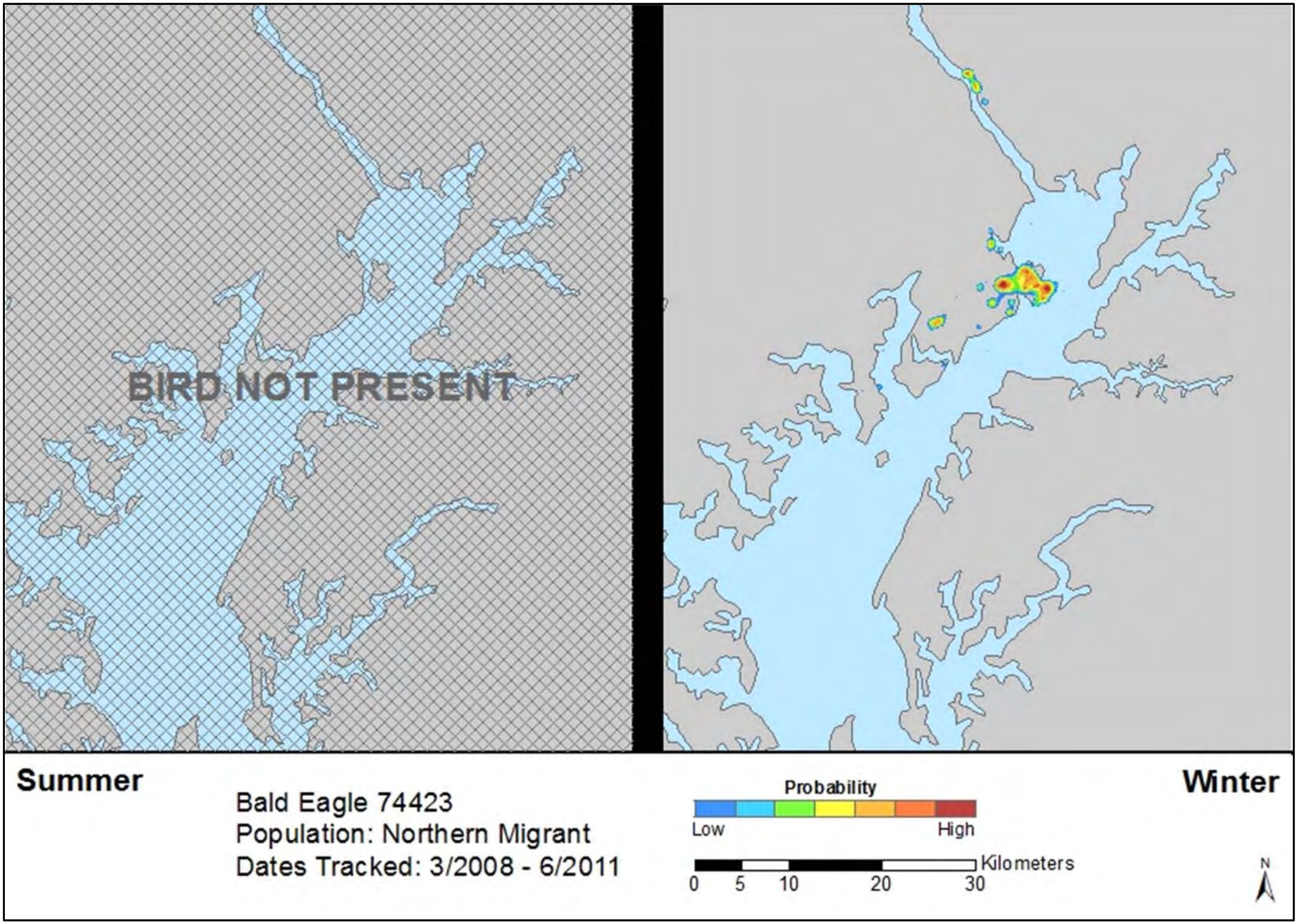

Summer
Bald Eagle 74416
Population: Chesapeake Bay
Dates Tracked: 3/2008 - 6/2011
Probability
Low
High
0 5 10 20 30 Kilometers
N
Winter

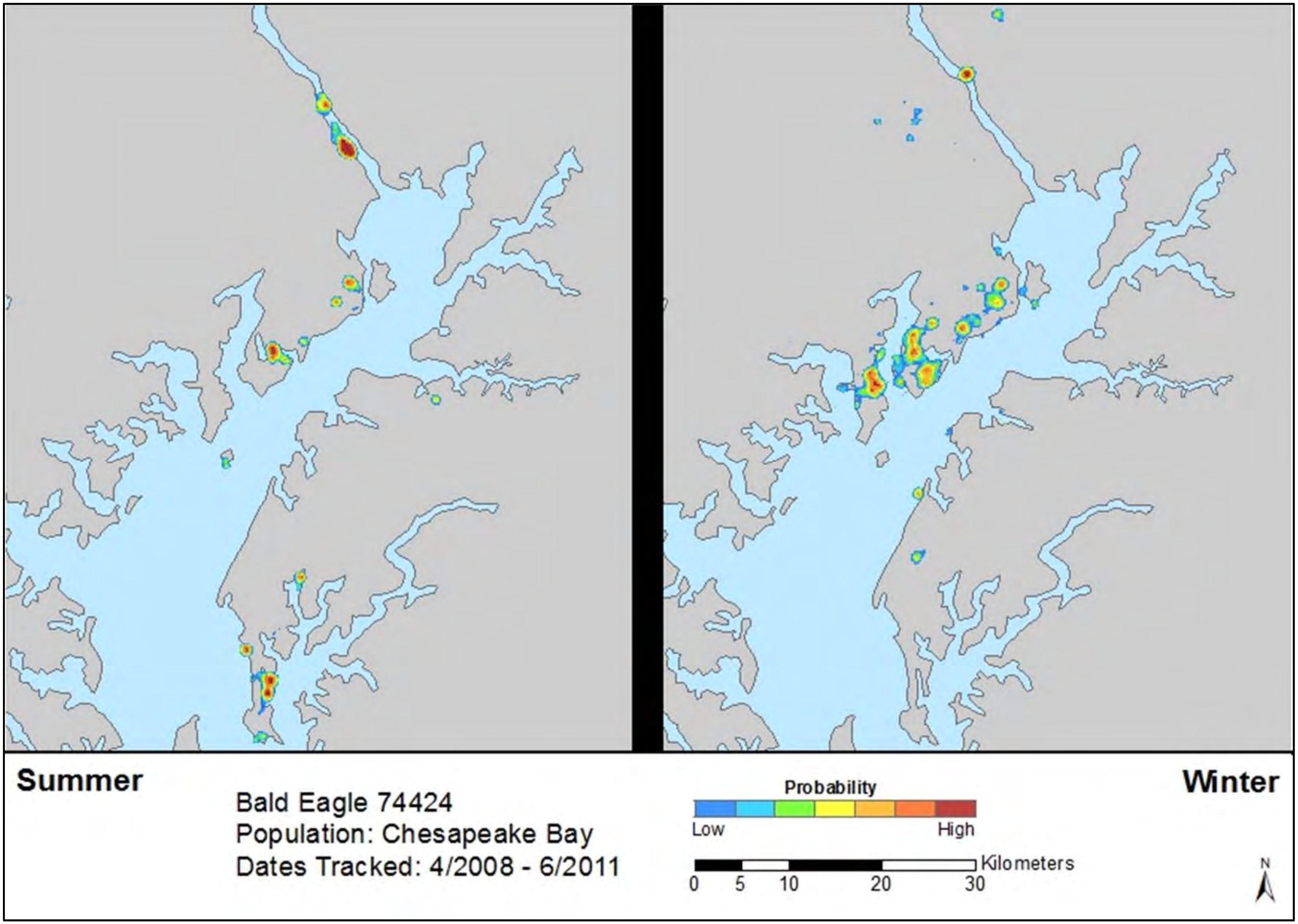

Summer
Winter
Bald Eagle 74420
Population: Chesapeake Bay
Dates Tracked: 3/2008 - 8/2009
Probability
Low
High
0 5 10 20 30 Kilometers
N

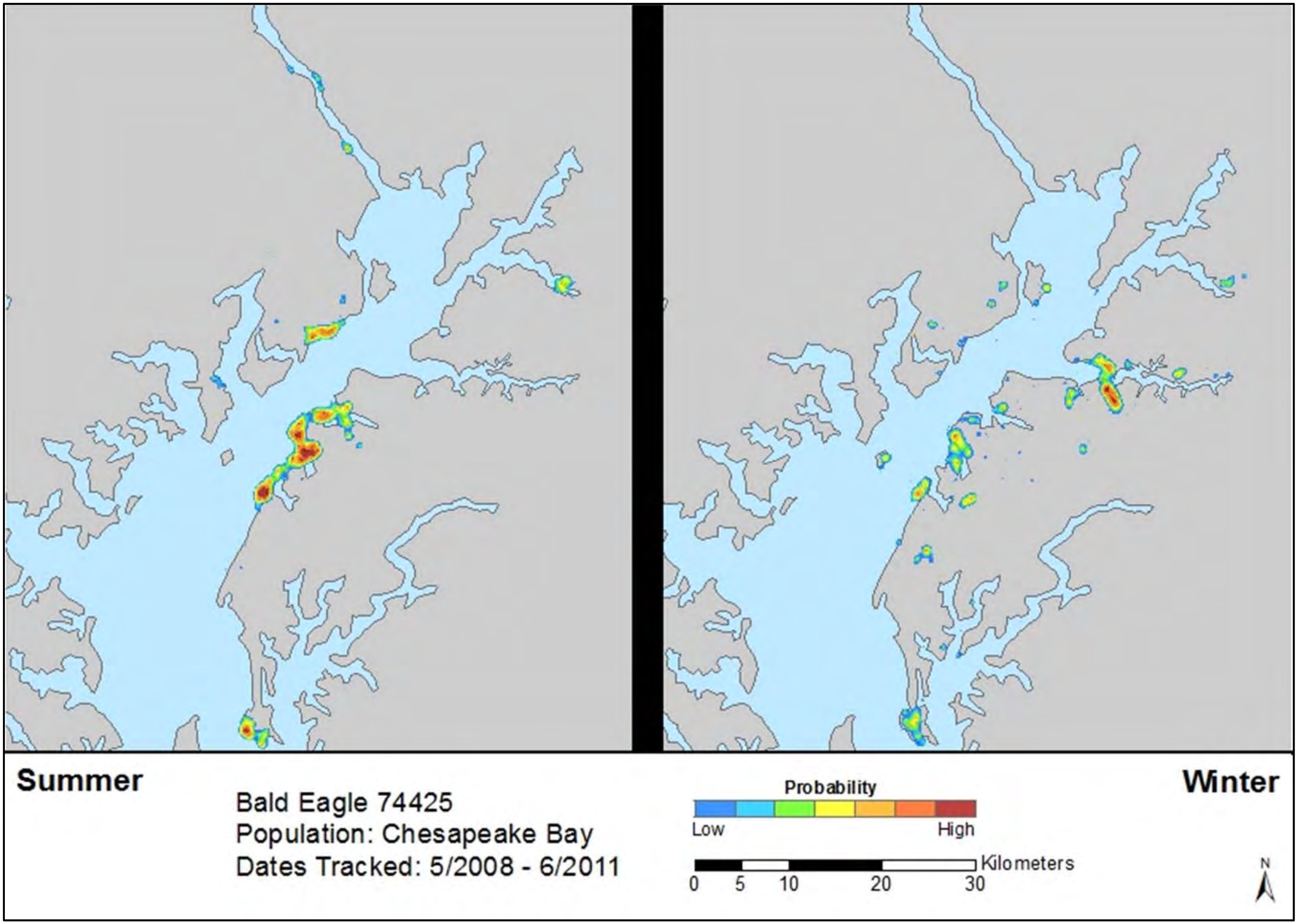

BIRD NOT PRESENT
Summer
Bald Eagle 74421
Population: Northern Migrant
Dates Tracked: 3/2008 - 6/2009
Probability
Low
High
Kilometers
0 5 10 20 30
N
Winter



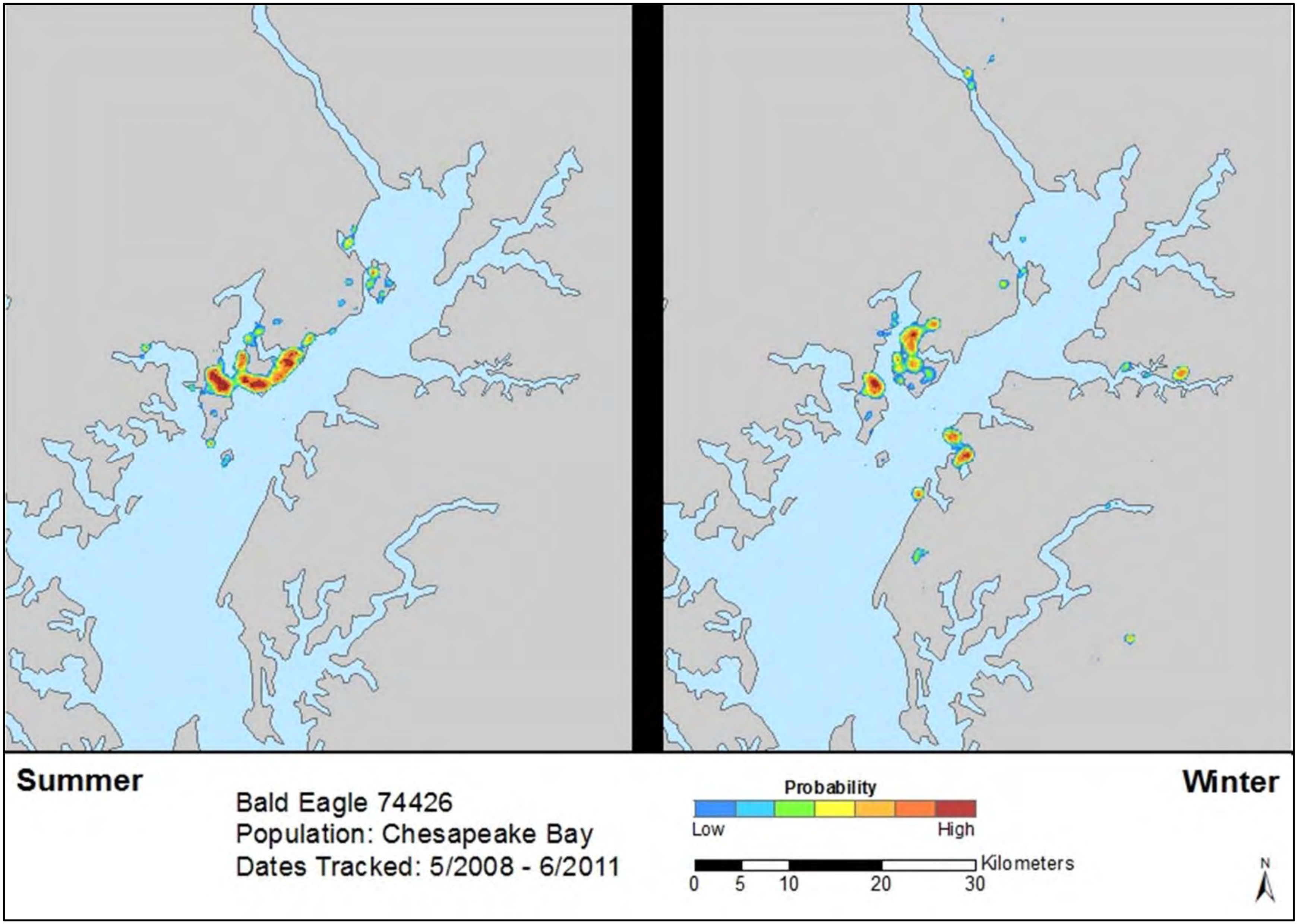
Summer
Bald Eagle 74422
Population: Chesapeake Bay
Dates Tracked: 3/2008 - 6/2011
Probability
Low
High
0 5 10 20 30 Kilometers
Winter
N

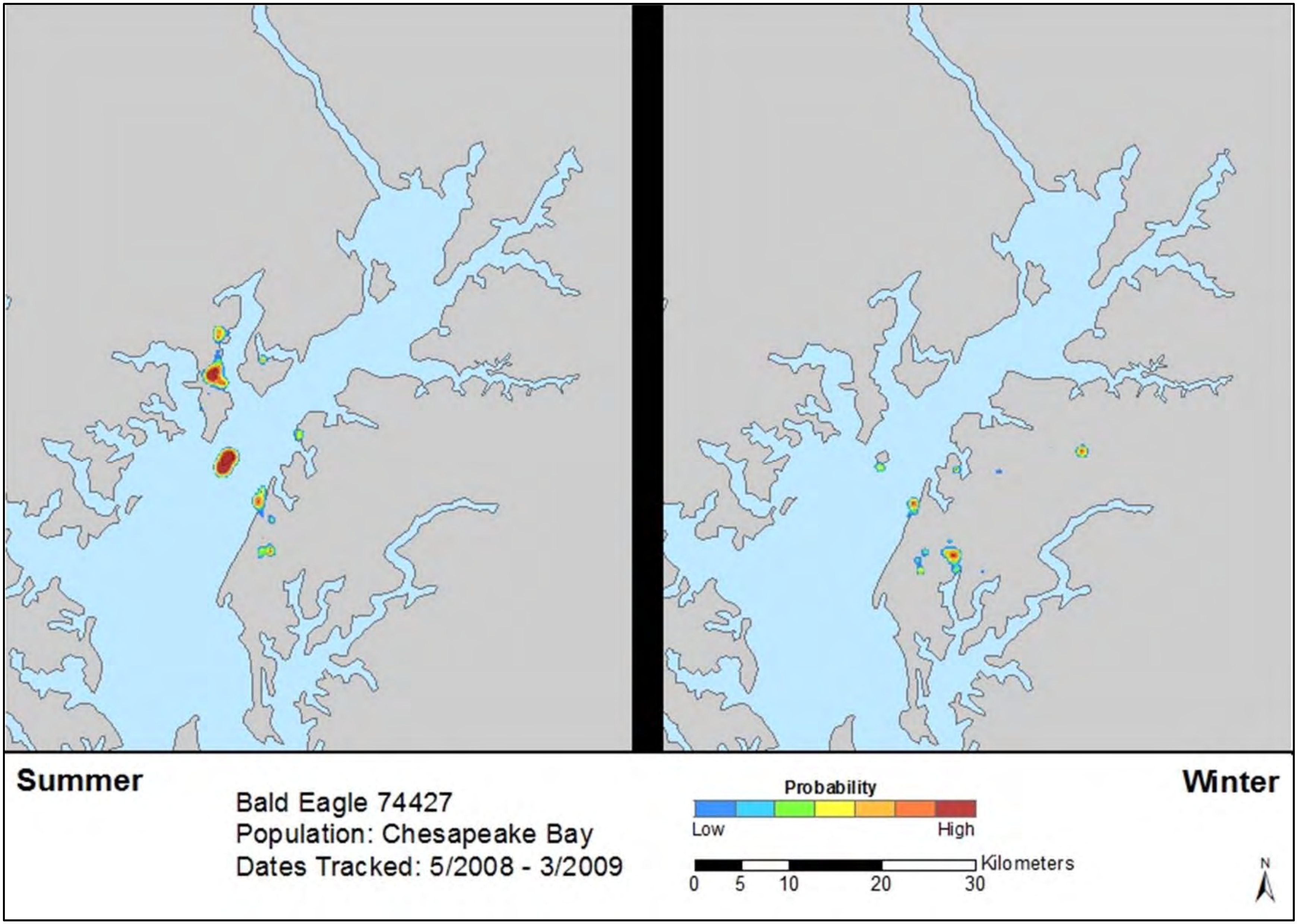

BIRD NOT PRESENT
Summer
Bald Eagle 74423
Population: Northern Migrant
Dates Tracked: 3/2008 - 6/2011
Probability
Low
High
Kilometers
0
5
10
20
30
Winter
N

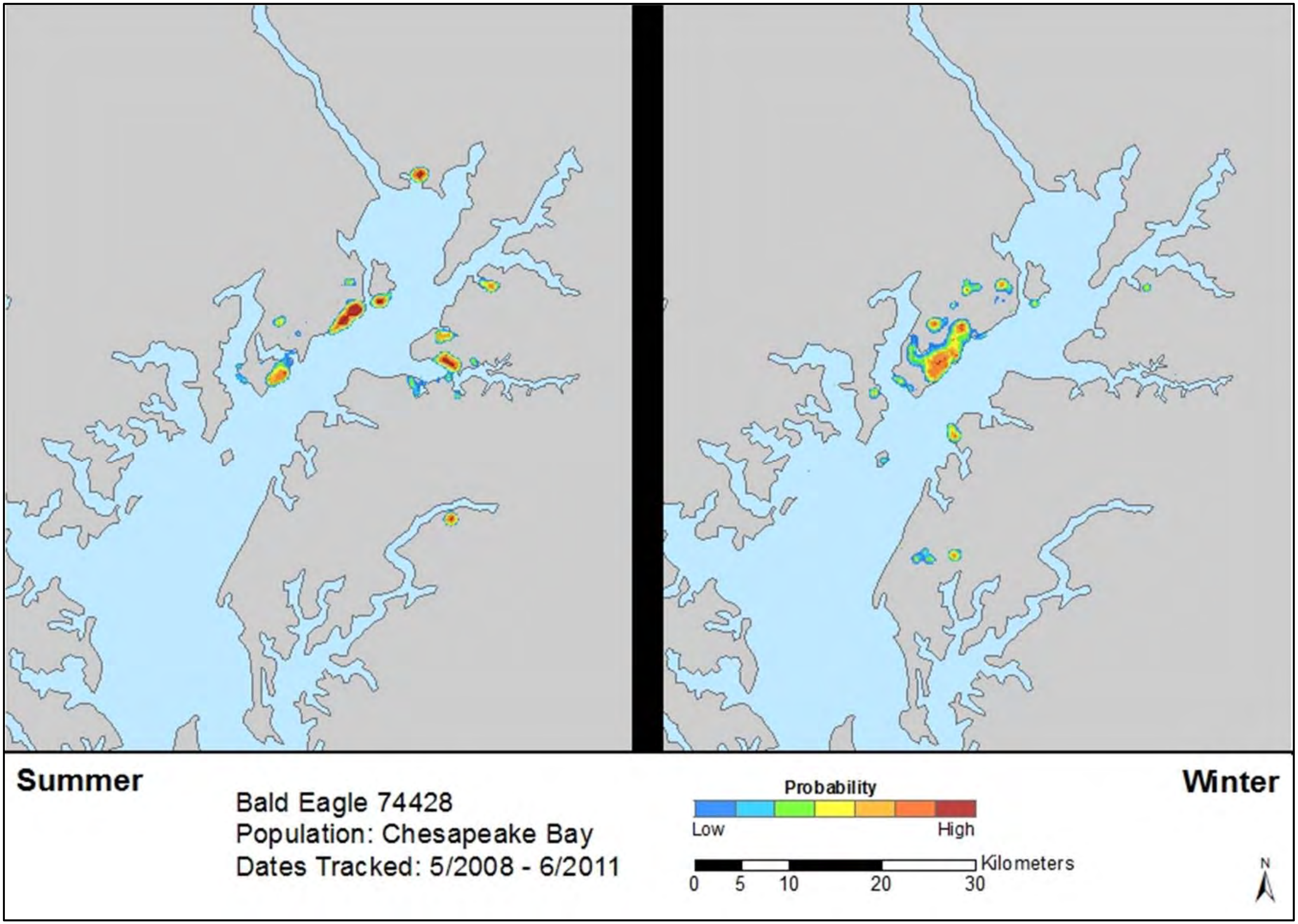

Summer
Winter
Bald Eagle 74424
Population: Chesapeake Bay
Dates Tracked: 4/2008 - 6/2011
Probability
Low
High
0 5 10 20 30 Kilometers
N

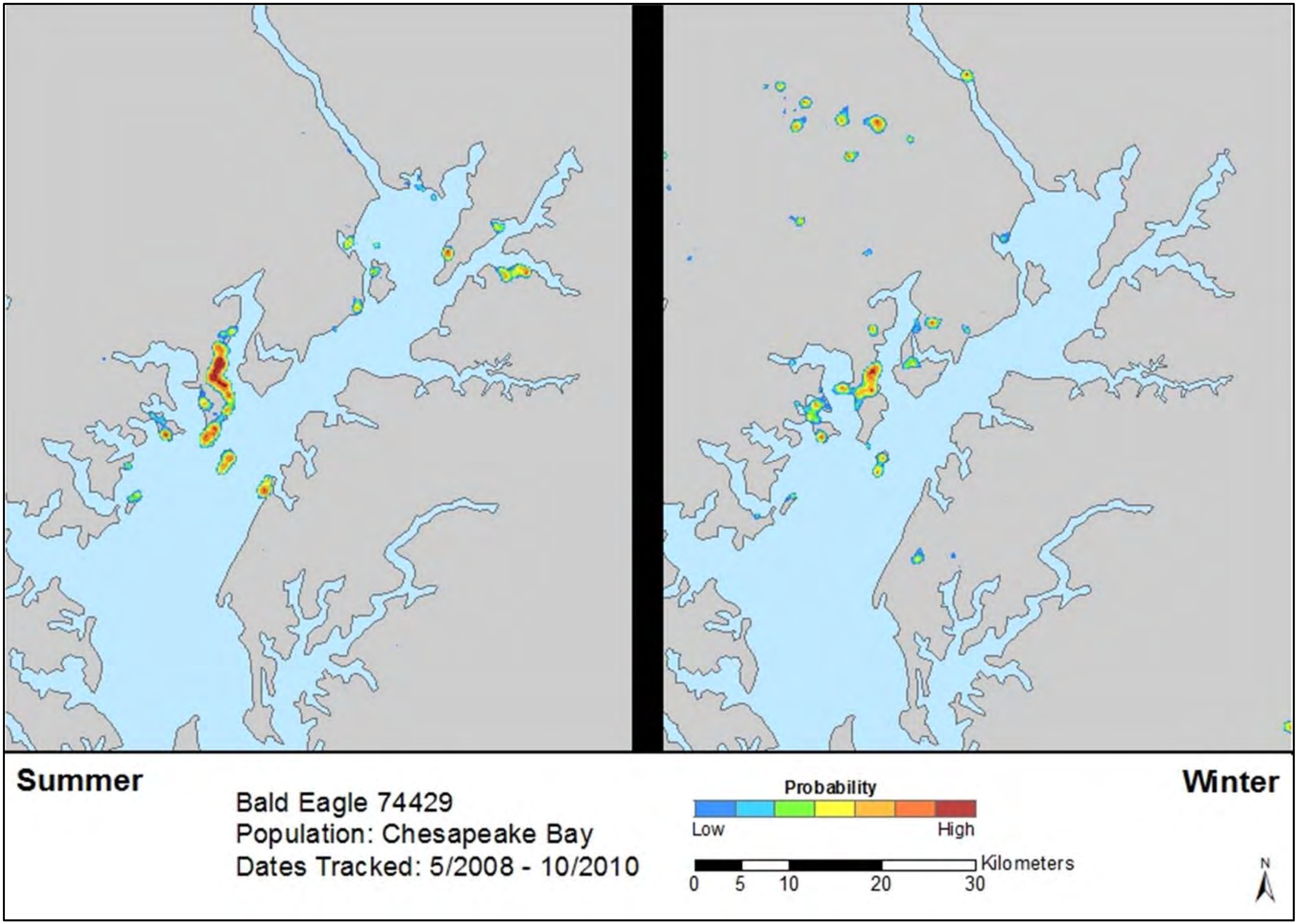


Summer
Winter
Bald Eagle 74425
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 6/2011
Probability
Low
High
Kilometers
0
5
10
20
30
N

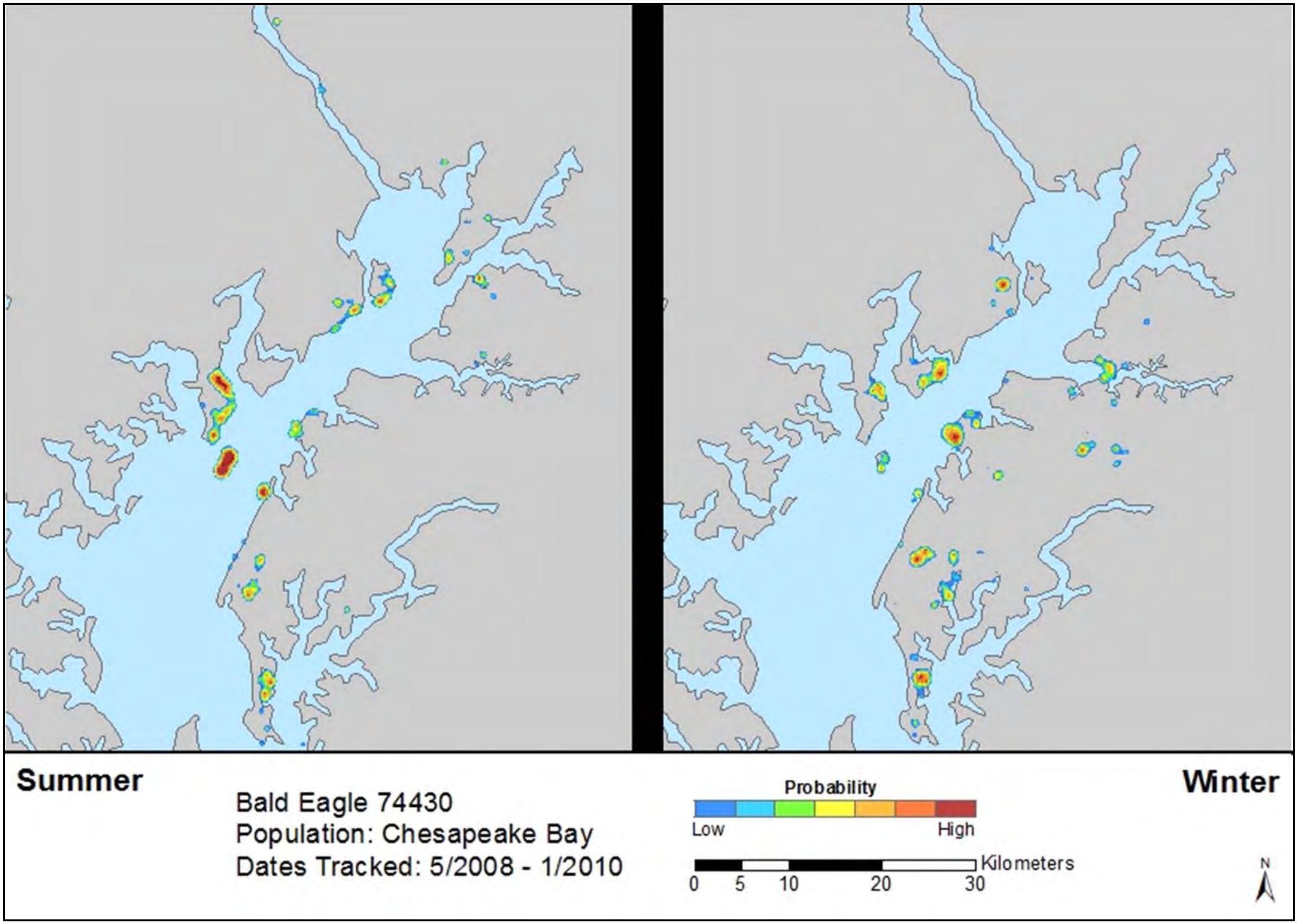

Summer
Winter
Bald Eagle 74426
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 6/2011
Probability
Low
High
0
5
10
20
30
Kilometers
N


Summer
Winter
Bald Eagle 74427
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 3/2009
Probability
Low
High
0 5 10 20 30 Kilometers
N

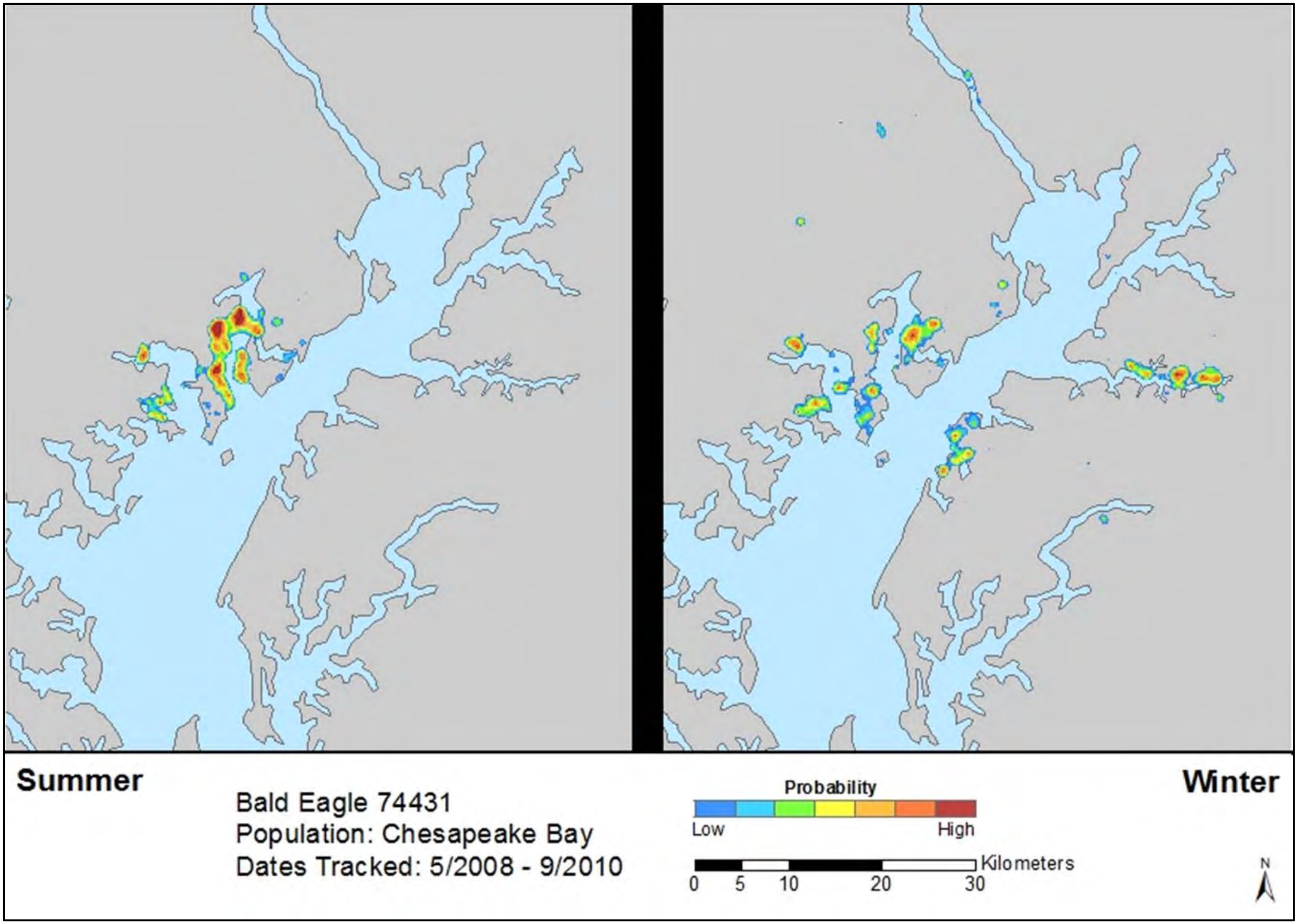

Summer
Bald Eagle 74428
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 6/2011
Probability
Low
High
0 5 10 20 30 Kilometers
N
Winter



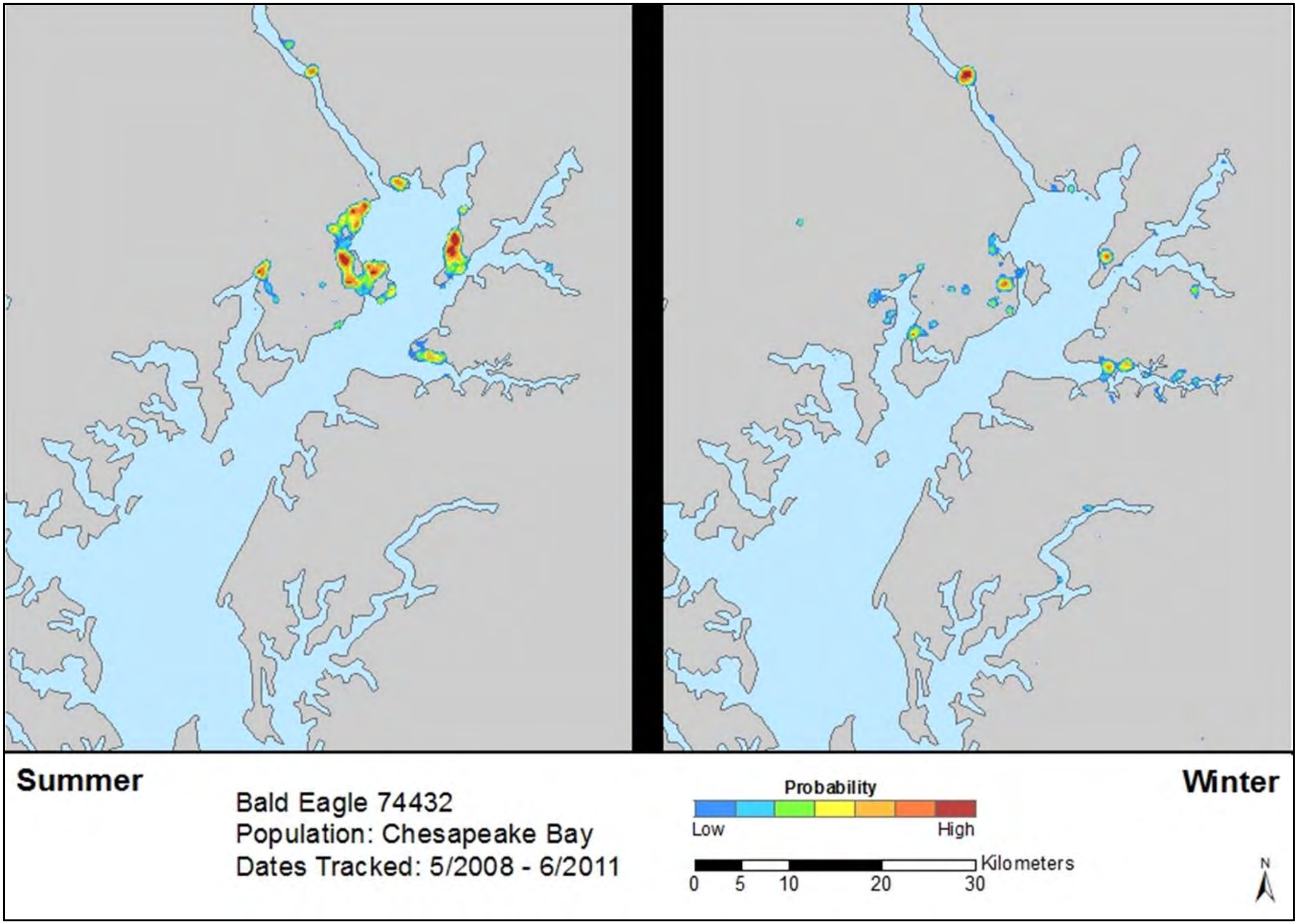
Summer
Bald Eagle 74429
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 10/2010
Probability
Low
High
0 5 10 20 30 Kilometers
N
Winter

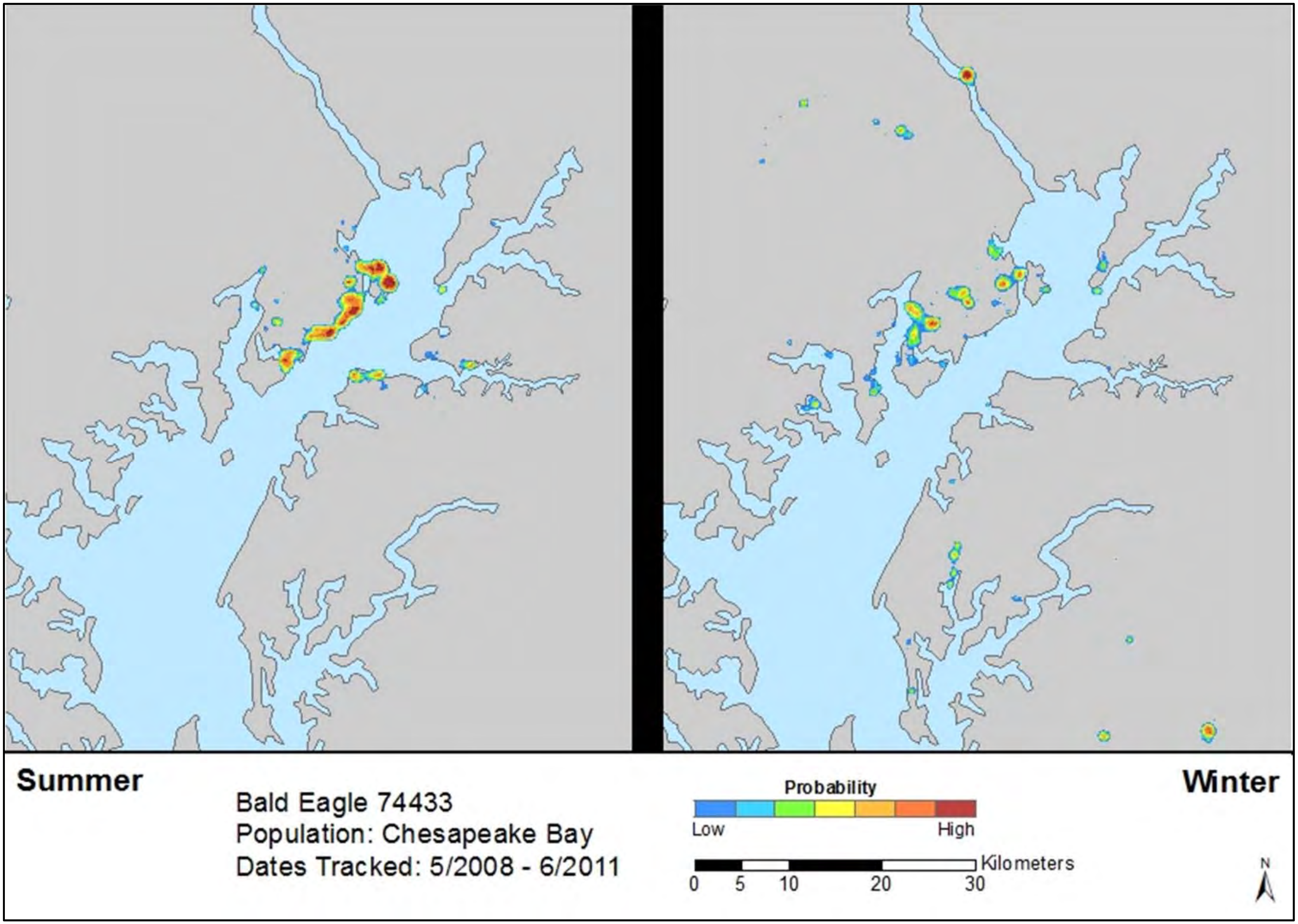


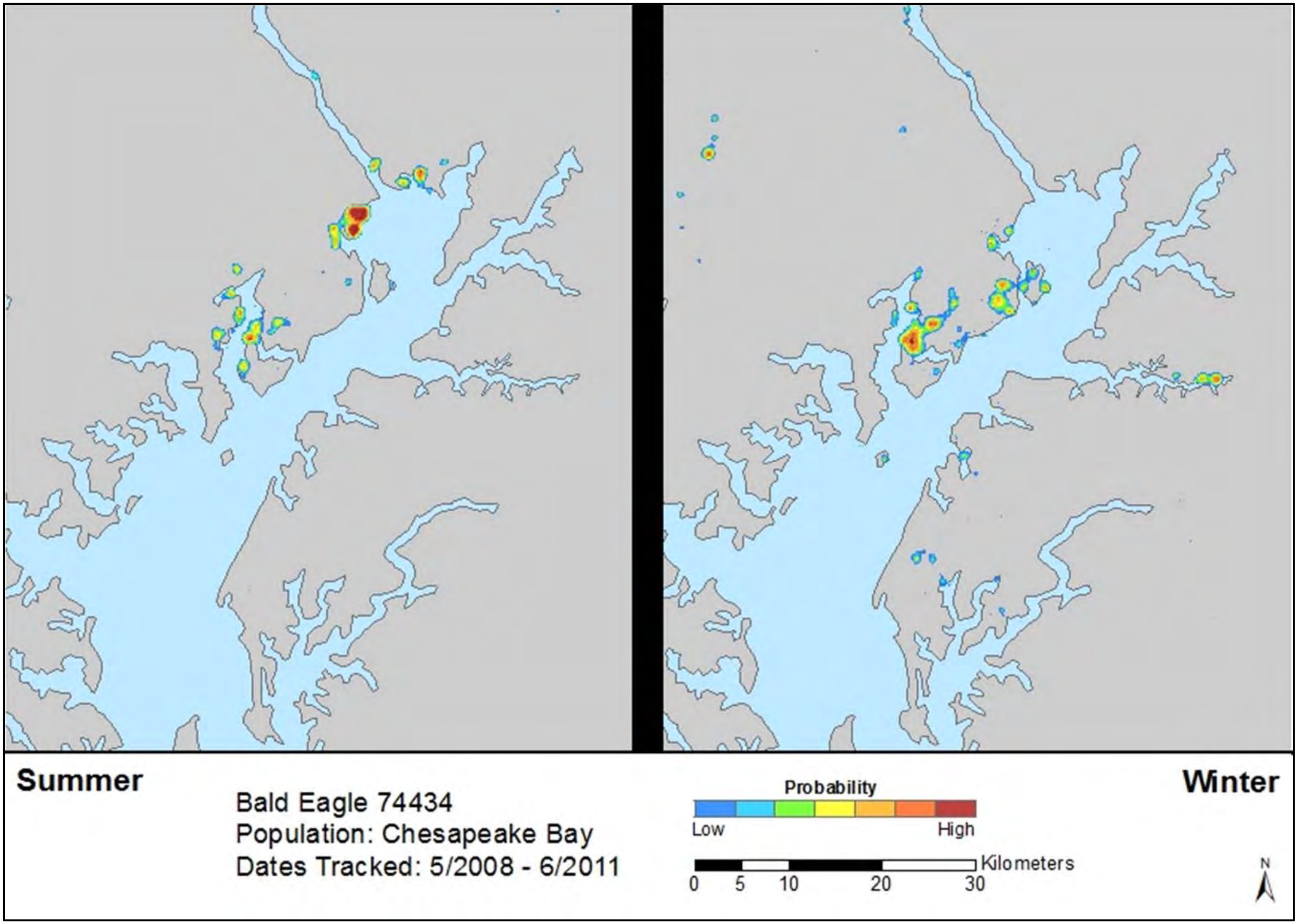
Summer
Bald Eagle 74430
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 1/2010
Probability
Low
High
Kilometers
0 5 10 20 30
Winter
N

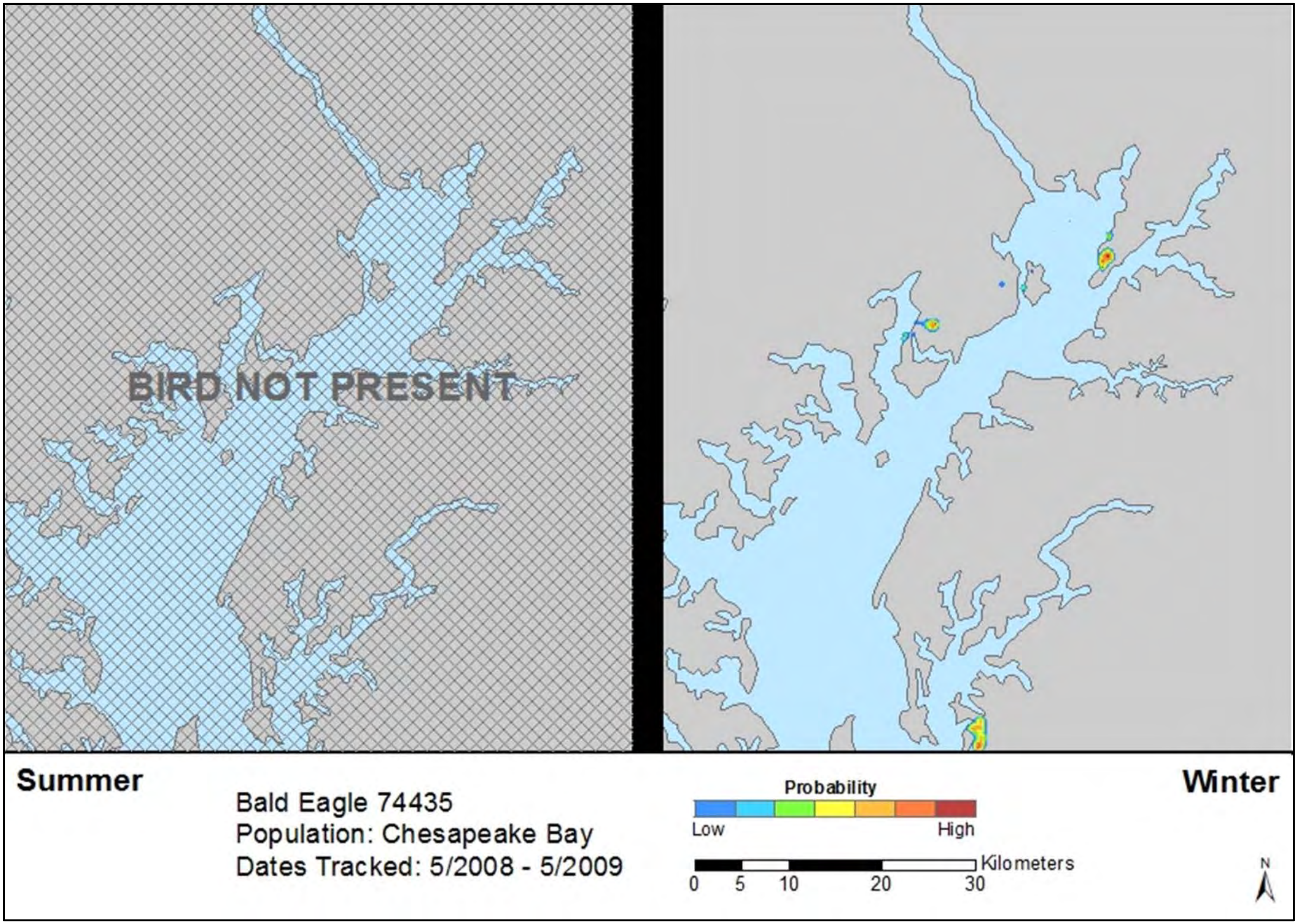


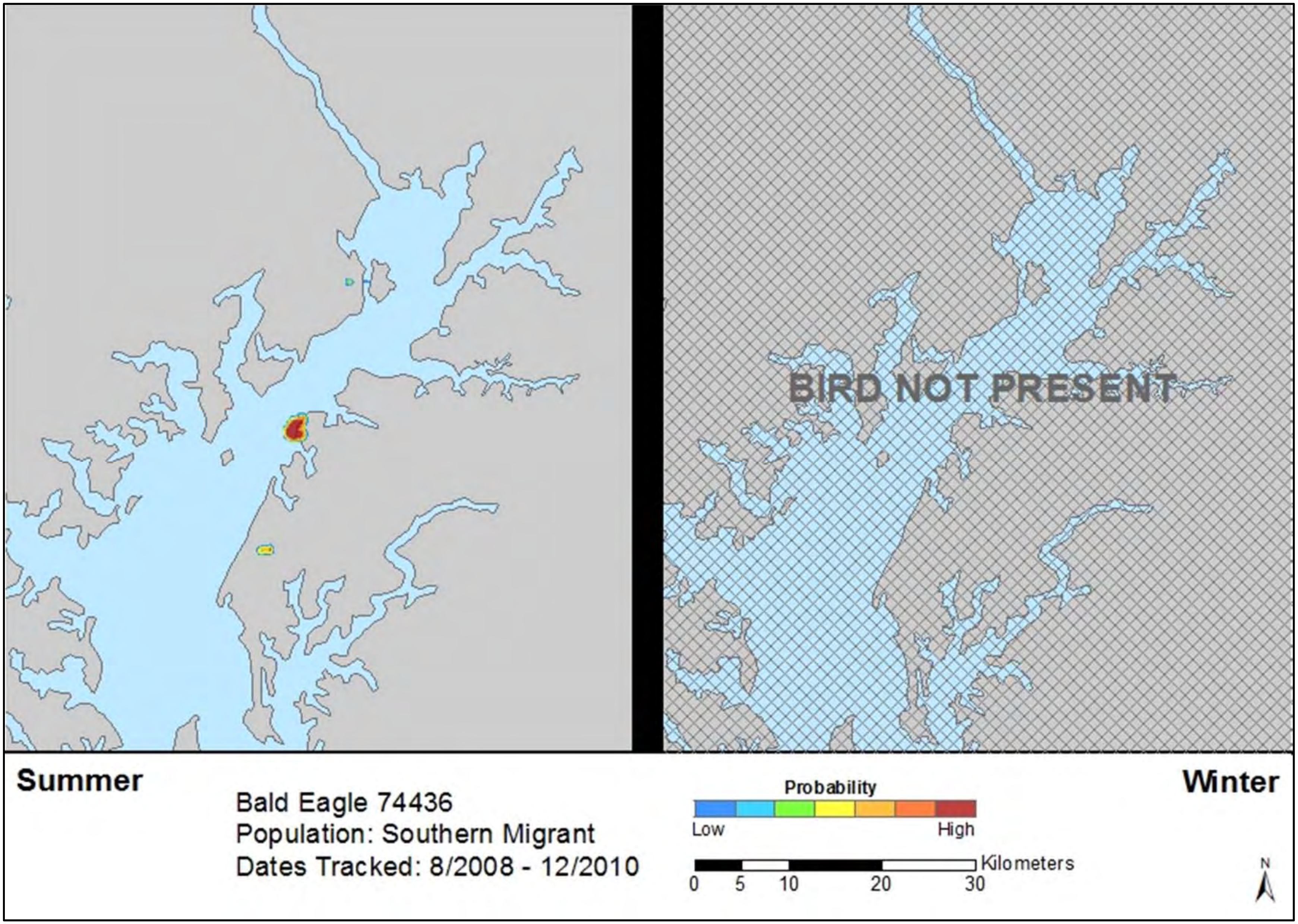
Summer
Bald Eagle 74431
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 9/2010
Probability
Low
High
0
5
10
20
30
Kilometers
N
Winter

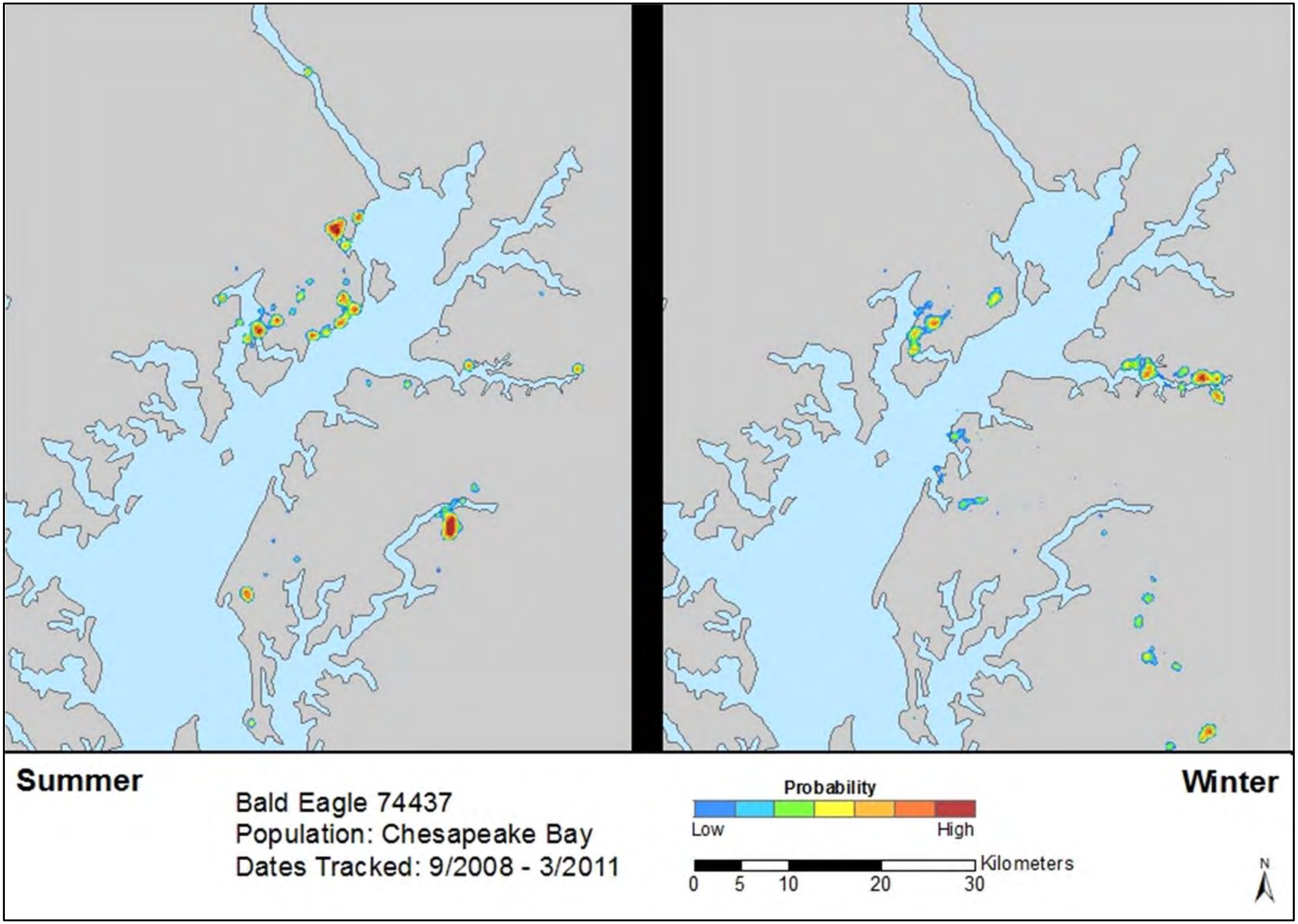

Summer
Winter
Bald Eagle 74432
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 6/2011
Probability
Low
High
0 5 10 20 30 Kilometers
N

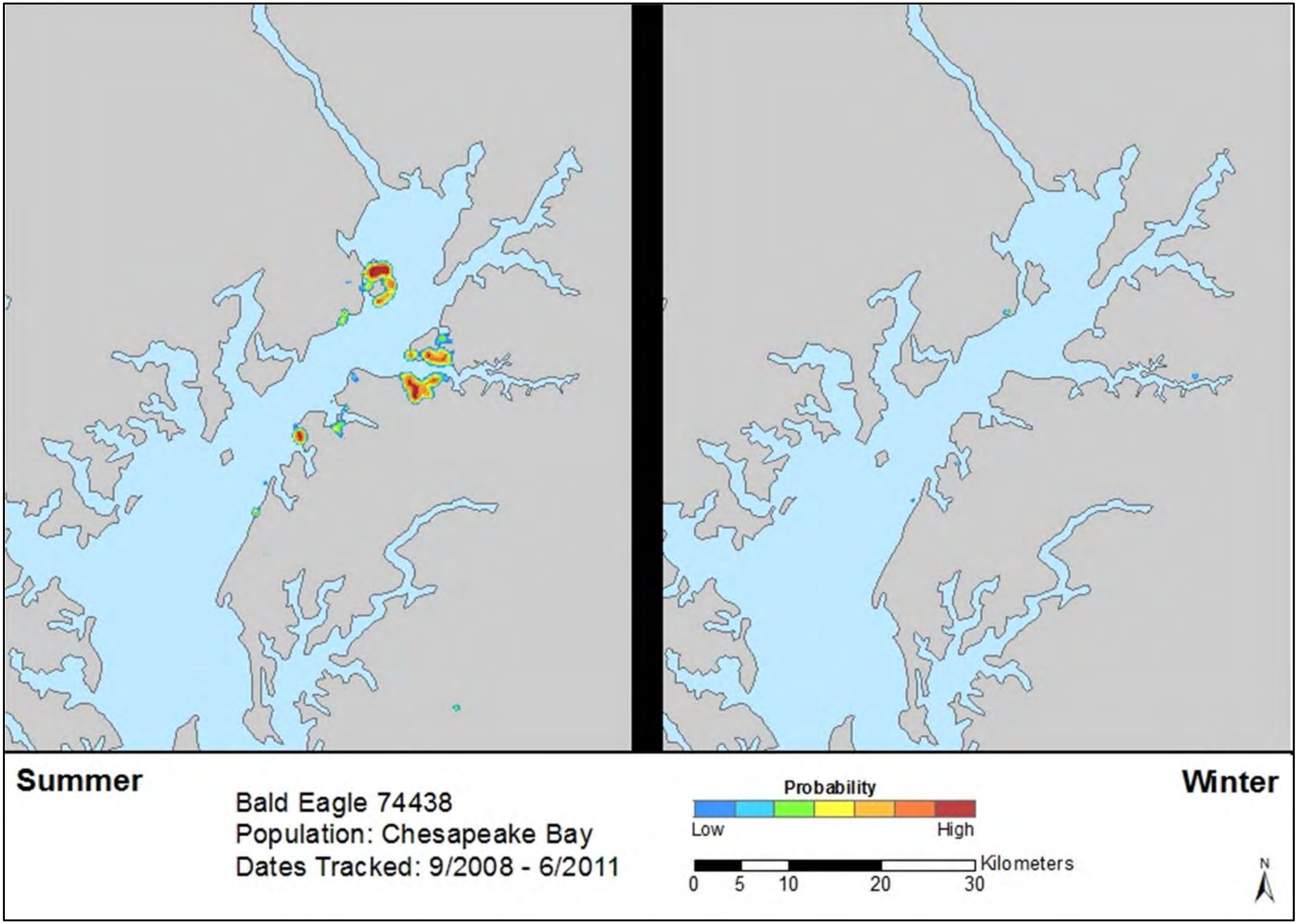

Summer
Bald Eagle 74433
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 6/2011
Probability
Low
High
Kilometers
0 5 10 20 30
Winter
N


Summer
Bald Eagle 74434
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 6/2011
Probability
Low
High
Kilometers
0
5
10
20
30
N
Winter


BIRD NOT PRESENT
Summer
Bald Eagle 74435
Population: Chesapeake Bay
Dates Tracked: 5/2008 - 5/2009
Probability
Low
High
0 5 10 20 30 Kilometers
N
Winter


BIRD NOT PRESENT
Summer
Winter
Bald Eagle 74436
Population: Southern Migrant
Dates Tracked: 8/2008 - 12/2010
Probability
Low
High
0 5 10 20 30
Kilometers
N


Summer
Bald Eagle 74437
Population: Chesapeake Bay
Dates Tracked: 9/2008 - 3/2011
Probability
Low
High
Kilometers
0 5 10 20 30
N
Winter



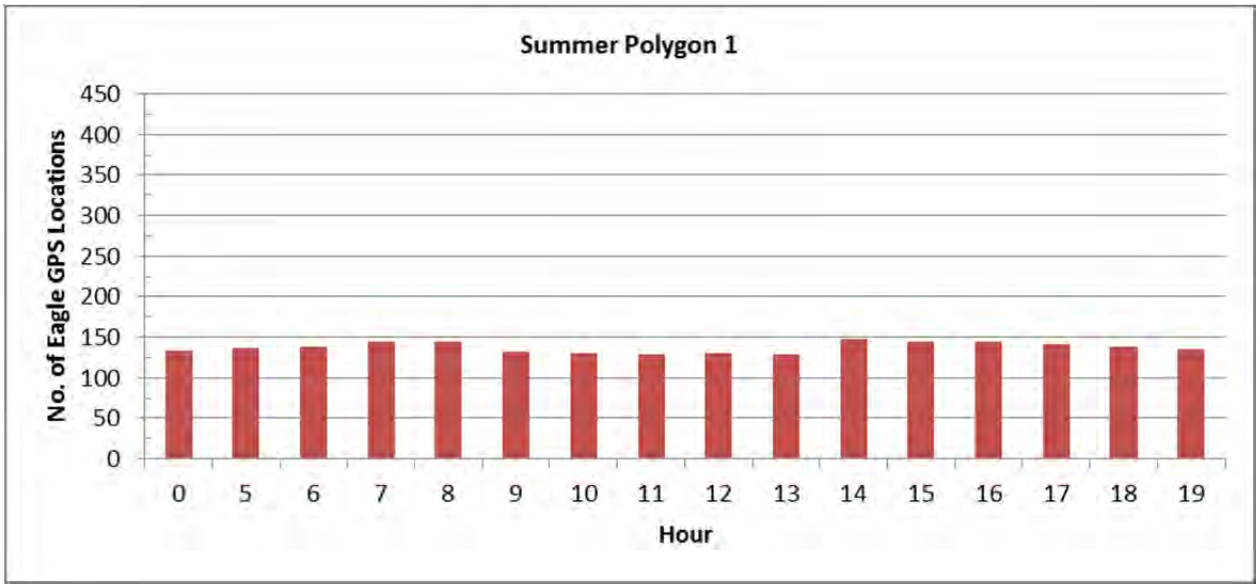
Summer
Bald Eagle 74438
Population: Chesapeake Bay
Dates Tracked: 9/2008 - 6/2011
Probability
Low
High
Kilometers
0
5
10
20
30
N
Winter

Appendix 12. Seasonal polygons indicating high use eagle activity areas. Polygons were generated with Brownian Bridge movement modeling for summer (May-August) and winter (November – March). Time of day histograms of eagle tracking data within each polygon are presented.

Summer Activity Centers – polygons refer to figure 4.4.7

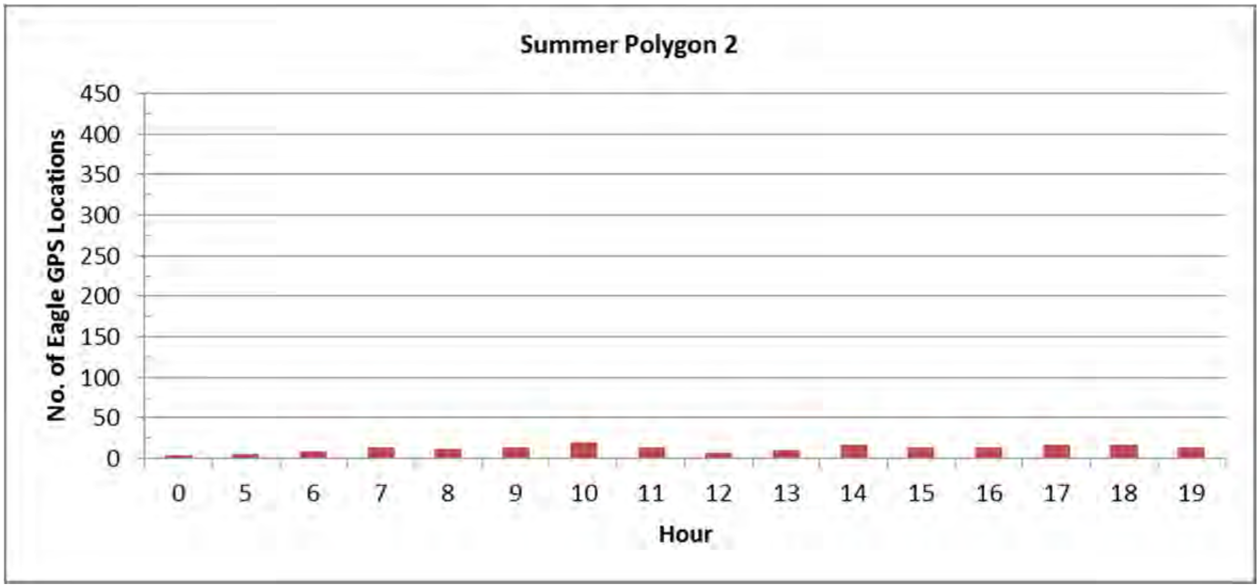
Polygon 1

This area is located on the north end of Pooles Island. There are 4 breeding territories and 4 communal roost in this area. Eagles utilize the shoreline of Pooles Island for foraging activities and breed and roost in the forested interior. There is also a 2,000+ pair heron rookery on the island, the largest in the Chesapeake Bay region.



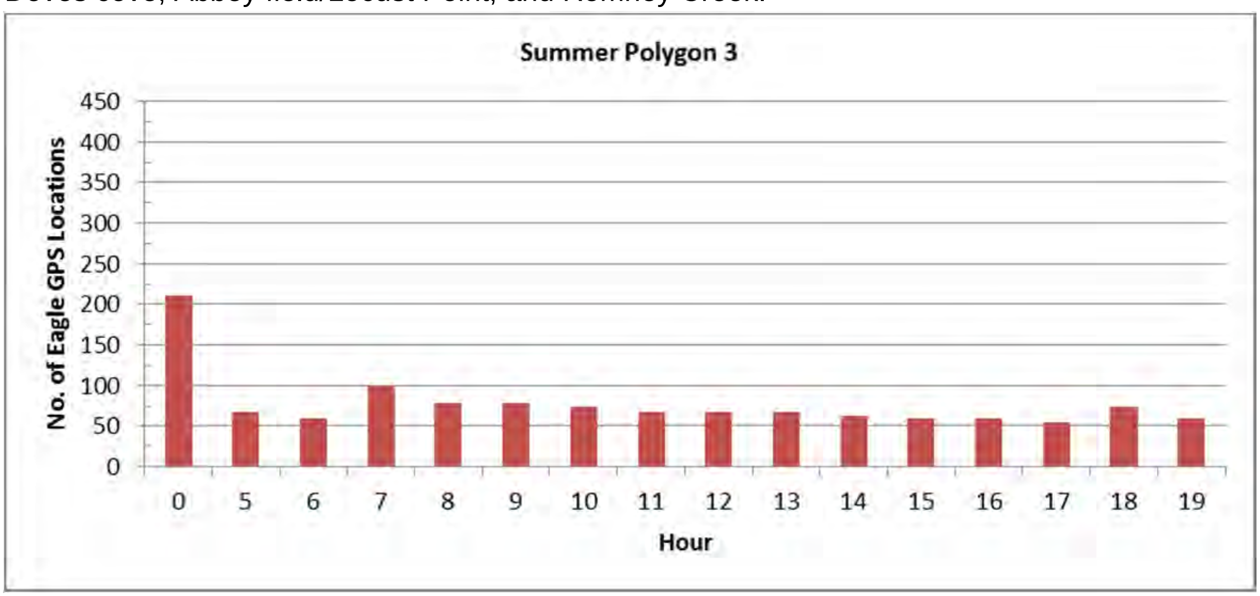
Polygon 2

This area is located on the Bush River north of Sandy Point and H-field. There are no known breeding territories or communal roosts in this area. The shoreline faces a shallow bay on the Bush that is used primarily for foraging. There is a movement corridor between this area, Doves Cove, and Coopers Creek.



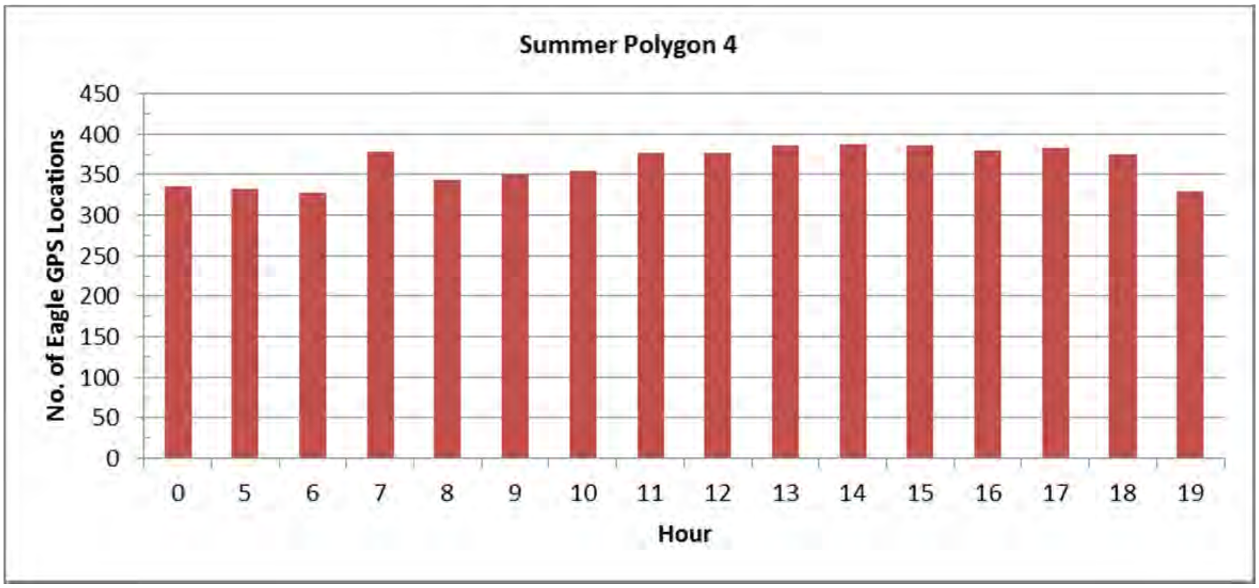
Polygon 3

This area is near Bush Point and the New Bombing Field impact area. There is one breeding territory and two communal roosts in the area. Two isolated hardwood stands provide shelter for roosting eagles overlooking the river. There is a movement corridor between this area and Doves cove, Abbey field/Locust Point, and Romney Creek.



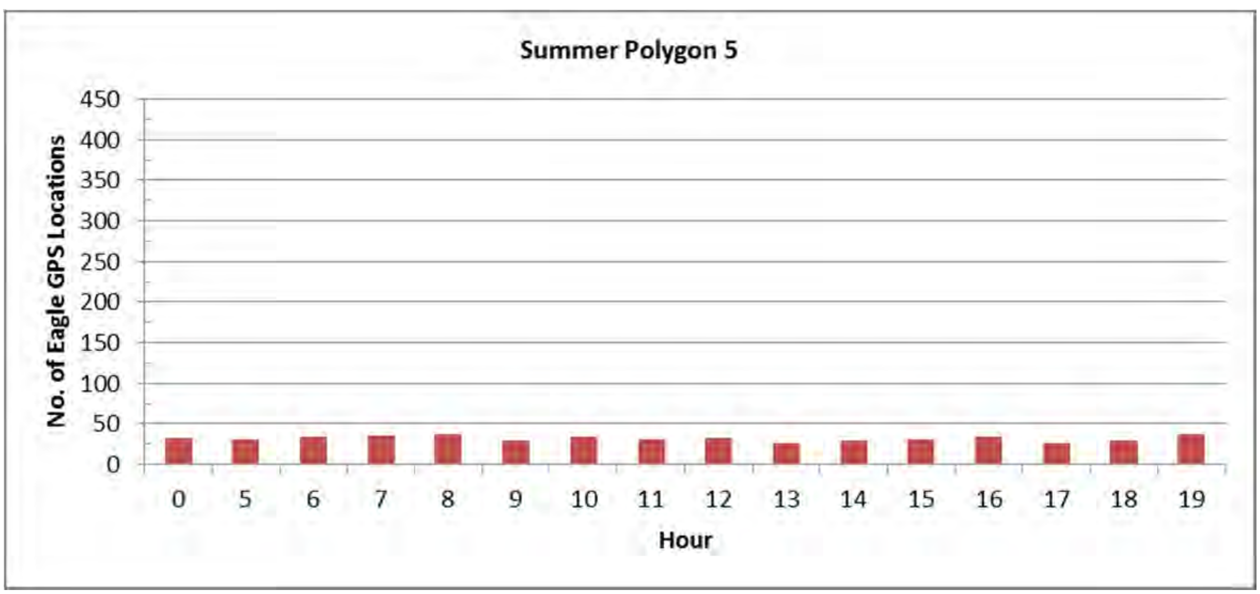
Polygon 4

This area includes C-field, Doves Cove, Briery Point, and Coopers Creek. There are 2 breeding territories and 5 communal roosts in the area. This area supports a large number of foraging and roosting birds. There is a movement corridor into the Bush River, north along the shoreline to Kings Creek, south along the shoreline to H-field, west to Watson Creek and Maxwell Point, and east to Towner Cove.



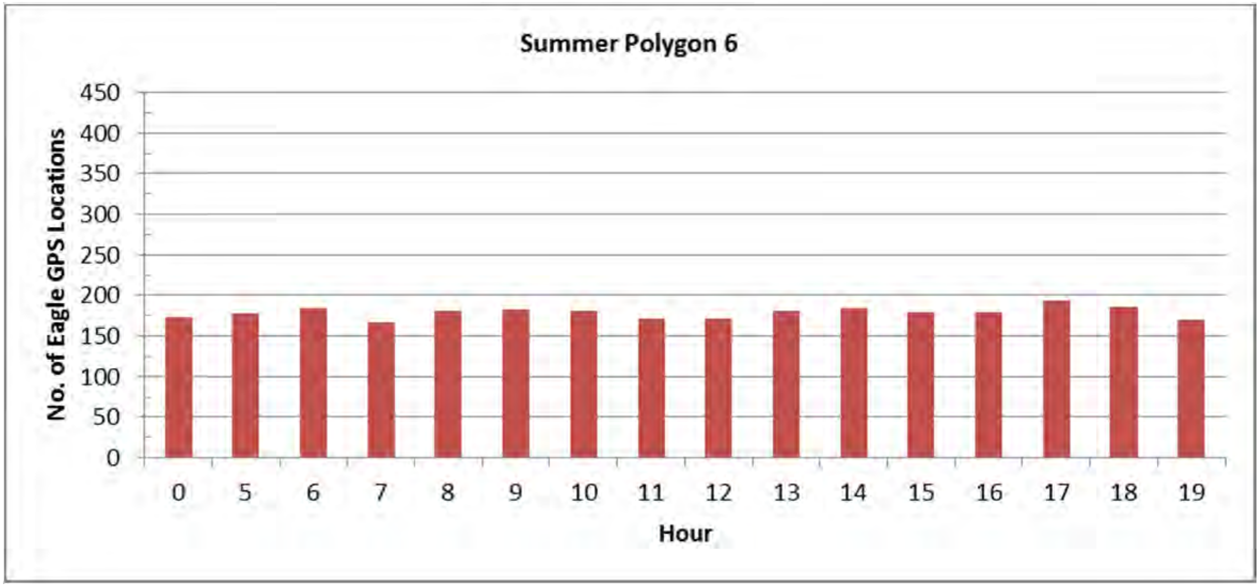
Polygon 5

This area encompasses forested shoreline on the southern portion of Redman Cove. There are no known breeding territories or communal roosts in this area. There is a movement corridor between this area and Towner Cove.



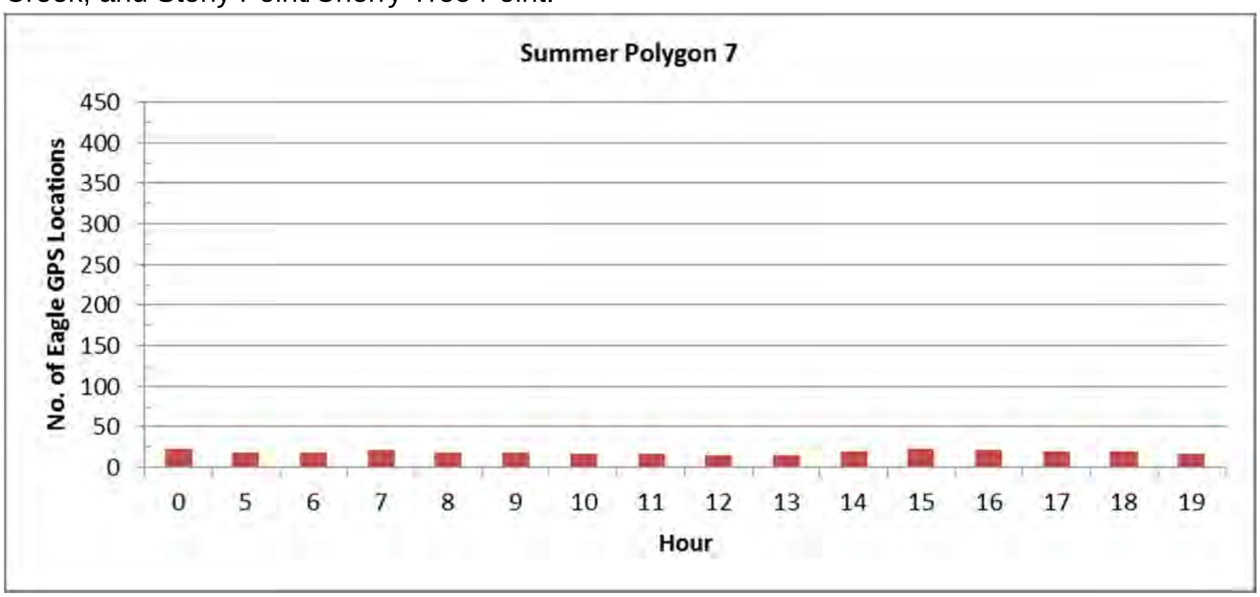
Polygon 6

This area includes shoreline between Abbey Point and Locust Point, the mouth of Romney Creek and Little Romney Creek, and Elm Tree Point. There is one breeding territory and 4 communal roosts in this area. Eagles forage and loaf around the mouth of Romney Creek near Locust and Elm Tree Points. There is a movement corridor between this area and Delph Creek, Abbey Point, Towner cove, and Little Romney Creek.



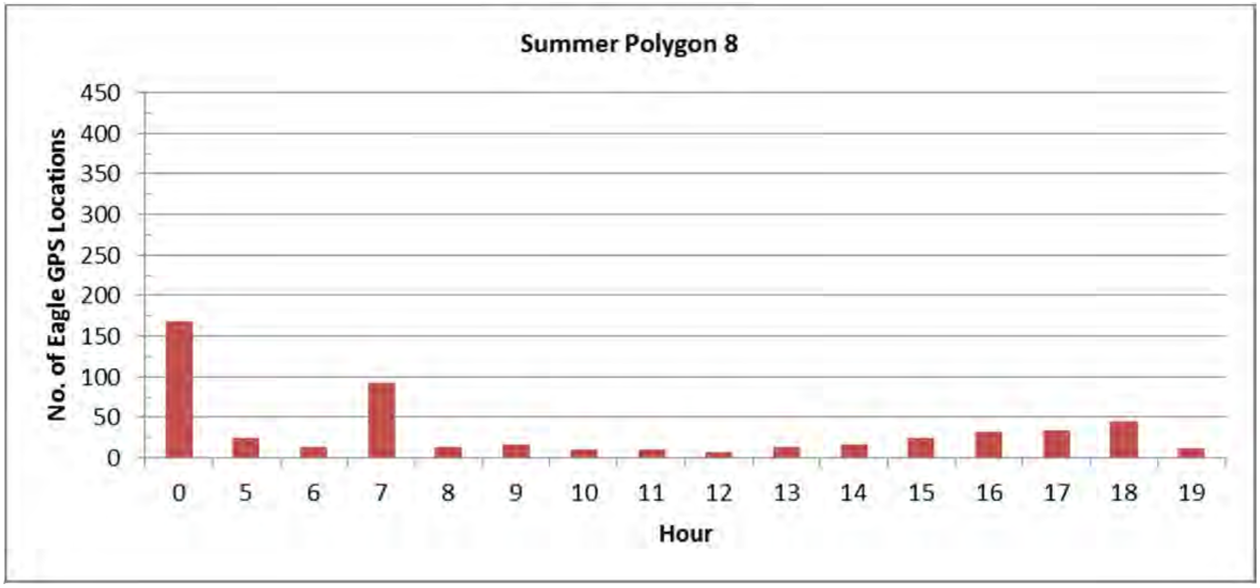
Polygon 7

This area includes forested shoreline along the mouth of Delph Creek. There is one breeding territory and one communal roost in the area. The forest patch is mostly surrounded by Phragmites on three sides and 9600 Yard Impact Area on the north side. This area is used in both summer and winter. There is a movement corridor between this area and Little Romney Creek, and Stony Point/Cherry Tree Point.



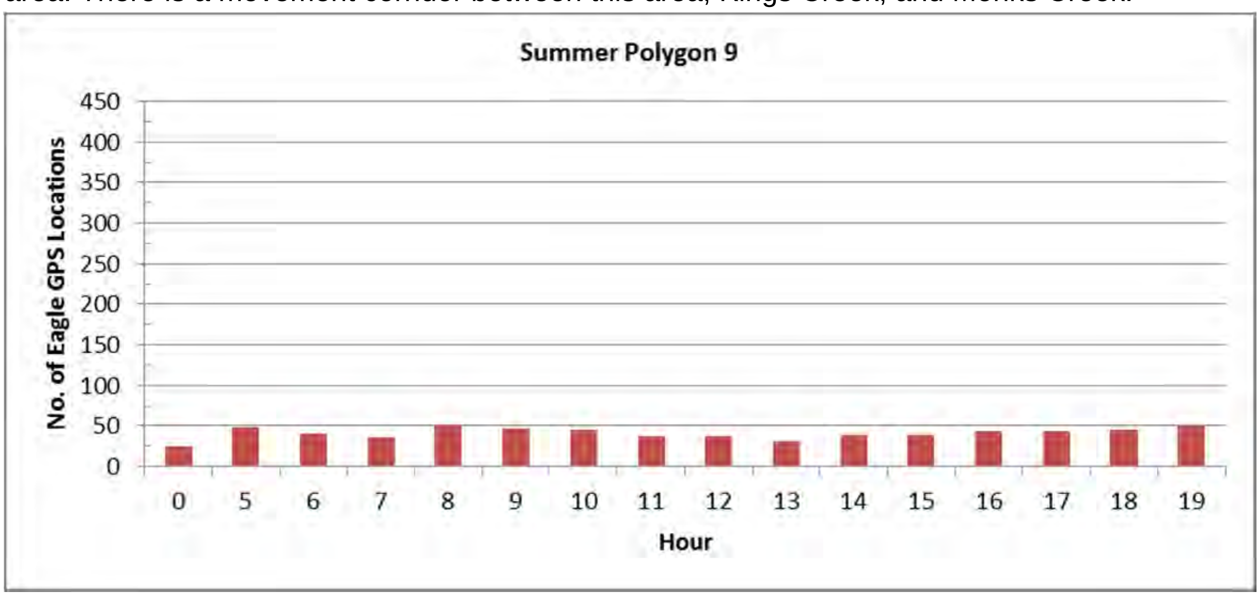
Polygon 8

This area is within the Romney Creek roost near the C-tower nests. This area is used for foraging, roosting, and breeding. There is a movement corridor between this area, the mouth of Sod Run creek, upstream to Sod Run roost, and across the Bush River to Fairview Point.



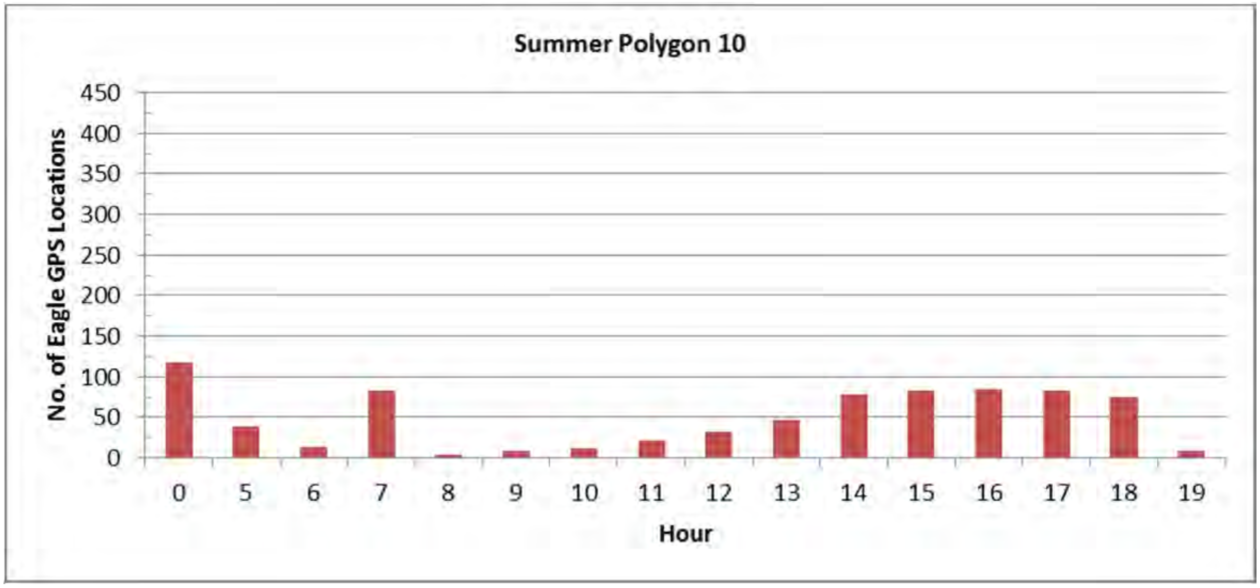
Polygon 9

This area is in the upper reaches of Lauderick Creek. There are two communal roosts in the area. There is a movement corridor between this area, Kings Creek, and Monks Creek.



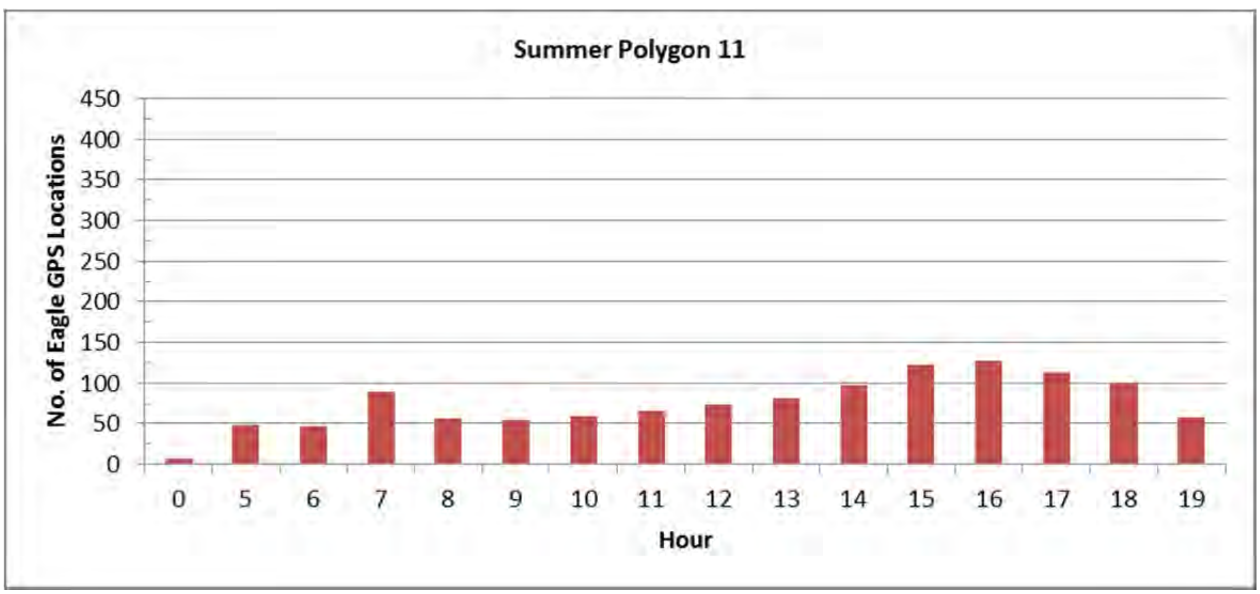
Polygon 10

This area is located at the Sod Run roosts along the upper reaches of Romney Creek. There are movement corridors between this area and Dynamometer, Delph Creek, and Romney Creek.



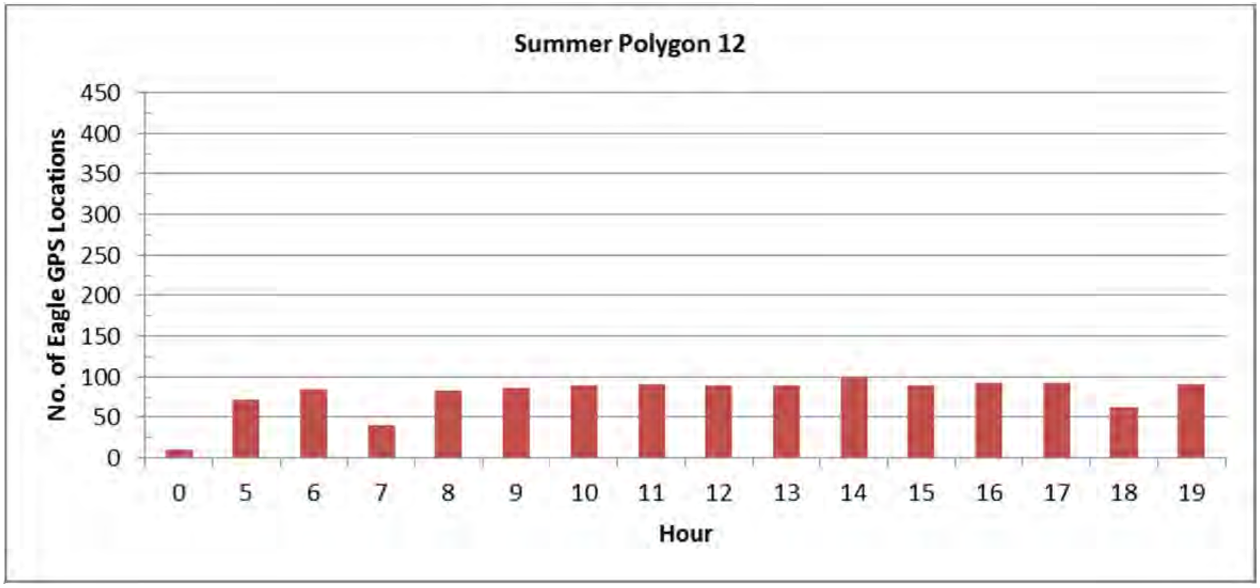
Polygon 11

This polygon is at the mouth of Sod Run where it meets the Bush River at the water treatment plant. There is one breeding territory in this area at Chelsea Chimney. There are movement corridors between this area and Monks Creek, Romney Creek, and Chilbury Point.



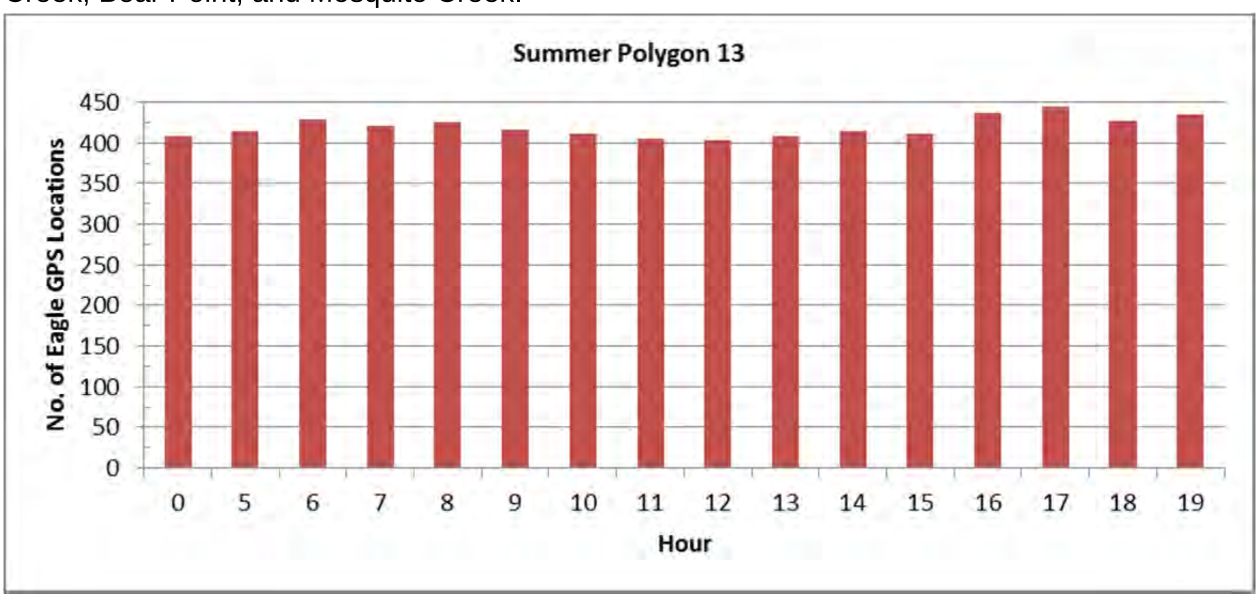
Polygon 12

This area includes forested shoreline around the mouth of Monk's Creek along the Bush River. There is one breeding territory in the area. There are movement corridors between this area, the mouth of Sod Run, and Lauderick Creek.



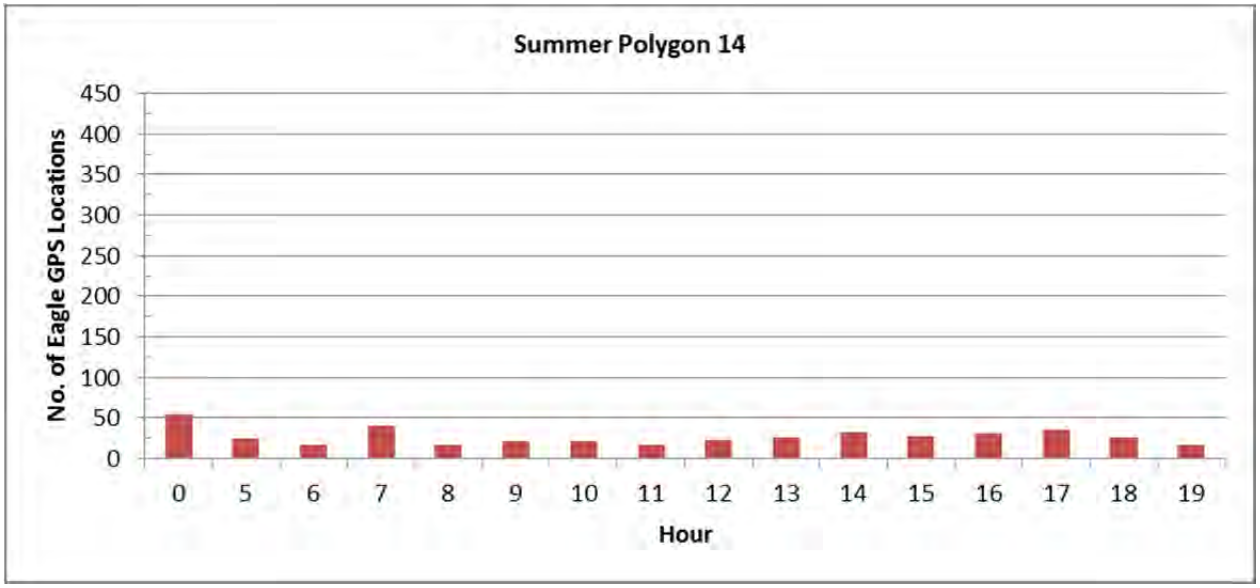
Polygon 13

This area includes the forested shoreline from Stony Point to Black Point on the Chesapeake Bay. There are upland areas fragmented by marsh. There is one breeding territory and 5 communal roosts in this area. There are movement corridors between this area and Delph Creek, Bear Point, and Mosquito Creek.



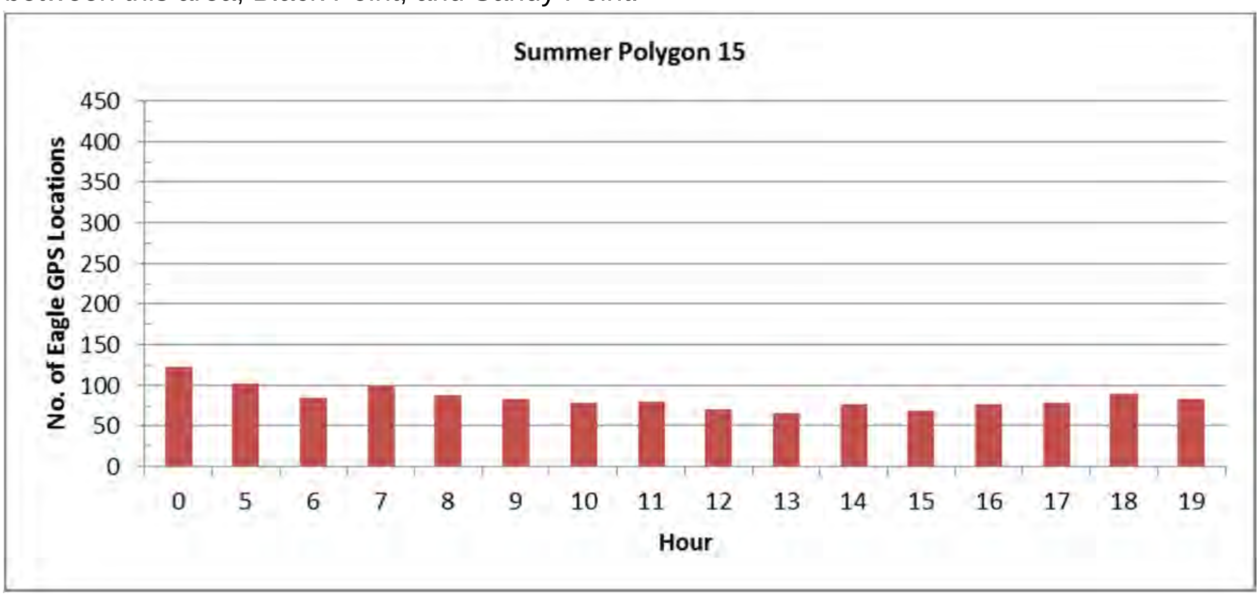
Polygon 14

This area encompasses the main roost on Mosquito Creek. There is one breeding territory in the area. This area overlaps the Hi Velocity range. There are movement corridors between this area and Black Point, Cherry Tree Point, and Woodrest Creek.



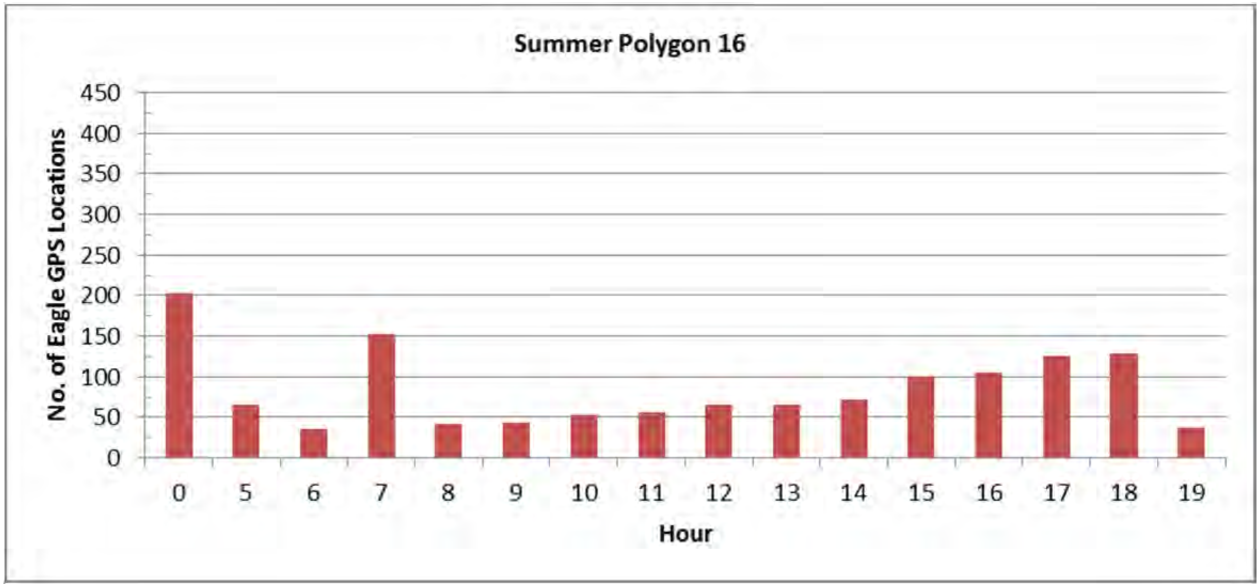
Polygon 15

This area is located at Bear Point on Spesutie Island. It overlaps the Fuse Range. There are two communal roosts and two breeding territories in this area. There are movement corridors between this area, Black Point, and Sandy Point.



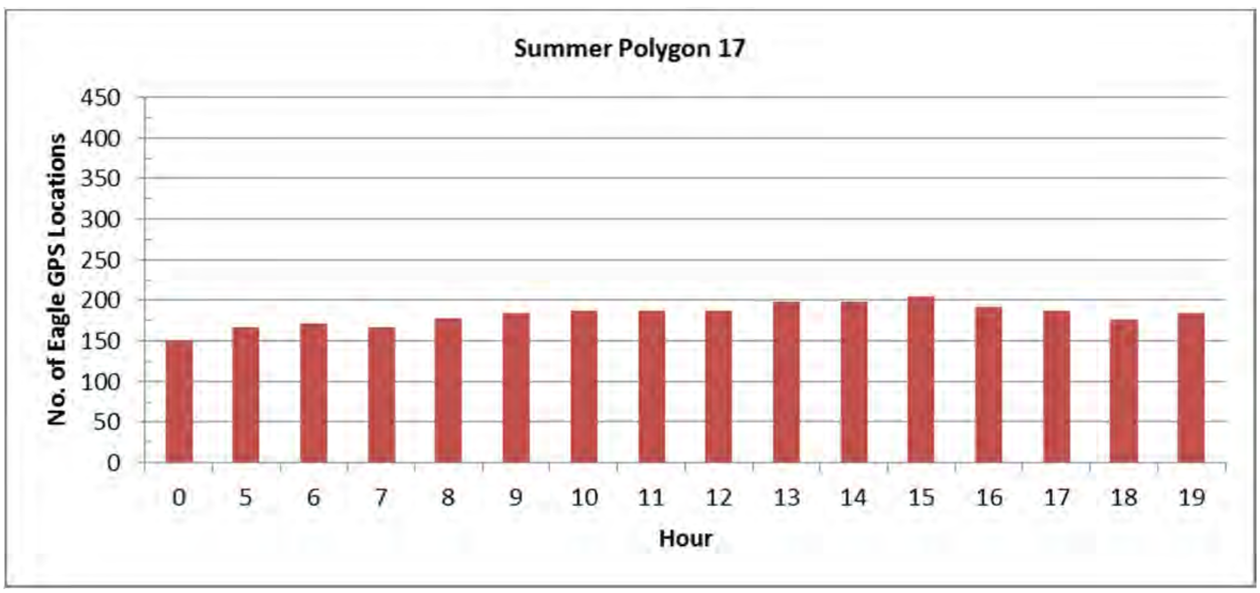
Polygon 16

This area encompasses the Woodrest Creek and breeding territory. It also overlaps the Vibration Facility. There are movement corridors between this area and Swan Creek, Spesutie Narrows, Mosquito Creek, and Back Creek.



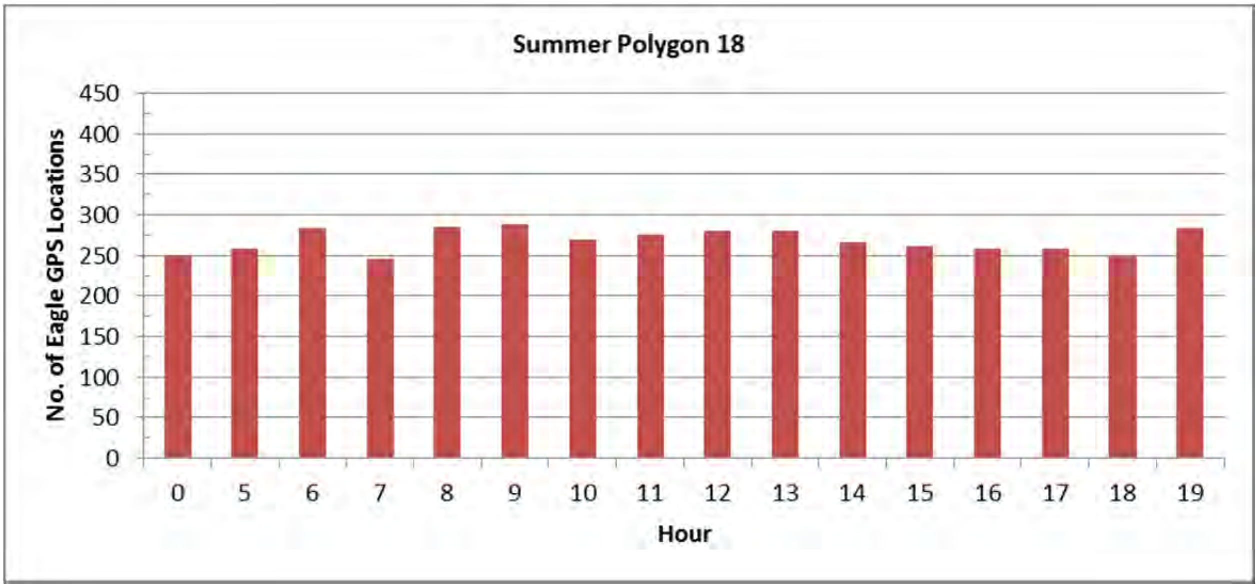
Polygon 17

This area includes Sandy Point and forested areas in the middle of the east leg of Spesutie Island. This area has numerous eagle mortalities. There are two breeding territories and 4 communal roosts in the area. There are movement corridors between this area and the north end of Spesutie Island and Bear Point.



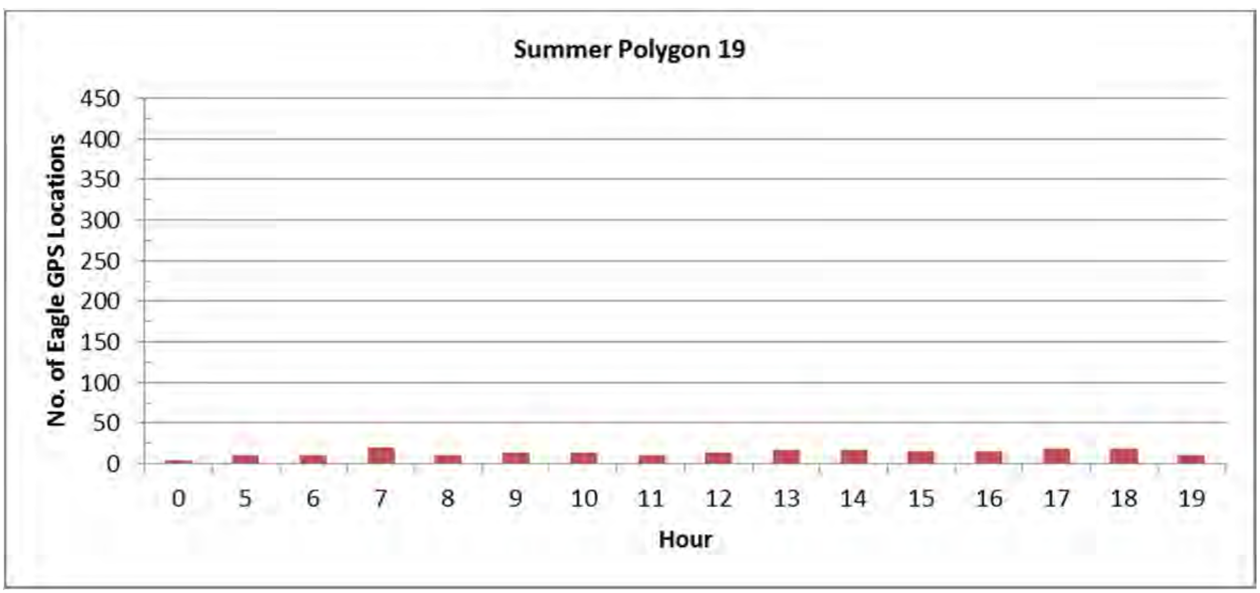
Polygon 18

This area includes the upper reaches of Back Creek and Spesutie Narrows and the northern shoreline of Spesutie Island. There is one breeding territory and 2 communal roosts in the area. There are movement corridors between this area and Plum Point, Woodrest Creek, Back Creek, Spesutie Narrows, and Sandy Point.



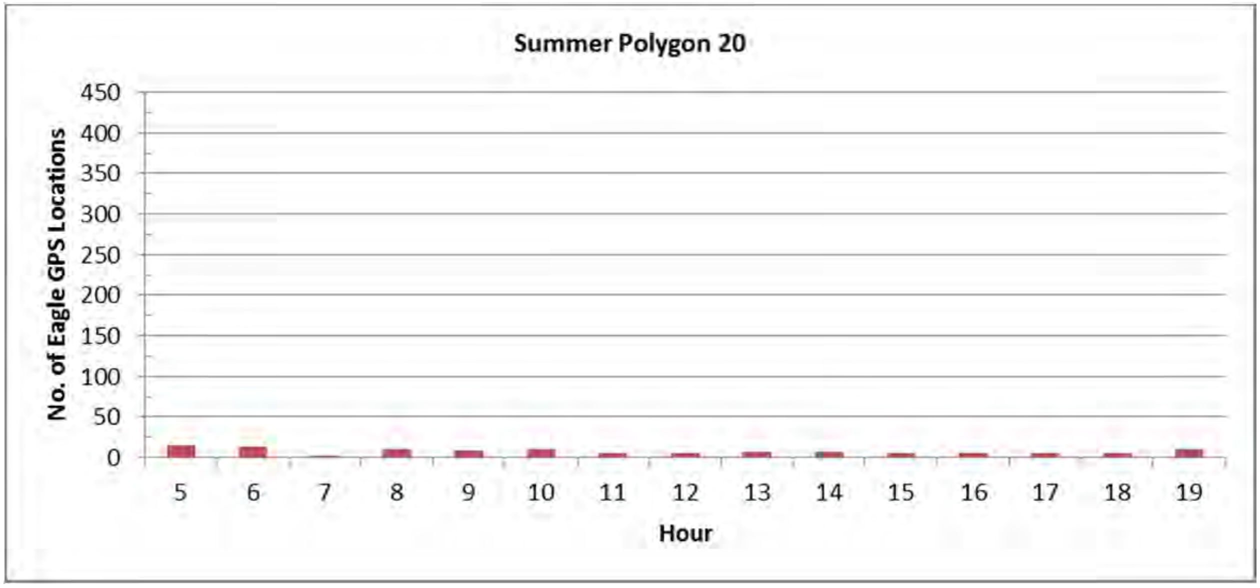
Polygon 19

This area is at the mouth of a small creek that feeds into Swan Creek near the Plum Point Golf Course. There are movement corridors between this area and Plum Point, Swan Creek, and Woodrest Creek.



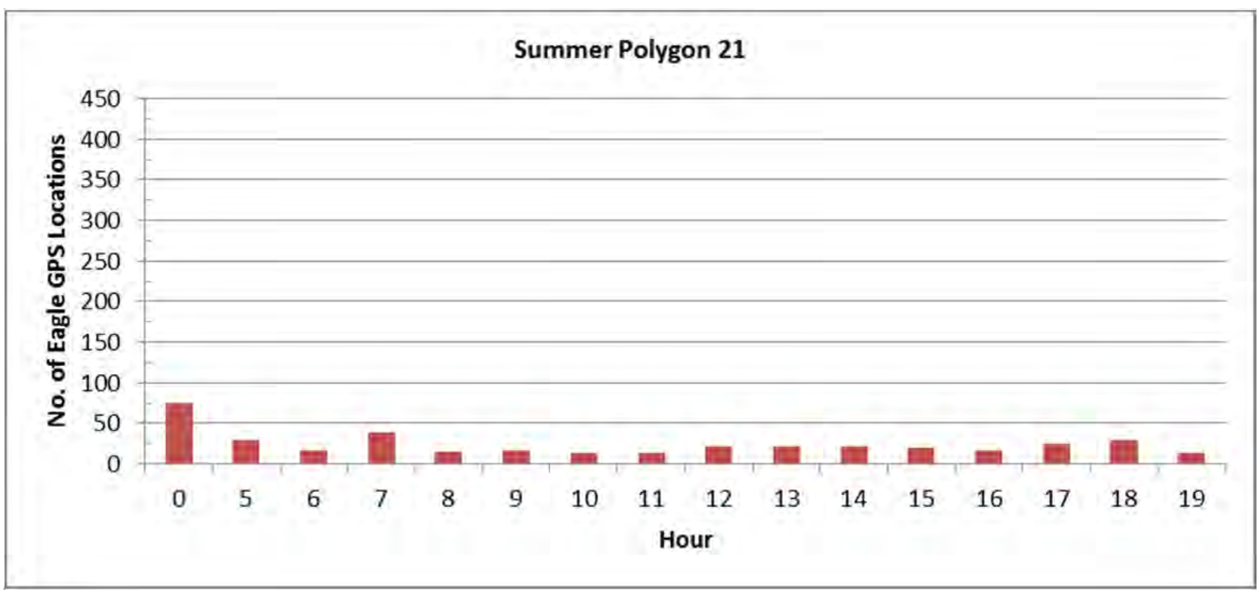
Polygon 20

This area is a small forest patch of shoreline on Swan Creek. There are movement corridors between this area and Plum Point, Swan Creek, and Woodrest Creek.



Polygon 21

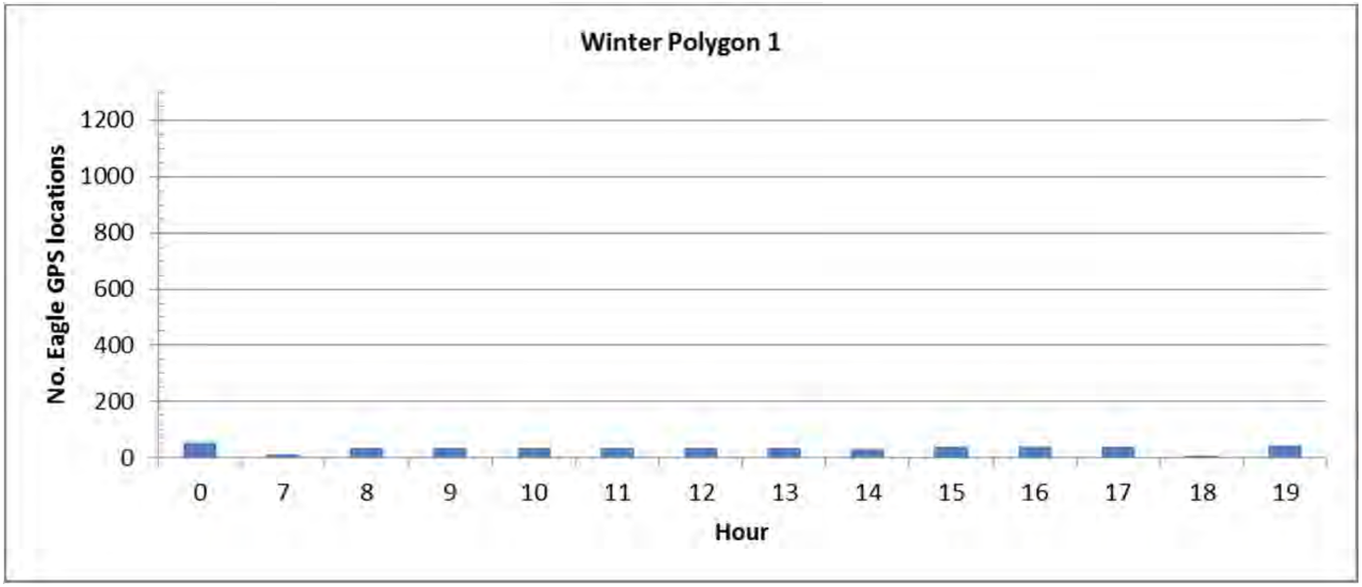
This area is in the upper reaches of Swan Creek and backs up against a residential area on post. There is one communal roost in this area. There are movement corridors between this area and Plum Point, Swan Creek, and Woodrest Creek.



Winter Activity Centers - polygons refer to figure 4.4.8

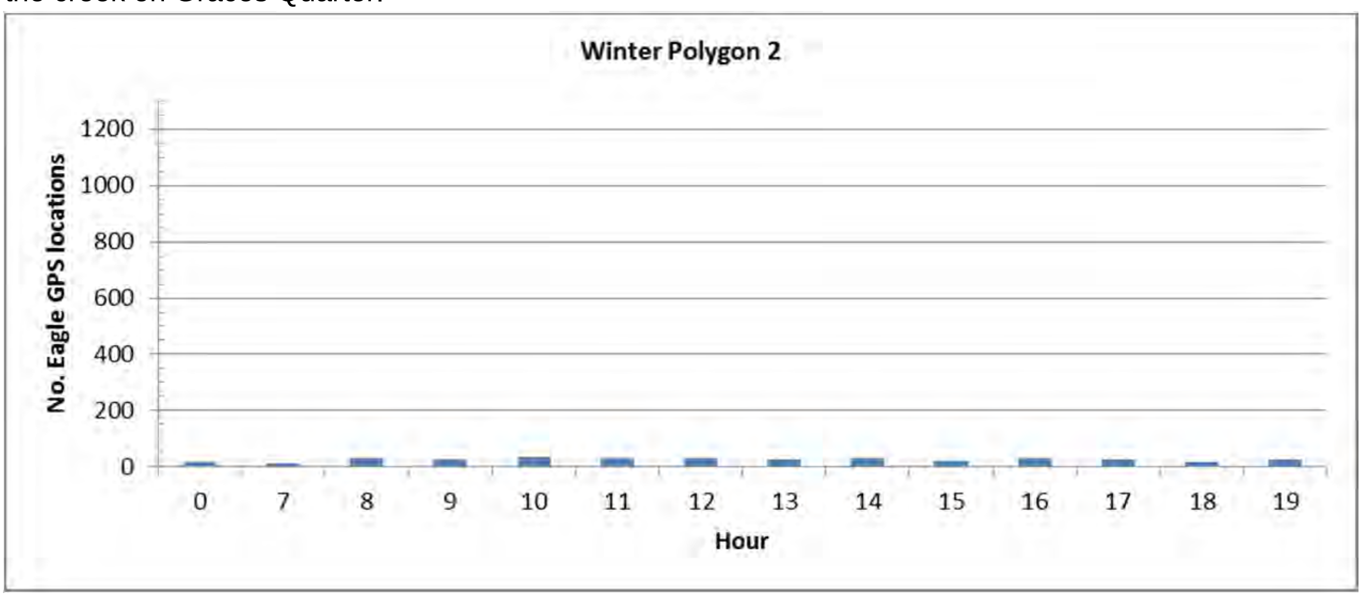
Polygon 1

This area is located on the north end of Pooles Island. There are two breeding territories and two communal roosts in the area. The northeastern shoreline is relatively buffered from prevailing winds moving up the Bay and provides winter foraging opportunities. Eagles move between this area and Edgewood and the Eastern Shore of Maryland.



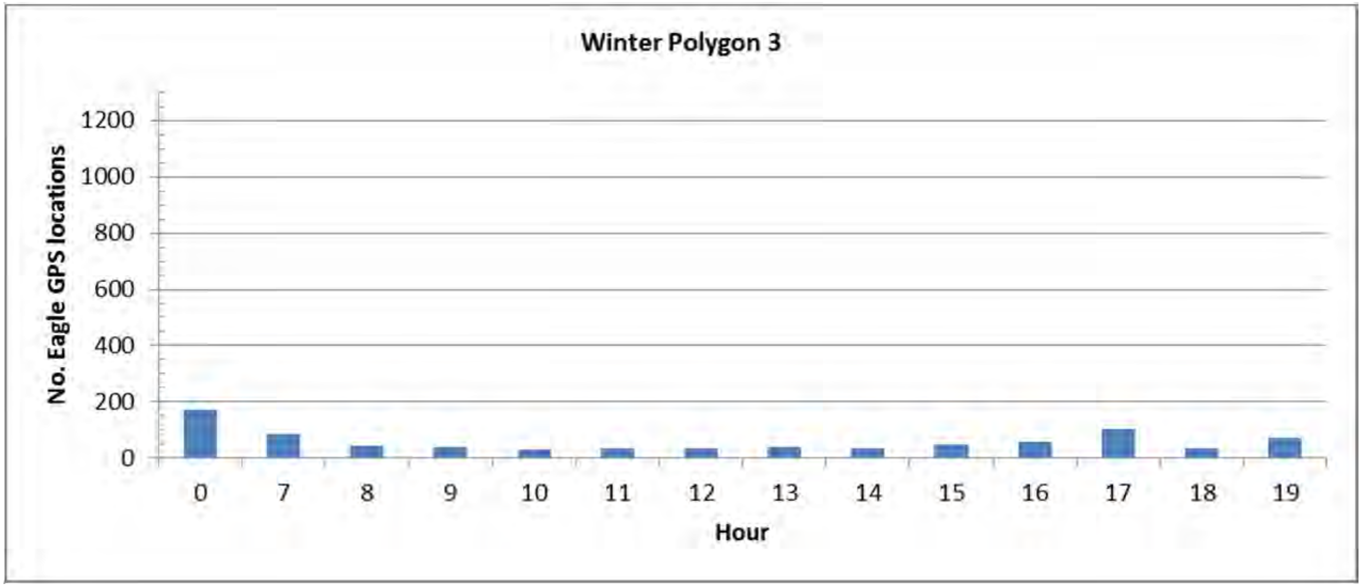
Polygon 2

This area is on Saltpeter Creek and includes Benges Point. There is one breeding territory and one communal roost in the area. There is a movement corridor between this area and across the creek on Graces Quarter.



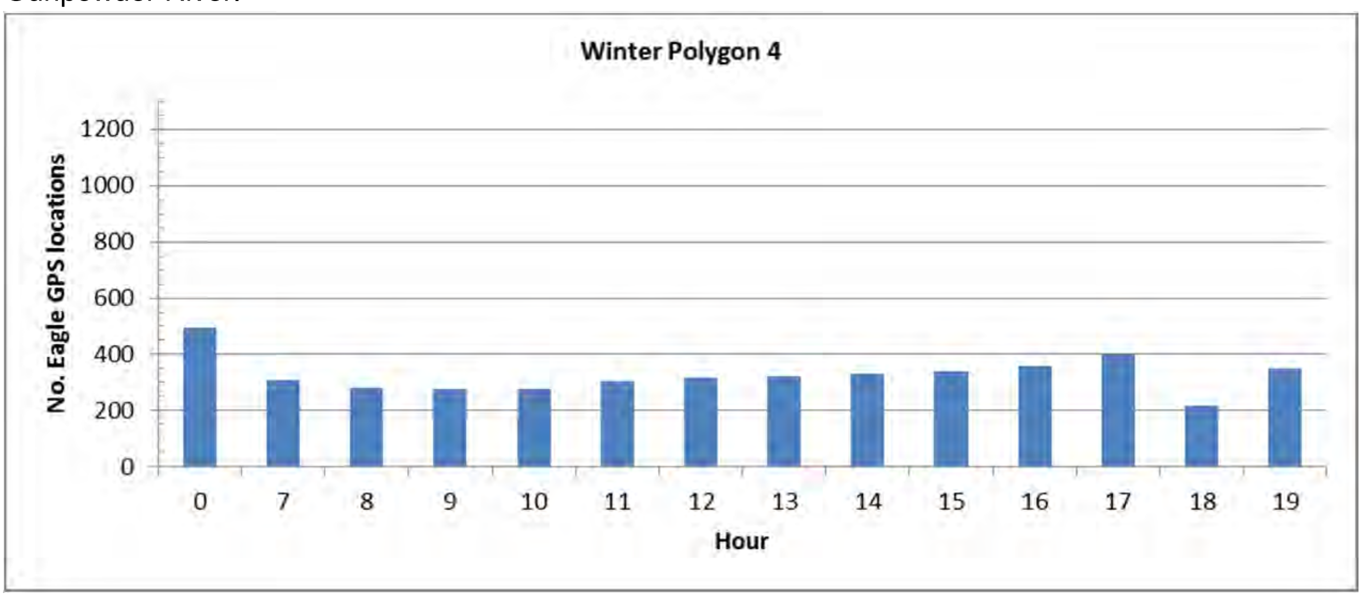
Polygon 3

This area is on Graces Quarters on the Dundee and Saltpeter Creeks. There is one breeding territory and one communal roost in the area. There is a movement corridor between this area and across the creek on Carroll Island.



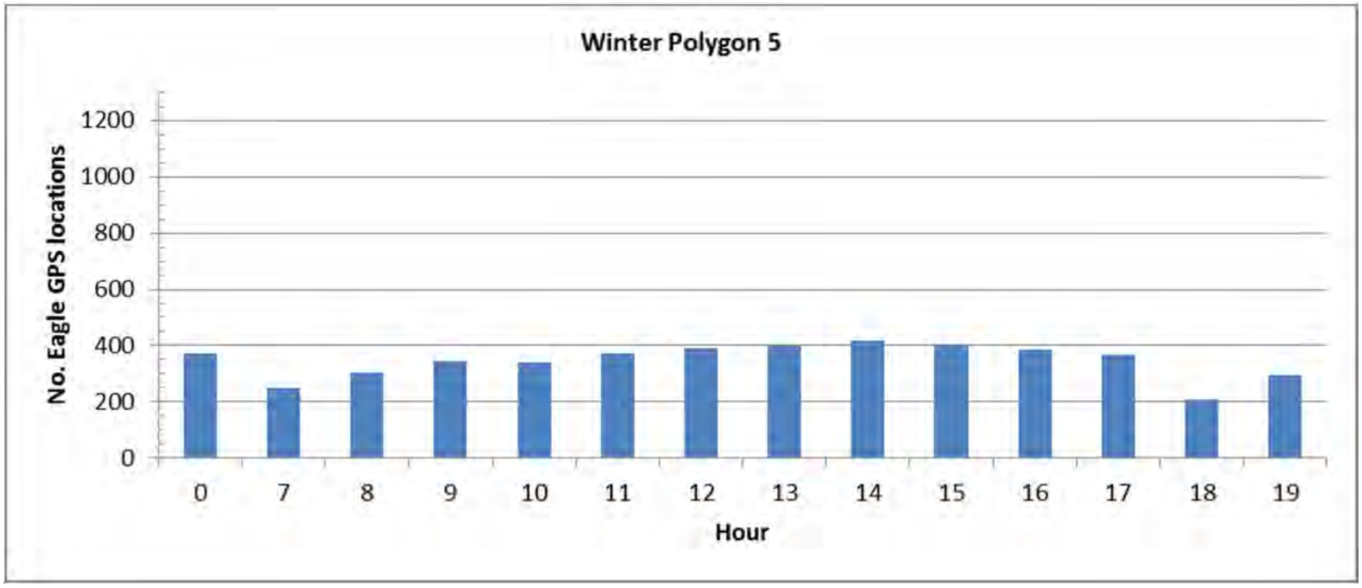
Polygon 4

This area includes M-field, L-field, N-field, D-field, Coopers Creek, Briery Point, Doves Cove, and C-field. There is one breeding territory and one communal roost in the area. Eagles primarily roost in the Coopers Creek roost during winter because it's protected by forest on all sides. Eagles were observed repeatedly using movement corridors north along Coopers Creek to perch and forage in Doves Cove, flying east to perch and forage on the Bush River, flying southeast toward H-field, and flying southeast over Watson Creek and M-field to access the Gunpowder River.



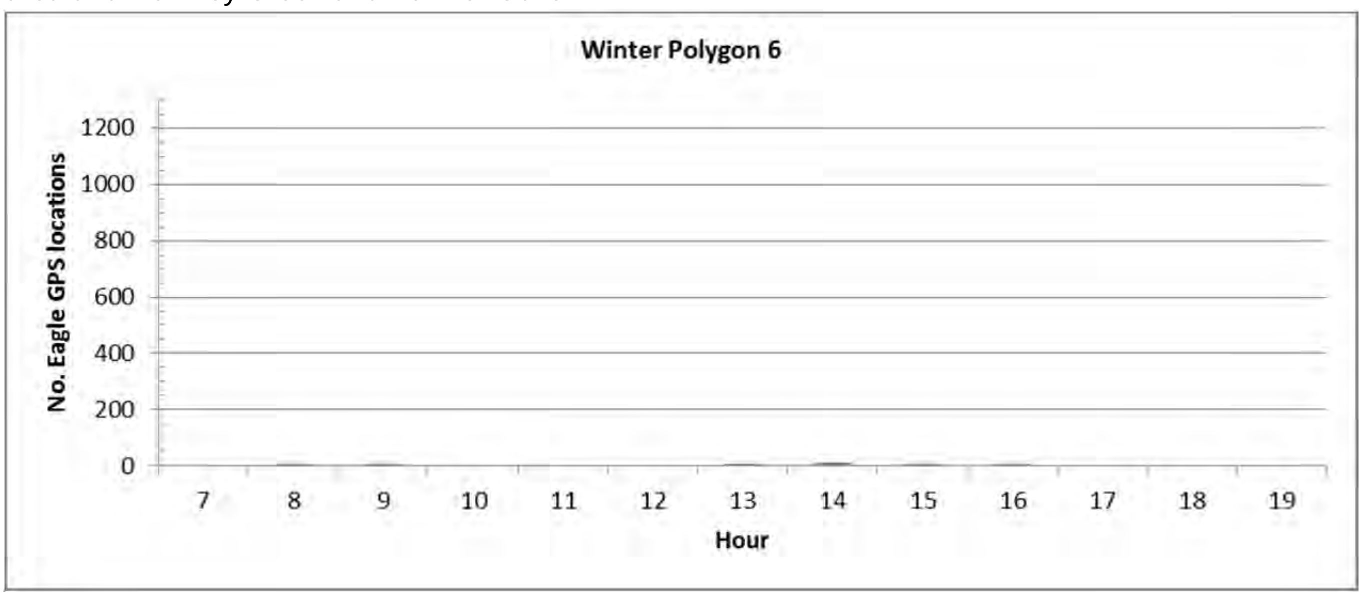
Polygon 5

This area is centered on Towner Cove and New Bombing Field Impact Area. There is one breeding territory and 4 communal roosts in the area. There are movement corridors to Doves Cove, Redman Cove, and Romney Creek.



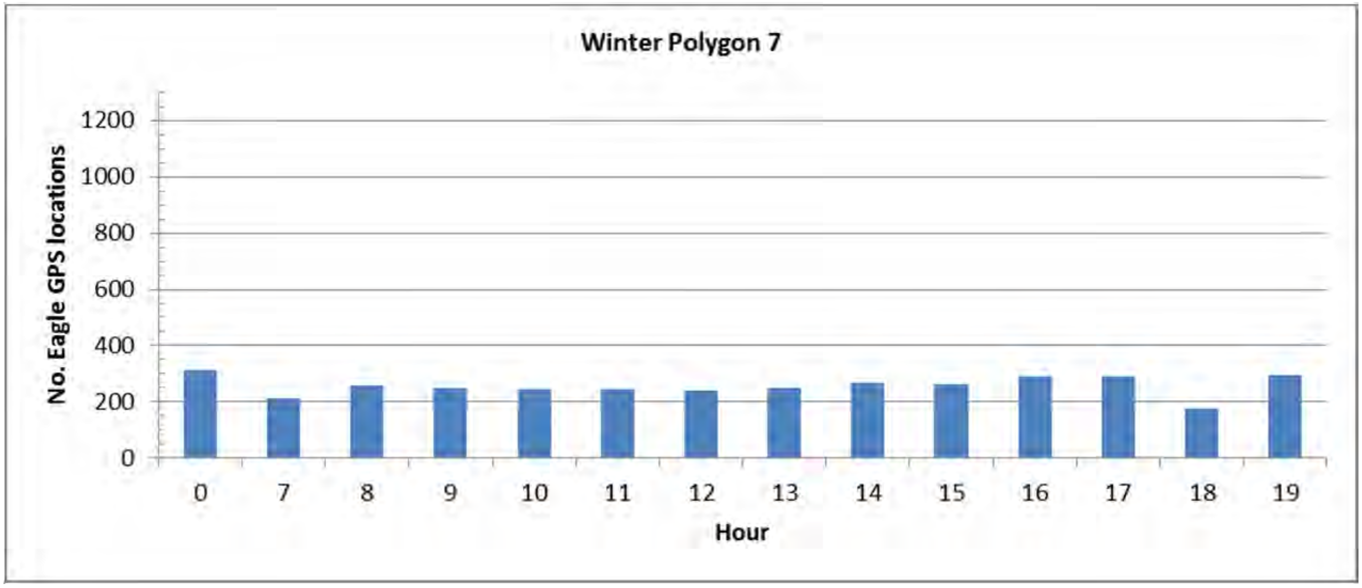
Polygon 6

This area is on the shoreline of Redman Cove adjacent to D-tower. Eagles move between this area and Romney Creek and Towner Cove.



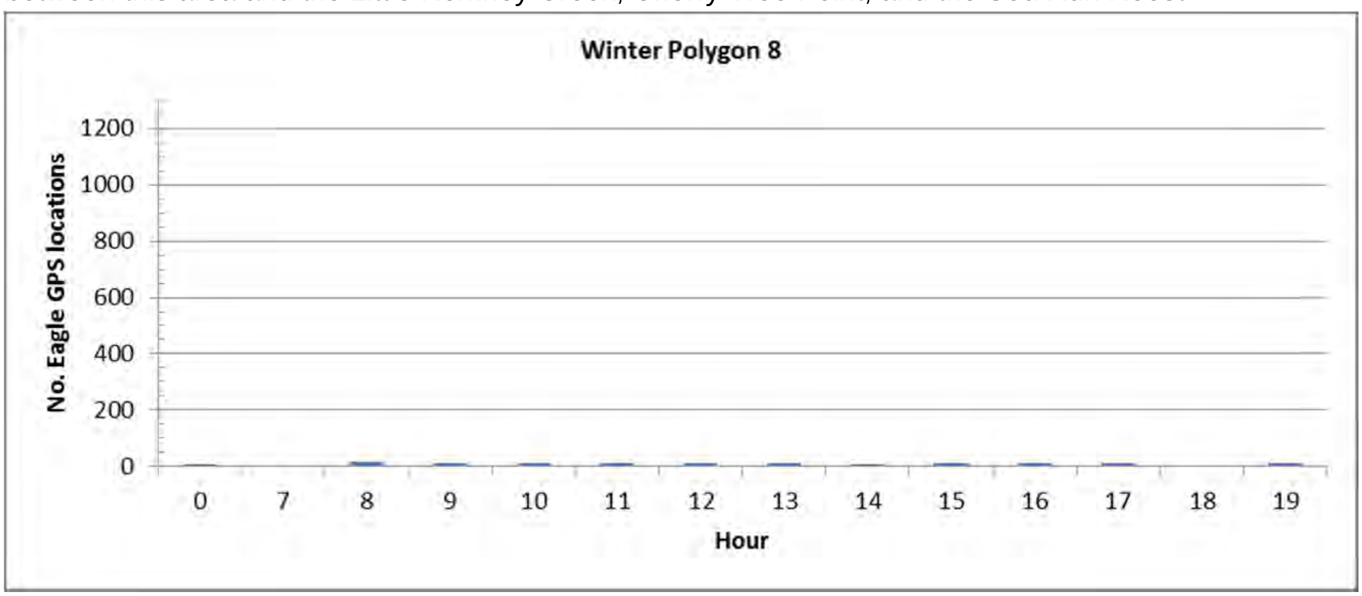
Polygon 7

This area includes the northern part of Abbey Point Impact Field, Locust Point, Elm Tree Point, and the mouth of Romney Creek. There are three breeding territories and four communal roosts in the area.



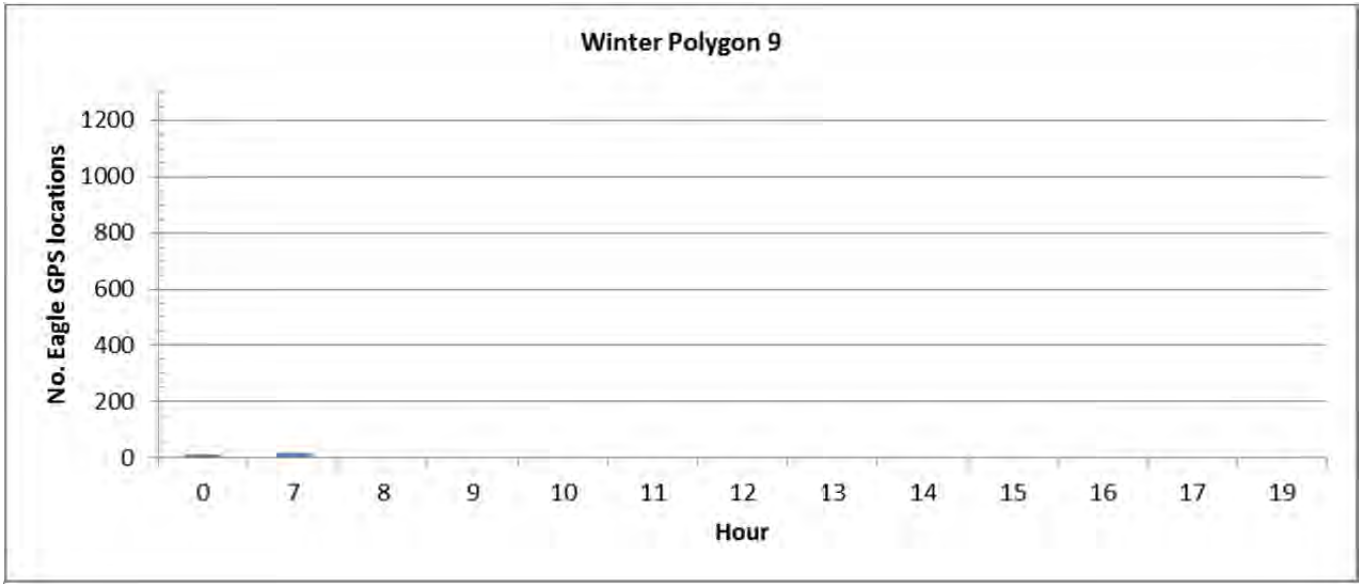
Polygon 8

This area is located at the mouth of Delph Creek. There is one breeding territory and one communal roost in the area. This area is adjacent to 9600 Yard Impact Area. Eagles move between this area and the Little Romney Creek, Cherry Tree Point, and the Sod Run Roost.



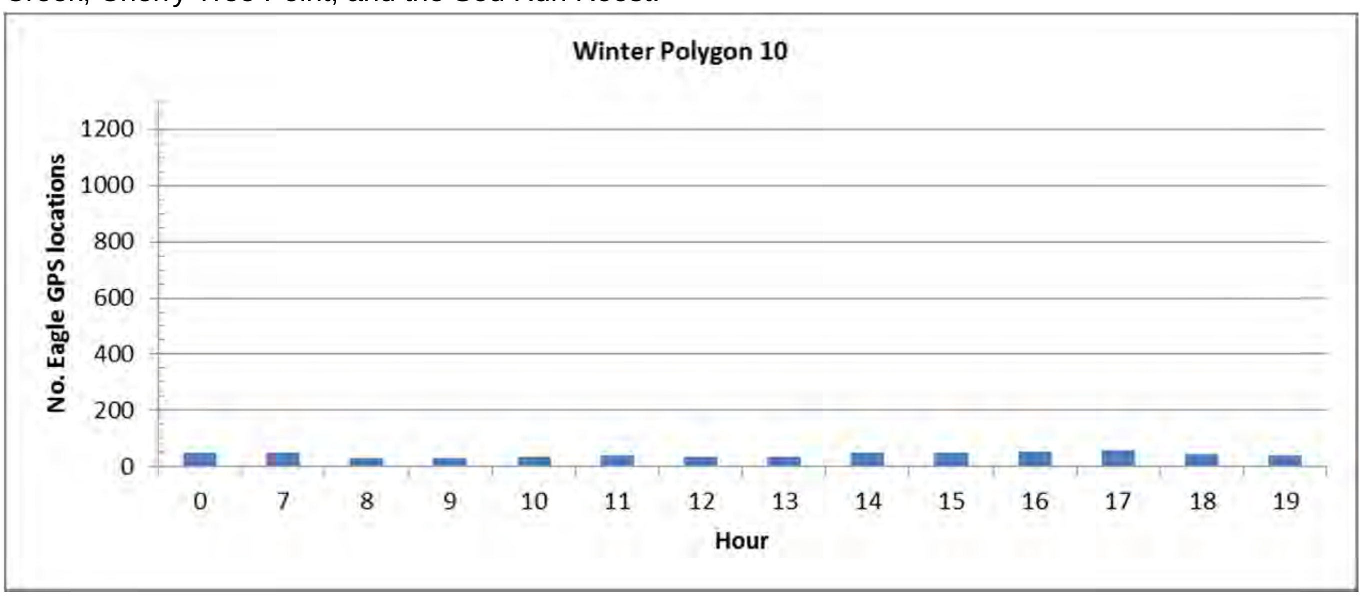
Polygon 9

This area is located on a tributary of Delph Creek. This area is adjacent to the 7600 Recoiless field. Eagles move between this area and the Little Romney Creek, Cherry Tree Point, and the Sod Run Roost.



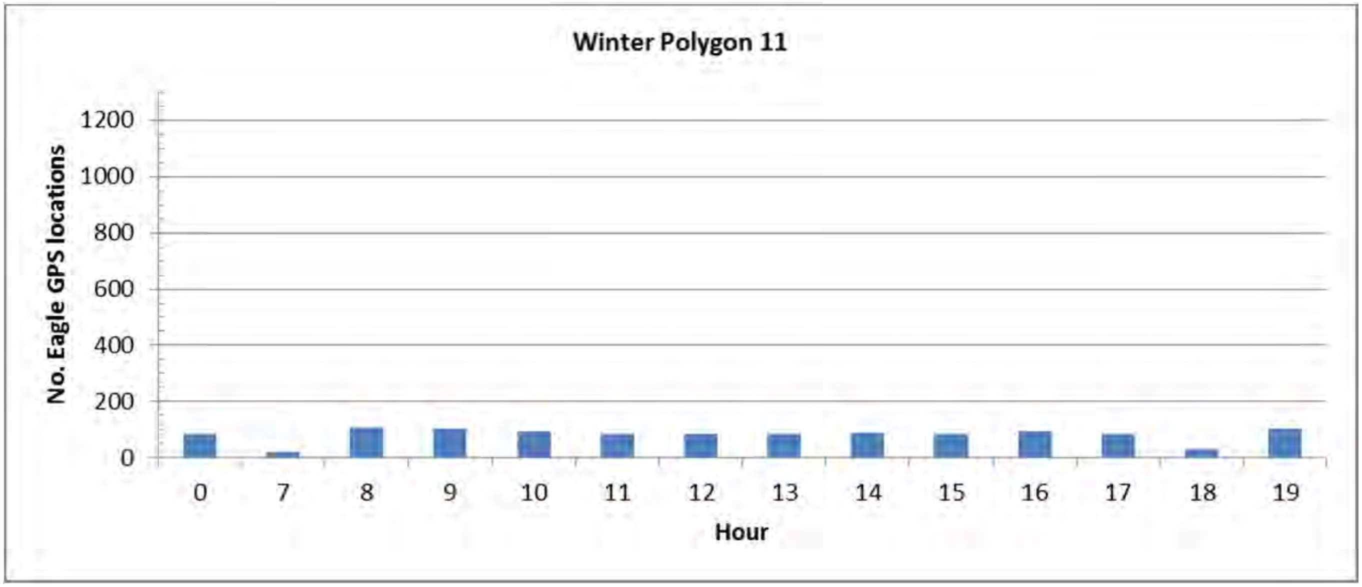
Polygon 10

This area is located at the upper reaches of Delph Creek. This area is adjacent to 9600 Yard Impact Area and 7600 Recoiless field. Eagles move between this area and the Little Romney Creek, Cherry Tree Point, and the Sod Run Roost.



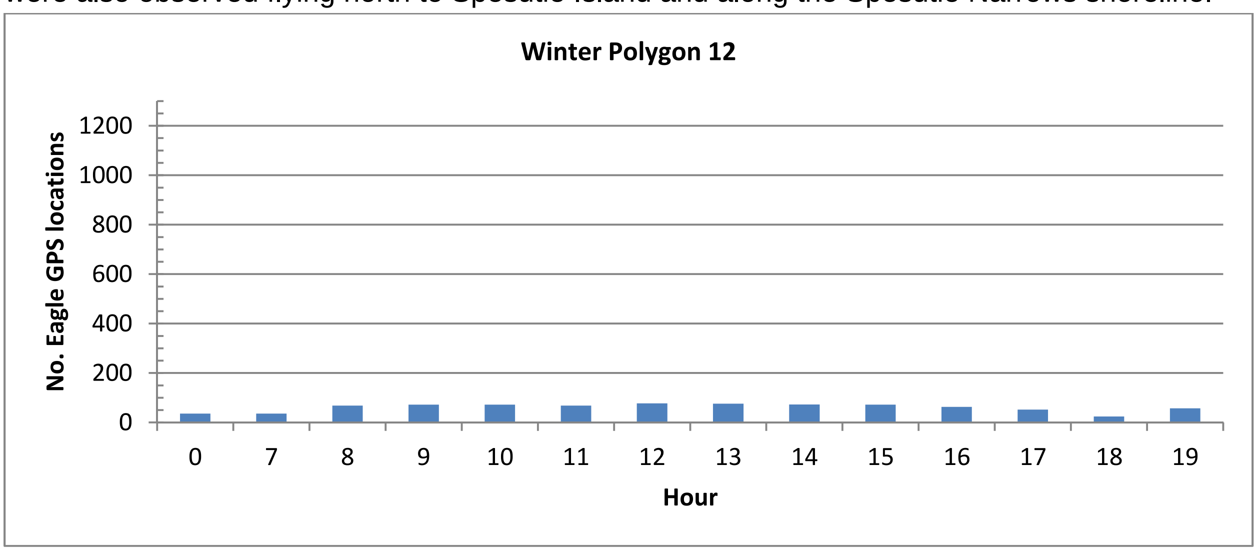
Polygon 11

This area is located on the Bush River from Fairview Point to the mouth of Monks Creek. There is one breeding territory and three communal roosts in the area. There are recessed shorelines surrounded by Phragmites marsh that provide buffer from winter winds and access to calm water to forage. Eagles move between this area and Chilbury Point on the opposite shoreline of the Bush.



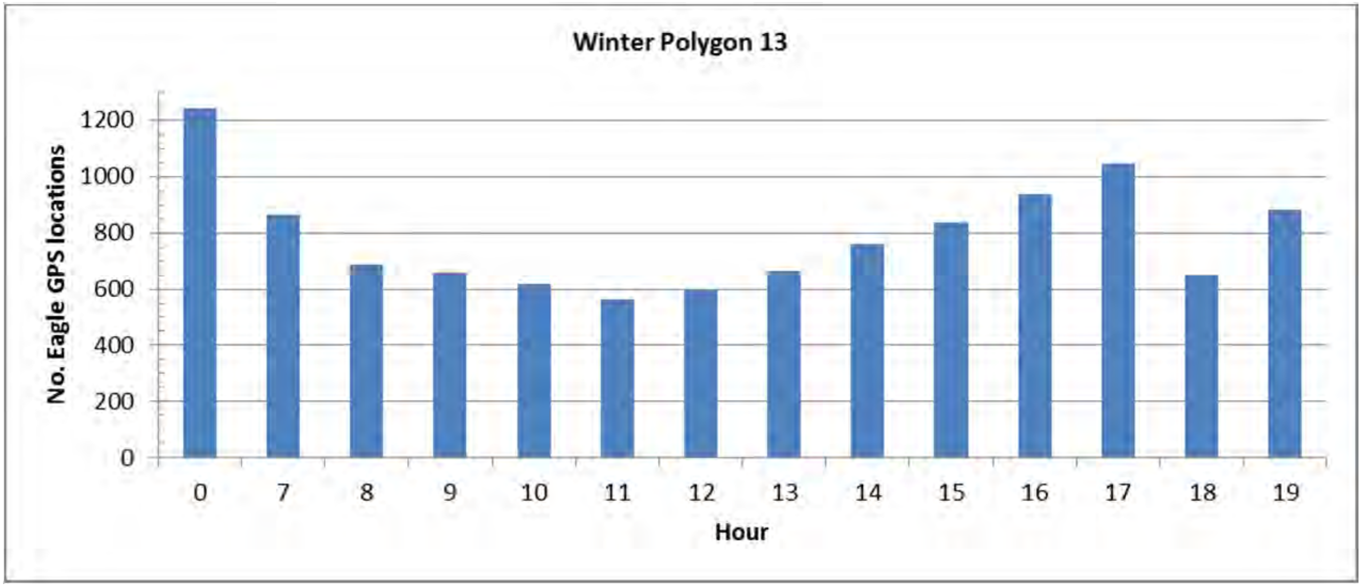
Polygon 12

This area is located on Black Point along the Chesapeake Bay shoreline. There is one breeding territory and one communal roost in the area. This area is a small upland area surrounded by water or marsh and provides protected perching locations while eagles forage in Mosquito Creek or on the Bay. Eagles were observed flying into this area from Mosquito Creek. Eagles were also observed flying north to Spesutie Island and along the Spesutie Narrows shoreline.



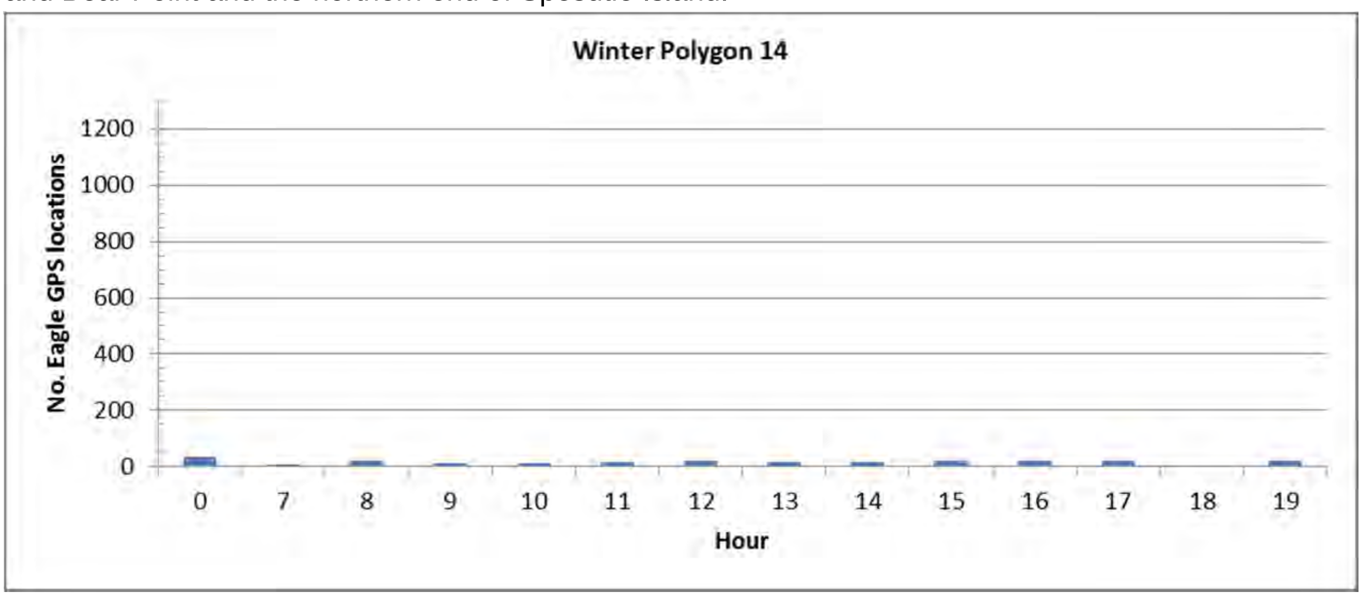
Polygon 13

This is the largest area and includes the middle and upper reaches of Romney Creek, Chilbury Point, Chelsea Chimney, Sod Run, and C-tower. This area overlaps with Old Bombing field, Drop Tower, Poverty Island, and the Romney Creek Ranges. There are 8 breeding territories and 8 communal roosts in the area. Movement corridors connect eagles from this area to the mouth of Romney, Dynomometer roost, Fairview Point, Towner Cove, and Delph Creek.



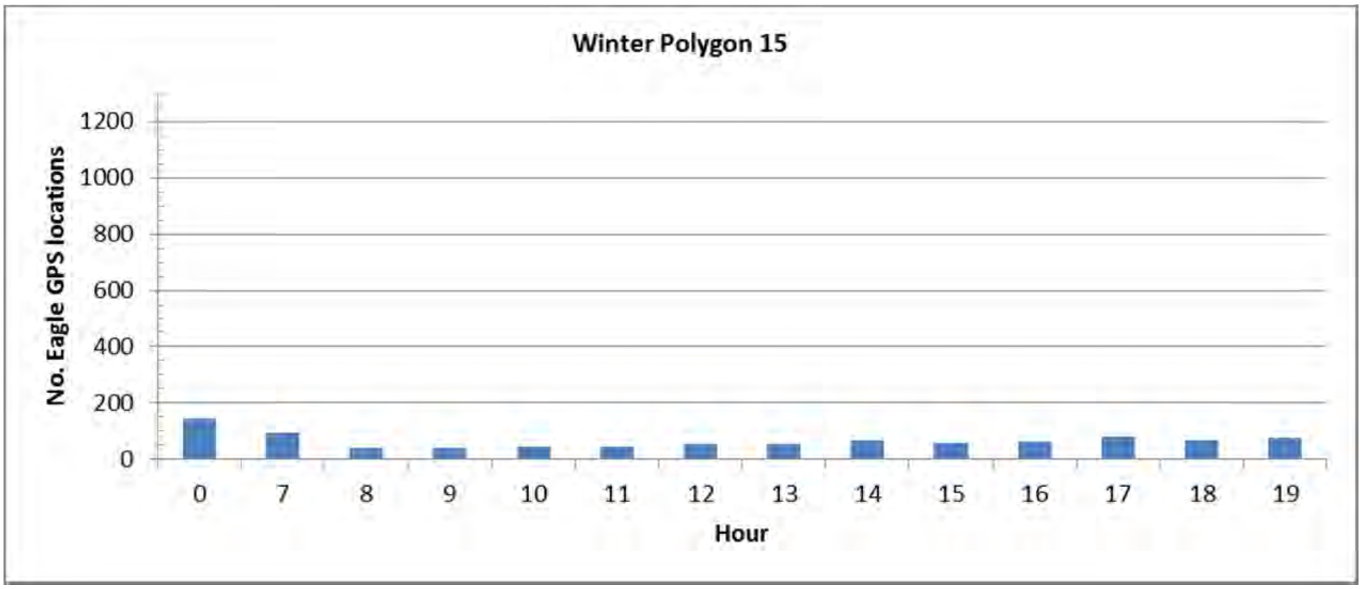
Polygon 14

This area is on Bear Point and overlaps the Fuse Range on Spesutie Island. There are two breeding territories and two communal roosts in the area. The area includes an upland forested area surrounded by marsh. Eagles were observed flying between Bear Point and Black Point and Bear Point and the northern end of Spesutie Island.



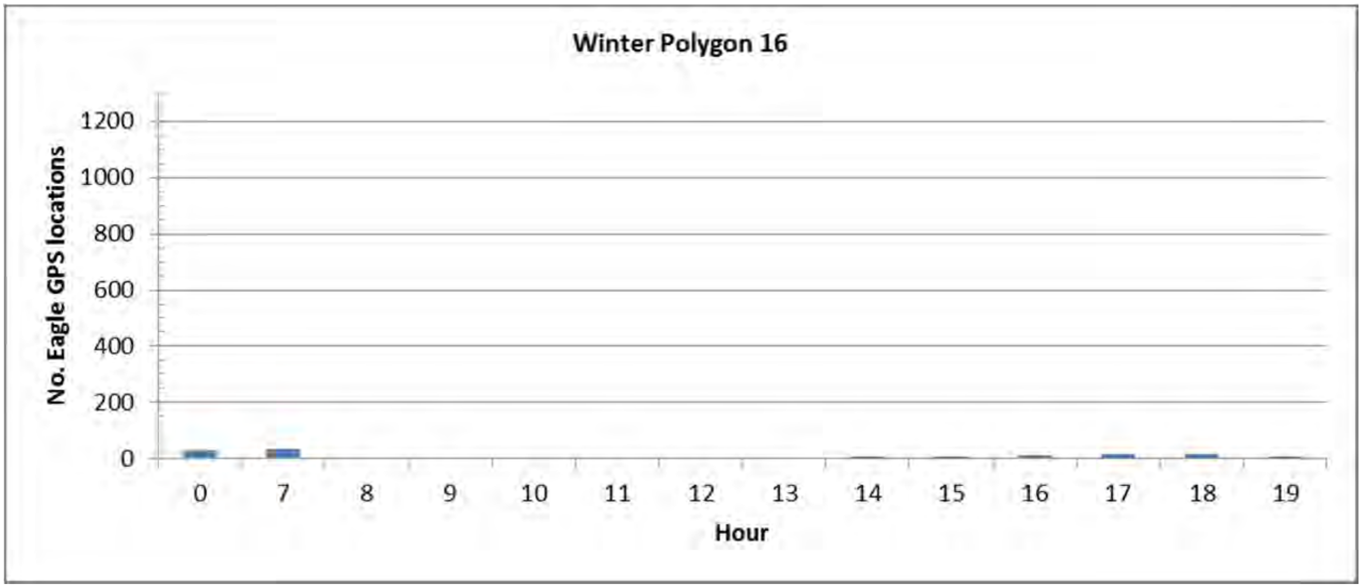
Polygon 15

This area includes the upper reaches of Mosquito Creek and overlaps the Hi Velocity range. There is one breeding territory and two communal roosts in this area. Eagles roost in the forested areas of this creek in the main roost and a smaller one on a northern branch of the creek. There are movement corridors between this area and Dynomometer roost, Woodrest Creek, Black Point, and Cherry Tree Point. They mainly enter and exit the roost flying downstream along the creek toward Black Point and Spesutie Narrows.



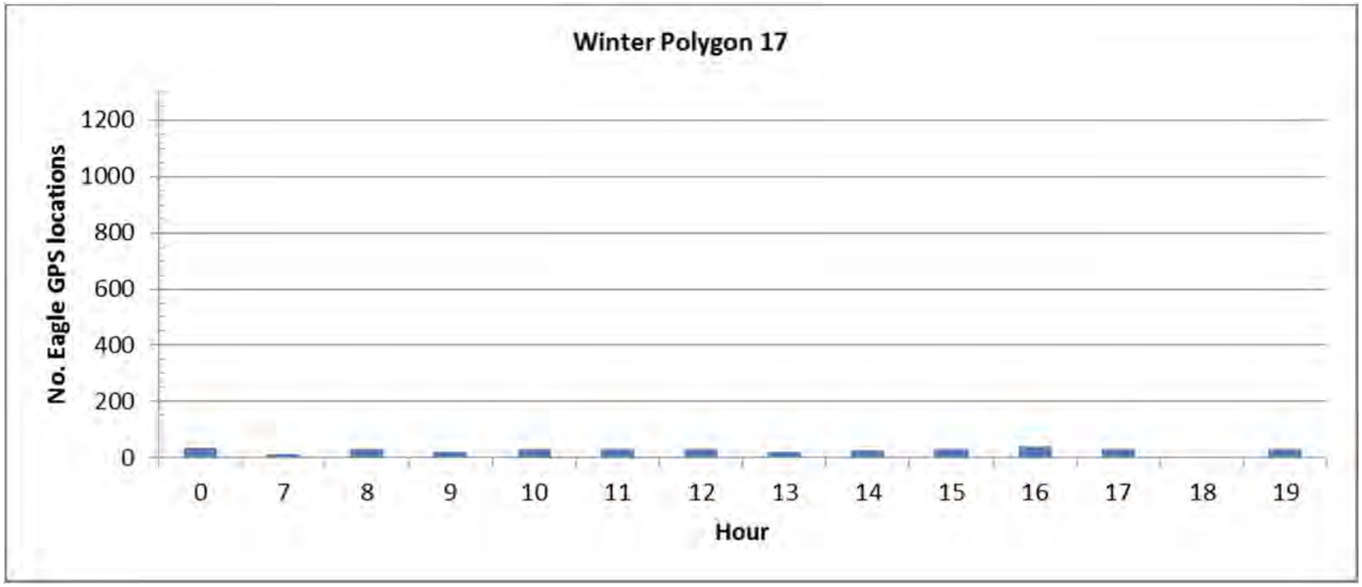
Polygon 16

This area is on the pond adjacent to Dynamometer Test Course. There is one breeding territory and one communal roost in the area. Eagles move in and out of this area via Romney Creek and flying across the Main Front ranges to Woodrest and Mosquito Creeks.



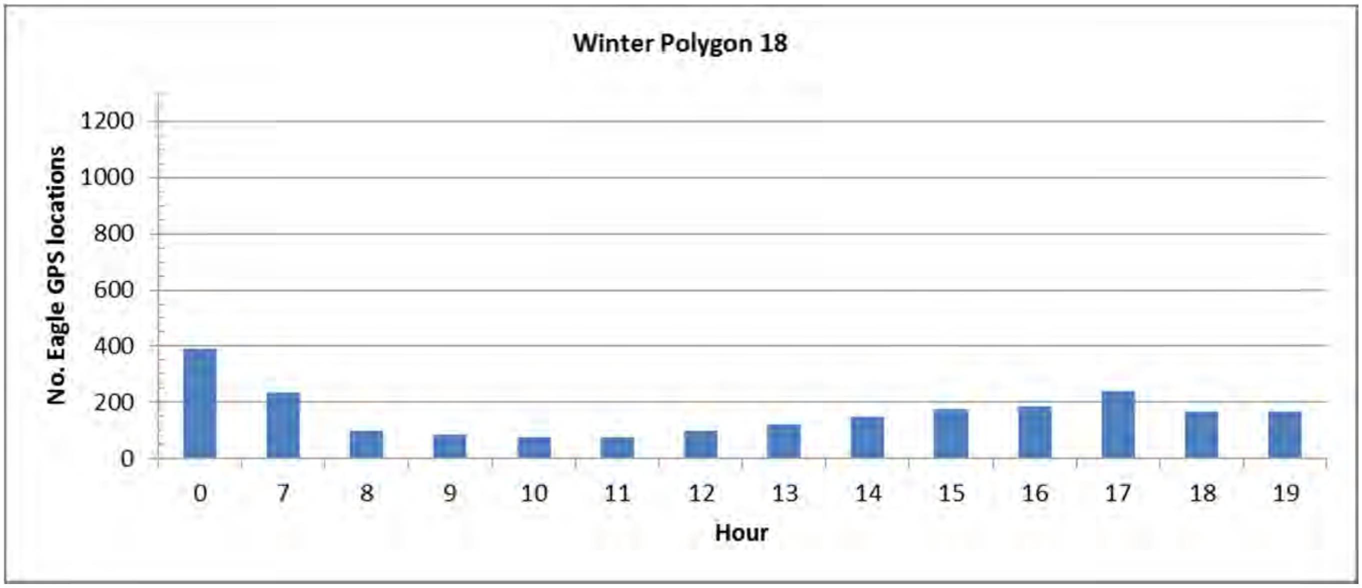
Polygon 17

This area is near Sandy Point on Spesutie Island. There is one breeding territory and one communal roost in the area.

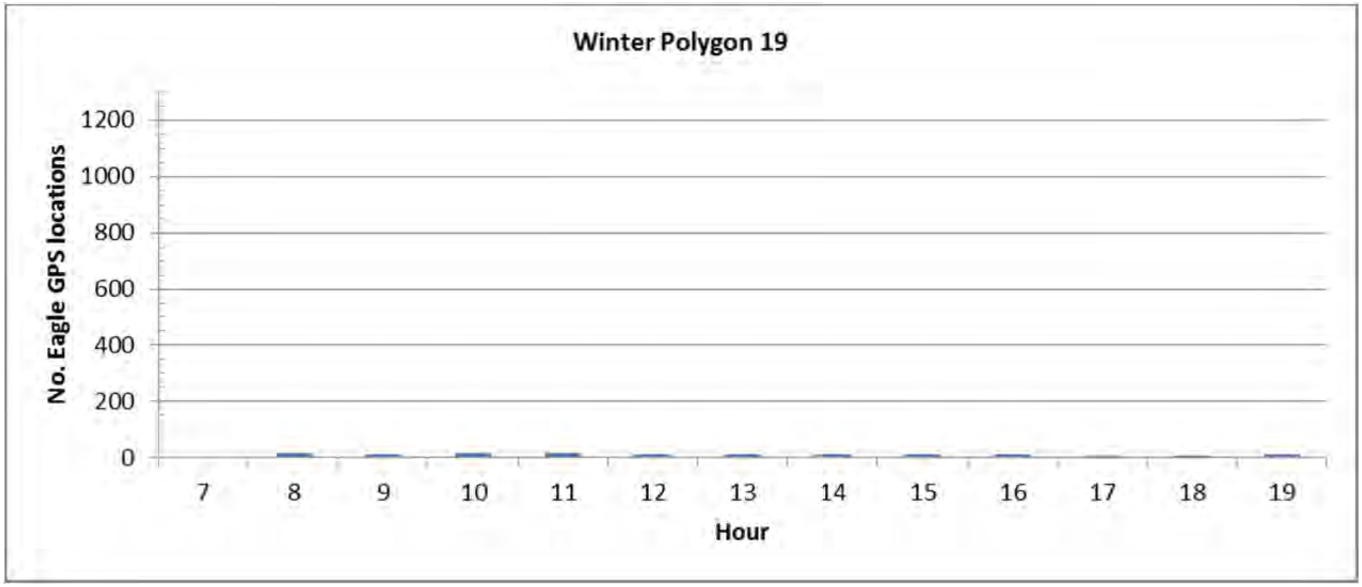


Polygon 18

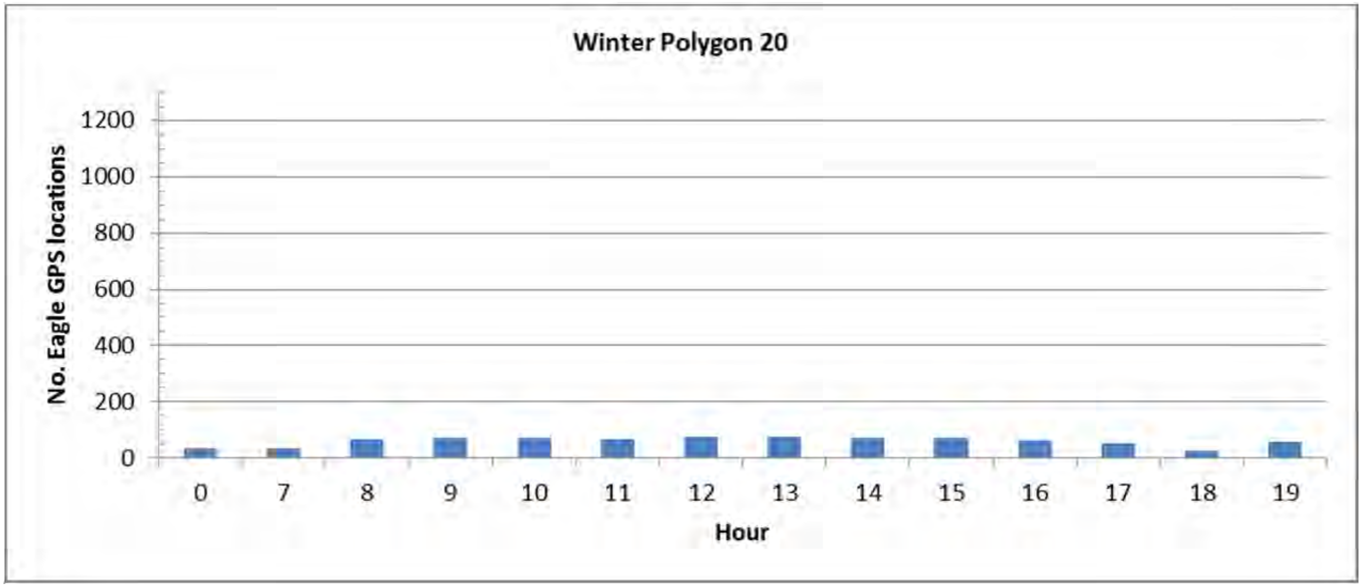
This area includes the upper reaches of Woodrest Creek. It overlaps the Vibration Facility and the eastern edge of the Main Front range. There is a movement corridor to and from this area on Woodrest Creek, over land from Swan Creek, over land from Dynomometer, and over land from Mosquito Creek.



Polygon 19
This area is near Neds Island on Spesutie Narrows and overlaps the Munson Test Area. Eagles move between this area, Woodrest Creek, and Spesutie Island.



Polygon 20
This area is on Swan Creek and includes High Point, Cedar Point, and Swan Creek Point. There are three communal roosts in the area. There is a movement corridor between this area and Woodrest Creek.



Appendix 13. Mojica, E. K., B. D. Watts, J. Pottie, J. T. Paul, and S. Voss. 2009. Factors contributing to bald eagle electrocutions on Aberdeen Proving Ground, Maryland. Journal of Raptor Research 43:80-83.

SHORT COMMUNICATIONS

J. Raptor Res. 43(1):57–61

FACTORS CONTRIBUTING TO BALD EAGLE ELECTROCUTIONS AND LINE COLLISIONS ON ABERDEEN PROVING GROUND, MARYLAND

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KEY WORDS: *Bald Eagle;* Haliaeetus leucocephalus*; Chesapeake Bay; collision; eagle concentration area; electrocution; electrical line; mortality.*

Avian electrocution is a widespread conservation problem affecting many taxonomic groups worldwide (Bevanger 1998, Bayle 1999, Lehman et al. 2007). The specific biological and technical aspects of electrocution are well documented, particularly for raptors. Several factors influence the risk of bird electrocution or collision, including design of electrical poles and lines, weather, visibility, wingspan, and bird age and experience (Avian Power Line Interaction Committee [APLIC] 2006). Electrocution can occur when a bird perches on a crossarm and completes an electrical circuit with two or more body parts (APLIC 2006). Line collisions (birds flying directly into electrical lines) are increasingly documented as a cause of avian mortality (Olendorff and Lehman 1986, Bevanger 1994, Bevanger 1998, Bayle 1999). Birds die either from the impact of hitting the line or from electrocution when they contact two lines simultaneously and complete the electrical circuit (Harness et al. 2003).

Placement of electrical lines on the landscape is increasingly recognized as an important factor contributing to avian mortality (APLIC 1994, Bayle 1999, Schomburg 2003, APLIC and USFWS 2005, APLIC 2006, Lehman et al. 2007). Birds are more susceptible to line collisions if lines cross flight paths or movement corridors (Thompson 1978, Bevanger 1994). This could be compounded if vegetation surrounding the lines is not tall enough to reach the line, as with early successional habitat (Thompson 1978). A solid row of vegetation at or above the height of the line acts as a flight barrier to large birds, forcing flight paths above the electrical lines, thereby reducing the risk of collision (APLIC 1994, Bevanger 1994).

Our objective was to investigate the landscape factors that influence mortality of Bald Eagles (*Haliaeetus leucocephalus*) related to electrical lines. We hypothesized that line proximity to shoreline and surrounding vegetation height would affect the distribution of eagle mortality on the landscape. We suspected lines close to open water and not surrounded by vegetation would have the highest rates of electrocution and collision.

STUDY AREA

Our study was conducted on the U.S. Army's Aberdeen Proving Ground (APG) located on the shore of the upper Chesapeake Bay, Maryland (39°23′N, 76°13′W). Aberdeen Proving Ground is home to one of the largest concentrations of Bald Eagles on the east coast of North America (Watts et al. 2007). The property supports 42 resident pairs and seven known communal roosts used by migrants from the north and south during the winter and summer months respectively (Buehler et al. 1991, General Physics 2004, E. Mojica and B. Watts unpubl. data). This study focused on the Edgewood and Aberdeen areas of the installation (total ca. 16 000 ha). Shoreline habitat includes stands of mixed hardwoods, tidal marsh, human-maintained grasslands, and urbanized areas (Maryland Department of Natural Resources 2002).

The electrical infrastructure on Aberdeen Proving Ground is composed of three-phase distribution lines

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(≤40 kv) with three phases on a 6′ crossarm and one neutral line located 5′ below the energized wires (General Physics 2004, APLIC 2006). This pole configuration was not classified as "avian-safe" (APLIC 2006) and the wingspan of eagles is sufficient to touch multiple conductors and lines simultaneously (General Physics 2004). Of the approximately 1500 km of overhead lines on APG, 91 km run along shoreline areas, which are important foraging habitat for resident and migrant eagles (Buehler et al. 1991, General Physics 2004).

METHODS

We used records of dead or injured eagles to evaluate the influence of surrounding vegetation and proximity to shoreline on the likelihood that eagles would be killed by the electrical infrastructure. We initiated a database in 1985 to record the location and circumstances of eagle mortalities as part of the installation's Bald Eagle management plan. Data from 1985 to 2007 was included in this analysis. Dead or injured eagles were discovered during routine maintenance, but no systematic surveys were conducted. We included reports of carcasses in our analysis if the cause of the eagle's death was identified as electrocution through necropsy or examination, or if there was strong circumstantial evidence that death was due to the electrical infrastructure. We excluded from analysis any eagle with injuries unrelated to electrical lines or located outside of the main Edgewood or Aberdeen study areas of APG ($N = 15$). Reports of eagles whose death or injuries were associated with the electrical infrastructure were pooled for analysis ($N = 62$). We assumed that carcass detection rates were equal across the study area. We feel that this is a reasonable assumption because all lines were subject to regular maintenance and the majority of electrical lines parallel well-traveled roads with mowed grass beneath the lines.

We used a simple two-way design with proximity to shoreline and surrounding vegetation height to evaluate the influence of line characteristics on eagle electrocutions. We classified all electrical lines according to proximity to bay shorelines by overlaying shoreline buffers on an electrical line map using ArcMap 9.1 (E.S.R.I., Redlands, CA U.S.A.). We used three proximity categories including near shore (<300 m), mid-range (300 m–1000 m), and interior (>1000 m). We evaluated vegetation associated with electrical lines by visual inspection. We classified lines as "exposed" if there was no vegetation (except mowed grass) within 100 m of the lines, "below" if vegetation existed within the surrounding area but was lower than the height of the line, or "concealed" if vegetation within the surrounding area was even with or above the line height. We assumed APG staff maintained consistent vegetation heights around lines from 1985 to 2007 except where natural shoreline erosion kept vegetation low on areas of Spesutie Island and at the mouths of creeks where they entered the Chesapeake Bay. A majority (92%) of lines were within 100 m of heavily trafficked roads with 32–72 km/hr (25–45 m/hr) speed limits. A mowed grass corridor 3–10 m wide was maintained directly under the lines and aided in visual detection of dead or injured eagles.

We evaluated the influence of proximity to shorelines and vegetation on mortality by overlaying eagle electrocutions and collisions on electrical lines and grouping mortality events according to landscape characteristics surrounding the line. We compared the distribution of electrocutions according to proximity and vegetation categories with distributions expected based on the length of lines within these categories using χ^2 goodness-of-fit test. We hypothesized that eagle electrocutions and collisions were more likely to occur close to the shoreline as eagles sought perches near water. Because many of the mortalities were midline collisions, we also hypothesized that exposed lines may have a higher probability of being struck by flying eagles compared to concealed lines.

RESULTS

During 1985–2007, we documented 77 eagle mortalities and injuries on APG. We confirmed that 62 were directly related to the electrical infrastructure. Forty-five had visible signs of electrocution (burn marks on foot pads, bill, or feathers; $N = 24$;) or collision (feathers on lines directly above carcass, signs of blunt-force trauma; $N = 21$). We assumed an additional 17 eagles were killed after contacting electrical structures because they were found decomposed under an electrical line or pole. The single injury was witnessed by base staff and occurred when an eagle flew into a line and lay paralyzed on the ground after being shocked. We excluded eagle mortalities from disease ($N = 2$), intraspecific aggression ($N = 3$), nest tree collapse ($N = 2$), electrocution outside study area ($N = 3$), and unknown ($N = 5$). In addition to eagles, carcasses of an Osprey (*Pandion haliaetus*), owls, swans, and a Great Blue Heron (*Ardea herodias*) were found under electrical lines and poles.

Bald Eagle electrocutions and collisions on APG were not randomly distributed with respect to shoreline proximity or surrounding vegetation (Table 1). Significantly more detected mortality was associated with lines closer to shorelines compared to lines inland than was expected based on the relative line lengths ($\chi^2 = 119.71$, df $= 2$, $P < 0.001$). Lines falling within the near-shore and mid-range categories both accounted for a greater number of mortalities than expected based on the availability of line. In contrast, inland lines accounted for fewer mortalities than expected.

The characteristics of vegetation surrounding electrical lines had a significant influence on the likelihood that lines would be associated with mortality events ($\chi^2 = 11.54$, df $= 2$, $P < 0.005$). We documented a higher number of eagle deaths associated with exposed electrical lines than expected based on their relative lengths. The presence of vegetation appeared to significantly reduce mortality events. The likelihood of mortality was particu-

Table 1. Bald Eagle injuries and mortalities associated with electrical lines on Aberdeen Proving Ground, MD, 1985–2007. Mortality events were significantly higher than expected for exposed lines within 1 km of shorelines.

HABITAT VARIABLE	EAGLE MORTALITIES	ELECTRICAL LINE (km)	DEVIATION (%)
Vegetation height			
No vegetation (line exposed)	9	91.8	138
Vegetation below line	17	652.8	−37
Vegetation above line (line concealed)	36	758.7	15
Shoreline distance			
<300 m	16	75.0	417
300 m–1000 m	26	179.7	251
>1000 m	20	1248.6	−61

larly low when lines were concealed below the height of vegetation.

DISCUSSION

The location of electrical lines relative to both vegetation and the shoreline had a significant influence on Bald Eagle mortality patterns within APG. Detected mortalities were higher than expected along exposed lines with no vegetative cover than along lines partially or completely concealed by vegetation. Our findings supported the current view that vegetation shields the lines and forces flight paths safely above lines (APLIC 1994, Bevanger 1994). Mortalities were also higher than expected along lines within 1 km of the shoreline compared to those further inland. Eagles concentrate on shoreline habitat at APG to forage and perch (E. Mojica and B. Watts unpubl. data). Placement of lines within these high-use areas appears to increase the risk of eagle electrocutions and line collisions (Bayle 1999).

In addition to the general influence of vegetation height and shoreline proximity on eagle mortality, we believe that the placement of lines perpendicular to major flight lines contributed to mortality patterns within APG. This was illustrated by two areas on the installation where we documented relatively large mortality clusters. Exposed lines on Spesutie Island occurred between two communal roosts and a segment of shoreline that was heavily used for foraging and loafing. The shoreline vegetation on the island consisted of mid-successional trees and shrubs that were not preferred perching substrates. More than 48% of the installation's mortalities occurred here, over half of which were line collisions. This finding is consistent with other studies that have documented heavy mortality along lines that were placed between foraging and roosting habitat (Anderson 1978, Olendorff and Lehman 1986, APLIC 1994, Harness et al. 2003). A second mortality cluster occurred where a line was placed across the mouth of Watson Creek. This site accounted for 8.1% of the total mortalities. We believe that eagles used Watson and similar creeks as flight corridors between inland roosts and shoreline foraging areas.

Mortality studies can greatly underestimate mortality rates by using inadequate carcass detection methods (Thompson 1978). We did not systematically survey for carcasses. However, we believe that most eagle mortalities associated with the electrical infrastructure were documented. Within the APG, electrical lines generally run parallel and in close proximity to the roadways. Roadways are frequented by APG personnel several times per day at low vehicle speeds such that the likelihood of discovering a carcass is high. In addition, there is a heightened awareness of eagle mortalities on the property, which we believe increased the rate of detection. Although it is likely that some carcasses were not detected because they were removed by scavengers, and that some of the injured eagles were not counted because they were capable of moving away from lines (Thompson 1978, APLIC 1994); however, we do not believe that these circumstances represent systematic sources of bias that would invalidate the comparisons presented here.

Interactions between eagles and electrical lines can be expected to increase as additional lines are erected within eagle habitat (Anderson 1978, Newton 1979). However, raptor line collisions and electrocutions can be reduced on both new and existing facilities by using "avian-safe" construction designs and siting techniques (APLIC 1994, APLIC and USFWS 2005, APLIC 2006). Retrofitting existing poles with perches and guards was a successful mitigation technique at APG. Lines were fitted with orange balls and swinging plate diverters to increase line visibility (Harness et al. 2003, General Physics 2004). Even with these retrofitting measures, line collisions continued to occur at Spesutie Island, until the lines were moved underground.

The National Bald Eagle Management Guidelines recommend siting lines away from eagle foraging and roosting concentration areas (Thompson 1978, USFWS 2007). This would reduce the risk of exposing large numbers of eagles to the hazards of electrical lines, as would avoiding perpendicular placement of lines, particularly <1 km from shorelines. Vegetation height and distance to foraging and roosting areas may be important factors influencing line-related mortality at other eagle concentration areas in the Chesapeake Bay and throughout the species range. We recommend siting new power lines to minimize collision risk near eagle roosts, monitoring existing lines in eagle concentration areas, and retrofitting lines and poles as needed using accepted and effective methods (APLIC 1994, 2006).

FACTORES QUE CONTRIBUYEN A LAS ELECTROCUCIONES Y LAS COLISIONES CON LOS TENDIDOS ELÉCTRICOS DE *HALIAEETUS LEUCOCEPHALUS* EN ABERDEEN PROVING GROUND, MARYLAND

RESUMEN.—Evaluamos los factores que contribuyen a las electrocuciones y las colisiones con los tendidos eléctricos de *Haliaeetus leucocephalus* en Aberdeen Proving Ground, un área importante de concentración de águilas en la bahía de Chesapeake. Durante el periodo de 1985 a 2007, documentamos la ubicación de 62 águilas muertas o recuperadas heridas bajo tendidos eléctricos. Usando un diseño de dos vías simple, superpusimos la mortalidad de las águilas sobre segmentos del tendido, clasificados por su proximidad a la costa y por la altura de la vegetación circundante. Documentamos una mortalidad significativamente mayor asociada con los tendidos más cercanos a la costa comparada con los tendidos del interior que lo esperado con base en la longitud relativa del tendido (χ^2 = 119.71, gl = 2, $P < 0.001$). Adicionalmente, el número de muertes de águilas asociado con los tendidos expuestos (sin vegetación que los oculte) fue mayor que el esperado con base a la longitud relativa del tendido (χ^2 = 11.54, gl = 2, $P < 0.005$). La presencia de vegetación circundante a los tendidos eléctricos parece reducir significativamente los eventos de mortalidad. Los tendidos eléctricos a menos de 1 km de la costa y descubiertos de vegetación representan un riesgo significativo para las águilas. Recomendamos monitorear sistemáticamente los tendidos de alto riesgo en las áreas conocidas de concentración de águilas para determinar la necesidad de esfuerzos de mitigación.

[Traducción del equipo editorial]

ACKNOWLEDGMENTS

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Appendix 14. Mercury levels sampled from Bald Eagle nestlings at Aberdeen Proving Ground, Harford Co, MD during the 2008 breeding season. All values in mg/kg (ppm) wet weight.

Band	Nest	Feather Hg	Blood Hg
0679-01239	Bridge Creek	0.7109	
0679-01240	Bridge Creek	0.7622	0.0300
0679-01245	White Oak Point	0.7102	
0679-01246	White Oak Point	0.6850	
0679-01247	White Oak Point	0.8409	0.0223
0679-01248	Chilbury Point	0.6416	
0679-01249	Chilbury Point	0.4761	0.0149
0679-01250	Poverty Island	1.1925	
0679-01301	Poverty Island	1.1730	0.0363
0679-01306	Monocacy Tower	0.9460	
0679-01307	Range 17	0.8872	
0679-01308	Range 17	0.9583	0.0255
0679-01312	Fuze Range	0.7103	0.0302
0679-01313	Towner Cove	0.5290	0.0332
0679-01314	Plumb Point	0.8408	0.0303
0679-01315	Woodrest Creek	0.7803	
0679-01316	Woodrest Creek	0.9009	0.0280
0679-01317	Aviation Arms	0.7570	0.0287
0679-01318	Twin Towers	1.0080	0.0369

Appendix 14. continued

PCB contaminant data for Bald Eagle nestlings sampled during the 2008 breeding season at Aberdeen Proving Ground, Harford Co, MD. Values in µg/g (ppm) wet weight.

Band No.	0679-01247	0679-01249	0679-01301	0679-01308	0679-01312	0679-01313	0679-01314	0679-01316	0679-01317	0679-01318
PCB-70/95/66	0.0011	0.0027	0.0023	0.0008	0.0011	0.0012	0.0010	0.0015	0.0016	0.0018
PCB-101/90	0.0011	0.0031	0.0022	0.0012	0.0012	0.0013	0.0019	0.0011	0.0023	0.0012
PCB-99	0.0013	0.0031	0.0019	0.0021	0.0026	0.0016	0.0027	0.0032	0.0033	0.0029
PCB-110	0.0008	0.0031	0.0019	0.0005	0.0006	0.0005	0.0009	0.0002	0.0006	0.0005
PCB-149	0.0026	0.0075	0.0044	0.0028	0.0031	0.0026	0.0048	0.0028	0.0034	0.0032
PCB-118	0.0013	0.0044	0.0019	0.0011	0.0030	0.0021	0.0021	0.0019	0.0020	0.0027
PCB-146	0.0009	0.0025	0.0014	0.0018	0.0014	0.0007	0.0015	0.0010	0.0012	0.0013
PCB-153/132	0.0049	0.0145	0.0090	0.0064	0.0079	0.0049	0.0092	0.0062	0.0067	0.0076
PCB-164/163	0.0019	0.0041	0.0026	0.0019	0.0022	0.0013	0.0027	0.0014	0.0022	0.0017
PCB-138/158	0.0034	0.0086	0.0053	0.0038	0.0049	0.0024	0.0052	0.0030	0.0041	0.0039
PCB-187	0.0027	0.0086	0.0043	0.0032	0.0042	0.0026	0.0049	0.0029	0.0029	0.0038
PCB-183	0.0009	0.0030	0.0015	0.0009	0.0012	0.0007	0.0015	0.0006	0.0008	0.0012
PCB-174	0.0011	0.0033	0.0018	0.0010	0.0008	0.0009	0.0017	0.0006	0.0011	0.0013
PCB-180/193	0.0035	0.0115	0.0053	0.0038	0.0044	0.0028	0.0055	0.0027	0.0032	0.0041
PCB-170/190	0.0012	0.0040	0.0020	0.0012	0.0014	0.0009	0.0018	0.0010	0.0010	0.0014
PCB-199	0.0010	0.0049	0.0027	0.0013	0.0020	0.0008	0.0018	0.0000	0.0014	0.0014
PCB-208	0.0020	0.0038	0.0026	0.0024	0.0030	0.0015	0.0024	0.0017	0.0014	0.0023
PCB-206	0.0036	0.0063	0.0039	0.0034	0.0048	0.0027	0.0045	0.0025	0.0023	0.0045
PCB-209	0.0070	0.0072	0.0067	0.0052	0.0070	0.0052	0.0055	0.0035	0.0038	0.0081
Total PCBs	0.0422	0.1060	0.0636	0.0450	0.0568	0.0367	0.0614	0.0382	0.0451	0.0547

Appendix 14. continued

Organochloride contaminant data for Bald Eagle nestlings sampled during the 2008 breeding season at Aberdeen Proving Ground, Harford Co, MD. Values in µg/g (ppm) wet weight.

Band No	Nest Territory	MC5	*Trans*-chlordane	*Cis*-chlordane	*Trans*-nonachlor	*Cis*-nonachlor	Σ chlordane
0679-01247	White Oak Point	0.0033	0.0026	0.0020	0.0026	0.0010	0.0115
0679-01249	Chilbury Point	0.0042	0.0028	0.0036	0.0054	0.0014	0.0173
0679-01301	Poverty Island	0.0021	0.0017	0.0019	0.0024	0.0010	0.0090
0679-01308	Range 17	0.0028	0.0022	0.0010	0.0024	0.0008	0.0091
0679-01312	Fuze Range	0.0023	0.0012	0.0012	0.0024	0.0006	0.0079
0679-01313	Towner Cove	0.0023	0.0011	0.0011	0.0015	0.0005	0.0065
0679-01314	Plumb Point	0.0026	0.0011	0.0018	0.0036	0.0007	0.0098
0679-01316	Woodrest Creek	0.0029	0.0027	0.0006	0.0022	0.0004	0.0089
0679-01317	Aviation Arms	0.0019	0.0018	0.0016	0.0024	0.0007	0.0084
0679-01318	Twin Towers	0.0025	0.0011	0.0019	0.0024	0.0011	0.0089

Pesticide contaminant data for Bald Eagle nestlings sampled during the 2008 breeding season at Aberdeen Proving Ground, Harford Co, MD. Values in µg/g (ppm) wet weight.

Band No	p,p'-DDT	p,p'-DDE	p,p'-DDD	DDMU	Σ DDT
0679-01247	0.0010	0.0089	0.0012	0.0007	0.0118
0679-01249	0.0000	0.0297	0.0045	0.0014	0.0356
0679-01301	0.0013	0.0142	0.0017	0.0009	0.0180
0679-01308	0.0000	0.0178	0.0018	0.0010	0.0207
0679-01312	0.0009	0.0129	0.0012	0.0013	0.0164
0679-01313	0.0009	0.0094	0.0013	0.0009	0.0123
0679-01314	0.0012	0.0156	0.0018	0.0011	0.0196
0679-01316	0.0000	0.0134	0.0013	0.0015	0.0162
0679-01317	0.0000	0.0173	0.0028	0.0012	0.0214
0679-01318	0.0000	0.0159	0.0020	0.0009	0.0189

Appendix 15. Cristol, D. A., E. K. Mojica, C. W. Varian-Ramos, and B. D. Watts. 2012. Molted feathers indicate low mercury in bald eagles of the Chesapeake Bay, USA. Ecological Indicators 18:20-24.

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Molted feathers indicate low mercury in bald eagles of the Chesapeake Bay, USA

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ABSTRACT

Mercury is a potent neurotoxin affecting birds and other wildlife worldwide. Bald eagles (*Haliaeetus leucocephalus*) are vulnerable to mercury bioaccumulation because they are high in the food web and associated with aquatic ecosystems prone to mercury methylation. Eagle populations, long endangered in the continental United States by contaminants and persecution, are recovering throughout their range. We used single adult eagle feathers collected near 83 occupied nests to show that mercury levels in the Chesapeake Bay eagle population are the lowest in North America (3.82 ± 5.15 µg/g dry weight). We then used 20 feathers from each of 20 salvaged eagles to calculate a confidence interval around the estimate based on single feathers from nesting eagles. Using an inexpensive and non-invasive method to assess mercury burdens we have demonstrated that few Chesapeake Bay bald eagles were above levels suspected of causing reproductive or survival effects in birds.

1. Introduction

Mercury contamination poses a threat to wildlife in ecosystems worldwide, particularly large, predatory species such as bald eagles (*Haliaeetus leucocephalus*). Mercury can affect behavior and reproduction in birds, and high levels in the diet can cause mortality (Seewagen, 2010). Bald eagles have been the focus of conservation efforts for decades, and populations are stable or increasing throughout the contiguous United States (Suckling and Hodges, 2007). Because eagles feed on large prey at the top of aquatic food chains they are prime candidates for elevated mercury contamination. Eagle tissues have frequently been monitored for contaminants, and they typically have mercury levels above published levels of concern for birds (Bechard et al., 2009). No data on mercury concentrations in adult eagle tissues have been published for the mid-Atlantic region of the United States (for eggs, see Wiemeyer et al., 1984), which includes Chesapeake Bay and is one of the bald eagle's major population strongholds. Chesapeake Bay (Fig. 1), the largest estuary in North America, has numerous tributaries that are subject to mercury fish consumption advisories and contains fish species with elevated methylmercury concentrations (Mason et al., 2006).

Recent research on avian mercury concentrations, especially for species of conservation concern, has focused on non-lethal sampling techniques, such as analysis of addled eggs, blood and feathers. Feathers accumulate mercury from the blood supply only during the few weeks that they are growing, but mercury concentration established at that time remains stable indefinitely and can be used to track historical trends in environmental mercury (Appelquist et al., 1984; Thompson et al., 1992). A feather that is grown on a breeding territory one summer, carried throughout the year, and molted near the nest the following summer will provide information about mercury in the diet during the weeks or months prior to the previous breeding season. Because eagles are highly territorial, and use the same territories for multiple years, freshly shed adult feathers collected near nests during the breeding season are likely to bear reliable information about mercury exposure on that territory. Even if the parents migrated, shifted diets, or altered their territory boundaries during the non-breeding season, feather mercury will not be affected by these changes. Sampling freshly molted feathers is a non-invasive and inexpensive way to monitor mercury exposure (Furness et al., 1986), but little has been published about the reliability of this increasingly popular technique (however, see Bond and Diamond, 2008). Thus, one objective of this study was to determine whether sampling a single adult eagle feather near a nest provides meaningful assessment of the overall mercury concentration in the parents' plumage.

The other objective of this study was to determine whether adult bald eagles breeding in the Chesapeake Bay are accumulating mercury at concentrations comparable to those reported for bald eagles in other parts of North America. These results are important because (1) they fill a major gap in the continent-wide assessment of contaminant levels in this important bioindicator

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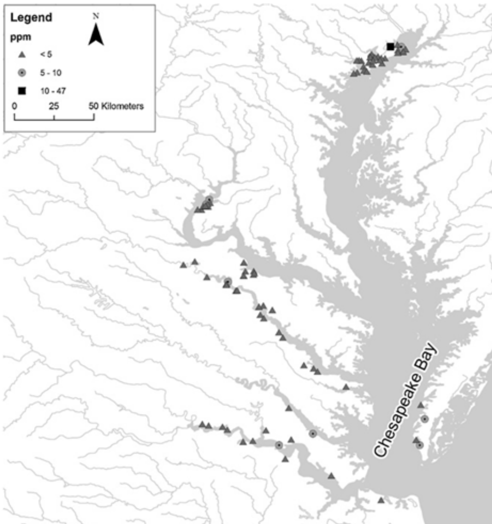

Fig. 1. Distribution of samples across Chesapeake Bay, with each symbol indicating one adult eagle feather mercury level.

species, (2) they establish a baseline against which to compare data gathered after any future change in mercury pollution policy, and (3) they are a first step in determining whether mercury is an ongoing conservation concern for this formerly endangered species.

2. Materials and methods

2.1. Sample collection

At 83 occupied eagle nests, a single body feather, determined to belong to an adult bird by wear, color and texture, was collected from the ground within 50 m of the nest in June–October 2007–2009. Chesapeake Bay bald eagles are territorial and resident year-round, and during or after nesting, adults frequently shed molted feathers while roosting or feeding on their nest tree or neighboring trees. It was not known whether the collected feather was from the male or female parent, but sampled feathers had been shed within a few weeks of collection based on condition and location. Because eagles in this population defend nest sites year-round, it is extremely unlikely that adults other than the parents would shed a feather near a nest tree. Feathers were stored at room temperature in a paper envelope until analysis for mercury concentration. Nests were located on all of the major tributaries of the Chesapeake Bay in Maryland and Virginia, USA (Fig. 1).

To determine the variance among body feathers on individual eagles, 20 body feathers were sampled from each of 20 adult eagles. These were either salvaged after accidental power-line electrocution, by the authors under permit (n = 6), or were injured or dead eagles (n = 14) found by the public and sampled by staff at The Wildlife Center of Virginia, in Waynesboro (www.wildlifecenter.org). Feathers were plucked or clipped at the base, 10 from the breast and 10 from the back, avoiding feathers from adjacent areas that likely molted simultaneously. Birds that had been in captivity for more than a few days, and thus might have molted feathers on a provisioned diet, were excluded.

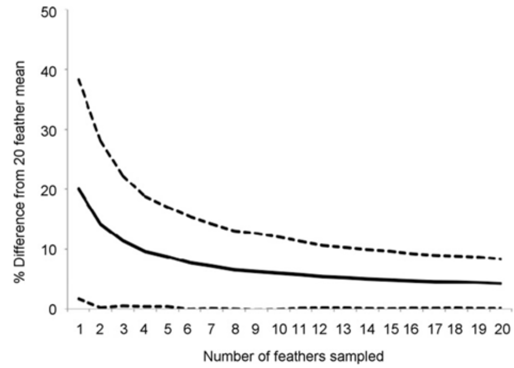

Fig. 2. Results from bootstrapping model of the accuracy of using different numbers of feathers to estimate mean feather mercury. Solid line is the average percent difference of the mean using various numbers of feathers from the 20-feather mean. Dashed lines are one standard deviation around the mean.

2.2. Mercury analysis

Samples were analyzed on a Milestone DMA-80 (Milestone, Shelton, CT). Each feather was washed with deionized water for 1 min to remove particulates, dried in a low humidity chamber for 48 h, and chopped into 1 mm pieces and mixed by hand for 1 min. Reported mercury values are technically wet weights, and it should be noted that we did not freeze-dry feathers. In most cases, two samples weighing approximately 0.02 g were run from each feather and their mercury value averaged; for smaller feathers the mercury value was based on one sample weighing approximately 0.02 g. Two blanks, two method blanks, and two samples of each of two certified reference materials (DORM-3, DOLT-4, National Research Institute, Canada) were run with each batch of 20 samples. The mercury analyzer was calibrated prior to the first samples being run and monthly thereafter. The factory calibrated minimum detection limit for the analyzer was 0.005 ng mercury. Recovery of standard reference materials was $103.0 \pm 3.9\%$ for DORM-3 (n = 106) and $99.3 \pm 4.8\%$ for DOLT-4 (n = 106) (means presented with SD throughout). When we spiked chopped domestic bird feathers with DOLT-4 (n = 10), recovery was $100.0 \pm 1.5\%$. The mean relative percent difference between pairs of feather samples run as duplicates was $7.0 \pm 6.6\%$ (n = 111).

2.3. Statistical methods

In order to assess the accuracy of using a single feather to estimate feather mercury levels in an individual eagle, we used the 20 feathers collected from each of 20 eagles found injured or freshly dead. We determined mercury concentration in each feather separately and calculated an average mercury concentration for each bird based on all 20 feathers. We then calculated the coefficient of variance (CV = standard deviation/mean) for each bird and calculated the average CV for all 20 birds. We then used the average CV to approximate a standard deviation (SD) around a single feather measurement (~SD = feather value × average CV).

To evaluate the optimal number of feathers to collect per bird in future studies we used a bootstrap resampling in which we selected a feather value at random from any of the 20 birds from which we had 20 feathers. We then calculated the percent difference of the mercury concentration of that feather from the mean feather mercury concentration based on 20 feathers from the same eagle. We repeated this process 10,000 times and determined mean

Table 1
Average adult bald eagle feather mercury (Hg) levels from North American states and provinces.

Location	Hg (ppm)	Date	Source
Virginia/Maryland	3.8	2007–2009	Body feathers; this study
Alaska	5.1	2004	Wing feathers; Burger and Gochfeld (2009)
Florida	11.5	1991–1993	Body feathers; Wood et al. (1996)
Montana	13.0	2006–2008	Body feathers; Harmata (2011)
Great Lakes	15.8	2002–2010	Body feathers; Rutkiewicz et al. (2011)[a]
Idaho	18.7	2004–2006	Mixed feathers; Bechard et al. (2009)
British Columbia[b]	21.0	2001–2002	Wing feathers, Weech et al. (2006)
Michigan	21.5	1985–1989	Mixed feathers; Bowerman et al. (1994)
New York	30.9	1998–2006	Mixed feathers; DeSorbo et al. (2008)
Maine	38.3	2001–2006	Mixed feathers; DeSorbo et al. (2009)

[a] Samples included a small percentage of nestling and immature birds.
[b] Sites included a lake impacted by a mercury mine.

difference of a single feather from the 20-feather mean for the same bird. We then repeated this process selecting 2–20 feathers at random with replacement and calculating a mean based on each number of feathers sampled and comparing that to the 20-feather mean. This allowed us to determine how much accuracy is gained by sampling each additional feather from a bird. It should be noted that this calculation was based on feathers known to be from the same bird.

3. Results and discussion

3.1. Single feathers as bioindicators

Resampling of 20 feathers from 20 eagles indicated that variation in mercury concentration among feathers on a single bird was relatively high. Only 15.1% of feathers had mercury concentrations within 5% of the mean concentration based on 20 feathers from the same bird, 38.3% of feathers were within 10% of the mean, and 71.9% of feathers were within 25% of the mean. The variation in mercury concentrations among feathers from a single individual is likely explained by the fact that bald eagles rarely, if ever, replace all body feathers within a single molt (Pyle, 2008), thus feathers collected may represent mercury burdens over several years. We calculated a 95% confidence interval around any given feather of 50.1%, which is applicable to the single feathers we collected from eagle nests in evaluating whether they are above or below levels of concern, and has applicability to any estimate based on a single feather. To produce an estimate that was within 10% of the mean based on 20 feathers one would have had to sample >4 feathers from a single bird at each nest (Fig. 2). It has long been appreciated that collecting more than one feather per individual is desirable for mercury sampling (Furness et al., 1986; Thompson et al., 1991), and high intra-individual variation was reported based on five feathers from individual seabirds (Bond and Diamond, 2008). Our results are the first statistically derived guideline for the minimum number of feathers to sample, and more importantly we are the first to estimate a population-level mercury concentration with a confidence estimate based on collecting single feathers. Because feathers sampled from beneath a nest can come from both members of the pair if they are molting simultaneously, the recommended sample size presented here is applicable when only one member of a pair is molting, when feathers can be collected under a roost used exclusively by one member of the pair, or if feathers are otherwise known to be from the same bird (e.g. collected during capture). It should also be noted that intra-individual plumage variance might be greater in areas with higher mercury exposure than experienced by the 20 injured birds and carcasses we sampled (4.27 ± 3.80 ppm; range 0.51–13.1 ppm), and thus more feathers should be sampled from each individual at such sites.

3.2. Mercury concentration

There was no indication of particular mercury hotspots or geographic trends, with the birds highest in mercury scattered around the study area (Fig. 1). However, it should be noted that sampling of the eastern shore of the Chesapeake Bay was not extensive. The average concentration of mercury in the feathers of bald eagles sampled in the Chesapeake Bay region was 3.82 ± 5.15 ppm. Based on the 95% confidence interval calculated, the mean plumage mercury concentration for the nesting eagles we sampled was between 1.91 and 5.73 ppm. Because we washed feathers in water, rather than a solvent, traces of exogenous mercury or mercury from preen gland oil may have been present and this range may be an overestimate.

In a recent study (2004–2006) from the northeastern USA, feathers from adult eagles in freshwater habitats in Maine averaged 38.3 ppm (DeSorbo et al., 2009). A less recent study from the southeastern USA reported 11.5 ppm in Florida in 1991–1993 (Wood et al., 1996). Overall, the levels we report for the Chesapeake Bay are the lowest eagle feather values yet sampled in North America and we have documented the first population in which nearly all individuals are below the typical level of concern for feather mercury (Table 1). This low mercury level, relative to other regions, is consistent with the robust recovery and rapid population growth rate observed in the region (Watts et al., 2008).

3.3. Is mercury affecting bald eagles?

It is not yet possible to set a reliable lowest observed adverse effects level for bald eagles based on literature from this or any other bird species. The lowest level commonly cited in the literature for feather concentrations is 5 ppm (fresh weight, 7.5 ppm dry weight), which is based on a widely cited review by Eisler (1987) but not on data from raptors or free-living birds. Another feather mercury value, 40 ppm, is sometimes cited as being associated with sub-lethal effects in free-living individual birds, based primarily on a study of feather asymmetry in common loons (Evers et al., 2008) and declines in populations of European raptors during a period of heavy environmental mercury exposure (usually attributed to Berg et al., 1966). In contrast, a recent dosing study in which captive raptors ate a diet containing 3 ppm mercury and attained primary feather mercury levels of 275 ppm suggests that reproduction and health were not compromised over a short time span even with exposure resulting in extremely high feather levels (Bennett et al., 2009). The range of values for possible adverse effects spans almost two orders of magnitude and is therefore nearly useless. In addition, the evidence linking effects and particular mercury levels is mostly indirect. Further work is urgently needed to establish lowest observed adverse effects levels for sub-lethal effects in birds.

Recent research on free-living tree swallows (a songbird, *Tachycineta bicolor*) with an average of 14 ppm in primary feathers molted on site suggests that the birds experienced reproductive, immunological and endocrine effects (Brasso and Cristol, 2008; Hawley et al., 2009; Wada et al., 2009). Heinz et al. (2009) compared sensitivity to injected mercury of embryos across many avian species, and found that the two raptors included in the study were highly sensitive to mercury, in contrast to tree swallows, which were moderately sensitive, and mallards (*Anas platyrhynchos*), which had low sensitivity. This suggests that a prudent estimate for the low adverse effects level in adult eagle feathers would be concentrations below the 14 ppm, as this has been shown to affect the less-sensitive tree swallow. A level of 9–11 ppm in primary ("forewing") feathers impacted mallard reproductive behavior when carefully monitored in captivity (Heinz, 1979). Because raptors are more sensitive than either tree swallows or mallards (Heinz et al., 2009), it would be reasonable to expect reproductive or health effects in eagles at levels somewhat below the 9–14 ppm range in primary feathers. Two studies of bald eagles (Bowerman et al., 1994; Rutkiewicz et al., 2011) have reported no difference in mercury value for body feathers (used in the present study) and primary feathers (used in the mallard and swallow studies cited above), although the timing of migration and location of molt would cause this to be true only for certain individuals, populations and species. A recent study that reported mercury-associated neurochemical changes in the brains of some bald eagles in a population with primary feather mercury averaging approximately 15 ppm is in accordance with the threshold suggested here (Rutkiewicz et al., 2011).

While there was variation in mercury level between individual Chesapeake Bay eagles, only one of the 83 sampled had a mercury level (47.6 ppm) clearly warranting concern based on current literature described above, and only 11 birds (13%) were above 5 ppm, the lowest level of concern ever stated in the literature (Eisler, 1987).

4. Conclusions

We found that collecting single molted feathers from near bald eagle nests provides an estimate of mercury concentration that was sufficient to assess whether the population is experiencing exposure to levels of mercury stated to be harmful in the literature on birds. Using larger samples of feathers from injured and dead birds, we showed that for this species, despite considerable variation between individual feathers, collecting five feathers from individual birds should suffice to provide an estimate that is within 10% of the value of that bird's plumage. Feathers from adult bald eagles nesting on the Chesapeake Bay, Virginia and Maryland, USA, had the lowest mercury levels ever reported for a population of this species in North America. Mercury level in most individuals was below all cited thresholds of concern for sub-lethal effects. Sampling species of conservation concern for contaminants can be expensive and invasive. Many studies have been performed in the past using feathers, typically more than one, to estimate mercury levels (Furness et al., 1986; Thompson et al., 1991, 1992). We suggest that expensive and invasive sampling of blood or other tissues for mercury is sometimes not warranted given the utility of sampling molted feathers.

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