Department of Defense
Legacy Resource Management Program

10-381

Avian Response to Grassland Management Around Military Airfields in the Mid-Atlantic and Northeast (Final Report)

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May 2012

Acknowledgements

This project was funded by the Department of Defense Legacy Resource Management Program. Fieldwork at Joint Base McGuire-Dix-Lakehurst (Lakehurst section) and Westover Air Reserve Base was performed by Sam Stuart and Mike Allen. Kyle Rambo, Jim Swift and Bob Boxwell performed fieldwork at Patuxent River Naval Air Station as in-kind support. John Joyce (Lakehurst), Drew Milroy (Westover), and Kyle Rambo (Patuxent) provided valuable logistical support to the project.

EXECUTIVE SUMMARY

Grasslands associated with airfields in the eastern U.S. frequently support breeding populations of grassland birds that are of conservation concern, but can also support bird species that are potentially hazardous to aircraft operations. A better knowledge of how various species respond to management actions in airfield grasslands will have benefits for both conservation and air safety. To address this need, we studied the relationships among avian habitat use, grassland habitat management, vegetation structure, and landscape characteristics on three military airfields: Westover Air Reserve Base ('WARB') in Massachusetts, the Lakehurst section of Joint Base McGuire-Dix-Lakehurst ('Lakehurst') in New Jersey, and Patuxent River Naval Air Station ('PRNAS') in Maryland.

During fall migration (2007, 2008, 2010), spring migration (2008, 2009, 2011), and the summer breeding season (2008, 2009, 2011), we estimated avian population densities using distance-sampling transect surveys performed bi-monthly. Data were analyzed as total avian density, as well as by functional group densities ('strike-risk' and 'conservation-value'). Conservation-value birds were defined as those above a predetermined priority ranking in relevant conservation plans. Strike-risk birds were defined in a similar manner, based on a published ranking of species hazardous to military aircraft. An alternative ranking system based on civilian aircraft strikes was also evaluated in a subset of analyses (the 'between-transects' scale; see below). This was based on a civil aviation bird-strike database which is thought to contain fewer off-airfield strikes and may therefore better represent hazardous species that inhabit the immediate airfield environment.

At each transect, we tracked mowing activity in cooperation with management crews, and measured both local (e.g., vegetation structure) and landscape-scale (e.g., land cover) parameters. The relationships between bird density and these factors were analyzed separately for each season, at three spatial/temporal scales: 1) 'between-transect' or the effects of vegetation and management factors on seasonally averaged bird densities, 2) 'within-transect' or the effects of vegetation and management factors on densities at individual transects over time, and 3) 'landscape' or the effects of landscape composition and configuration on seasonally averaged bird densities. To quantify overall bird-aircraft collision risks at each site, we also documented rates of avian runway crossings during bi-monthly behavioral observation surveys, and related them to temporal and landscape composition factors.

At the between-transect scale, we analyzed strike-risk bird density in two ways, defining 'strike-risk' birds based on 1) a military aviation bird-strike hazard ranking, and 2) a ranking based solely on civil aviation bird-strike data. Based on the military ranking, strike-risk bird density at PRNAS during breeding season and spring migration decreased with increasing vegetation heights from about 0 to 20 inches; during breeding season densities increased again in vegetation greater than 20 inches (up to ~35 inches). No significant relationships were found at WARB or Lakehurst. Based on the civil aviation ranking, strike-risk bird density was negatively related to vegetation height at all sites during the breeding season and at PRNAS during spring. For both the military and civilian rankings, strike-risk bird densities in fall were significantly higher at frequently mowed versus infrequently mowed transects. Densities of conservation-value species were positively related to vegetation height during breeding season at WARB and Lakehurst, while at PRNAS a parabolic relationship was evident (i.e., increasing until ~ 20-25 inches, and then decreasing). No significant relationships were found for conservation-value species during other seasons. Other vegetation characteristics, such as shrub and grass cover, were significant predictors of avian densities in some models, though these effects were not consistent among sites and seasons.

Models relating avian densities to conditions at each transect over time (i.e., the within-transect scale) indicated that birds did track local habitat conditions to some degree. Results were generally similar to those at the between-transect scale, especially for strike-risk species (military ranking) at PRNAS during breeding and spring (decreasing relationships up to ~ 20-25 inches). Relationships between conservation-value density and vegetation height were also similar to the between-transect analyses (increasing relationships at all sites during breeding season up to ~ 20 inches).

Landscape-scale models indicated a positive association between the density of strike-risk species and the percent cover of developed land (e.g., buildings, pavement, lawn), though these results were based on small sample sizes (i.e., a subset of transects) and thus should be interpreted with caution.

The most frequent runway-crossing groups during behavioral observation surveys were vultures, blackbirds/starlings, swallows, and gulls. Crossing rates of strike-risk species varied by time of day (lowest in evening [1400-1800]), and were positively related to the percent cover of pavement within 300 m of the survey point.

During the three years of this study, we amassed a substantial dataset of information concerning bird use patterns on the three airfields studied. Data collected on bird densities (transect surveys), vegetation structure, management practices, and potentially hazardous bird activity at each site have proven useful to evaluate the effectiveness of existing grassland management regimes on these airfields, and could be of use to evaluate the consequences of any potential future changes to these regimes. They also identified areas within individual airfields that appeared to be 'hot spots' for avian activity, thus potentially directing current deterrence actions towards these areas. Results suggest that management practices geared toward minimizing bird-aircraft collisions on airfields may not necessarily be in conflict with efforts designed to encourage less risky, vulnerable species. However, further work at other locations, as well as the adoption of an experimental habitat manipulation approach, will be needed to more fully understand the effects of vegetation management and landscape characteristics on airfield bird populations.

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BACKGROUND AND OBJECTIVES

Benefits from proper management of vegetation proximal to airfields may be twofold; 1) a reduction in risk of bird-aircraft collisions, and 2) habitat enhancement for grassland species of conservation concern. Typically, habitat management and maintenance at military airfields focus on mowing and other mechanical methods to comply with Bird/Wildlife Aircraft Strike Hazard (BASH) regulations and minimize risk of bird strikes (USAF 2004a). However, although high collision-risk species such as Laughing Gull (*Larus atricilla*), Canada Goose (*Branta canadensis*), Red-winged Blackbird (*Agelaius phoeniceus*) and European Starling (*Sturnus vulgaris*) likely respond to specific grassland management regimes, the direction and extent to which these responses occur is unclear (Fitzpatrick 2003). Management of airfield groundcover and how it can best minimize high-risk bird activity is still a controversial subject in North America, with current recommendations based primarily on European studies from the 1960s and 1970s (Cleary and Dolbeer 2005). Although it has been demonstrated that mowing and burning can be successful in restricting shrub encroachment and maintaining grassland habitat, questions remain about the direct and indirect effects of management practices on avian communities in general (Van Dyke et al. 2004, Zuckerberg and Vickery 2006), and collision-risk species in particular (Fitzpatrick 2003). For example, BASH management generally adheres to a strict mowing regime, with vegetation directly adjacent to runways consistently managed to 7-14 inches (USAF 2004a). Although this "tall-grass" management approach has been identified as the best practice for deterring problem species, few data are available to support the probability that such management is preferable to maintaining grass at shorter or taller thresholds in the eastern United States or other regions. In fact, some studies have shown either no effect (Milroy 2007) or a negative effect (Fitzpatrick 2003) of these accepted vegetation-height standards on airport safety (e.g., as measured by the presence of strike-risk species).

Furthermore, several studies suggest that airports in general, if properly managed, can be important for maintaining stable breeding populations of grassland birds (Askins 1993, Vickery et al. 1994, Kershner and Bollinger 1996). Military airports have been specifically identified as key components in the conservation of rare and threatened grassland birds (Osborne and Peterson 1984), and current Department of Defense (DoD) policy includes provisions for the protection and conservation of state-listed species, so long as such actions do not interfere with the military mission (e.g., USAF 2004b). Grassland birds are experiencing severe declines both regionally and nationally (Askins 1993, Brennan and Kuvlesky 2005), but have been shown in some cases to respond positively to management practices. Grasshopper Sparrow (*Ammodramus savannarum*), for instance, may respond quickly to changes in mowing regimes (Vickery 1996), and Upland Sandpiper (*Bartramia longicauda*) preferentially uses burned sites (Houston and Bowen 2001). These two species recently were identified as conservation targets by the U.S. Fish and Wildlife Service's Focal Species Strategy for Migratory Birds (USFWS 2005), and are listed as threatened or endangered in several northeastern/mid-Atlantic states. The DoD as a federal agency has responsibility to protect migratory birds of conservation concern to the extent that such actions do not interfere with military readiness (e.g., Migratory Bird Treaty Act, Sikes Act, Executive Order 13186, National

Defense Authorization Act). Small grassland birds are also not likely to pose a significant risk to aircraft, based on current risk-ranking schemes (Dolbeer et al. 2000, Zakrajsek and Bissonette 2005, Dolbeer and Wright 2009, DeVault et al. 2011).

Overall, a clear understanding of how alternative grassland habitat management practices can benefit conservation concern species, while reducing airfield use by potentially hazardous species, is currently lacking. Reducing the risk of bird strikes and managing for targeted bird species may not be be mutually exclusive (Eberly 2003), but much research is needed to determine how management practices affect avian use of airfields (Sodhi 2002). It is also likely that best practices vary among regions or even among specific airports depending upon the habitats or species present. Management plans should therefore be tailored to address regional or local conditions (Transport Canada 2002). Habitat management is an important, long-term component to an overall effective BASH plan (Kuzir and Muzinic 1999), that may also include short-term active procedures such as deterrence (e.g., decoys, audio, repellents), harassment (e.g., dogs, falcons), and removal (e.g., shooting, avicides). Active bird control, although often effective, can be susceptible to habituation (non-lethal methods) and may skew populations towards more naïve individuals (removal methods; York et al. 2000, Sodhi 2002). Resource and airfield operations managers will clearly benefit from tools that allow sustainable operation of airfields while simultaneously managing for rare grassland birds.

In this study, we investigated relationships among grassland habitat management methods, vegetation characteristics, and avian habitat use during spring migration, breeding (summer), and fall migration periods on three military airfields: Westover Air Reserve Base, MA (WARB), the Lakehurst section of Joint Base McGuire-Dix-Lakehurst, NJ (Lakehurst), and Patuxent River Naval Air Station, MD (PRNAS). We explicitly accounted for imperfect detection, providing reliable, unbiased estimates of species densities and occupancies within and across sites. Past avian monitoring on military lands generally has not accounted for problems with detection probability (DP). Consequently, estimates of species density and occupancy are likely biased, and in many cases substantial field efforts may have produced results that are unreliable (MacKenzie et al. 2006). This could result in faulty inferences about the abundance and distribution of avian populations and their relationships to vegetative or management histories (Farnsworth et al. 2002, Diefenbach et al. 2003, Norvell et al. 2003, MacKenzie 2006). Avian inventory work on DoD lands in the mid-Atlantic/New England region has also typically focused on breeding birds. However, habitat characteristics, including management history, also likely influence habitat use by birds during spring and fall migration. Use of airfield habitats during these periods, particularly by waterfowl and by smaller flocking species, could pose strike hazard problems and thus is a critical consideration for base operations. Jerome (1976) estimated that the chance of a bird strike is five times higher during migration periods than at other times, and the U.S. Air Force reported air strikes typically peak during spring and fall migration (Neubauer 1990). In some cases, air traffic is highest when bird activity is also high, compounding problems even further (Servoss et al. 2000). A broader temporal view of avian habitat use at airfields is essential to a comprehensive assessment of existing management practices.

In this study we coupled DP-adjusted avian density estimates with (1) ground-based vegetation measurements and (2) grassland management histories, which were obtained from DoD resource managers and contracted mowing crews. Our primary goal was to provide core information to enhance the development of sound management plans for each site and for the region as a whole. Specific questions we addressed included; 1) How were birds distributed across each site during the migratory and breeding periods? (e.g., were there avian activity "hot spots" on individual bases that could pose higher risk?); 2) How was total avian density, density of high strike-risk species, and density of high conservation-value species related to vegetation characteristics and management history on each site? 3) At what spatial and temporal scales were birds responding to habitat characteristics, including management history?, and 4) Were patterns of avian activity across high risk areas (i.e., runways, approach zones) nonrandom with respect to season, time of day, landscape characteristics or management history?

This report summarizes combined findings from Year 1 (fall 2007-summer 2008; Peters and Allen 2009), Year 2 (fall 2008 - summer 2009; Peters and Allen 2010), and Year 3 (fall 2010 - summer 2011) of the study.

STUDY SITES

Westover Air Reserve Base ('WARB')

Westover Air Reserve Base in Chicopee, Massachusetts contains approximately 2,511 acres of land in an area of the Connecticut River Valley characterized by gently sloping terrain of medium fertile, sandy, well-drained loams. WARB maintains the largest contiguous grasslands in the Connecticut River watershed (>1,200 ac). The grasslands contain over 100 species of plants but large areas are dominated by alien vegetation. WARB's grasslands provide breeding habitat to New England's largest populations of three rare species: Upland Sandpiper, Grasshopper Sparrow, and Phyllira tiger moth (*Grammia phyllira*). The sandpiper and moth are listed by Massachusetts as endangered and the sparrow is state-listed as threatened. Continentally, Upland Sandpiper is considered to be a "species of high concern" and Grasshopper Sparrow is considered "at risk" due to steep population declines (Brown et al. 2001, Rich et al. 2004). At WARB, the 1987 populations of 25 Upland Sandpipers and 55 singing male Grasshopper Sparrows increased to 150 and 182 of the birds, respectively, by 2003 (Melvin 1994). The U.S. Fish and Wildlife Service identified WARB as a Special Focus Area with "high" priority within the Silvio O. Conte National Fish and Wildlife Refuge. Mowing frequency for 523 acres of vegetation within 300 feet of runways and most taxiways is determined by the time it takes vegetation to approach an average height of 14 inches (A. Milroy, *personal comm.*). The remaining 690 ac are mowed after 1 August each year to avoid the rare bird nesting season. Prescribed fire (~50-300 acres per year) was introduced in 2002, with subsequent burns in 2004, 2006, 2010, and 2011. WARB is building toward a three- to five-year return interval for burning the grasslands, contingent upon weather, funding, and available personnel. The base has begun integrated pest management of invasive plant species.

Lakehurst section of Joint Base McGuire-Dix-Lakehurst ('Lakehurst')

The Lakehurst section of Joint Base McGuire-Dix-Lakehurst in Lakehurst, New Jersey, consists of ~ 7,400 acres and is located within the Pinelands National Reserve. The mission of the Lakehurst Environmental Department includes land management, forestry, threatened and endangered species management, and habitat improvement. Approximately 1,700 acres of the site are considered grassland habitat, 1,200-1,300 acres of which are actively managed (J. Joyce, *personal comm.*). Species of concern on the site include Upland Sandpiper (state endangered) and Grasshopper Sparrow (state threatened), both regarded as grassland obligates during the breeding season. Lakehurst supports the largest known breeding population of Upland Sandpipers in New Jersey (up to 10-12 pairs), and the second-largest known population of Grasshopper Sparrows in the state (after Atlantic City International Airport; J. Joyce, *personal comm.*). Habitat improvement measures for grassland birds have been implemented over the last 14 years and have included controlled burns, mowing, and mechanical shrub-removal methods. Burn schedules currently run on a four-year basis, and affect 145-185 acres of the site per year. Approximately 750-1,141 acres of grassland are mowed annually between late-fall and early spring.

Patuxent River Naval Air Station ('PRNAS')

Patuxent River Naval Air Station is located in St. Mary's County, Maryland, and consists of ~ 6,800 acres along the western shore of Chesapeake Bay near its confluence with the Patuxent River. Another ~ 1,000 acres of Navy land occurs at a nearby outlying field known as Webster Field Annex. The mission of the PRNAS Environmental Department includes land management, forestry, threatened and endangered species management, and habitat improvement. Several hundred acres of the site are considered grassland habitat, with most of that under some form of active management (mainly regular mowing to maintain a height of 7-14 inches; K. Rambo, *personal comm.*). Species of concern on the site include Upland Sandpiper and Buff-breasted Sandpiper (*Tryngites subruficollis*) during migration, and breeding populations of Grasshopper Sparrow, Eastern Meadowlark (*Sturnella magna*), and Northern Bobwhite (*Colinus virginianus*); the latter three are regarded as grassland obligates during the breeding season. Upland sandpiper is considered endangered in Maryland (MDNR 2007), while Buff-breasted Sandpiper is considered a "species of high concern" continentally (Brown et al. 2001). Concentrations of migrating Upland Sandpipers typically reach into the 40's and 50's during the non-breeding season and numbers of Buff-breasted Sandpipers often are in the 30's. These are some of the highest densities reported within the mid-Atlantic region (K. Rambo, *personal comm.*). Habitat improvement measures for grassland birds have been implemented over the last 5-10 years and have included establishment of native warm-season grasses, regulated mowing heights and frequency, controlled burns, and various shrub-removal methods (mechanical, manual, and chemical).

METHODS

New Jersey Audubon Society (NJAS) staff conducted all fieldwork at WARB and Lakehurst. PRNAS staff conducted all fieldwork at that site, as in-kind support. Fieldwork took place within the following time periods: 20 August - 15 November 2007 (fall, Year 1), 29 March - 15 May 2008 (spring, Year 1), 16 May - 15 July 2008 (breeding, Year 1), 19 August - 11 November 2008 (fall, Year 2), 31 March - 15 May 2009 (spring, Year 2), and 19 May - 13 July 2009 (breeding, Year 2), 17 August - 15 November 2010 (fall, Year 3), 4 April - 12 May 2011 (spring, Year 3), and 16 May - 14 July 2011 (breeding, Year 3).

Line-Distance Sampling

We conducted line-distance sampling (Buckland et al. 2001) at 44 transects. Sixteen transects were located at WARB, 16 at Lakehurst, and 12 at PRNAS (Appendix A, Figures A1-A3). Transects were located along runways, with a minimum distance to runway of 50 m, and within other grassland habitats according to availability on each site. Prior to the initiation of sampling, transect ends were marked and flagged; lengths averaged 380.2 m (SD = 115.6; WARB mean = 313.1 m, Lakehurst = 448.6 m, PRNAS = 378.3 m). Transect locations were initially chosen based on remotely-sensed maps and preliminary site visits. Transects were configured to maximize the area sampled within each grassland "patch", while remaining a minimum of 50 m from any paved surface (including runways) or forest edge. Patches were defined as grassland habitats uninterrupted by large paved areas (runways, taxiways, parking lots), structures (buildings, hangars), or forested areas. The minimum patch size sampled was 8.8 ha (mean: 34.9 ± 25.2 SD).

Sampling periods were defined as the time taken to sample all transects on a site, and generally took three (PRNAS) or four (WARB, Lakehurst) days to complete. Transects were grouped into general 'regions' within each base (four on WARB, four on Lakehurst, three on PRNAS), with one transect from each region sampled per day. Each base was surveyed approximately every two weeks, with the goal of completing 13 sample periods per site per year. All morning sampling took place between first light and approximately four hours past first light. At WARB and Lakehurst, four 'evening' transect surveys were also completed per sampling period, between 1400 and 1800 hours; these included one randomly chosen transect per 'region' of the site. Due to logistic constraints, less than three evening samples were sometimes completed at PRNAS.

During each sample, an observer walked the length of a transect recording his position and the relative position of all birds seen and deemed to be using the habitat. Universal Transverse Mercator (UTM) coordinates of observers along transects were obtained using a Garmin GPSmap60 global positioning device (Garmin International, Olathe, Kansas), with an accuracy of two to five meters. Direction and distance of observed individual birds or flocks were recorded using a compass and Bushnell® Yardage Pro 500 digital rangefinder (accuracy ± 1.5 m). Birds identified as 'fly-overs' – those not using the habitat, but simply passing through – were also georeferenced at WARB and Lakehurst, but not at PRNAS. For comparative purposes, these observations were not included in our analyses.

Vegetation Sampling and Management History Information

Vegetation was sampled within four 1 x 1 m quadrats per transect. To locate a quadrat, an observer stood at a transect endpoint and walked in each of the two cardinal directions leading into the transect survey area. The distance walked for each cardinal direction was randomly determined prior to the start of the field season and remained constant for all transects during the study. Distances were as follows: north – 24 m, east – 2 m, south – 15 m, and west – 22 m.

Within each quadrat, the horizontal percent cover of grasses, shrubs, forbs, bare ground (e.g., soil, lichens, matted litter), and 'other' were estimated in 5 % classes. Categories could sum to greater than 100 % due to overlap among cover types. At five locations within each quadrat (the center and each corner) a meter stick was used to take the following measurements: (1) vegetation height (i.e., the maximum height at which vegetation touched the stick), and (2) vegetation height-density (visual obstruction readings of a meter stick at arm's-length distance; scale-modified Robel method; Robel et al. 1970). Vegetation was sampled approximately every two weeks, typically during the third day of transect surveys in a sample period.

Management data from the three sites were also recorded. Mowing at Lakehurst took place only in mid to late winter, except in 2010, when it occurred in September and October. Records of mowing dates for each transect were obtained directly from Lakehurst natural resource staff or from direct observation. Mowing regimes on WARB and PRNAS were more intensive (see 'Study Sites'). In fall 2007, we used visual cues and vegetation measurements to best identify whether a transect had been mowed within two weeks or had been mowed within one month. To increase precision and confidence in our management assessments, NJAS initiated an information-transfer agreement with mowing crews on WARB and PRNAS in spring 2008. Crews on both sites recorded the dates and provided maps of areas on each base that received mowing or other mechanical treatments during all subsequent sampling periods. These maps helped clarify short-term management associations with the avian data recorded during transect sampling.

Behavioral Observations

Behavioral observations, in the form of scan samples (Altmann 1974), were conducted from four locations at each base that were chosen to maximize runway visibility (Appendix A, Figure A4-A6). The four points were surveyed three times per sample period: once in the morning (0600 to 1000), mid-day (1000 to 1400), and evening (1400 to 1800) hours. Morning, mid-day, and evening samples were generally performed on separate days.

During each scan survey, the observer scanned with binoculars for 15 minutes and recorded all bird activity on and around runways. Instances in which a bird or flock crossed or alighted on a runway surface were noted. Additional data recorded for each bird or flock included species, number of individuals, direction of travel, height above ground, closest distance to a runway, behavior (e.g., walk, fly, perch), distance from the observer, compass bearing from the observer, and approximate location relative to "distance remaining" markers positioned along runways (i.e., distance to end of runway).

GIS Processing

All GIS processing was executed using ArcGIS Desktop (v. 9-10, ESRI, Redlands, CA). The coordinates of each individual bird or flock centroid (i.e., estimated center of a flock) were calculated from the observer coordinates using the following formulae:

Easting = (observer easting) + (distance to bird) * sin([bearing to bird] * π/180)
Northing = (observer northing) + (distance to bird) * cos([bearing to bird] * π /180)

Prior to calculation, compass bearings were adjusted for magnetic declination based on the U.S. National Oceanic and Atmospheric Administration (NOAA) declination calculator (www.ngdc.noaa.gov/geomagmodels/Declination.jsp).

The spatial distributions of bird observations along transects were analyzed using kernel density estimation (KDE), a technique that estimates relative point density across a surface. KDE was performed in the Geospatial Modeling Environment (version 0.5.4; Beyer 2011), a stand-alone application that extends the analytical capabilities of ArcGIS. A Gaussian kernel with a standard deviation of 100 meters and a scaling factor of 10^6 was used. All KDE analyses were based on point locations of individuals or flock centroids, weighted by the number of birds per point. Fly-overs and birds observed during evening surveys were excluded to maintain equal effort among transects within seasons.

KDE analyses for the full study (i.e., Years 1-3) at WARB and Lakehurst represent all 39 sample periods completed (or 13 for those specific to Year 3). Due to time/logistical constraints, sampling effort at PRNAS was not equal among transects. Thus, density contour maps may not reflect true spatial differences in activity among transects (see Appendix C for sampling effort at PRNAS).

Flocks of 50 or more birds were excluded from the KDE analyses, and instead were plotted as individual points (annotated with flock size). This was done to avoid a skewing effect of these observations, which tended to "smooth out" much of the detail in other parts of the density surfaces.

Statistical Analyses

Strike-Risk, Conservation and Size Scoring

Prior to analysis, birds were assigned "Conservation" and "Strike-Risk" scores based on relevant conservation plan priority ratings and Hazard Indices (HI_S; Zakrajsek and Bissonette 2005). Conservation scores were calculated by referencing conservation priority scores from the Partners In Flight (PIF) Continental Plan (Rich et al. 2004), Regional PIF plans for Regions 9 (Southern New England; WARB; Dettmers and Rosenberg 2000) and 14 (Mid-Atlantic Coastal Plain; Lakehurst, PRNAS; Rosenberg et al. 2002), U.S. Shorebird Conservation Plan (Brown et al. 2001), North American Waterfowl Management Plan (NAWMP Plan Committee 2004), North American Waterbird Plan (Kushlan et al. 2002), and North American Solitary Nesting Waterbird Species Plan (Waterbird Conservation for the Americas 2006; Table 1). Referenced conservation scores were relativized to a 1-5 scale, with 1 representing lowest conservation priority and 5 representing highest conservation priority. Each species was assigned the maximum prioritization score of all relevant plans (Table 2).

Species strike-risk values were assigned based on the species groupings (e.g., swallow, blackbird-starling) defined by Zakrajsek and Bissonette (2005; E. Zakrajsek, *personal comm.*). We used their Hazard Index (HI_S), which was based on DoD strike data from 1985-1998, and was calculated for each species group as

$$HI_S = (C_S \text{ x } W_C) + (B_S \text{ x } W_B) + (A_S \text{ x } W_A)$$

where

HI_S = hazard index per species group
C_S = the number of Class-C strikes ($10,000-$200,000 damage or injury resulting in a lost workday) per species group per year
B_S = the number of Class-B strikes ($200,000-$1 million damage, permanent partial disability, or inpatient hospitalization of $\geq$ 3 personnel) per species group per year
A_S = the number of Class-B strikes ($\geq$ $1 million damage, the loss of an aircraft, the loss of human life, or permanent total disability of personnel) per species group per year
$W_{A,}$ $W_{B,}$ W_C = the weighting constants, described in Zakrajsek and Bissonette (2005), used to adjust for the increased severity of Class-A and Class-B strikes.

HI_S indices ranged from 0-127.89 (Zakrajsek and Bissonette 2005). We relativized these indices to a 1-5 score, with 1 representing lowest strike-risk, and 5 representing highest strike-risk groups (i.e., vulture; Table 2).

While in previous reports we only assigned high-risk values as defined by Zakrajsek and Bissonette (2005), in the current report (i.e., encompassing data from years 1-3), we also evaluated an alternative hazard ranking system based on the Federal Aviation

Administration (FAA) bird-strike database from 1990 – 2007 (Dolbeer and Wright 2009). The ranking in Dolbeer and Wright (2009) includes only species with 25 or more strikes in the database, and is based on a simple metric: the percent of bird-strikes for each species that resulted in visible damage to an aircraft. We decided on this approach because military bird-strike data is thought to include a large number of strikes from low altitude training flights occurring off-airfield, whereas most civil aviation bird-strikes occur on or near the airfield (Zakrajsek and Bisssonette 2005). Because our focus is on assessing the effects of on-airfield management activities, this is potentially a more appropriate risk ranking.

Species detected during line-transect surveys were also grouped into size categories, based on average mean weights reported in their respective Birds of North America accounts. Species were classified as ‘small’ (under 100 g), ‘medium’ (between 100 g and 200 g), and ‘large’ (over 200 g). Size categories were used to determine detection probability functions for each group.

Detection Probability

Detection probability functions were determined using program Distance 6.0 (release 2; Thomas et al. 2010). A set of candidate models was constructed for each of the three avian size-class groups (small, medium, large) separately by season (spring migration, breeding season, and fall migration). Initially, six candidate models were tested, representing suitable detection functions that varied by key function and series expansion (Buckland et al. 2001). The initial set of models included uniform simple polynomial, uniform cosine, half-normal cosine, hazard-rate cosine, hazard-rate simple polynomial, and half-normal hermite polynomial. For small and medium sized birds, the model with the best fit, as determined by Akaike’s Information Criterion (AIC), was rerun with several stratifications representing factors that potentially affected detection probability. Further stratification for large birds was precluded by limited sample sizes, so only the six covariate-free models were run. Covariates for small and medium birds included Season, Time of Day (morning or evening), Site (i.e., base), Mean Grass Height Category (short, under 7 inches; medium, 7-14 inches; long, greater than 14 inches), and Observer. All models included a data filter for maximum distance and truncation was set to 100 m.

Models with the best fit for small birds included a vegetation height effect (breeding season), or an observer effect (spring and fall migration; Table 3). The best-fitting models for medium birds included both a vegetation-height and an observer effect (breeding season), or an observer effect alone (spring and fall migration). Detection probabilities for large birds were obtained through model averaging as all models were competitive ($\Delta AIC \leq 2$). Data for each size group and season were adjusted based on the model results. In other words, for each sample, appropriate observer and/or grass-height category detection probabilities were used to generate density parameters (birds/ha), by species, for inclusion in subsequent analyses.

Model-based Analyses

Avian Densities

Inferences about the relationships among vegetation structure, management history and avian densities were derived from an information-theoretic approach (Burnham and Anderson 2000). In reports from previous years, we analyzed the data separately by site, and included season as a covariate. For the current report, we chose to run separate analyses by season (i.e., breeding, spring migration, fall migration), and included site and a site interaction term as covariates. This was done because bird habitat-use patterns and management regimes have been shown to differ markedly by season (Peters and Allen 2009, 2010). Also, the inclusion of site and site interaction terms in models allows detection of possible differing responses by site. We included data from all three years of the study and examined three sets of models for each season representing three spatial/temporal scales: 'between-transects', 'within-transects', and 'landscape-scale'. Specific approaches to each scaled analysis (including explanatory and response variables used) are discussed below. At each scale, linear or generalized linear models were used to assess potential effects on total bird density, high strike-risk species, and high conservation-value species. Strike-risk species were defined as those with risk scores ≥ 1.06, representing the highest 10 rated species groups listed by Zakrajsek and Bissonett (2005; Table 2). In addition, we included American kestrel in this category (though its risk score was < 1.06) due to its history as a perceived species of strike-risk concern at some of the sites (A. Milroy, *personal comm.*). For analysis at the 'between-transect' scale only, we also evaluated an alternative method of defining strike-risk species based on the civil aviation hazard ranking in Dolbeer and Wright (2009; see *Strike-Risk, Conservation and Size Scoring* above). For this method, strike-risk species were defined as those with a hazard ranking of "moderate" and above, representing 51 species that caused damage in ≥ 4% of strikes they were involved in. The resulting list (see Table 2 and Dolbeer and Wright 2009) had many species in common with the list based on Zakrajsek and Bissonette (2005; e.g., Red-tailed Hawk, European Starling), but also lacked some species (e.g., swallows, Horned Lark) and contained some additional species (e.g., Mourning Dove, Upland Sandpiper; Table 2). Conservation-value species were defined as species with a conservation concern score ≥ 3, which represented the 26 highest priority species in the region (Table 2). Prior to all analyses, a correlation matrix was constructed for all independent parameters, and highly correlated parameters ($r \geq 0.50$) were not included in any model to avoid problems associated with collinearity (Zar 1999).

Between-transects

At the between-transect scale, we examined relationships among transects with differing vegetation and management histories. In other words, were birds more or less likely to use transects that were consistently mowed, or had different vegetation characteristics, as compared to other transects? We used a seasonal-averaging approach to density estimation that addressed problems associated with non-independence among repeated samples from individual transects, and provided relatively precise estimates of density at individual transects (i.e., compared to estimates from individual samples; Bibby et al. 1998).

Prior to analysis, data were averaged for each transect – by Season (fall migration, spring migration, breeding), Time of Day (morning or evening), and Study Year (one, two, or three) – so that the final dataset represented the mean values for bird density, management activity and vegetation parameters for one period (e.g., breeding/morning/year 2). The general management regime for each transect was categorized as intensively mowed or not intensively mowed. Intensively mowed transects were defined as those that were mowed regularly (approximately once per month) throughout the growing season to maintain a grass height of 7-14 inches or less. Other transects were generally mowed only once per year between fall and early spring. Avian density values for each transect were assumed to be independent among years.

The set of models we examined consisted of General Linear Models (function: lm, R Development Core Team 2011). Percent horizontal cover of bare ground negatively correlated with other vegetation parameters (e.g., percent grass cover, vegetation height-density) and was thus removed from all models. Vegetation height-density was also positively correlated with mean vegetation height and was removed, as was 'forb cover' which covaried with several other ground cover estimates. Final candidate models included a base model, vegetation structure model, and management model. The base model included the class variables Study Year (one, two, or three), Site (WARB, Lakehurst, PRNAS), and Time of Day (morning or evening). Parameters included in the vegetation structure model included those in the base model as well as percent shrub cover, percent grass cover, linear and quadratic components of mean vegetation height, and a vegetation height x site interaction term. The interaction term was included to account for the likelihood that bird density relationships varied among sites (Peters and Allen 2009, 2010). A second version of this model was run without the interaction term. The management model included all parameters in the base model, the class variable Mow (1 = intensively mowed, 0 = not intensively mowed). An interaction term was not included in this model due to singularities encountered in model fitting, likely due to the lack of intensively mowed transects at Lakehurst. Vegetation parameters representing percent cover were arcsine transformed, and avian density estimates were log transformed, prior to analysis to increase normality in data distribution. Findings presented in graphs and in the text of this report represent raw, untransformed values of these variables. Residuals from all models were examined graphically (e.g., histograms, plots vs. fitted values) to confirm that model assumptions were met (e.g., approximate normal distribution, homogeneity of variance).

Within-transects

To determine if birds were tracking management or vegetation characteristics within transects, we examined a set of Generalized Linear Mixed Models using a Poisson link function (R function glmer, fitted by the Laplace approximation; Bolker et al. 2009, Bates et al. 2011). The mixed-model method allowed for repeated observations nested within transects, so that each transect had an individual intercept that was treated as a random effect. In this way, we were able to ask the question, "Regardless of overall use of a transect, were birds more likely to be observed under specific vegetation or management conditions on that transect?" In other words, were birds tracking conditions on a short (i.e., within seasons) time scale? For these analyses, we focused only on those parameters that were assumed to vary substantially within seasons (e.g., vegetation height, recent mow history).

Models used to explore within-transect patterns included a base model, vegetation model, and management model. The base model included the class variables Time of Day (morning or evening), Site (WARB, Lakehurst, PRNAS), and Study Year (one, two, or three). The vegetation model included all class variables from the base model, vegetation height, and a vegetation height x site interaction. A second version of this model was run without an interaction term. The management model included class variables from the base model, a Mow parameter (1 = mowed within one month, 0 = not mowed within one month). An interaction term was not included in this model for reasons described above (in '*Between transects*'). Also, for each model set we tested a global model (i.e., a model including all parameters) for overdispersion, or excessive variation, using a chi-square test of residuals (Bolker et al. 2009). When overdispersion was detected ($P < 0.05$) we accounted for it by including an additional random effect term representing individual-level variation (i.e., Poisson-lognormal models; Elston et al. 2001, Bates et al. 2011).

Individual Species and Species Groups

We related the abundance of individual strike-risk and conservation-concern species/groups to mow history and vegetation characteristics using either linear or logistic models, depending on species abundance. Data were analyzed at the between-transect scale only due to sample-size limitations, and separate analyses were performed for each season. Species groups analyzed included blackbird-starling, Horned Lark, swallow, and Grasshopper Sparrow, which were chosen due to their relatively high abundance at all sites. One species (Grasshopper Sparrow) was sufficiently abundant (i.e., few zero-density observations) to analyze using linear models (i.e., GLM) with density (log transformed) as a response variable. Other species/groups were analyzed using logistic regression on presence/absence data. Candidate models were similar to those used in the 'between-transects' analysis above. Models for Grasshopper Sparrow were run for breeding season data only, as this species was scarce in other seasons.

Landscape

For the landscape-scale analyses, we created a reduced set of transects that were spatially separated enough to be considered independent at the landscape-scale. First, a 500 m buffer was generated around each transect (ArcGIS). If buffers from two or more transects overlapped, transects were removed in succession until no overlap existed. Removal was based on the following criteria: 1) if only two overlapped, one of the two was selected at random for removal; 2) if more than two overlapped, buffers that overlapped the most other buffers were given priority for elimination. This process maximized the number of non-overlapping buffers, and resulted in a dataset consisting of

16 transects (five to six at each site, Appendix D). For each of these 16 buffer areas, we created digital land cover maps in ArcGIS using land cover files provided by each base. These files were first checked for accuracy and supplemented or corrected as needed based on recent aerial photos, field visits, and communication with natural resource managers. Eight mutually exclusive land cover types were mapped including grasslands, croplands (PRNAS only; row crops including barley, soybeans, and wheat), forests, buildings, paved areas, disturbed areas, open water, and wetlands. The 'disturbed areas' category consisted of golf courses, ball fields, residential developments, and other human-altered areas. 'Wetlands' consisted of wetland areas not included in other land cover categories (i.e., those not occurring in forests or managed grasslands). An additional category, 'all wetlands', represented all wetlands regardless of vegetation type, and included forested, shrub-dominated, and emergent wetlands, plus wetlands occurring within managed grasslands. The areas and percent cover of land covers within each transect buffer were calculated in ArcGIS.

Three landscape configuration metrics were also calculated based on the land cover data. The first, an index of landscape diversity was calculated using Simpson's Index (Simpson 1949) based on all mutually exclusive cover types (i.e., those listed above, excluding "all wetlands"). Two other metrics were calculated using the program Fragstats (v. 3.3; McGarigal and Marks 1995). Land cover maps for each transect buffer were converted to raster files, coded as either grassland or non-grassland, and analyzed in Fragstats to calculate 1) edge density – the amount of grassland/non-grassland boundary (not-including buffer boundaries) in $m \cdot ha^{-1}$, and 2) core area – the percent cover of "core" grasslands, defined as those occurring farther than 50 m from a non-grassland edge (i.e., edges of runways, taxiways, forest).

The final list of landscape parameters retained for analysis (i.e., after correlated parameters were removed or combined) included percent of surrounding landscape represented by grassland (i.e., grassland and cropland), percent covered by developed land (i.e., pavement, buildings, and disturbed areas), percent covered by water/wetlands (i.e., 'all wetlands' and water), Simpson's Index (SI), edge density (ED), and core area. Three a priori GLM models were constructed: a base model, a landscape composition model, and a landscape configuration model. The base model included the class variables Site (WARB, Lakehurst, or PRNAS), Study Year (one, two, or three), Season (spring, breeding, or fall), and Time of Day (morning or evening). The landscape composition model included the base model variables, percent grassland, percent developed, and percent water/wetlands. The landscape configuration model included the base model variables, SI, ED, and core area.

Model Selection

For all model sets, Akaike's Information Criterion adjusted for small sample size (AIC_c) was used to determine the best approximating model of habitat use (Burnham and Anderson 2000). Models that fell within 2 AIC_c units of the lowest-ranked model were considered equally plausible. We present parameter estimates and 95% confidence intervals from all strong candidate models (within 2 ΔAIC_c), and provide model-averaged estimates where appropriate (Burnham and Anderson 2000). The alpha-level for all significance tests was set at 0.05. We also present R^2 (GLM) or Nagelkerke's pseudo R^2 (for logistic models) as a measure of model fit. Nagelkerke's pseudo R^2 is analogous to conventional R^2 in that it ranges from 0 to 1, with higher values indicating better model fit (Nagelkerke 1991). For Generalized Linear Mixed Models (i.e., 'within transect' analyses), we used Wald *t*-tests to evaluate the significance of individual explanatory variables (Bolker et al. 2009). When significant site x vegetation height interactions were detected, we interpreted them using post hoc simple main effect tests (i.e., separate tests by site; Quinn and Keough 2002). To reduce problems associated with multiple significance tests, a sequential Bonferonni correction was applied when interpreting *P*-values from tests (Holm 1979, Quinn and Keough 2002). In this case, six tests were performed for each model set (one for each linear and quadratic parameter at each of the three sites), so the alpha level was set at $\frac{0.05}{6}$ for the lowest *P*-value observed, $\frac{0.05}{5}$ for the second lowest, $\frac{0.05}{4}$ for the third lowest, etc. (Holm 1979).

Behavioral Observations

We generated summary statistics for data gathered during behavioral observation periods by site, time of day, and species group. We also used a model-based approach to examine the relationships between potentially hazardous avian activity and several spatial, temporal, and landscape variables. Landscape data were obtained by mapping land cover types within 300 m of each behavioral observation point and calculating areas and percent cover in ArcGIS. Cover types included all grasslands, regularly mowed grasslands, forests, paved areas, water, and wetlands. Mapping was based on land cover GIS files obtained from each base, and was verified and supplemented using recent digital aerial photography.

The number of times birds were observed flying over or alighting on a runway surface (hereafter called 'runway crossings') served as the dependent variable in all analyses. We felt this to be the best measure of potentially hazardous activity, and least likely to be influenced by observer bias. Two sets of general linear models were run, with dependent variables as: 1) the number of runway crossings of all species, or 2) the number of runway crossings of only high strike-risk species (risk score $\geq$ 1.06, plus American kestrel, Table 2). Dependent variables were log transformed prior to analysis to improve normality. Histograms of residuals from all models were examined to verify assumptions of normality and homogeneity of variance. Both model sets included a base model consisting of the following independent variables: Site (WARB, Lakehurst, or PRNAS), Study Year (one, two, or three), Season (spring, breeding, or fall), and Time of Day (morning, mid-day, or evening). Six other models included the base model, plus each of the abovementioned percent land cover variables. A final model included variables in the base model plus a measure of landscape diversity, calculated using Simpson's diversity index on percent cover data (Simpson 1949). As above, model performance was evaluated using AIC_c and R^2, and significance was assumed at $P \leq$ 0.05.

FINDINGS

In the third and final year of the study, we conducted 715 transect surveys, bringing the total combined for all years to 2049 (WARB, n = 778; Lakehurst, n = 773; PRNAS, n = 498). Of these, 32 were missing accompanying vegetation data and were therefore excluded from all models. For 76 additional surveys, we were unable to determine if mowing had occurred in the previous month, and these were excluded from the within-transect analyses only (as between-transect analyses did not include this variable). Final sample sizes with complete data were: WARB, n = 753, Lakehurst, n = 765, and PRNAS, n = 423.

Avian Densities - Between Transects

Models depicting the relationship between average seasonal avian densities and average transect characteristics (breeding, n = 227; spring, n = 209; fall, n = 237) revealed varied results. Model performance rankings and parameter associations differed among functional species groups and seasons. For instance, the vegetation model (with site interaction) performed best for predicting total bird densities in breeding season and spring, whereas the base model performed best in fall (Tables 4-6). Strike-risk species density (based on Zakrajsek and Bissonette 2005) was similarly best predicted by the vegetation model (with interaction) in breeding and spring, but by the vegetation model (without interaction; $\Delta AIC_c = 0$) or the management model ($\Delta AIC_c = 1.6$) in fall (Tables 4-6). For strike-risk species densities based on Dolbeer and Wright (2009), the vegetation models also performed best in breeding (with and without the interaction effect) and spring (with interaction), but not in fall when the management model performed best (Tables 4-6). The vegetation model (without interaction) was the best-performing model for conservation-value densities in breeding and spring, while in fall the base model out-performed all other candidate models (Tables 4-6). Model fit among competitive models was generally weaker in fall (R^2 = 0.10-0.24), with the lowest R^2 (0.10) occurring for strike-risk birds (based on Dolbeer and Wright 2009; Table 6). Model fits were stronger in breeding (R^2 = 0.25-0.49) and spring (R^2 = 0.26-0.48), with the strongest fit found for total bird densities in breeding season (0.49, Table 4).

Mean densities for each functional species group (total, strike-risk, and conservation-value) are shown by site and season in Figure 1. According to the top-ranked models depicted in Table 7, total, strike-risk, and conservation-value densities differed significantly by site for all seasons (F-tests, $P < 0.05$; Table 7). Densities were significantly higher during morning versus evening surveys in all functional groups and seasons, except for strike-risk species in spring and conservation-value species in fall, which showed no difference (Table 7). Significant year effects were also observed across all three functional groups (Table 7), though these did not show a consistent pattern among seasons (i.e., one year wasn't consistently higher or lower).

Relationships between avian densities and vegetation structure also varied by functional group, season, and site (Table 7, Figures 2-8). For total bird densities, vegetation structure models performed well only in breeding season and spring (Tables 4-6). Model results indicated a significant positive association with shrub cover in breeding season, and a negative relationship with vegetation height in spring (Table 7, Figures 2 and 3). Significant site x vegetation height interaction effects were also apparent during spring and breeding season (Table 7). Post hoc testing revealed that the negative association with vegetation height in spring was significant at PRNAS (linear component only: $F = 15.4$, df = 1 and 47, $P < 0.001$), but not at WARB or LNAES ($P \geq 0.085$; Figure 2). The interaction effect during breeding season was driven by a positive association between vegetation height and total density at WARB ($F = 11.5$, df = 1 and 71, $P = 0.001$) that was not evident at PRNAS or Lakehurst ($P \geq 0.133$; Figure 2).

Strike-risk species densities based on Zakrajsek and Bissonette (2005; 'ZB') exhibited significant relationships with vegetation height, as well as significant site x vegetation height interaction effects, during breeding season and spring, but not during fall (Table 7). Post hoc testing revealed significant effects of vegetation height at PRNAS during breeding season (quadratic component only: $F = 16.1$, df = 1 and 56, $P < 0.001$) and spring (linear component only: $F = 26.8$, df = 1 and 47, $P < 0.001$), but no significant effects at Lakehurst or WARB ($P \geq 0.107$). At PRNAS, predicted associations between strike-risk density and vegetation height were either u-shaped (breeding) or negative (spring; Figure 4). Additional associations between strike-risk (ZB) density and vegetative cover were noted in spring (positive association with grass cover) and fall (negative association with shrub cover; Table 7, Figure 5). In fall, the 'Management' model performed as well as the vegetation structure model ($\Delta AIC_c = 1.6$), and predicted significantly higher strike-risk densities on frequently mowed transects (Table 7). Large strike-risk (ZB) density values (> 3 birds/ha) were observed more frequently during spring and fall (n = 8 and 9, respectively), but also occurred during breeding season (n = 4). All but two of these observations were at transects with an average vegetation height < 11 inches (the others occurred at 15.1 and 16.7 inches, respectively). Of the 21 samples with greater than 3 birds/ha, 13 occurred at PRNAS, 7 occurred at WARB, and one occurred at Lakehurst.

Strike-risk bird densities based on Dolbeer and Wright (2009; 'DW') exhibited somewhat different relationships. Significant relationships with vegetation height were found during breeding season and spring migration, with a significant site x vegetation height interaction effect present during spring. Post hoc simple main effects testing for spring models revealed significant effects of vegetation height at PRNAS (linear component only: $F = 27.7$, df = 1 and 47, $P < 0.001$), but not at Lakehurst ($P \geq 0.13$) or WARB ($P \geq 0.017$; not significant after Bonferroni correction). The predicted relationship of strike-risk (DW) species densities and vegetation height in breeding season was a decreasing curve at all sites (linear, $P < 0.001$; quadratic, $P = 0.008$; Figure 6). A similar relationship was also predicted at PRNAS during spring (simple main effects test: linear, $P < 0.001$; quadratic, $P = 0.602$; Figure 6). In fall, the 'Management' model performed best, and (similar to the ZB-based analysis) predicted significantly higher strike-risk densities on frequently mowed transects (Table 7).

Conservation-value bird density was significantly related to vegetation height during breeding season, but not in spring or fall (Table 7). Predicted density exhibited a positive relationship (WARB and Lakehurst) or a parabolic relationship (i.e., increasing and then decreasing; PRNAS) with vegetation height (Figure 7). No site x vegetation height interaction terms were present in the best-performing conservation-value density models (Table 7). Significant associations between conservation-value bird density and percent vegetative cover were noted during spring migration, including a positive association with shrub cover and a negative association with grass cover (Table 7, Figure 8).

Maps depicting the distribution and relative densities of total birds, strike-risk (ZB) species, and conservation-value species for the third year of the study and for all years combined are in Appendix B, Figures B1-B54. Several clusters of strike-risk species were evident, particularly at WARB (e.g., transects 1 & 5; Figures B50-B54) and PRNAS (e.g., transects 1 & 11; Figures B44-B46). Clusters of conservation-value species (during breeding season) were also apparent at each site: e.g., WARB: transects 13 & 14 (Figure B36); Lakehurst: transects 13 & 14 (Figure B24); and PRNAS: transects 5 & 7 (Figure B30).

Avian Densities - Within Transects

Models depicting relationships among avian densities and conditions in each transect over time (i.e., the within-transect scale) revealed similar patterns, in general, to the between-transect analyses. Vegetation structure models (with site x vegetation height interaction) best predicted total and strike-risk (ZB) densities during breeding and spring; in fall, vegetation models without an interaction terms performed equally well or better (Tables 8-10). (No within-transect analyses were performed for strike-risk densities based on Dolbeer and Wright [2009]). Densities of conservation-value species were best predicted by the vegetation model without an interaction term in breeding and fall, while vegetation models both with and without interaction terms performed similarly in spring (Tables 8-10).

For total bird density, vegetation height effects in top-ranked models (both linear and quadratic) were significant during spring and fall, but not breeding (Table 11). A significant site x vegetation height interaction was detected in spring (Table 12), and post hoc testing revealed a significant vegetation height effect at PRNAS ($|t| \geq 3.3$, $P \leq 0.001$), but not at WARB or Lakehurst ($|t| \leq 2.0$, $P \geq 0.045$, not significant after Bonferroni correction; Figure 9).

Top-ranked models for strike-risk species had significant vegetation height effects during breeding and spring, but not fall (Table 11). Significant site x vegetation height interaction effects were present during all three seasons. Post hoc testing revealed a significant vegetation height effect during breeding season at PRNAS ($|t| \geq 3.1$, $P \leq 0.003$; Figure 10). During spring, a significant negative relationship with vegetation height was found at Lakehurst ($|t| \geq 2.4$, $P \leq 0.017$), while a u-shaped relationship was apparent at PRNAS ($|t| \geq 3.5$, $P < 0.001$; Figure 10). During fall, none of the sites showed significant vegetation height effects ($|t| \leq 2.6$, $P \geq 0.011$; not significant after Bonferroni correction; Figure 10).

Conservation-value species density was significantly related to vegetation height during breeding and fall, but not in spring (Table 11). Predicted densities during breeding and fall showed positive or parabolic (n-shaped) relationships with vegetation height (Figure 11). A significant site x vegetation height interaction was detected in spring. However, post hoc testing revealed no significant vegetation height effects at any of the three sites ($|t| \leq 1.0$, $P \geq 0.313$; Figure 11).

Similar to the between-transect analyses, predicted densities for all three functional groups were lower during evening transects in most cases (Table 11). Differences among sites and years were evident, but these effects were not consistent across all seasons (Table 11).

Individual Species and Species Groups

Model rankings and parameter estimates for individual species and species groups can be found in Tables 12-16. Management and vegetation models predicting blackbird-starling presence did not out-perform the base model (Tables 12). Model-averaged parameter estimates also revealed no significant effects of vegetation height or mowing on blackbird/starling occurrence, and no consistent differences were evident by site or by year among the three seasons. Predicted probability of occurrence was generally lower during evening surveys, but this effect was only significant during breeding season (Table 13).

For swallows, no models out-performed the base model in spring and summer (Table 12), while in fall the vegetation model (with no site interaction) was top-ranked, followed closely by the management model ($\Delta AIC_c = 0.2$). In fall, swallows were more likely to occur on transects that had more shrub cover and that were infrequently mowed (Table 14, Figure 12). A positive association with shrub cover was also noted in breeding season (Table 14). All top-ranked models predicted a significantly lower probability of occurrence in evening versus morning surveys. Direction and significance of other 'base model' parameters (including Site and Study Year) varied by season and are presented in Table 14.

Horned lark occurrence was best predicted by the vegetation models in summer (without a site interaction) and in fall (both without [$\Delta AIC_c = 0$] and with [$\Delta AIC_c = 0.7$] a site interaction). In spring, the management model performed best (Table 12). Parameter estimates from top-ranked models indicated a higher likelihood of occurrence in areas of shorter vegetation height (breeding and fall), and in areas that are frequently mowed (spring; Table 15, Figure 13). They were less likely to be observed during evening versus morning surveys in all seasons, while no consistent year and site effects among seasons were noted (Table 15).

Grasshopper Sparrow density in breeding season was best explained by the vegetation model with a site x vegetation height interaction term (Table 12). This model predicted greater Grasshopper Sparrow densities at transects with taller vegetation and more shrubs, although a significant vegetation height x site interaction (and graphical examination of the model by site) indicated that the vegetation height effect was nonexistent at PRNAS (Table 16, Figure 14). Predicted Grasshopper Sparrow density was lower during evening surveys, but did not differ by site or year (Table 17).

Maps of individual species and species groups from the third year of the study are shown in Appendix B, Figures B55-B91; maps from previous years are presented elsewhere (Peters and Allen 2009, 2010). Several focal species and species groups exhibited clustered spatial distributions within each site (Figures B58-B60 and B65-B88). Observations of blackbirds and starlings occurred mainly near transects 1, 10, and 16 on WARB (Figures B70-B72), near transect 3 at Lakehurst (Figures B65-B66), and near transects 1, 10, and 11 at PRNAS (Figures B67-B69). Areas of high Horned Lark densities included transects 5 and 7 on WARB (Figures B79-B81), transect 16 on Lakehurst (Figures B73-75), and transects 1 and 2 on PRNAS (Figures B76-B78). Swallows showed a fairly widespread and/or random distribution at the three sites (Figures B82-B88). Grasshopper Sparrows were abundant near transects 13-14 on WARB, were fairly uniform throughout Lakehurst, and were most abundant near transects 5 and 7 on PRNAS (Figures B58-B60).

Avian Densities - Landscape

Of the three landscape-scale models examined, the Land Cover model ranked highest for predicting total avian density and strike-risk bird density, whereas the Landscape Configuration model performed best for predicting conservation-value bird density (Table 17). According to these models, total and strike-risk bird densities were greatest in areas with increased development within 500 m (i.e., pavement, buildings, lawns; Table 18). It appears that these findings were primarily driven by patterns observed at PRNAS and WARB, as Lakehurst study sites were generally located in less-developed areas (Figure 15A-B). Conservation-value bird densities were negatively related to the percent of grasslands considered to be "core area" (i.e., > 50 m from a non-grassland edge; Table 18, Figure 15C). Note that sample sizes of transects for landscape analyses were smaller (n = 5-6 per site) due to the necessity of using a subset of spatially separated (and therefore independent) transects.

Behavioral Observations

The average number of runway crossings for all species was 12.0 ± 2.7 (SE) per 15-minute survey at WARB (n = 468; median = 3), 7.7 ± 0.5 at Lakehurst (n = 467; median = 5), and 7.9 ± 1.0 at PRNAS (n = 441; median = 2). The average crossing rate for strike-risk species was 7.7 ± 2.5 at WARB (median = 1), 4.8 ± 0.4 at Lakehurst (median = 3), and 5.0 ± 0.9 at PRNAS (median = 0). At WARB, the most frequent runway-crossing strike-risk species groups were Swallows during breeding and spring (5.7 and 0.6, respectively) and Blackbird-Starlings in fall (7.2; Table 19). At Lakehurst, the most frequent crossers were Vultures in spring and breeding season (2.0 and 1.7, respectively) and Swallows in fall (1.4). At PRNAS, Gulls crossed most often in spring (2.1), while Blackbird-Starlings crossed most often in breeding and fall (1.6 and 4.6, respectively).

Crossing rates of all strike-risk species groups by season and site (along with mean flock size and height of crossing) are presented in Table 19. Frequent runway crossers (≥ 1/survey) that were not members of strike-risk groups included Crows at WARB and PRNAS in fall (4.6 and 2.3, respectively), and Thrushes (mainly American Robin) at Lakehurst in fall (1.2).

Models evaluating the effects of landscape composition, site, season, and time of day indicated that the amount of pavement within 300 m was the strongest landscape-scale predictor of both total and strike-risk runway crossings (Table 20). Crossings of both species groups were positively related to percent pavement cover ($P < 0.001$), though models for both groups had relatively low R^2 (0.11; Tables 20 and 21). The models also indicated significant differences by Study Year (Year 3 highest), Site (Lakehurst highest), and Time of Day (morning highest), but no significant differences by Season. Mean crossing rates by Site and Time of Day are illustrated in Figure 16. While WARB had the highest overall mean crossing rates (as seen in Figure 16 and in the means presented above), this is partly due to the influence of infrequent large crossing events (e.g., 1100 European Starlings in one survey during fall 2007). However, the models presented here are based on log-transformed data, which give less weight to extreme observations and provide estimates closer to the median, therefore predicting higher crossing rates at Lakehurst. Median crossing rates were also highest at Lakehurst and lowest at PRNAS, and are shown in Figure 16 (horizontal lines).

DISCUSSION

General Findings

By the completion of the third and final year of this study, we have amassed a substantial dataset of information concerning bird use patterns on the three military airfields studied. Data collected on bird densities (transect surveys), vegetation structure, management practices, and potentially hazardous bird activity at each site have provided useful insights into the effectiveness of existing grassland management regimes on these airfields, and could be of use to evaluate the consequences of any future changes to these regimes. Our data and methods may also be applicable to other airfields, regionally or internationally.

The final dataset was analyzed separately for each season, which contrasts with previous years in which data were combined or analyzed separately by site (Peters and Allen 2009, 2010). We feel the substantial differences among seasons in bird behavior (e.g., flocking, territoriality), vegetation structure (e.g., height), and management regimes (e.g., mow frequency) justified this approach. At the same time, the use of Site and Site Interaction terms in our models (with adequate sample sizes from three years of data) allowed us to effectively evaluate site-based differences and the potential for differing responses among sites. The larger dataset also increased our ability to examine the data at multiple scales to determine if birds; (1) exhibited preferences for transects with specific characteristics and management histories, (2) tracked conditions within transects over time, and 3) responded to meso-scale landscape characteristics.

When data were analyzed at the 'between-transects' scale (i.e., pooled within seasons), a significant relationship between strike-risk species (defined based on Zakrajsek and Bissonette 2005; 'ZB') and vegetation height was apparent at PRNAS during breeding season and spring migration. Densities were predicted to decrease with increasing vegetation height up to ~ 20 inches, and then (in breeding season only) to increase again in exceptionally tall vegetation (> 20 in.; Figure 4). No significant relationships were detected at WARB or Lakehurst. When we defined strike-risk species based on the ranking in Dolbeer and Wright (2009; i.e., based on the FAA database of civil aviation bird-strikes), model results were more broadly significant. For example, in breeding season, a significant negative relationship between strike-risk bird density and vegetation height was present across all sites (Figure 6). A similar relationship was also present during spring at PRNAS, but not at the other sites.

The u-shaped effect of vegetation height on strike-risk (ZB) bird density observed at PRNAS during the breeding season was largely driven by the three transects (transects 9, 10, and 12) that consistently had average heights of > 20 inches. These three transects were also spatially separated from the immediate airfield area and located in smaller grassland patches (Figure A2); thus, they may have been confounded by factors not directly related to vegetation height, such as patch size, patch shape, landscape context, or disturbance levels. Because very few transects sampled on WARB or Lakehurst had mean vegetation heights > 20 in, we cannot assess whether avian densities would have increased in taller vegetation at these sites. In order to adequately address these and other uncertainties encountered in this study, an increased sample size of sites and/or the adoption of an experimental approach would be useful. Finally, it is notable that transects with the highest observed densities of strike-risk (ZB) birds were almost always characterized by shorter vegetation, and this was true across sites and seasons. For example, nearly all (19 of 21) observations of average strike-risk densities > 3 birds/ha were at transects with an average vegetation height of < 11 inches. Such high densities also seemed more likely to occur during migration periods as most were observed during spring (n = 8) or fall (n = 9). Other studies have similarly found peaks in hazardous bird abundance or bird-aircraft strikes during migratory periods (Jerome 1976, Neubauer 1990, Servoss et al. 2000).

The discrepancies between our two methods of analyzing strike-risk species (i.e., based on military or civil aviation bird-strike data) highlight the importance of how "strike-risk" or "hazardous" species are defined. Zakrajsek and Bissonette (2005) point out that the military (DoD) bird-strike database likely contains a higher proportion of off-airfield strikes than does the FAA database due to frequent low-altitude military training flights and patrols. Therefore, a ranking based on the FAA database (e.g., Dolbeer and Wright 2009) may be more appropriate to investigations that relate to on-airfield habitat management. Ultimately, however, as bird-strike databases grow, a more localized system of ranking strike risk (e.g., a region- or even airport-specific approach) may be preferable to either of these methods. This would help address specific local concerns and/or locally problematic species that may be missed by national or global ranking systems.

Conservation-value species demonstrated a different response in relation to vegetation height than did strike-risk species. At Lakehurst and WARB during the breeding season, they were predicted to occur at higher densities in taller vegetation (Figure 7), while densities at PRNAS showed a curvilinear trend, increasing until ~ 20-25 inches, before decreasing. It is possible that confounding effects discussed for strike-risk species at PRNAS in tall vegetation (noted above) were also present for conservation-value species (i.e., landscape differences unrelated to vegetation height). Contrary to these findings, a study in Oklahoma found that Grasshopper Sparrows (an abundant conservation-value species at our sites) were less abundant in patch-managed areas with taller vegetation (mean ~ 10 in) as compared to traditionally managed areas with shorter vegetation (mean ~ 4.5 in; Fuhlendorf et al. 2006, Coppedge et al. 2008). In contrast, we found Grasshopper Sparrows to increase in abundance with increasing vegetation height at Lakehurst and WARB (Figure 14). While this could have been related to the avoidance of mowed areas on WARB, other processes must have been driving this apparent preference at Lakehurst as no mowing took place there during the breeding season.

Results for within-transect analyses (i.e., densities measured on individual transect surveys within each transect) were somewhat similar to those of between-transect analyses. For example, predicted strike-risk species densities at PRNAS in breeding season and spring followed a similar decreasing relationship with increasing vegetation height up to ~ 20-25 inches (Figures 4 and 10). An additional (negative) relationship between strike-risk densities and vegetation height was identified at Lakehurst in spring (Figure 10). Within-transect analyses for conservation-value birds in breeding season revealed very similar patterns to the between-transect analyses (i.e., increasing or parabolic relationships; Figures 7 and 11). Additional relationships between conservation-value densities and vegetation height (increasing or parabolic trends) were identified by within-transect analyses during fall at all three sites (Figure 11).

Other habitat characteristics that appeared to drive selection among transects at the between-transect scale included shrub cover and grass cover (Figures 3, 5, and 8), though these effects were not consistently observed across all seasons. Total density and conservation-value bird density were predicted to be higher in areas with more shrub cover in spring, while strike-risk bird densities were predicted to be lower in areas with more shrub cover in fall. These results were somewhat unexpected as the prevention of shrub encroachment into grasslands is a management strategy often used to favor conservation-value species and to discourage strike-risk species (USAF 2004a, Zuckerberg and Vickery 2006). Other regional studies have not revealed clear relationships between breeding grassland bird densities and shrub cover (Norment et al. 1999, Runge et al. 2004), and have found that grassland obligate species richness may sometimes decrease with shrub cover during the breeding season (Norment et al. 1999). Alternatively it has been shown that some species, such as Grasshopper Sparrows, can breed in areas with moderate shrub cover in the eastern U.S., and even prefer shrubbier habitat in western states including Arizona and Montana (Vickery 1996). Our analysis of Grasshopper Sparrow densities during breeding season suggested that they may similarly prefer to breed in areas with more shrub cover at our sites (Table 16, Figure

14). The absolute (rather than relative) level of shrub-encroachment at a given site likely plays an important role in habitat selection, though this information is often lacking from published studies (e.g., Norment et al. 1999). For example, there may be thresholds of shrub cover below which this cover type is preferred by grassland birds, and above which it is avoided. Average shrub cover levels at our transects in breeding season were relatively low, ranging from 5% at WARB to 14% at PRNAS. Besides shrub cover, other factors including food availability, other vegetation composition and structure, and the availability of alternative habitat also likely play a role in habitat selection.

The negative association we found between conservation-value species and grass cover merits further examination as well. Some studies suggest that certain grassland birds prefer increased grass cover. Bobolink, for instance, have been shown to prefer areas with greater grass cover in northern tallgrass prairie habitats (Winter et al. 2005). However, there may be regional differences in these relationships. Grasshopper Sparrow, for example, appears to prefer lusher vegetation in prairie habitats, but sparser vegetation in the east (Vickery 1996). It is possible that areas with greater grass cover on our study sites did not promote use by grassland birds of conservation concern because they did not provide enough bare ground for movement, visibility, dusting and foraging. We did in fact find a strong negative correlation between grass cover and bare ground cover in our a priori Pearson tests, which prompted us to remove the bare ground parameter from further analyses. This relationship is in agreement with other regional studies which suggest that, at least for many grassland obligates, relatively sparse vegetation characterizes preferred habitat (Bollinger 1995, Vickery and Dunwiddie 1997, Norment et al. 1999).

Similar to our preliminary findings (Peters and Allen 2009, 2010), management models (i.e., those incorporating mowing history) at the between-transect scale did not perform well overall, indicating that mowing history alone likely does not effectively predict habitat use by the three avian functional groups. One exception was strike-risk bird density in fall, for which the Management model performed similarly to the Vegetation model ($\Delta AIC_c = 1.6$), and predicted significantly higher strike-risk densities on frequently mowed transects (Table 7). For certain individual species or species groups, management models also performed well (e.g., Horned Larks in spring, swallows in fall; Figures 12B and 13B). We were unable to find data from comparable regional studies examining the effects of management at a fine temporal scale. There is, however, some evidence to suggest that mowing affects avian use of habitat on an annual scale. For instance, in a previous study we found increased breeding Grasshopper Sparrow and Eastern Meadowlark presence one year and two years post-mow, respectively, on Lakehurst (1999-2006; Peters and Mizrahi 2007). Runge et al. (2004) found that on cool season grass fields, mowing increased breeding grassland bird density the following year but that the increase was lost by the second year post-mow.

Patterns of use among transects generally paralleled those reported in our preliminary reports (Peters and Allen 2009, 2010) despite a slightly different analytical approach (i.e., analyzing separately by season). Fit for top-ranked between-transect models in Year 3 (R^2 = 0.14-0.49; average = 0.32) was slightly lower than in Year 2 (0.19-0.70;

average = 0.38), but still considerably better than models in Year 1 (0.08-0.22). Thus, analyzing the data separately by season (rather than by site as in Year 2) did not appear to impair the predictive power of our models. Site differences were captured through the inclusion of 'Site' effect and interaction terms in the models. For example, significant relationships between strike-risk bird density (as defined based on Zakrajsek and Bissonette 2005) and vegetation height were found at PRNAS, but not at WARB or Lakehurst (Figure 4). Runge et al. (2004) similarly found that their models for predicting grassland bird abundance at northeastern National Wildlife Refuges, which incorporated up to 12 vegetation parameters, only explained 11.5% of the variation in their data. In these models, the parameter "Refuge" accounted for over 86% of the variation, indicating that geographic location and landscape context can be more important than local characteristics in determining breeding grassland bird densities. We suggest that future efforts to examine relationships between management and avian airfield use either treat geographically remote sites independently, or include site and site interaction terms in models, provided that sample sizes are adequate. While some patterns of use may be robust across sites, ultimately management research and decisions need to be made on a site-by-site basis, as discussed below.

We also feel that taking a within-transect approach was an important step in understanding how habitat selection processes take place on airfields. By using a mixed model methodology, we were able to examine avian habitat use on a small time scale to determine if birds were tracking mowing activities and responding accordingly. Potential problems with this approach include smaller sample sizes (i.e., limited by the number of transects) and the potential for wide variation among individual transect surveys. Still, all avian functional groups analyzed did appear to be tracking habitat changes on a short time scale, at least during some seasons, and these responses were largely similar to those observed when average transect survey values were used (i.e., between-transect analyses). Using this method also helped avoid confounding factors among transects that could have influenced the findings observed at other scales. Ultimately, the most reliable way to circumvent these problems will be to implement controlled, experimental manipulation that will isolate and directly assess the effects of management actions.

In our landscape-scale analysis, we incorporated several meso-scale landscape factors and found that strike-risk species were more common on grasslands embedded in developed areas of the airfields (i.e., near lawns, buildings, and pavement). This finding warrants further examination, however, as it was influenced by a small number of "developed" transects in the sample. Increasing the scale of our analysis necessitated reducing sample sizes (i.e., creating a subset of transects), which minimized problems associated with pseudoreplication, but also affected our ability to make inferences. A similar concern underlies our finding that conservation-value densities decreased with increasing amounts of "core" grassland area in the immediate surroundings (Figure 15C). Our understanding of landscape-scale dynamics would benefit from the inclusion of other regional airfields. This would allow increased sample sizes, and could also facilitate the examination of still broader patch-scale relationships (i.e., at the airfield level). Indeed, several studies have determined that broad-scale landscape variables may be the most important factors for predicting breeding grassland bird densities (Johnson and Igl 2001, Fletcher and Koford 2002).

While our transect surveys only measured birds actually using the grassland habitats on the airfield (i.e., excluding "fly-overs"), the most significant threat to air safety may be large birds or large flocks of small birds passing through the airfield's airspace en route to other areas (e.g., wintering grounds, feeding areas; Dolbeer et al. 2000, Servoss et al. 2000, Blackwell et al. 2009). The data we collected during behavioral observation surveys near runways addressed this concern, and provided useful data on species groups that are potentially most hazardous to air-safety at each site and season (Table 19). For example, linear models for runway crossings of strike-risk species revealed significant differences in crossing rates by time of day (lowest in 'evening' [1400-1800]), and suggested a positive relationship with the amount of surrounding pavement cover. While the latter relationship is intriguing and warrants further investigation, we urge caution when interpreting it due to the small number of point locations on which it is based (n = 12). The lower crossing rates observed in late-afternoon / evening hours is consistent with several studies reporting peak aircraft-strikes in morning hours (0500-0900; reviewed in Sodhi 2002). We found no significant differences by season, despite the generally higher numbers of aircraft strikes reported during spring and fall nationally (Jerome 1976, Neubauer 1990).

The species most frequently observed crossing runways uniformly belonged to our 'high strike-risk' category, which was based on birds shown to be historically hazardous to military aircraft (Zakrajsek and Bissonette 2005). The most frequently crossing groups included Vulture, Blackbird-Starling, Gull, and Swallow (Table 19). Only two non-strike-risk species groups had comparably high runway crossing rates (i.e., > 1 per 15 min survey), and all occurred during fall migration: Crows at WARB and PRNAS, and Thrushes (mainly American Robin) at Lakehurst. Smaller, grassland-breeding species, many of which are declining in population and are of conservation concern (Askins 1993), are not considered to be of high strike-risk based on published hazard rankings and reviews of damage-causing species (Dolbeer et al. 2000, Sodhi 2002, Zakrajsek and Bissonette 2005, Dolbeer 2006, Dolbeer and Wright 2009, DeVault et al. 2011). Our data support this, as these species had low runway crossing rates during the summer breeding season when they are most likely to be present: Grasshopper Sparrow (≤ 0.01); Savannah Sparrow (≤ 0.01); Bobolink (≤ 0.12); Eastern Meadowlark (≤ 0.20).

There is no widely-accepted protocol for assessing bird strike risk on a particular airfield, but the typical methods (when not based on reported strikes) are based on counts made during standardized surveys of varying time periods and spatial extents (e.g., Servoss et al. 2000, Seamans et al. 2007, Soldatini et al. 2010). We believe our method of counting the number actually observed crossing runways provides a reasonable method of assessing strike-risk for individual species or groups at a given site, especially as it only includes birds that are exhibiting hazardous behaviors (i.e., crossing runways). Nevertheless, our approach has certain limitations. (1) We did not account for differences in risk based on weight or flocking habits. For example, despite their differing potential for inflicting damage to aircraft, Swallow and Vulture crossing rates were ranked on the same scale. This could be addressed by weighting count data by mass (e.g., Searing 2001, Soldatini et al. 2010) or by published hazard indices (e.g., Zakrajsek and Bissonette 2005, Dolbeer and Wright 2009, DeVault et al. 2011) in future analyses. (2) Detection probabilities of crossing events likely vary by observer, species group, and possibly other factors. This could possibly be addressed by using a distance sampling approach (e.g., Buckland et al. 2001) in future analyses of the data, although distances of birds in flight were difficult to estimate and resulting estimates would likely be imprecise. Despite these limitations, our methods still provide airfield managers with standardized, easily interpretable information regarding potential problem species or species groups on the airfield and their patterns of occurrence.

Airfield Management Decisions and Future Directions

In our preliminary reports we made several suggestions for enhancing DoD management decisions regarding airfield safety and functionality (Peters and Allen 2009, 2010). The expanded results presented herein further substantiate the need to take a multifaceted approach to airfield management questions. In particular, we strongly reemphasize several recommendations and observations discussed in detail in our 2009 and 2010 reports and addressed throughout the current document: (1) Objectives for DoD airfield management should be more clearly defined (i.e., reduce all birds? reduce strike-risk birds?); (2) Management decisions should be made on a site-by-site basis due to geographic differences in avian response; (3) Additional sites should be incorporated into future research, with the goal of identifying landscape factors associated with avian airfield use; (4) An experimental approach should be implemented to more directly address management questions; and (5) A process should be initiated in which information gained from this study and others are used in a Structured Decision Making (SDM)/Adaptive Resource Management (ARM) context.

As noted in previous reports, a sound decision process should start with basic questions addressing overall management goals and objectives, potential conflicts among objectives, available management options, the current state of the system, and the likely results of alternate management options (Lancia et al. 1996, Lyons et al. 2008). To help address some of these issues, NJAS has expanded its current research program to include a grassland bird productivity study through the DoD Legacy Resource Management Program (Peters and Allen 2011). The primary goal of the study is to assess how airfield management affects nesting success of species of conservation concern, and to determine if managed sites are functioning as ‘ecological traps’. We are also in the process of identifying opportunities to expand the geographic scope of our work and to incorporate an experimental manipulation component into our monitoring. Taking an experimental approach will greatly strengthen any inferences garnered from the research by controlling for random factors not related to management. Findings from these research efforts, when combined with data from other regional studies, should help DoD decision-makers define management goals and identify appropriate management tools to meet those goals. If used in an SDM - ARM context, results from each management decision will feed back into the decision-making process to further refine and strengthen predictive models.

The DoD can begin using information gained from this study, coupled with similar monitoring protocols, to simultaneously increase confidence in the effectiveness of its management actions while generating information that could lead to better results. There are a large set of decision-support tools available to help evaluate and choose among alternative management actions (Peterson and Schmoldt 1999, Mendoza and Martins 2006, *review in* Lyons et al. 2008). Examples of how various support tools, such as analytic hierarchy processing (AHP, Peterson and Schmoldt 1999) and multi-criteria decision analysis (MCDA, Mendoza and Martins 2006), have been used to address natural resource problems are available throughout the literature. The U.S. Fish and Wildlife Service (USFWS) and U.S. Geological Survey (USGS) also offer workshops and courses to address resource management issues. For example, several courses on Structured Decision Making and Adaptive Management are offered through the USFWS National Conservation Training Center in Shepherdstown, West Virginia (http://nctc.fws.gov/nctcweb/catalog/coursesearch.aspx?CategoryName=Science). Some model structures allow for the weighting and evaluation of potentially conflicting management objectives (Mendoza and Martins 2006), although based on our finding thus far, conflicts between conservation and safety objectives may not be as apparent as once believed. In the end, we feel that that DoD can simultaneously provide a conservation benefit while minimizing risk from problem species, and that an optimal management solution can be reached through this collaborative process.

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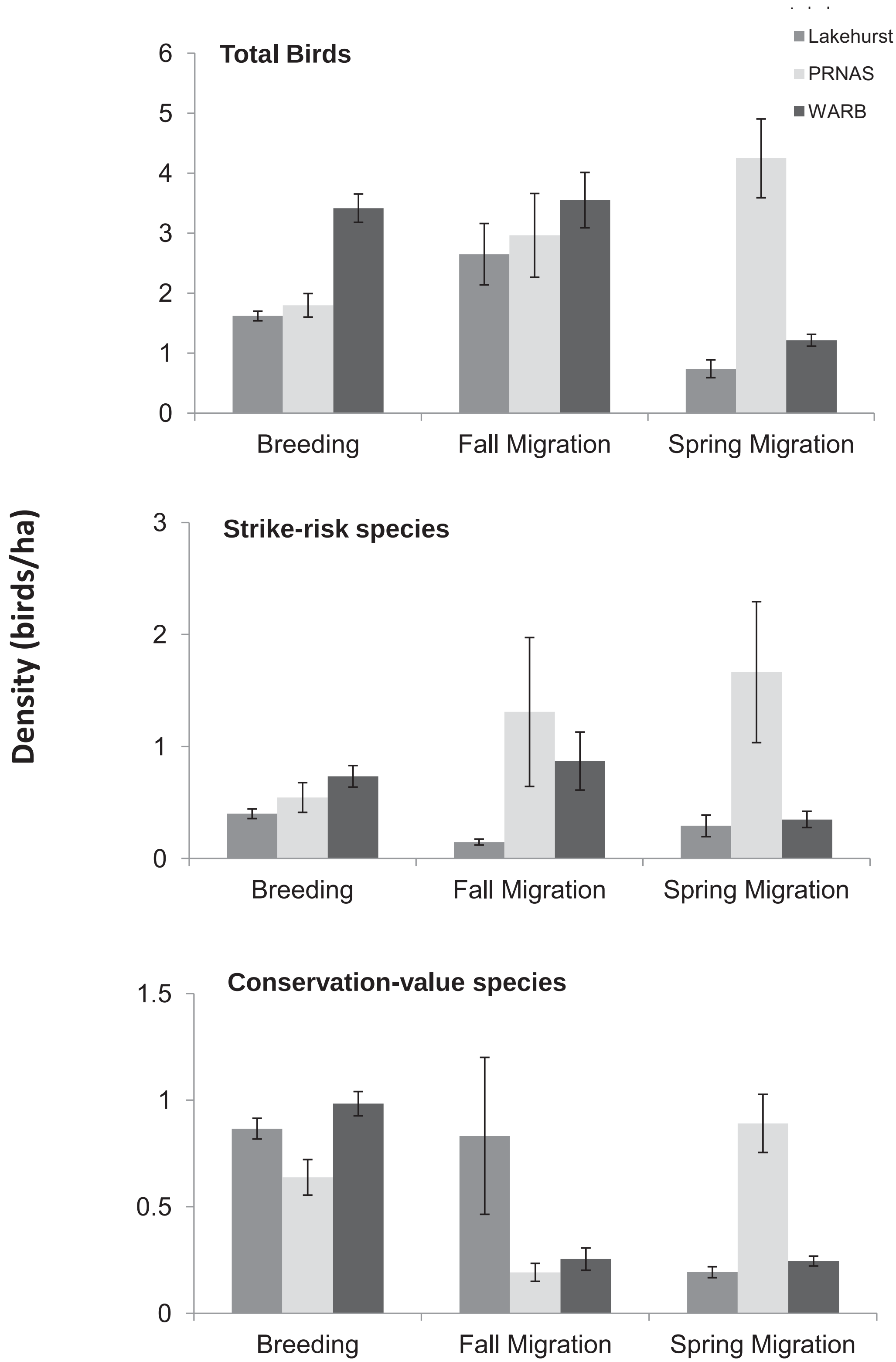


Figure 1. Mean bird density by season for WARB, Lakehurst, and PRNAS. Estimates based on line-transect surveys (averaged by year) conducted fall 2007 through summer 2009, and fall 2010 through summer 2011.

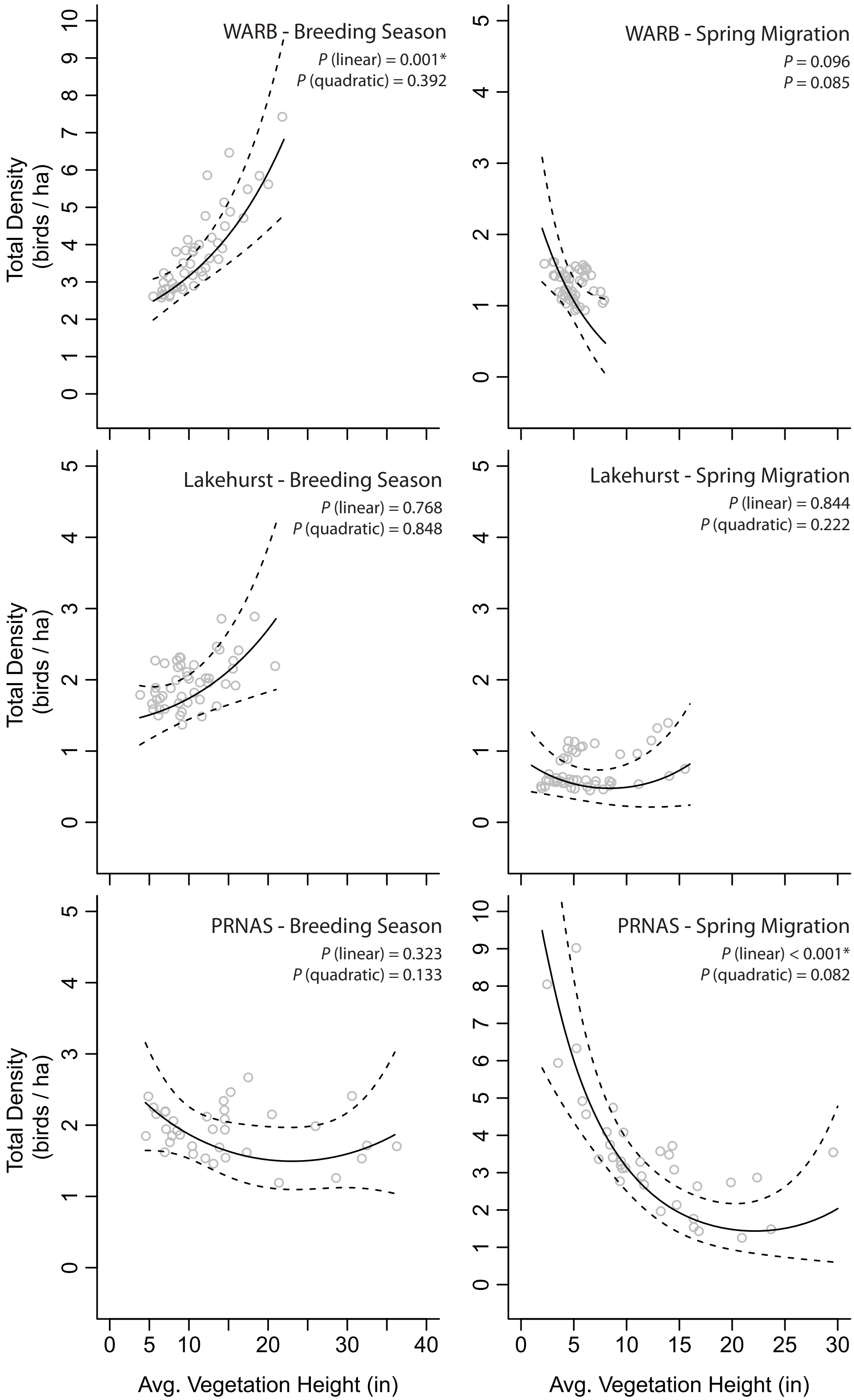


Figure 2. Total bird density in relation to vegetation height at WARB, Lakehurst, and PRNAS in breeding season and spring migration. Gray circles represent predicted densities for morning surveys derived from the corresponding best-fitting model (Tables 4-7). Curves show predicted density (with all other model parameters set at their mean value) and 95% confidence intervals. In Spring, the effect of Veg. Height was significant ($P \leq 0.021$), and in Breeding Season and Spring, a significant Site x Veg. Height interaction effect was detected. *P*-values are shown from post hoc *F*-tests. An asterisk (*) indicates significance after sequential Bonferroni correction (Holm 1979). No significant effect of Veg. Height was found in Fall. Note that scales differ.

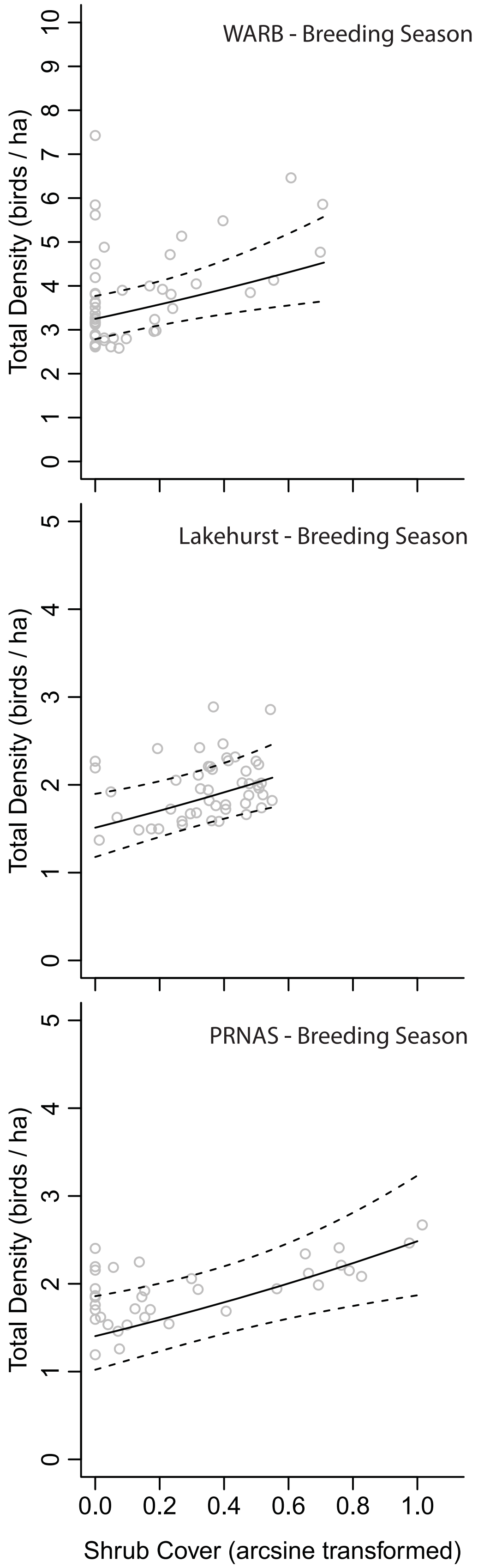


Figure 3. Total bird density in relation to shrub cover at WARB, Lakehurst, and PRNAS in breeding season. Gray circles represent predicted densities for morning surveys derived from the corresponding best-fitting model (Tables 4-7). Curves show predicted density (with all other model parameters set at their mean value) and 95% confidence intervals . The Shrub effect during Breeding Season was significant at $P = 0.003$. No significant effects of vegetation cover were found during Spring or Fall. Note that scales differ.

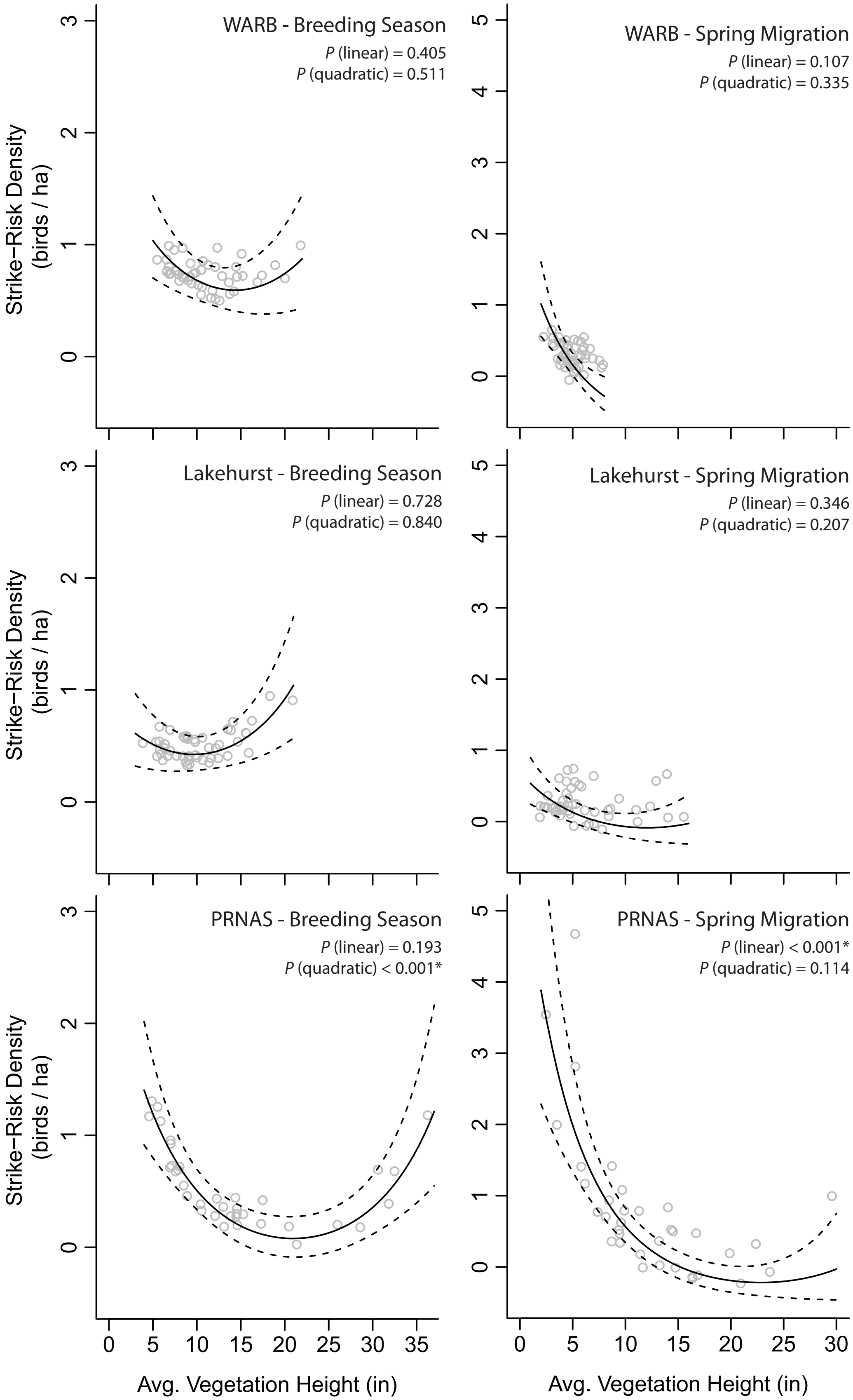


Figure 4. Strike-risk bird density (based on the risk ranking in Zakrajsek and Bissonette 2005) in relation to vegetation height at WARB, Lakehurst, and PRNAS in breeding season and spring migration. Gray circles represent predicted densities for morning surveys derived from the corresponding best-fitting model (Tables 4-7). Curves show predicted density (with all other model parameters set at their mean value) and 95% confidence intervals. In Breeding Season and Spring, significant Veg. Height effects were found ($P \leq 0.001$), along with significant Site x Veg. Height interaction effects. *P*-values from post hoc *F*-tests are shown. An asterisk (*) indicates significance after sequential Bonferroni correction (Holm 1979). No significant effect of Veg. Height was found in Fall. Note that scales differ.

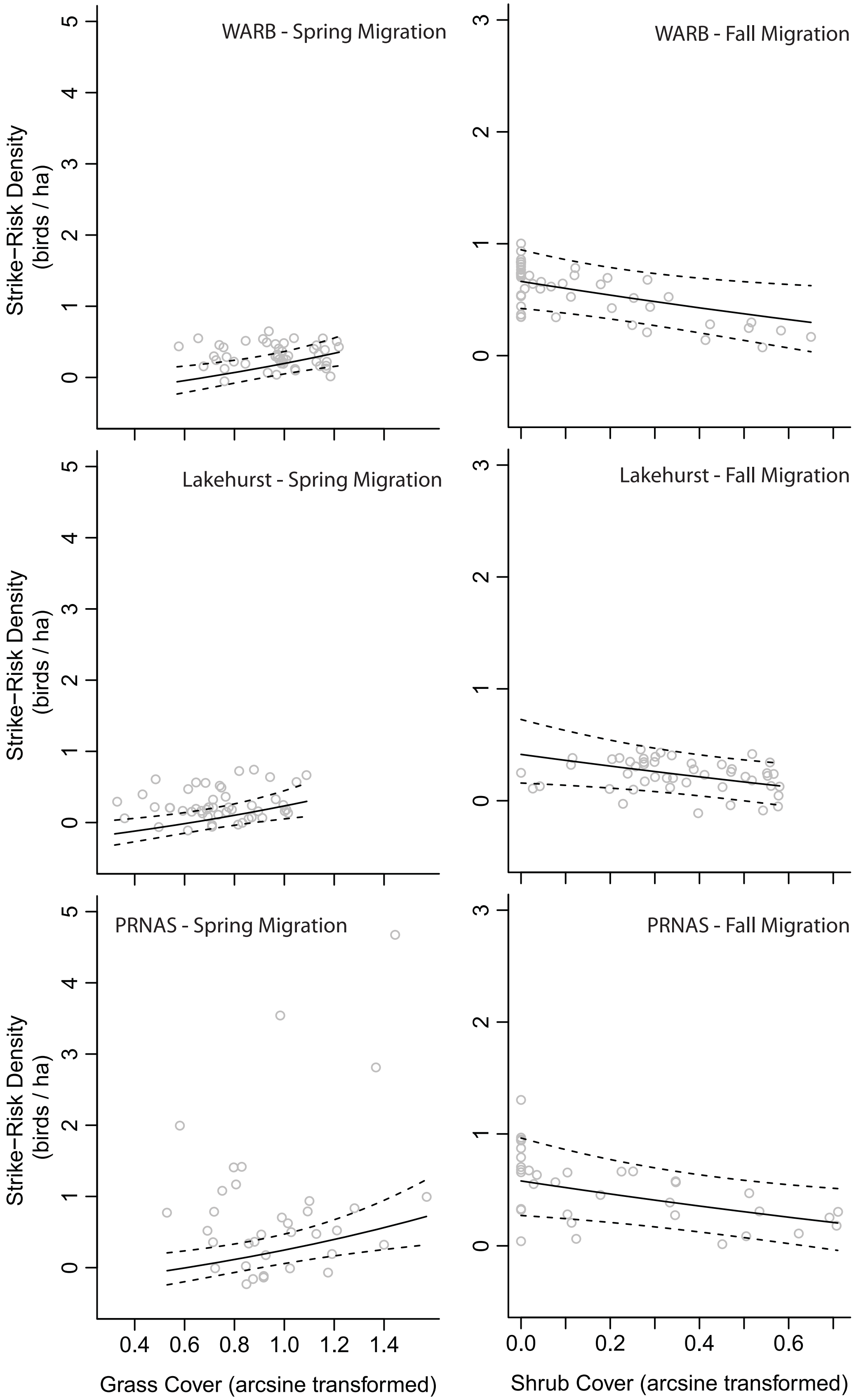


Figure 5. Strike-risk bird density (based on the risk ranking in Zakrajsek and Bissonette 2005) in relation to grass and shrub cover at WARB, Lakehurst, and PRNAS in Spring and Fall Migration. Gray circles represent predicted densities for morning surveys derived from the corresponding best-fitting model (Tables 4-7). Curves show predicted density (with all other model parameters set at their mean value) and 95% confidence intervals. The Grass effect during spring migration was significant at $P = 0.002$. The Shrub effect during fall migration was significant at $P = 0.030$. No significant effects of vegetation cover were found during Breeding Season. Note that scales differ.

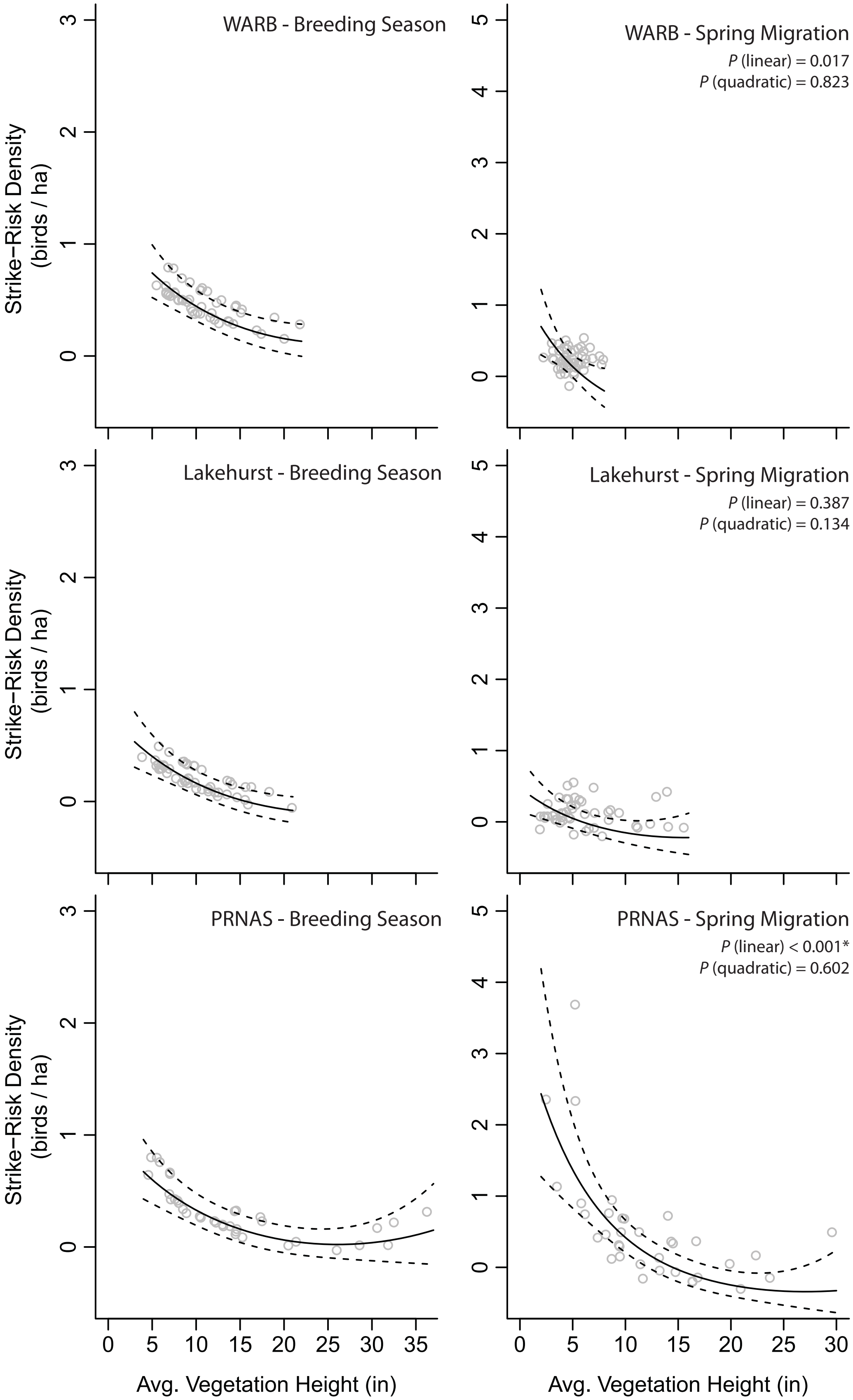


Figure 6. Strike-risk bird density (based on the risk ranking in Dolbeer and Wright 2009) in relation to vegetation height at WARB, Lakehurst, and PRNAS in breeding season and spring migration. Gray circles represent predicted densities for morning surveys derived from the corresponding best-fitting model (Tables 4-7). Curves show predicted density (with all other model parameters set at their mean value) and 95% confidence intervals. In Breeding Season, the effect of Veg. Height was significant (linear: $P \leq 0.001$, quadratic: $P = 0.008$), with no Site x Veg. Height interaction effect. In Spring, a Site x Veg. Height interaction effect was detected, and *P*-values from post hoc *F*-tests are shown. An asterisk (*) indicates significance after sequential Bonferroni correction (Holm 1979). No significant effect of Veg. Height was found in Fall. Note that scales differ.

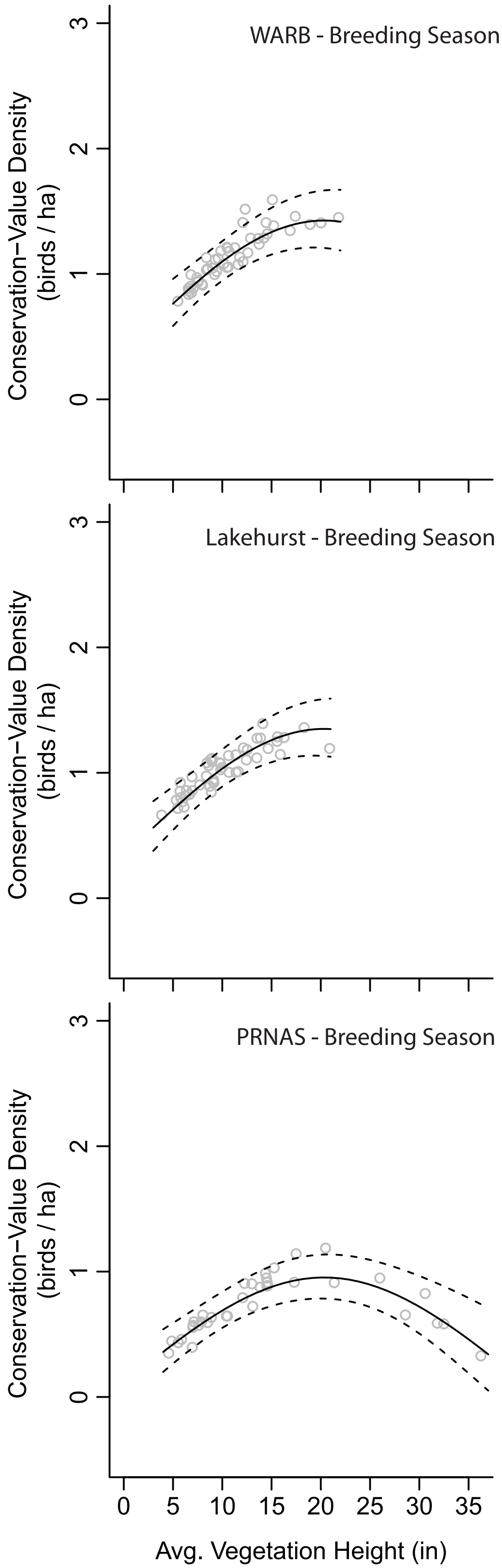


Figure 7. Conservation-value bird density in relation to vegetation height at WARB, Lakehurst, and PRNAS during breeding season. Gray circles represent predicted densities for morning surveys derived from the corresponding best-fitting model (Tables 4-7). Curves show predicted density (with all other model parameters set at their mean value) and 95% confidence intervals. Both the linear and quadratic components of Veg. Height during Breeding Season were significant at $P < 0.001$, with no significant Site x Veg. Height interaction effects. No significant Veg. Height or interaction effects were found in Spring or Fall.

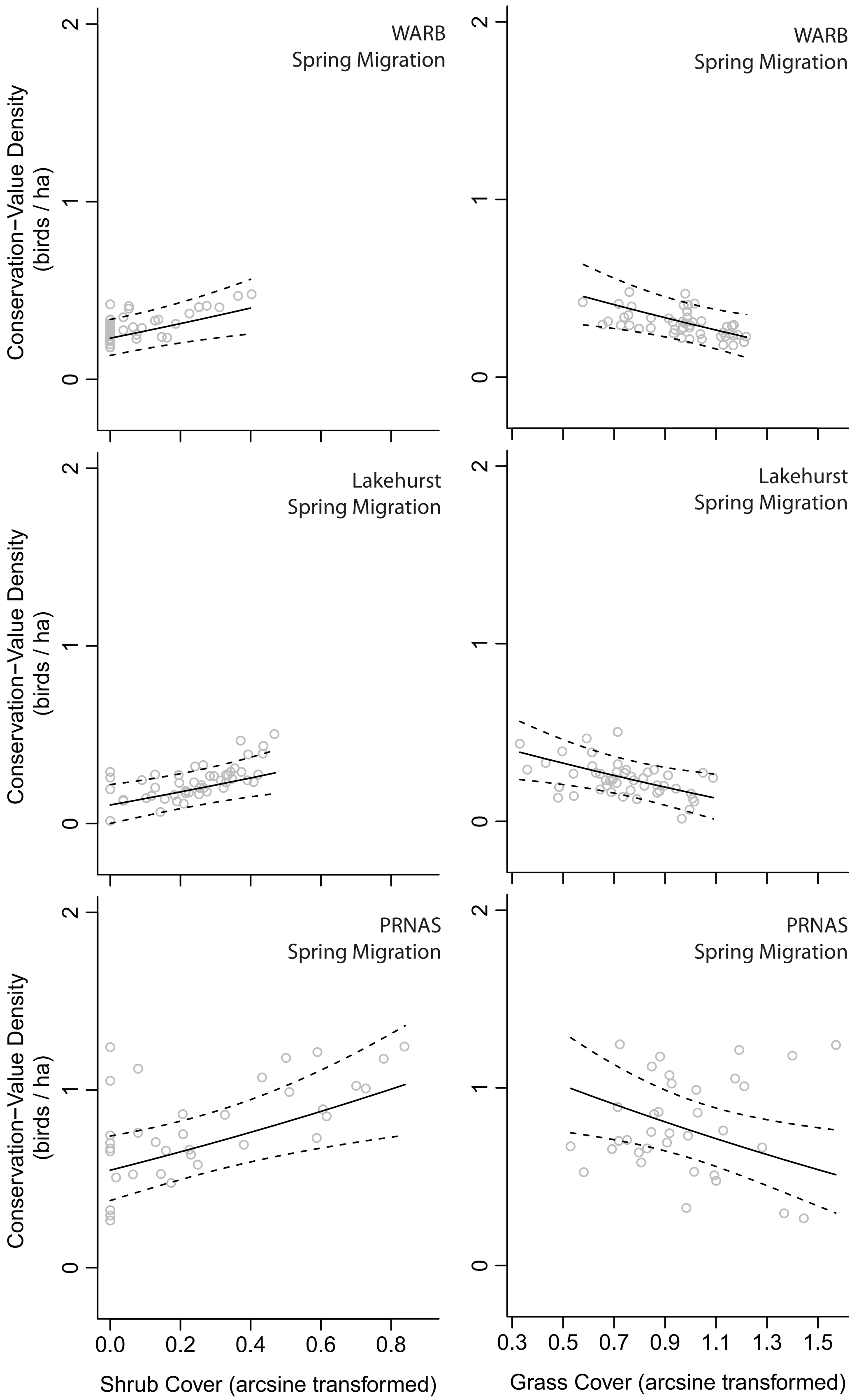


Figure 8. Conservation-value bird density in relation to shrub and grass cover at WARB, Lakehurst, and PRNAS in spring migration. Gray circles represent predicted densities for morning surveys derived from the corresponding best-fitting model (Tables 4-7). Curves show predicted density (with all other model parameters set at their mean value) and 95% confidence intervals. The Shrub effect during Spring Migration was significant at $P = 0.004$, while the Grass effect was significant at $P = 0.014$. No significant effects of vegetation cover were found during Breeding Season or Fall Migration. Note that scales differ.

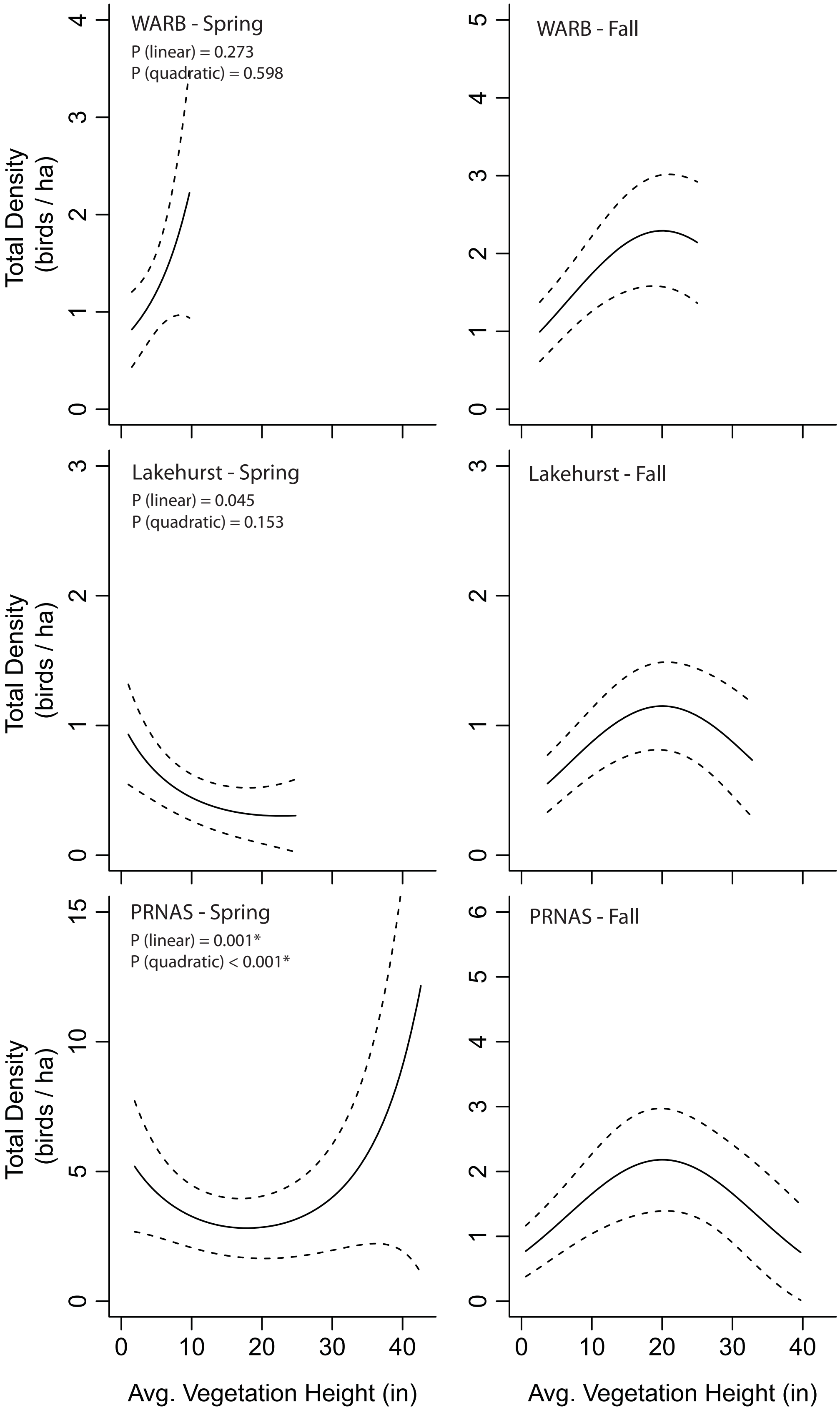


Figure 9. Predicted total bird densities in relation to vegetation height at WARB, Lakehurst, and PRNAS based on "within-transect" analyses. Predicted densities (solid lines) and 95% confidence intervals (dashed lines) were generated based on fixed-effects from the corresponding best-fitting model (Tables 8-11; Time set to "morning"; all other parameters set at mean value). In Spring, the effect of Veg. Height was significant at $P < 0.001$, with a significant Site x Veg. Height interaction effect; P-values from post hoc Wald t-tests are shown. An asterisk (*) indicates significance after sequential Bonferroni correction (Holm 1979). In Fall, the effect of Veg. Height was significant ($P \leq 0.001$), with no significant interaction effects. No effect of Veg. Height was found in Breeding Season. Note that scales differ.

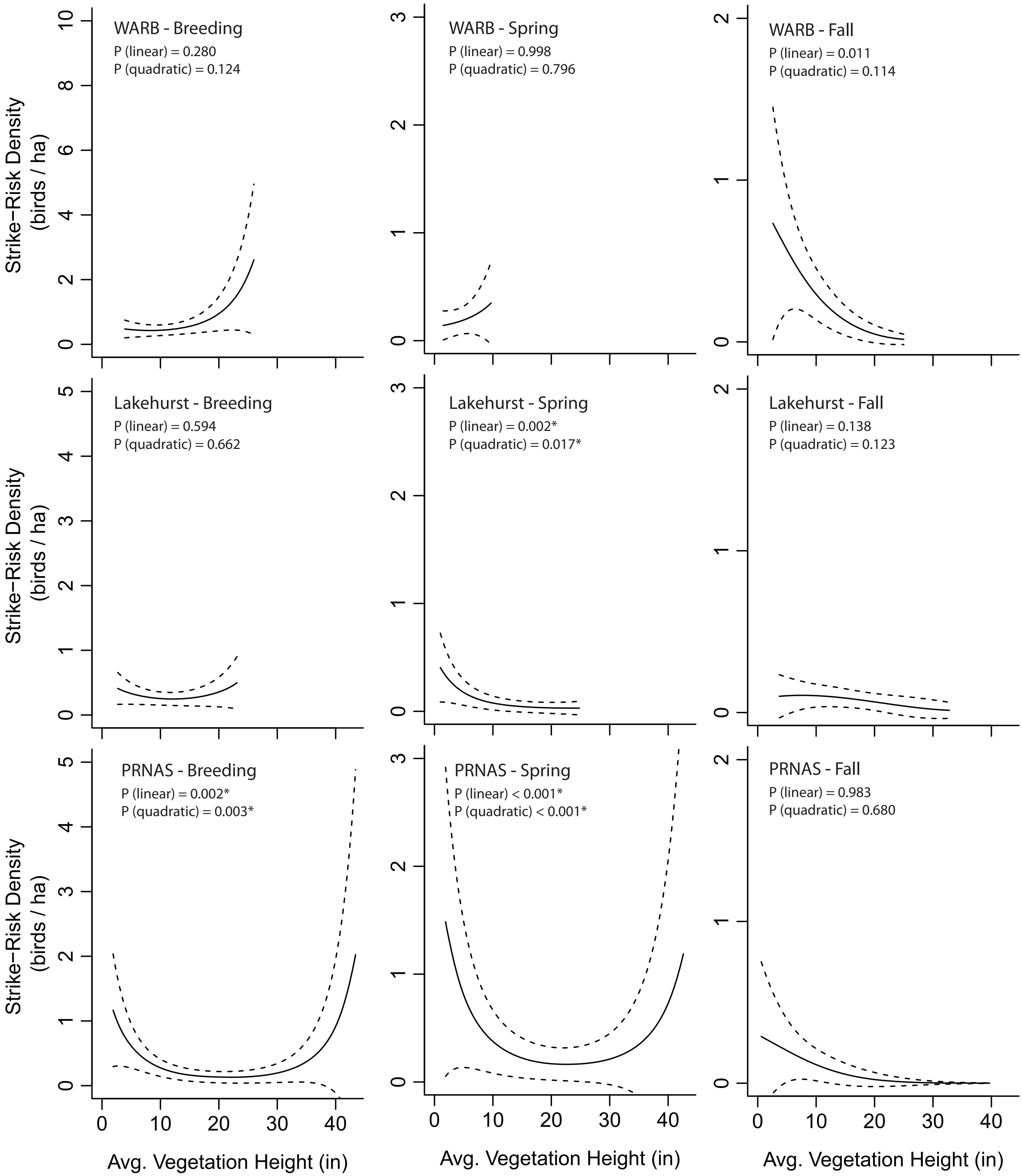


Figure 10. Predicted strike-risk bird densities (based on the risk ranking in Zakrajsek and Bissonette 2005) in relation to vegetation height at WARB, Lakehurst, and PRNAS based on "within-transect" analyses. Predicted densities (solid lines) and 95% confidence intervals (dashed lines) were generated based on fixed-effects from the corresponding best-fitting model (Tables 8-11; Time set to "morning"; all other parameters set at mean value). Significant effects of Veg. Height were found during Breeding Season and Spring ($P < 0.001$), and a significant Site x Veg. Height interaction effect was detected during all seasons. *P*-values from post hoc Wald *t*-tests are shown. An asterisk (*) indicates significance after sequential Bonferroni correction (Holm 1979). Note that scales differ.

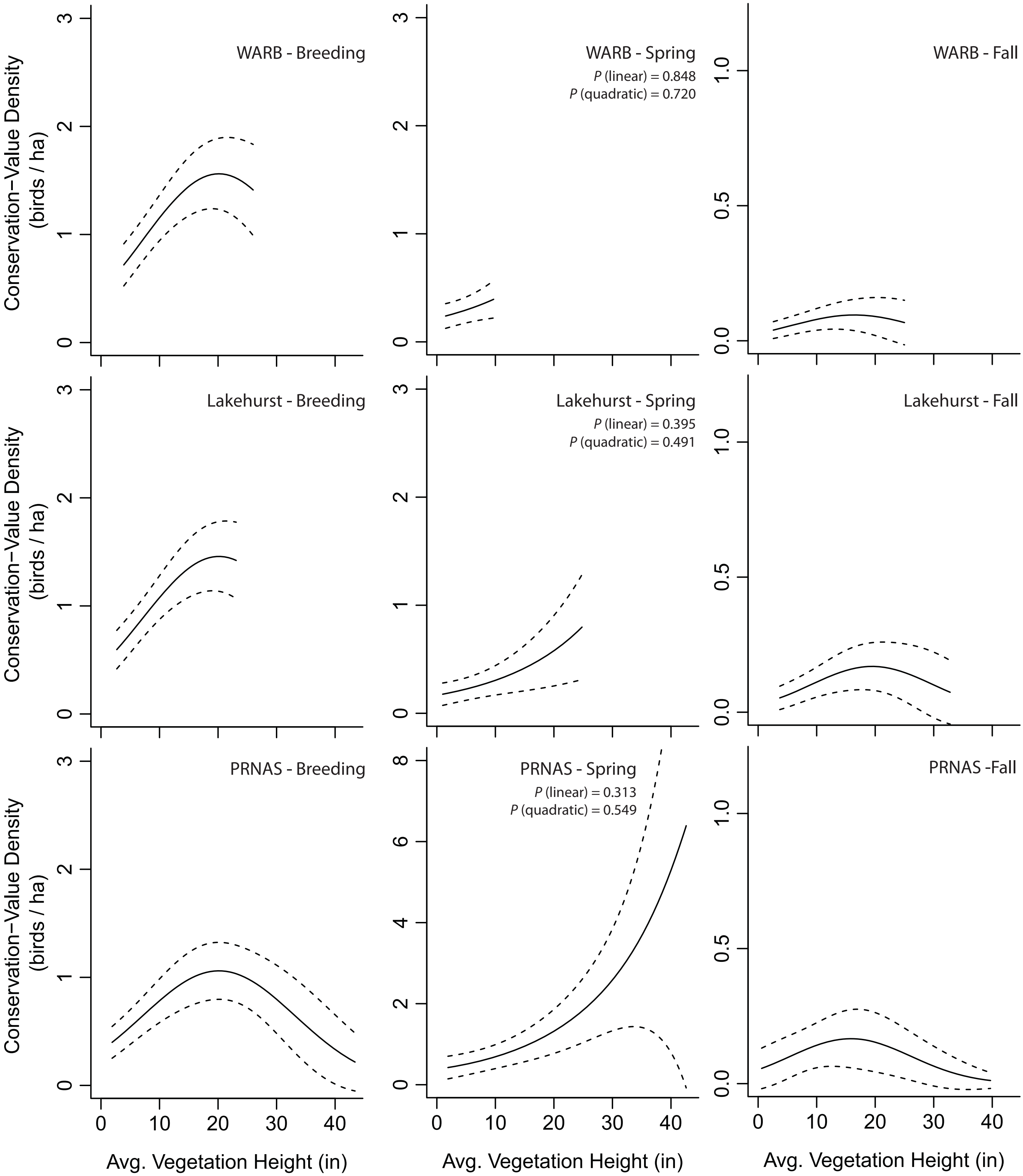
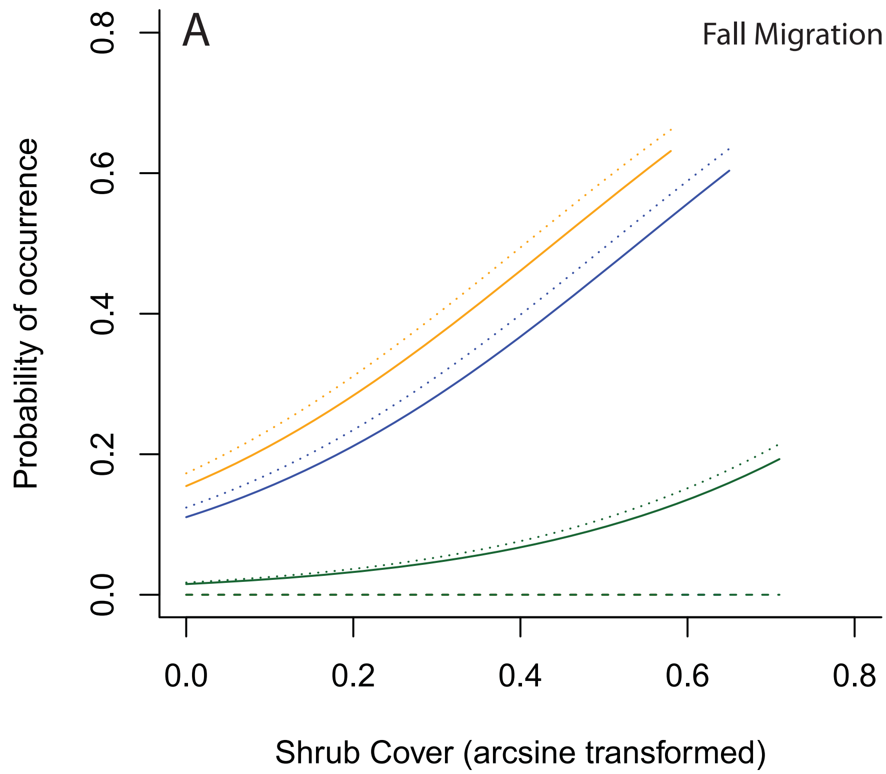


Figure 11. Predicted conservation-value bird densities in relation to vegetation height at WARB, Lakehurst, and PRNAS based on "within-transect" analyses. Predicted densities (solid lines) and 95% confidence intervals (dashed lines) were generated based on fixed-effects from the corresponding best-fitting model (Tables 8-11; Time set to "morning"; all other parameters set at mean value). In Breeding Season and Fall, significant effects of Veg. Height were found ($P \leq 0.017$), with no significant Site x Veg. Height interaction effects. In Spring, a significant Site x Veg. Height interaction effect was detected, and *P*-values from post hoc Wald *t*-tests are shown. An asterisk (*) indicates significance after sequential Bonferroni correction (Holm 1979). Note that scales differ.



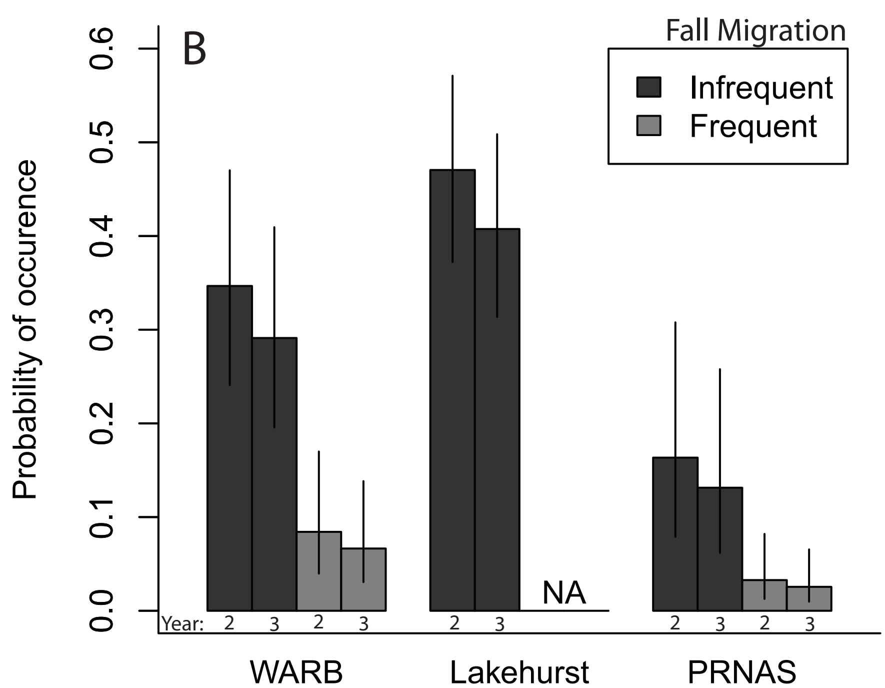


Figure 12. Predicted probability of swallow/swift presence during transect surveys in fall migration in relation to (A) percent shrub cover (arcsine transformed), or (B) management history (frequently mowed vs. infrequently mowed; ± 1 SE). Predicted probabilities are from the two best-performing models for fall in table 12, with Time set to "morning", and all other parameters set to the mean value. In (A), dashed lines = Year 1, solid = Year 2, dotted = Year 3; blue = WARB, orange = Lakehurst, green = PRNAS. No swallows were observed during fall of Year 1 (thus, predicted probability of occurence = zero). There were no frequently mowed transects on Lakehurst.

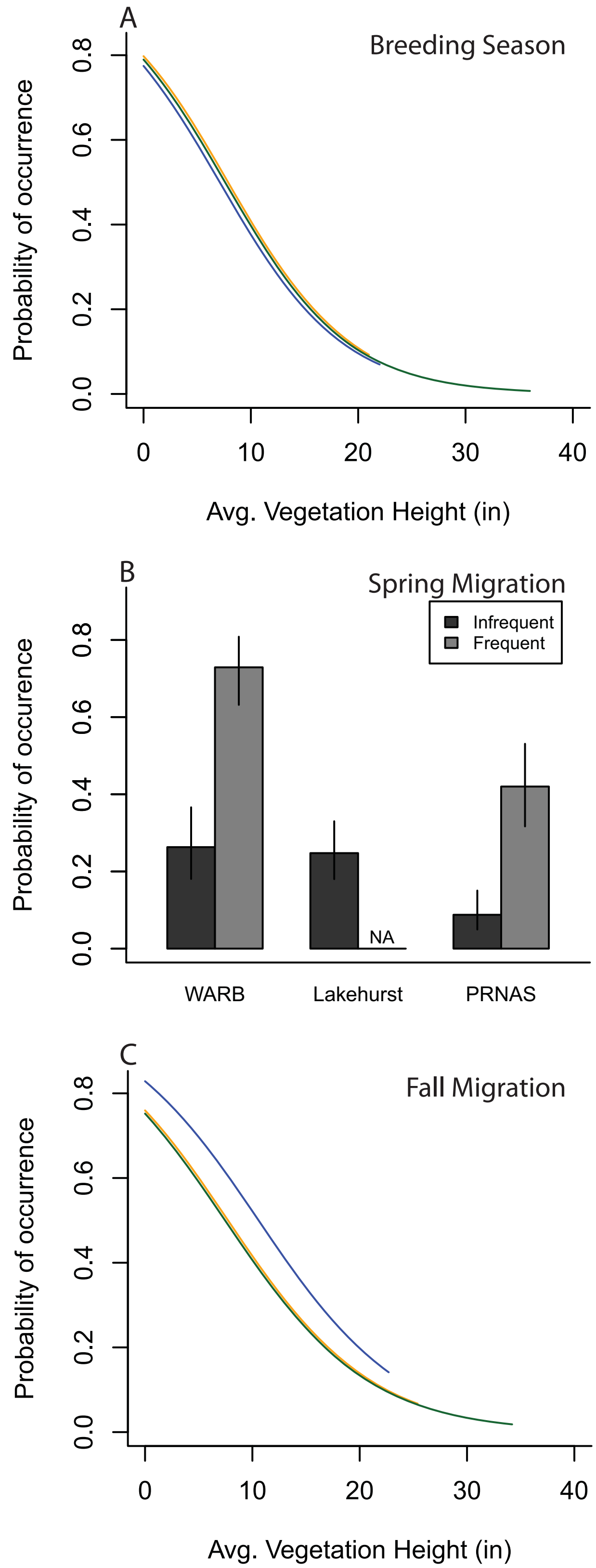


Figure 13. Predicted probability of horned lark presence during transect surveys (breeding, spring, and fall) in relation to average vegetation height (A and C), or management history (B) (frequently vs. infrequently mowed; ± 1 SE). Predicted probabilities are from the corresponding best-performing model in tables 12 and 15., with Time set to "morning", and all other parameters set to the mean value. For lines, blue = WARB, orange = Lakehurst, green = PRNAS. There were no frequently mowed transects on Lakehurst.

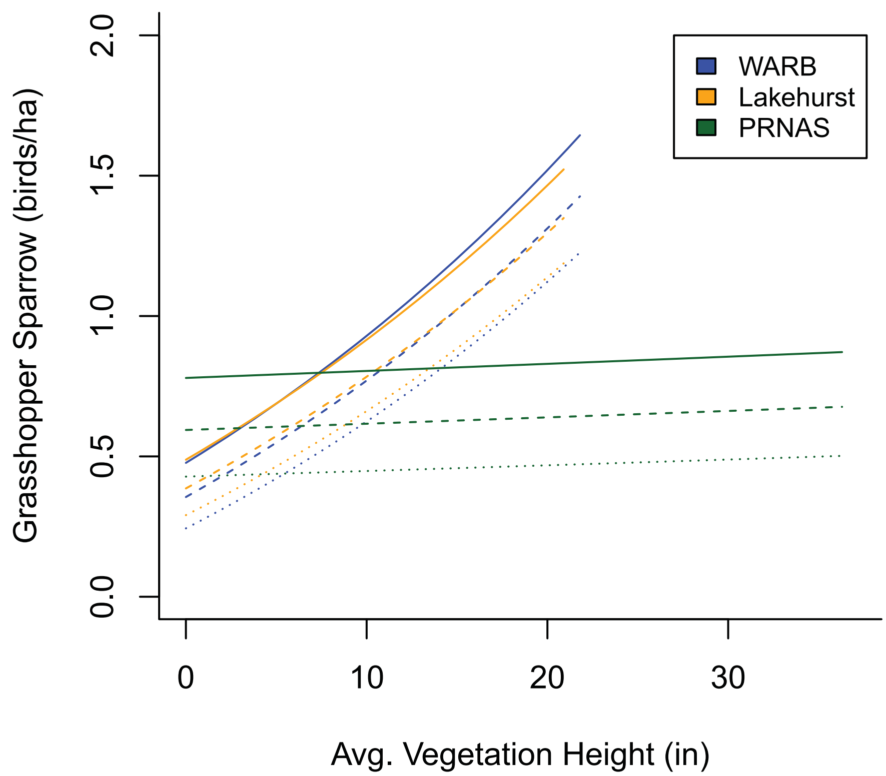


Figure 14. Predicted densities of grasshopper sparrows during breeding season at WARB, Lakehurst, and PRNAS in relation to vegetation height and shrub cover. Dashed, dotted, and solid lines show predicted density with shrub cover set at the mean value, 2 SD below the mean, and 2 SD above the mean, respectively. Predicted densities are based on the best-performing model in Table 16, with Time set to "morning", and all other parameters set at the mean value.

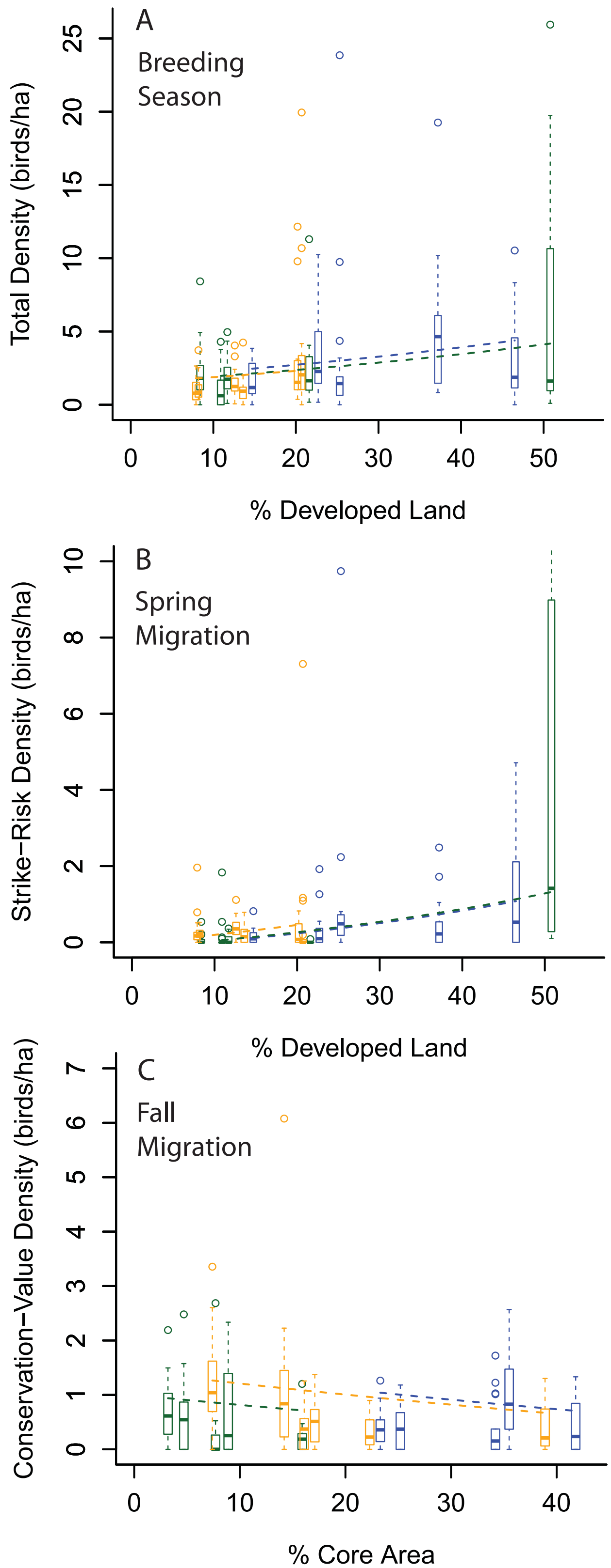


Figure 15. Relationships between bird density and landscape characteristics for (A) all species, (B) strike-risk species, and (C) conservation-value species. Data (boxplots) are from the subset of transects included in the landscape-scale analysis (see text; Appendix D). Developed land included pavement, buildings, lawns and other disturbed areas. Core area included grasslands > 50 m from a non-grassland edge. Predicted densities (lines) are from the best-fitting landscape models in Tables 17-18 (Time set to "Morning"; Season set to "Breeding"; all other parameters set at mean value). Colors: blue = WARB; orange = Lakehurst; green = PRNAS. Note that scales on y-axes differ, and in (B), the right-most boxplot is truncated for clarity (max value = 25.7 birds/ha).

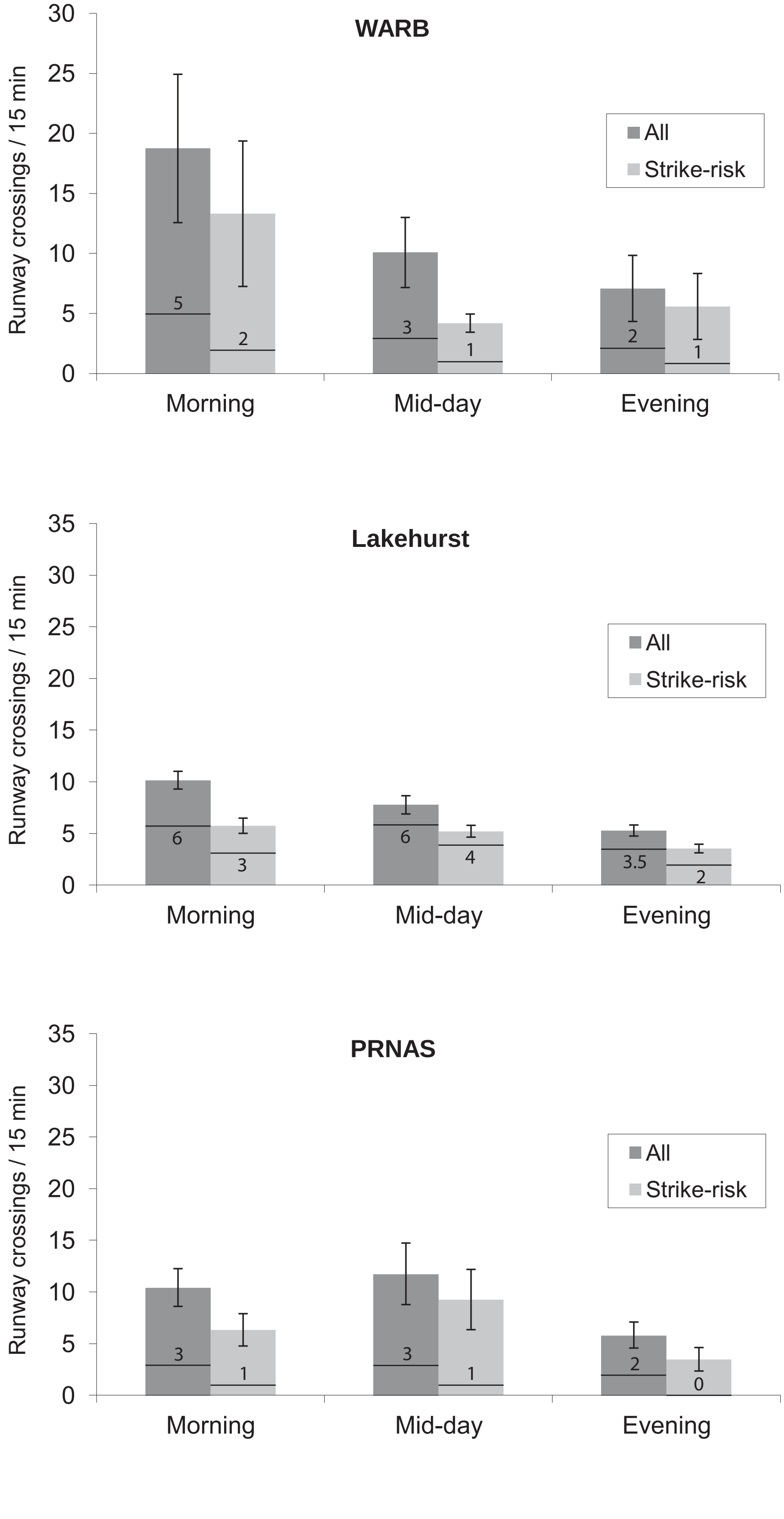


Figure 16. Mean runway crossing rates (± 1 SE) for all species and for strike-risk species (see Table 2) in relation to time of day. Data are from 15-minute behavioral observation surveys conducted during morning (0600-1000), mid-day (1000-1400), and evening (1400-1800) time periods, during fall (2007, 2008, and 2010), spring and summer (2008, 2009, and 2011). Numbers/horizontal lines show median.

Table 1. Conservation Plan scores used to calculate Maximum Conservation Score for birds observed on WARB, Lakehurst, and PRNAS.

Conservation Plan*	Score used to calculate minimum value	Description	Range
PIF Continental Plan	Continental Combined Score [CCS]	Sum of the higher of either Breeding or Non-breeding Distribution scores, Population Size, Population Trend, and the higher of either the continental Threats to Breeding or Non-breeding scores.	1-20, Low to High Conservation Priority
PIF Regional Plans (9, 44)	Tier Level for Priority Species Pool	Tier I=High Continental Priority, Tier II=High Regional Priority, Tier III=Additional Watch List, Tier IV=Additional Federally Listed, Tier V=Additional State Listed	1-5, Highest to Lower Conservation Priority
U.S. Shorebird Conservation Plan	Conservation Assessment Score	5=Highly Imperiled, 4=High Concern, 3=Moderate Concern, 2=Low Concern, 1=Not Currently at Risk	1-5, Low to High Conservation Priority
N. American Waterbird Conservation Plan	Categories of Conservation Concern	5=Highest Concern, 4=High Concern, 3=Moderate Concern, 2=Low Concern, 1=Not Currently at Risk	1-5, Low to High Conservation Priority
N. American Solitary Nesting Waterbird Species Plan	Categories of Conservation Concern	5=Highest Concern, 4=High Concern, 3=Moderate Concern, 2=Low Concern, 1=Not Currently at Risk	1-5, Low to High Conservation Priority
N. American Waterfowl Conservation Plan	Continental Priority Score	5=High, 4=Moderately High, 3=Moderate, 2=Moderately Low, 1=Low	1-5, Low to High Conservation Priority

*References in text; full citations provided in Literature Cited.

Table 2. Risk and Conservation scores used to categorize density estimates from line-distance sampling. Detailed explanations of score derivations are provided in text. Counts for each base (n = total transects) represent the total number of observations (individual or flock) during fall migration, spring migration and breeding season transect surveys.

Strike-risk Species (based on ranking in Zakrajsek and Bissonette 2005;)
Strike-risk Species (based on ranking in Dolbeer and Wright 2009)
Conservation-value Species (based on priority scores in relevant conservation plans)

Common Name	Latin Name	Species Risk Group[a]	Risk score[a]	Risk Category (FAA database)[b]	Conservation score	Size	LNAES (n=773)	PRNAS (n=498)	WARB (n=778)
American Crow	Corvus brachyrhynchos	Crow	1.01	High	1.50	Large	0	15	4
American Golden Plover	Pluvialis dominica	Large shorebird	1.00	Low	4.00	Med	0	1	0
American Goldfinch	Carduelis tristis	Sparrow	1.01	--	1.50	Small	9	10	12
American Kestrel	Falco sparverius	Kestrel	1.01	Very Low	1.75	Med	128	10	146
American Pipit	Anthus rubescens	Thrush	1.05	--	1.75	Small	2	5	16
American Robin	Turdus migratorius	Thrush	1.05	Moderate	1.25	Small	19	0	18
Bald Eagle	Haliaeetus leucocephalus	Eagle	1.02	Extrem. High	2.50	Large	0	1	1
Bank Swallow	Riparia riparia	Swallow	1.73	Low	2.00	Small	5	0	63
Barn Swallow	Hirundo rustica	Swallow	1.73	Very Low	2.00	Small	62	7	73
Black-bellied Plover	Pluvialis squatarola	Large shorebird	1.00	Moderate	3.00	Med	1	0	0
Blue Grosbeak	Passerina caerulea	Other	1.00	--	2.25	Small	32	18	0
Blue Jay	Cyanocitta cristata	Other	1.00	--	2.25	Small	0	2	0
Bobolink	Dolichonyx oryzivorus	Sparrow	1.01	--	2.75	Small	21	45	245
Brown Thrasher	Toxostoma rufum	Thrasher	1.00	--	4.00	Small	2	3	0
Brown-headed Cowbird	Molothrus ater	Blackbird-Starling	2.45	Low	1.75	Small	17	5	0
Buff-breasted Sandpiper	Tryngites subruficollis	Small shorebird	1.00	--	4.00	Small	0	1	0
Canada Goose	Branta canadensis	Goose	3.38	Extrem. High	1.00	Large	8	1	4
Carolina Wren	Thryothorus ludovicianus	Other	1.00	--	2.00	Small	0	2	0
Cedar Waxwing	Bombycilla cedrorum	Waxwing	1.00	--	1.75	Small	6	0	0
Chimney Swift	Chaetura pelagica	Swallow	1.73	Very Low	4.00	Small	9	1	10
Chipping Sparrow	Spizella passerina	Sparrow	1.01	--	1.75	Small	43	9	3
Common Grackle	Quiscalus quiscula	Grackle	1.00	Moderate	2.00	Med	3	16	0
Common Nighthawk	Chordeiles minor	Nighthawk	1.01	Very Low	2.50	Small	36	0	0
Common Raven	Corvus corax	Crow	1.01	--	1.50	Large	0	0	16
Common Yellowthroat	Geothlypis trichas	Warbler	1.00	--	2.00	Small	1	15	0
Cooper's Hawk	Accipiter cooperii	Accipiter	1.01	--	2.00	Large	5	1	0
Dark-eyed Junco	Junco hyemalis	Sparrow	1.01	--	2.00	Small	1	0	0
Dickcissel	Spiza americana	Other	1.00	--	3.50	Small	0	1	0
Downy Woodpecker	Picoides pubescens	Woodpecker	1.00	--	1.75	Small	1	0	0
Eastern Bluebird	Sialia sialis	Thrush	1.05	--	1.75	Small	107	10	1
Eastern Kingbird	Tyrannus tyrannus	Other	1.00	--	4.00	Small	47	0	15
Eastern Meadowlark	Sturnella magna	Meadowlark	1.05	Very Low	2.75	Med	232	363	514
Eastern Phoebe	Sayornis phoebe	Other	1.00	--	2.00	Small	1	1	0
Eastern Towhee	Pipilo erythrophthalmus	Sparrow	1.01	--	4.00	Small	0	2	0
European Starling	Sturnus vulgaris	Blackbird-Starling	2.45	Moderate	1.75	Small	26	75	76
Field Sparrow	Spizella pusilla	Sparrow	1.01	--	5.00	Small	192	29	5
Fish Crow	Corvus ossifragus	Crow	1.01	--	2.25	Large	4	0	0
Grasshopper Sparrow	Ammodramus savannarum	Sparrow	1.01	--	4.00	Small	906	553	700
Gray Catbird	Dumetella carolinensis	Other	1.00	--	2.25	Small	0	1	0
Great Blue Heron	Ardea herodias	Egret-Heron	1.04	Very High	1.00	Large	2	0	0
Greater Yellowlegs	Tringa melanoleuca	Large shorebird	1.00	--	3.00	Med	1	0	1
Horned Lark	Eremophila alpestris	Horned Lark	1.78	Low	2.00	Small	103	138	251
House Finch	Carpodacus mexicanus	Other	1.00	--	1.50	Small	1	0	0
House Sparrow	Passer domesticus	Sparrow	1.01	Low	2.00	Small	0	2	0
House Wren	Troglodytes aedon	Other	1.00	--	1.50	Small	1	0	0
Indigo Bunting	Passerina cyanea	Sparrow	1.01	--	2.75	Small	1	17	0
Killdeer	Charadrius vociferus	Killdeer	1.01	Low	3.00	Med	84	34	48
Lapland Longspur	Calcarius lapponicus	Sparrow	1.01	--	1.75	Small	0	1	5
Le Conte's Sparrow	Ammodramus leconteii	Sparrow	1.01	--	3.25	Small	0	1	0

Table 2 (cont.). Risk and Conservation scores used to categorize density estimates from line-distance sampling. Detailed explanations of score derivations are provided in text. Counts for each base (n = total transects) represent the total number of observations (individual or flock) during fall migration, spring migration and breeding season transect surveys.

Common Name	Latin Name	Species Risk Group[a]	Risk score[a]	Risk Category (FAA database)[b]	Conservation score	Size	LNAES (n=773)	PRNAS (n=498)	WARB (n=778)
Lincoln's Sparrow	Melospiza lincolnii	Sparrow	1.01	--	1.75	Small	1	0	0
Mallard	Anas platyrhynchos	Duck	1.17	Very High	2.00	Large	0	1	0
Marsh Wren	Cistothorus palustris	Other	1.00	--	4.00	Small	1	0	0
Merlin	Falco columbarius	Kestrel	1.01	Very Low	1.75	Med	3	0	7
Mourning Dove	Zenaida macroura	Mourning dove	1.03	Moderate	1.25	Med	67	14	82
N. Rough-winged Swallow	Stelgidopteryx serripennis	Swallow	1.73	--	2.50	Small	3	0	1
Northern Bobwhite	Colinus virginianus	Quail	1.00	--	4.00	Med	0	4	0
Northern Cardinal	Cardinalis cardinalis	Other	1.00	--	1.25	Small	1	2	0
Northern Flicker	Colaptes auratus	Woodpecker	1.00	Moderate	2.25	Small	5	1	2
Northern Harrier	Circus cyaneus	Accipiter	1.01	Low	2.75	Large	15	7	27
Northern Mockingbird	Mimus polyglottos	Other	1.00	Low	2.00	Small	13	5	5
Orchard Oriole	Icterus spurius	Other	1.00	--	3.00	Small	0	1	1
Osprey	Pandion haliaetus	Osprey	1.01	Very High	2.00	Large	0	2	0
Ovenbird	Seiurus aurocapilla	Warbler	1.00	--	2.50	Small	0	1	0
Palm Warbler	Setophaga palmarum	Warbler	1.00	--	2.00	Small	11	6	0
Peregrine Falcon	Falco peregrinus	Falcon	1.00	Moderate	4.00	Large	0	0	2
Pine Warbler	Setophaga pinus	Warbler	1.00	--	4.00	Small	17	0	0
Prairie Warbler	Setophaga discolor	Warbler	1.00	--	5.00	Small	0	2	0
Purple Martin	Progne subis	Swallow	1.73	Low	2.00	Small	18	0	0
Red-bellied Woodpecker	Melanerpes carolinus	Woodpecker	1.00	--	3.25	Small	0	1	0
Red-tailed Hawk	Buteo jamaicensis	Buteo	1.95	High	1.50	Large	13	1	20
Red-winged Blackbird	Agelaius phoeniceus	Blackbird-Starling	2.45	Low	2.00	Small	18	56	17
Ring-billed Gull	Larus delawarensis	Gull	1.22	High	1.00	Large	0	1	0
Rock Pigeon	Columba livia	Rock dove	1.04	High	1.00	Large	0	2	1
Ruby-throated Hummingbird	Archilochus colubris	Other	1.00	--	2.00	Small	0	0	1
Sanderling	Calidris alba	Small shorebird	1.00	--	4.00	Small	0	1	0
Savannah Sparrow	Passerculus sandwichensis	Sparrow	1.01	Very Low	2.25	Small	290	334	1183
Sedge Wren	Cistothorus platensis	Other	1.00	--	2.25	Small	0	1	0
Semipalmated Plover	Charadrius semipalmatus	Small shorebird	1.00	--	2.00	Small	0	1	0
Sharp-shinned Hawk	Accipiter striatus	Accipiter	1.01	--	2.00	Med	2	0	1
Short-eared Owl	Asio flammeus	Owl	1.03	Low	4.00	Large	0	0	3
Snow Bunting	Plectrophenax nivalis	Sparrow	1.01	--	1.75	Small	4	1	8
Solitary Sandpiper	Tringa solitaria	Small shorebird	1.00	--	4.00	Small	1	0	0
Song Sparrow	Melospiza melodia	Sparrow	1.01	Very Low	2.00	Small	18	25	0
Sora	Porzana carolina	Other	1.00	--	4.00	Small	0	2	0
Swamp Sparrow	Melospiza georgiana	Sparrow	1.01	--	1.75	Small	19	0	3
Tree Swallow	Tachycineta bicolor	Swallow	1.73	Very Low	2.00	Small	190	1	31
Turkey Vulture	Cathartes aura	Vulture	5.00	Extrem. High	1.50	Large	4	5	0
Unknown Bird	--	--	--	--	--	--	1	6	0
Unknown Crow	Corvus sp.	Crow	1.01	High	--	Large	4	7	1
Unknown Sparrow	Emberizidae, gen. sp.	Sparrow	1.01	--	--	Small	16	8	15
Unknown Swallow	Hirundinidae, gen. sp.	Swallow	1.73	Low	--	Small	2	0	0
Unknown Warbler	Parulidae, gen. sp.	Warbler	1.00	--	--	Small	3	0	0
Upland Sandpiper	Bartramia longicauda	Killdeer	1.01	Moderate	5.00	Med	100	14	307
Vesper Sparrow	Pooecetes gramineus	Sparrow	1.01	--	2.75	Small	0	3	0
Wild Turkey	Meleagris gallopavo	Pheasant	1.00	Very High	2.00	Large	3	0	0
Wilson's Snipe	Gallinago delicata	Small shorebird	1.00	--	3.00	Med	7	10	5
Wood Duck	Aix sponsa	Duck	1.17	--	1.00	Large	1	0	0
Yellow Warbler	Setophaga petechia	Warbler	1.00	--	1.75	Small	0	1	0
Yellow-breasted Chat	Icteria virens	Other	1.00	--	2.50	Small	0	4	0
Yellow-rumped Warbler	Setophaga coronata	Warbler	1.00	--	1.50	Small	2	1	0

[a]From Zakrajsek and Bissonette (2005), based on a ranking of bird-strike hazard to military aircraft. See text for detailed explanation.
[b]From Dolbeer and Wright (2009), based on a ranking of bird-strike hazard to civil aircraft.

Table 3. Candidate models examined to determine detection probability of small, medium and large birds during transect surveys in the breeding season, spring migration, and fall migration periods. Model AIC values and number of estimable parameters were calculated in program DISTANCE (Thomas et al. 2010). Models used to adjust density estimates are highlighted in red. Covariates were not included for large birds due to sample size limitations, and detection probabilities were estimated using model averaging.

Breeding Season (16 May - 15 July)

Small Birds (≤100 g)			Medium Birds (101-200 g)			Large Birds (>200 g)		
Model	**k***	**Δ AIC**	**Model**	**k***	**Δ AIC**	**Model**	**k***	**Δ AIC**
haz-rate cos - veg ht	13	0.00	half-norm cos - veg ht, observer	6	0.00	uniform simple poly	0	0.00
haz-rate cos - veg ht, observer	6	5.43	half-norm cos - veg ht	3	18.38	uniform cos	0	0.00
haz-rate cos	5	32.64	half-norm cos - observer	4	30.72	half-norm cos	1	0.30
haz-rate cos - observer	12	33.30	half-norm hermite poly	1	55.61	half-norm hermite poly	1	0.30
haz-rate cos - day vs. eve	10	38.70	half-norm cos	1	55.61	haz-rate simple poly	2	2.33
uniform cos	1	57.83	uniform cos	2	56.29	haz-rate cos	2	2.33
uniform simple poly	2	60.64	uniform simple poly	1	57.04			
half-norm hermite poly	1	61.13	haz-rate cos	2	57.08			
half-norm cos	1	61.13	haz-rate simple poly	2	57.08			
haz-rate simple poly	5	65.32	half-norm cos - day vs. eve	2	57.57			

Spring Migration (1 April - 15 May)

Small Birds (≤100 g)			Medium Birds (101-200 g)			Large Birds (>200 g)		
Model	**k***	**Δ AIC**	**Model**	**k***	**Δ AIC**	**Model**	**k***	**Δ AIC**
half-norm cos - observer	9	0.00	uniform cos - observer	3	0.00	uniform simple poly	0	0.00
half-norm cos - veg ht, observer	6	18.96	uniform cos - veg ht	3	10.16	uniform cos	0	0.00
half-norm cos - veg ht	8	42.22	uniform cos - day vs. eve	2	26.50	half-norm hermite poly	1	1.46
half-norm cos - day vs. eve	3	94.67	uniform cos	1	28.63	half-norm cos	1	1.46
half-norm cos	2	97.92	half-norm hermite poly	1	28.76	haz-rate cos	2	3.12
haz-rate simple poly	3	99.59	half-norm cos	1	28.76	haz-rate simple poly	2	3.12
uniform cos	3	99.76	uniform simple poly	1	29.48			
uniform simple poly	4	101.16	haz-rate cos	2	30.34			
half-norm hermite poly	1	103.74	haz-rate simple poly	2	30.34			
haz-rate cos	2	113.37	uniform cos - veg ht, observer**	-	-			

Fall Migration (16 August - 15 November)

Small Birds (≤100 g)			Medium Birds (101-200 g)			Large Birds (>200 g)		
Model	**k***	**Δ AIC**	**Model**	**k***	**Δ AIC**	**Model**	**k***	**Δ AIC**
haz-rate simple poly - observer	17	0.00	haz-rate cos - observer	10	0.00	uniform cos	2	0.00
haz-rate simple poly - day vs. eve	7	59.46	haz-rate cos - day vs. eve	4	26.92	half-norm cos	2	0.48
haz-rate simple poly - veg ht	13	72.19	haz-rate cos	3	34.73	haz-rate cos	2	1.46
haz-rate simple poly	5	81.15	haz-rate simple poly	2	35.11	haz-rate simple poly	2	1.46
uniform cos	5	110.05	half-norm cos	2	37.10	half-norm hermite poly	1	1.67
haz-rate simple poly - veg ht, observer	7	115.52	haz-rate cos - veg ht	6	38.29	uniform simple poly	3	1.68
haz-rate cos	2	129.38	uniform cos	2	38.45			
half-norm cos	2	148.98	uniform simple poly	3	40.90			
uniform simple poly	5	153.23	haz-rate cos - veg ht, observer	8	41.34			
half-norm hermite poly	1	271.42	half-norm hermite poly	1	48.64			

* Number of estimable model parameters
**Model failed to converge

Table 4. Model comparisons and fit statistics for candidate General Linear Models predicting bird density, averaged by year (i.e., "between-transect" analyses). Bird density estimates derived from line-transect surveys conducted at WARB, Lakehurst, and PRNAS during the breeding season, 2008, 2009 and 2011. Bolded models represent those within ≤ 2 AIC_c points of the best-performing model.

Model ID	k^*	(-)2 Log-Likelihood	AIC_c	ΔAIC_c	w_i	Model R^2
Breeding Season - Total Bird Density						
Base Model	7	185.17	199.7	17.4	0.00	
Vegetation Model (without Veg. Height x Site interaction)	11	173.66	196.9	14.7	0.00	
Vegetation Model (with Veg. Height x Site interaction)	**13**	**154.52**	**182.2**	**0.0**	**0.99**	**0.49**
Management Model	8	175.49	192.2	9.9	0.01	
Breeding Season - Strike-Risk Bird Density (based on ranking in Zakrajsek and Bissonette 2005)						
Base Model	7	158.88	173.39	13.7	0.00	
Vegetation Model (without Veg. Height x Site interaction)	11	148.75	171.98	12.3	0.00	
Vegetation Model (with Veg. Height x Site interaction)	**13**	**131.94**	**159.65**	**0.0**	**1.00**	**0.27**
Management Model	8	158.37	175.03	15.4	0.00	
Breeding Season - Strike-Risk Bird Density (based on ranking in Dolbeer and Wright 2009)						
Base Model	7	117.58	132.09	23.2	0.00	
Vegetation Model (without Veg. Height x Site interaction)	**11**	**85.66**	**108.89**	**0.0**	**0.61**	**0.25**
Vegetation Model (with Veg. Height x Site interaction)	**13**	**82.06**	**109.77**	**0.9**	**0.39**	**0.26**
Management Model	8	107.17	123.83	14.9	0.00	
Breeding Season - Conservation-Value Bird Density						
Base Model	7	15.87	30.38	28.8	0.00	
Vegetation Model (without Veg. Height x Site interaction)	**11**	**-21.60**	**1.63**	**0.0**	**0.90**	**0.40**
Vegetation Model (with Veg. Height x Site interaction)	13	-21.78	5.93	4.3	0.10	
Management Model	8	12.72	29.38	27.8	0.00	

* The number of estimable parameters in the model including intercept and error term.

Table 5. Model comparisons and fit statistics for candidate General Linear Models predicting bird density, averaged by year (i.e., "between-transect" analyses). Bird density estimates derived from line-transect surveys conducted at WARB, Lakehurst, and PRNAS during spring migration, 2008, 2009 and 2011. Bolded models represent those within ≤ 2 AIC_c points of the best-performing model.

Model ID	k^*	**(-)2 Log-Likelihood**	***AICc***	**ΔAIC_c**	w_i	**Model R^2**
Spring Migration - Total Bird Density						
Base Model	7	278.21	292.8	17.1	0.00	
Vegetation Model (without Veg. Height x Site interaction)	11	265.17	288.5	12.9	0.00	
Vegetation Model (with Veg. Height x Site interaction)	**13**	**247.77**	**275.6**	**0.0**	**1.00**	**0.48**
Management Model	8	271.84	288.6	12.9	0.00	
Spring Migration - Strike-Risk Bird Density (based on ranking in Zakrajsek and Bissonette 2005)						
Base Model	7	276.71	291.3	52.2	0.00	
Vegetation Model (without Veg. Height x Site interaction)	11	230.57	253.9	14.8	0.00	
Vegetation Model (with Veg. Height x Site interaction)	**13**	**211.21**	**239.1**	**0.0**	**1.00**	**0.32**
Management Model	8	266.28	283.0	43.9	0.00	
Spring Migration - Strike-Risk Bird Density (based on ranking in Dolbeer and Wright 2009)						
Base Model	7	281.09	295.6	39.5	0.00	
Vegetation Model (without Veg. Height x Site interaction)	11	236.14	259.5	3.3	0.16	
Vegetation Model (with Veg. Height x Site interaction)	**13**	**228.30**	**256.2**	**0.0**	**0.84**	**0.26**
Management Model	8	266.38	283.1	26.9	0.00	
Spring Migration - Conservation-Value Bird Density						
Base Model	7	37.95	52.5	16.4	0.00	
Vegetation Model (without Veg. Height x Site interaction)	**11**	**12.75**	**36.1**	**0.0**	**0.80**	**0.37**
Vegetation Model (with Veg. Height x Site interaction)	13	11.16	39.0	2.9	0.18	
Management Model	8	36.69	53.4	17.3	0.00	

* The number of estimable parameters in the model including intercept and error term.

Table 6. Model comparisons and fit statistics for candidate General Linear Models predicting bird density, averaged by year (i.e., "between-transect" analyses). Bird density estimates derived from line-transect surveys conducted at WARB, Lakehurst, and PRNAS during fall migration, 2007, 2008 and 2010. Bolded models represent those within ≤ 2 AIC_c points of the best-performing model.

Model ID	k^*	**(-)2 Log-Likelihood**	***AICc***	**ΔAIC_c**	w_i	**Model R^2**
Fall Migration - Total Bird Density						
Base Model	**7**	**469.95**	**484.4**	**0.0**	**0.59**	**0.24**
Vegetation Model (without Veg. Height x Site interaction)	11	464.52	487.7	3.3	0.12	
Vegetation Model (with Veg. Height x Site interaction)	13	460.88	488.5	4.1	0.08	
Management Model	8	469.84	486.5	2.0	0.21	
Fall Migration - Strike-Risk Bird Density (based on ranking in Zakrajsek and Bissonette 2005)						
Base Model	7	339.14	353.6	11.7	0.00	
Vegetation Model (without Veg. Height x Site interaction)	**11**	**318.73**	**341.9**	**0.0**	**0.55**	**0.16**
Vegetation Model (with Veg. Height x Site interaction)	13	316.29	343.9	2.0	0.20	
Management Model	**8**	**326.89**	**343.5**	**1.6**	**0.25**	**0.13**
Fall Migration - Strike-Risk Bird Density (based on ranking in Dolbeer and Wright 2009)						
Base Model	7	240.26	254.8	2.3	0.21	
Vegetation Model (without Veg. Height x Site interaction)	11	232.82	256.0	3.5	0.11	
Vegetation Model (with Veg. Height x Site interaction)	13	231.08	258.7	6.2	0.03	
Management Model	**8**	**235.84**	**252.5**	**0.0**	**0.65**	**0.10**
Fall Migration - Conservation-Value Bird Density						
Base Model	**7**	**176.12**	**190.6**	**0.0**	**0.65**	**0.14**
Vegetation Model (without Veg. Height x Site interaction)	11	172.85	196.0	5.4	0.04	
Vegetation Model (with Veg. Height x Site interaction)	13	172.11	199.7	9.1	0.01	
Management Model	8	176.12	192.8	2.1	0.22	

* The number of estimable parameters in the model including intercept and error term.

Table 7. Parameter estimates from best-fitting General Linear Models (Tables 4-6) depicting the relationship between vegetative structure, mowing, and mean seasonal bird density (Total, Strike-Risk, and Conservation-Value) among transects. Bird density estimates derived from line-transect surveys conducted at WARB, Lakehurst, and PRNAS during fall migration, spring migration and breeding season, 2007-2011.

	Breeding Season					Spring Migration					Fall Migration				
Model Parameters	Estimate	SE	*P*	Lower CI	Upper CI	Estimate	SE	*P*	Lower CI	Upper CI	Estimate	SE	*P*	Lower CI	Upper CI
Total Bird Density															
Intercept	0.913	0.155	**< 0.001**	0.608	1.219	0.354	0.193	0.067	-0.025	0.734	1.502	0.100	**<0.001**	1.305	1.699
Study Year (vs. Year 1)															
Year 2	0.111	0.060	0.065	-0.007	0.228	0.283	0.088	**0.002**	0.109	0.457	-0.541	0.107	**<0.001**	-0.752	-0.331
Year 3	-0.051	0.062	0.414	-0.173	0.071	-0.028	0.078	0.716	-0.182	0.125	-0.578	0.105	**<0.001**	-0.786	-0.371
Site (vs. Lakehurst)															
Patuxent	0.518	0.199	**0.010**	0.126	0.909	1.919	0.258	**<0.001**	1.410	2.429	0.125	0.110	0.258	-0.092	0.342
Westover	0.321	0.179	0.073	-0.031	0.674	0.741	0.251	**0.004**	0.246	1.236	0.286	0.100	**0.004**	0.090	0.483
Time (vs. Morning)															
Evening	-0.372	0.047	**<0.001**	-0.466	-0.279	-0.237	0.065	**<0.001**	-0.364	-0.110	-0.453	0.086	**<0.001**	-0.624	-0.283
% Shrub Cover	0.371	0.125	**0.003**	0.126	0.617	0.185	0.206	0.368	-0.220	0.591	--	--	--	--	--
% Grass Cover	-0.181	0.157	0.251	-0.49	0.1288	0.334	0.197	0.093	-0.056	0.723	--	--	--	--	--
Vegetation Height (linear)	0.005	0.017	0.752	-0.028	0.039	-0.060	0.026	**0.021**	-0.112	-0.009	--	--	--	--	--
Vegetation Height (quadratic)	0.0008	0.0006	0.187	-0.0004	0.0021	0.0036	0.0013	**0.007**	0.0010	0.0062	--	--	--	--	--
Vegetation Height x Site (Patuxent)	-0.044	0.016	**0.009**	-0.076	-0.011	-0.099	0.027	**<0.001**	-0.151	-0.046	--	--	--	--	--
Vegetation Height x Site (Westover)	0.021	0.015	0.173	-0.009	0.051	-0.099	0.048	**0.044**	-0.194	-0.003	--	--	--	--	--
Strike-Risk Bird Density (based on ranking in Zakrajsek and Bissonette 2005)															
Intercept	0.486	0.147	**0.001**	0.195	0.776	0.174	0.176	0.326	-0.174	0.522	0.422	0.270	0.119	-0.108	0.952
Study Year (vs. Year 1)															
Year 2	0.138	0.057	**0.016**	0.026	0.250	0.350	0.081	**<0.001**	0.190	0.510	0.152	0.082	0.065	0.010	0.314
Year 3	0.045	0.059	0.441	-0.071	0.161	-0.056	0.071	0.438	-0.197	0.085	0.122	0.079	0.124	-0.033	0.277
Site (vs. Lakehurst)															
Patuxent	0.698	0.189	**<0.001**	0.325	1.070	1.291	0.237	**<0.001**	0.824	1.758	0.080	0.122	0.513	-0.159	0.319
Westover	0.467	0.170	**0.006**	0.132	0.803	0.405	0.230	0.080	-0.048	0.859	0.101	0.089	0.258	-0.073	0.275
Time (vs. Morning)															
Evening	-0.249	0.045	**<0.001**	-0.337	-0.160	-0.049	0.059	0.412	-0.165	0.068	-0.154	0.064	**0.016**	-0.280	-0.028
% Shrub Cover	0.194	0.119	0.103	-0.040	0.428	-0.247	0.188	0.192	-0.618	0.125	-0.383	0.175	**0.030**	-0.726	-0.039
% Grass Cover	0.020	0.149	0.892	-0.274	0.315	0.563	0.181	**0.002**	0.206	0.920	-0.053	0.179	0.768	-0.404	0.298
Vegetation Height (linear)	-0.054	0.016	**0.001**	-0.086	-0.022	-0.102	0.024	**<0.001**	-0.149	-0.055	-0.020	0.023	0.379	-0.065	0.025
Vegetation Height (quadratic)	0.0028	0.0006	**<0.001**	0.0016	0.0040	0.0042	0.0012	**0.001**	0.0018	0.0066	0.0000	0.0007	0.991	-0.0013	0.0013
Vegetation Height x Site (Patuxent)	-0.063	0.016	**<0.001**	-0.094	-0.032	-0.091	0.024	**<0.001**	-0.139	-0.043	--	--	--	--	--
Vegetation Height x Site (Westover)	-0.026	0.014	0.069	-0.055	0.002	-0.112	0.044	**0.013**	-0.199	-0.024	--	--	--	--	--
Mow (vs. Infrequent)															
Frequent	--	--	--	--	--	--	--	--	--	--	0.289	0.083	**0.001**	0.127	0.451

Table 7 (cont.). Parameter estimates from best-fitting General Linear Models (Tables 4-6) depicting the relationship between vegetative structure, mowing, and mean seasonal bird density (Total, Strike-Risk, and Conservation-Value) among transects. Bird density estimates derived from line-transect surveys conducted at WARB, Lakehurst, and PRNAS during fall migration, spring migration and breeding season, 2007-2011.

	Breeding Season					Spring Migration					Fall Migration				
Model Parameters	Estimate	SE	*P*	Lower CI	Upper CI	Estimate	SE	*P*	Lower CI	Upper CI	Estimate	SE	*P*	Lower CI	Upper CI
Strike-Risk Bird Density (based on ranking in Dolbeer and Wright 2009)															
Intercept	0.496	0.121	**<0.001**	0.258	0.735	-0.078	0.184	0.671	-0.441	0.284	0.135	0.061	**0.028**	0.015	0.256
Study Year (vs. Year 1)															
Year 2	0.153	0.049	**0.002**	0.056	0.249	0.279	0.084	**0.001**	0.113	0.446	-0.014	0.065	0.836	-0.142	0.115
Year 3	0.038	0.051	0.461	-0.063	0.140	-0.047	0.074	0.531	-0.194	0.100	-0.019	0.064	0.763	-0.147	0.108
Site (vs. Lakehurst)															
Patuxent	0.116	0.057	**0.044**	0.003	0.228	0.934	0.247	**<0.001**	0.448	1.421	0.072	0.081	0.377	-0.088	0.232
Westover	0.201	0.053	**<0.001**	0.096	0.306	0.196	0.240	0.414	-0.276	0.669	0.061	0.069	0.373	-0.074	0.197
Time (vs. Morning)															
Evening	-0.145	0.040	**<0.001**	-0.225	-0.066	-0.034	0.062	0.585	-0.155	0.088	-0.188	0.053	**<0.001**	-0.292	-0.084
% Shrub Cover	-0.022	0.095	0.816	-0.210	0.166	-0.322	0.196	0.103	-0.709	0.065	--	--	--	--	--
% Grass Cover	0.066	0.132	0.615	-0.193	0.326	0.748	0.188	**<0.001**	0.376	1.119	--	--	--	--	--
Vegetation Height (linear)	-0.052	0.014	**<0.001**	-0.079	-0.026	-0.082	0.025	**0.001**	-0.131	-0.033	--	--	--	--	--
Vegetation Height (quadratic)	0.0010	0.0004	**0.008**	0.0003	0.0017	0.0026	0.0013	**0.038**	0.0001	0.0051	--	--	--	--	--
Vegetation Height x Site (Patuxent)	--	--	--	--	--	-0.060	0.025	**0.019**	-0.110	-0.010	--	--	--	--	--
Vegetation Height x Site (Westover)	--	--	--	--	--	-0.071	0.046	0.128	-0.162	0.021	--	--	--	--	--
Mow (vs. Infrequent)															
Frequent	--	--	--	--	--	--	--	--	--	--	0.142	0.068	**0.038**	0.008	0.276
Conservation-Value Bird Density															
Intercept	0.325	0.096	**0.001**	0.137	0.514	0.266	0.100	0.008	0.069	0.462	0.521	0.054	**< 0.001**	0.415	0.627
Study Year (vs. Year 1)															
Year 2	0.054	0.039	0.167	-0.023	0.130	-0.001	0.046	0.985	-0.091	0.089	-0.220	0.057	**< 0.001**	-0.333	-0.107
Year 3	0.015	0.041	0.706	-0.065	0.095	-0.044	0.044	0.316	-0.130	0.042	-0.227	0.057	**< 0.001**	-0.338	-0.115
Site (vs. Lakehurst)															
Patuxent	-0.149	0.045	0.001	-0.238	-0.060	0.297	0.057	**<0.001**	0.184	0.409	-0.181	0.059	**0.003**	-0.297	-0.064
Westover	0.075	0.042	0.076	-0.008	0.158	0.190	0.053	**<0.001**	0.086	0.294	-0.154	0.054	**0.005**	-0.259	-0.048
Time (vs. Morning)															
Evening	-0.244	0.032	**<0.001**	-0.307	-0.181	-0.135	0.037	**<0.001**	-0.207	-0.063	-0.081	0.046	0.084	-0.172	0.011
% Shrub Cover	0.113	0.075	0.134	-0.035	0.262	0.323	0.110	**0.004**	0.106	0.540	--	--	--	--	--
% Grass Cover	-0.118	0.104	0.257	-0.323	0.087	-0.268	0.108	**0.014**	-0.480	-0.056	--	--	--	--	--
Vegetation Height (linear)	0.055	0.011	**<0.001**	0.034	0.076	0.009	0.014	0.501	-0.018	0.037	--	--	--	--	--
Vegetation Height (quadratic)	-0.0014	0.0003	**<0.001**	-0.0019	-0.0008	0.0004	0.0005	0.361	-0.0005	0.0014	--	--	--	--	--
Vegetation Height x Site (Patuxent)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Vegetation Height x Site (Westover)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 8. Model comparisons and fit statistics for candidate mixed models depicting bird density association with daily vegetative structure and recent mowing activity within transects (i.e., "within-transect" analyses). Bird density estimates derived from line-transect surveys conducted at WARB (n = 12-19 rounds/transect), Lakehurst (n = 13-17 rounds/transect), and PRNAS (n = 10-18 rounds/transect) during breeding season, 2008, 2009, and 2011. Bolded models represent those that best fit the data.

Model ID	k^*	(-)2 Log-Likelihood	*AICc*	Δ AIC$_c$	w_i
Breeding Season: Total Bird Density					
Base Model	8	702.0	718.2	20.5	0.0
Vegetation Structure (without Veg. Height x Site interaction)	10	686.7	707.1	9.3	0.0
Vegetation Structure (with Veg. Height x Site interaction)	**12**	**673.2**	**697.7**	**0.0**	**1.0**
Recent Management History	9	699.4	717.7	20.0	0.0
Breeding Season: Strike-Risk Bird Density					
Base Model	8	689.5	705.8	17.4	0.0
Vegetation Structure (without Veg. Height x Site interaction)	10	681.7	702.0	13.7	0.0
Vegetation Structure (with Veg. Height x Site interaction)	**12**	**663.9**	**688.4**	**0.0**	**1.0**
Recent Management History	9	689.4	707.7	19.3	0.0
Breeding Season: Conservation-Value Bird Density					
Base Model	7	303.4	317.6	20.3	0.0
Vegetation Structure (without Veg. Height x Site interaction)	**9**	**279.0**	**297.3**	**0.0**	**0.8**
Vegetation Structure (with Veg. Height x Site interaction)	11	278.3	300.7	3.4	0.2
Recent Management History	8	296.5	312.7	15.5	0.0

* The number of estimable parameters in the model.

Table 9. Model comparisons and fit statistics for candidate mixed models depicting bird density association with daily vegetative structure and recent mowing activity within transects (i.e., "within-transect" analyses). Bird density estimates derived from line-transect surveys conducted at WARB (n = 9-13 rounds/transect), Lakehurst (n = 9-13 rounds/transect), and PRNAS (n = 5-11 rounds/transect) during spring migration, 2008, 2009, and 2011. Bolded models represent those that best fit the data.

Model ID	k^*	(-)2 Log-Likelihood	*AICc*	Δ AIC$_c$	w_i
Spring Migration: Total Bird Density					
Base Model	7	606.21	620.5	20.4	0.00
Vegetation Structure (without Veg. Height x Site interaction)	9	591.48	609.9	9.8	0.01
Vegetation Structure (with Veg. Height x Site interaction)	**11**	**577.46**	**600.1**	**0.0**	**0.99**
Recent Management History	8	598.09	614.4	14.4	0.00
Spring Migration: Strike-Risk Bird Density					
Base Model	7	429.88	444.1	28.3	0.00
Vegetation Structure (without Veg. Height x Site interaction)	9	401.67	420.1	4.2	0.11
Vegetation Structure (with Veg. Height x Site interaction)	**11**	**393.25**	**415.8**	**0.0**	**0.89**
Recent Management History	8	429.87	446.2	30.3	0.00
Spring Migration: Conservation-Value Bird Density					
Base Model	7	279.00	293.2	19.2	0.00
Vegetation Structure (without Veg. Height x Site interaction)	**9**	**256.59**	**275.0**	**1.0**	**0.38**
Vegetation Structure (with Veg. Height x Site interaction)	**11**	**251.44**	**274.0**	**0.0**	**0.62**
Recent Management History	8	270.83	287.1	13.1	0.00

* The number of estimable parameters in the model.

Table 10. Model comparisons and fit statistics for candidate mixed models depicting bird density association with daily vegetative structure and recent mowing activity within transects (i.e., "within-transect" analyses). Bird density estimates derived from line-transect surveys conducted at WARB (n = 17-25 rounds/transect), Lakehurst (n = 21-24 rounds/transect), and PRNAS (n = 8-17 rounds/transect) during fall migration, 2007, 2008, and 2010. Bolded models represent those that best fit the data.

Model ID	k^*	**(-)2 Log-Likelihood**	***AICc***	ΔAIC_c	w_i
Fall Migration: Total Bird Density					
Base Model	8	1721.02	1737.19	13.01	0.00
Vegetation Structure (without Veg. Height x Site interaction)	**10**	**1703.91**	**1724.18**	**0.00**	**0.85**
Vegetation Structure (with Veg. Height x Site interaction)	12	1703.68	1728.06	3.88	0.12
Recent Management History	9	1713.15	1731.37	7.19	0.02
Fall Migration: Strike-Risk Bird Density					
Base Model	8	750.77	766.94	21.81	0.00
Vegetation Structure (without Veg. Height x Site interaction)	**10**	**726.81**	**747.07**	**1.95**	**0.27**
Vegetation Structure (with Veg. Height x Site interaction)	**12**	**720.75**	**745.13**	**0.00**	**0.73**
Recent Management History	9	742.50	760.72	15.59	0.00
Fall Migration: Conservation-Value Bird Density					
Base Model	8	763.80	779.98	6.08	0.04
Vegetation Structure (without Veg. Height x Site interaction)	**10**	**753.63**	**773.89**	**0.00**	**0.76**
Vegetation Structure (with Veg. Height x Site interaction)	12	752.37	776.74	2.85	0.18
Recent Management History	9	763.07	781.29	7.40	0.02

* The number of estimable parameters in the model.

Table 11. Fixed-effect parameter estimates from best-fitting Generalized Linear Mixed Models (Tables 8-10) depicting the relationship between vegetative structure, recent mowing history, and bird density (Total, Conservation-Value, and Strike-Risk) within individual transects (i.e., "within transect" analyses). Bird density estimates derived from line-transect surveys conducted at WARB, Lakehurst, and PRNAS during fall migration, spring migration and breeding season, 2007-2011.

	Breeding Season			Spring Migration			Fall Migration		
Model Parameters	Estimate	SE	*P*	Estimate	SE	*P*	Estimate	SE	*P*
Total Bird Density									
Intercept	0.367	0.168	**0.030**	0.035	0.220	0.875	-0.049	0.260	0.850
Study Year (vs. Year 1)									
Year 2	0.176	0.075	**0.019**	0.186	0.099	0.061	-0.915	0.112	**< 0.001**
Year 3	0.025	0.075	0.745	-0.154	0.095	0.105	-0.930	0.113	**< 0.001**
Site (vs. Lakehurst)									
Patuxent	0.411	0.229	0.073	1.767	0.322	**< 0.001**	0.641	0.207	**0.002**
Westover	0.317	0.206	0.125	-0.382	0.364	0.296	0.691	0.176	**< 0.001**
Time (vs. Morning)									
Evening	-0.533	0.081	**< 0.001**	-0.158	0.094	0.094	-0.590	0.118	**< 0.001**
Vegetation Height (linear)	0.007	0.019	0.710	-0.109	0.024	**< 0.001**	0.110	0.028	**< 0.001**
Vegetation Height (quadratic)	0.0007	0.0006	0.244	0.0024	0.0007	**< 0.001**	-0.0028	0.0008	**0.001**
Vegetation Height x Site (Patuxent)	-0.028	0.017	0.098	0.023	0.027	0.389	--	--	--
Vegetation Height x Site (Westover)	0.031	0.016	0.054	0.204	0.054	**< 0.001**	--	--	--
Strike-Risk Bird Density									
Intercept	-0.600	0.367	0.102	-0.669	0.423	0.115	-4.037	1.071	**< 0.001**
Study Year (vs. Year 1)									
Year 2	0.405	0.178	**0.023**	0.540	0.158	**< 0.001**	1.593	0.369	**< 0.001**
Year 3	0.042	0.185	0.819	-0.670	0.178	**< 0.001**	1.165	0.370	**0.002**
Site (vs. Lakehurst)									
Patuxent	1.158	0.480	**0.016**	1.484	0.643	**0.022**	1.241	1.039	0.233
Westover	0.095	0.460	0.837	-1.382	0.718	0.055	2.367	0.810	**0.004**
Time (vs. Morning)									
Evening	-0.798	0.205	**< 0.001**	0.175	0.153	0.256	-0.520	0.328	0.113
Vegetation Height (linear)	-0.138	0.041	**< 0.001**	-0.240	0.054	**< 0.001**	0.051	0.143	0.719
Vegetation Height (quadratic)	0.0057	0.0013	**< 0.001**	0.0051	0.0014	**< 0.001**	-0.0033	0.0049	0.498
Vegetation Height x Site (Patuxent)	-0.108	0.038	**0.005**	0.010	0.059	0.866	-0.115	0.090	0.203
Vegetation Height x Site (Westover)	0.044	0.037	0.228	0.294	0.106	**0.006**	-0.133	0.064	**0.040**

Table 11 (cont.). Fixed-effect parameter estimates from best-fitting Generalized Linear Mixed Models (Tables 8-10) depicting the relationship between vegetative structure, recent mowing history, and bird density (Total, Conservation-Value, and Strike-Risk) at individual transect surveys (i.e., "within transect" analyses). Bird density estimates derived from line-transect surveys conducted at WARB, Lakehurst, and PRNAS during fall migration, spring migration and breeding season, 2007-2011.

	Breeding Season			**Spring Migration**			**Fall Migration**		
Conservation-Value Bird Density									
Model Parameters	Estimate	SE	*P*	Estimate	SE	*P*	Estimate	SE	*P*
Intercept	-0.831	0.188	**< 0.001**	-1.555	0.333	**< 0.001**	-1.957	0.489	**< 0.001**
Study Year (vs. Year 1)									
Year 2	0.015	0.104	0.886	-0.109	0.213	0.607	-1.362	0.236	**< 0.001**
Year 3	0.017	0.103	0.872	-0.140	0.205	0.494	-1.355	0.246	**< 0.001**
Site (vs. Lakehurst)									
Patuxent	-0.318	0.126	**0.012**	0.463	0.484	0.339	0.085	0.303	0.779
Westover	0.069	0.099	0.488	-0.972	0.618	0.116	-0.440	0.217	**0.043**
Time (vs. Morning)									
Evening	-0.537	0.121	**< 0.001**	-0.546	0.226	**0.016**	-0.440	0.261	0.093
Vegetation Height (linear)	0.118	0.025	**< 0.001**	0.027	0.040	0.504	0.168	0.063	**0.008**
Vegetation Height (quadratic)	-0.0029	0.0008	**< 0.001**	0.0001	0.0010	0.914	-0.0048	0.0020	**0.017**
Vegetation Height x Site (Patuxent)	--	--	--	0.042	0.043	0.322	--	--	--
Vegetation Height x Site (Westover)	--	--	--	0.226	0.100	**0.025**	--	--	--

Table 12. Logistic and linear models used to predict relationships among individual species group occurrence (strike-risk species) or abundance (grasshopper sparrow), vegetation structure, and mowing history on WARB, Lakehurst, and PRNAS, 2007-2011. Best-performing models (within 2 AIC_c) are bolded.

		k	AIC_c	ΔAIC_c	w_i	R^{2*}
Blackbird/Starling (logistic)						
Breeding Season	**Base Model**	**6**	**235.8**	**0.0**	**0.35**	**0.16**
	Vegetation Model	**9**	**237.5**	**1.7**	**0.15**	**0.18**
	Veg. Model (w/ interaction)	**11**	**237.2**	**1.4**	**0.17**	**0.22**
	Management Model	**7**	**235.9**	**0.1**	**0.33**	**0.17**
Spring Migration	**Base Model**	**6**	**149.7**	**0.0**	**0.46**	**0.14**
	Vegetation Model	**9**	**151.7**	**2.0**	**0.17**	**0.18**
	Veg. Model (w/ interaction)	11	153.6	3.9	0.07	
	Management Model	**7**	**150.5**	**0.8**	**0.30**	**0.15**
Fall Migration	**Base Model**	**6**	**80.1**	**0.0**	**0.35**	**0.21**
	Vegetation Model	**9**	**80.2**	**0.1**	**0.33**	**0.29**
	Veg. Model (w/ interaction)	11	82.9	2.9	0.08	
	Management Model	**7**	**80.9**	**0.8**	**0.24**	**0.23**
Swallow (logistic)						
Breeding Season	**Base Model**	**6**	**173.7**	**0.0**	**0.41**	**0.65**
	Vegetation Model	**9**	**174.0**	**0.3**	**0.35**	**0.67**
	Veg. Model (w/ interaction)	11	177.3	3.6	0.07	
	Management Model	**7**	**175.5**	**1.8**	**0.17**	**0.66**
Spring Migration	**Base Model**	**6**	**215.0**	**0.0**	**0.68**	**0.28**
	Vegetation Model	9	220.8	5.8	0.04	
	Veg. Model (w/ interaction)	11	225.0	10.0	0.00	
	Management Model	**7**	**216.8**	**1.8**	**0.27**	**0.29**
Fall Migration	Base Model	6	138.2	3.5	0.07	
	Vegetation Model	**9**	**134.7**	**0.0**	**0.42**	**0.41**
	Veg. Model (w/ interaction)	11	137.0	2.3	0.13	
	Management Model	**7**	**135.0**	**0.2**	**0.37**	**0.38**
Horned Lark (logistic)						
Breeding Season	Base Model	6	273.8	23.2	0.00	
	Vegetation Model	**9**	**250.6**	**0.0**	**0.88**	**0.26**
	Veg. Model (w/ interaction)	11	254.6	3.9	0.12	
	Management Model	7	268.9	18.2	0.00	
Spring Migration	Base Model	6	225.7	17.3	0.00	
	Vegetation Model	9	214.6	6.3	0.04	
	Veg. Model (w/ interaction)	11	216.5	8.2	0.02	
	Management Model	**7**	**208.4**	**0.0**	**0.94**	**0.28**
Fall Migration	Base Model	6	232.0	14.6	0.00	
	Vegetation Model	**9**	**217.4**	**0.0**	**0.58**	**0.37**
	Veg. Model (w/ interaction)	**11**	**218.1**	**0.7**	**0.41**	**0.38**
	Management Model	7	225.3	7.9	0.01	
Grasshopper Sparrow (linear)						
Breeding Season	Base Model	7	30.9	18.4	0.00	
	Vegetation Model	10	21.9	9.4	0.01	
	Veg. Model (w/ interaction)	**12**	**12.5**	**0.0**	**0.99**	**0.39**
	Management Model	8	26.9	14.5	0.00	

*For logistic models, this is Nagelkerke's pseduo R2: a relative measure of model performance vs. an empty (null) model (range: 0-1).

Table 13. Parameter estimates depicting the relationship between blackbird-starling occurrence, vegetation structure, and mowing history on WARB, Lakehurst, and PRNAS, 2007-2011. Estimates derived from best-performing models (within 2 AIC_c) listed in Table 12.

	Estimate	LCI	UCI	P
Blackbird-Starling - Breeding Season				
Intercept	-1.547	-3.145	0.051	0.058
Study Year (vs. Year 1)				
Year 2	0.806	-0.010	1.621	0.053
Year 3	0.157	-0.741	1.055	0.731
Site (vs. Lakehurst)				
PRNAS	1.420	-0.755	3.595	0.201
WARB	0.949	-1.292	3.189	0.407
Time (vs. Morning)				
Evening	-1.499	-2.274	-0.724	**< 0.001**
%Shrub Cover	0.876	-0.578	2.331	0.237
% Grass Cover	-1.841	-4.073	0.390	0.106
Vegetation Height	0.139	-0.076	0.353	0.205
Veg. Height x Site (PRNAS)	-0.192	-0.372	-0.012	**0.037**
Veg. Height x Site (WARB)	-0.189	-0.406	0.028	0.089
Mow (vs. Infrequent)				
Frequent	-0.585	-1.396	0.226	0.157
Blackbird-Starling - Spring Migration				
Intercept	-2.975	-4.515	-1.435	**< 0.001**
Study Year (vs. Year 1)				
Year 2	1.076	-0.015	2.168	0.053
Year 3	-0.213	-1.488	1.062	0.743
Site (vs. Lakehurst)				
PRNAS	1.322	-0.021	2.664	0.054
WARB	0.304	-1.102	1.709	0.672
Time (vs. Morning)				
Evening	-0.740	-1.747	0.268	0.150
%Shrub Cover	-1.164	-3.726	1.399	0.373
% Grass Cover	1.891	-0.634	4.415	0.142
Vegetation Height	-0.093	-0.220	0.035	0.155
Mow (vs. Infrequent)				
Frequent	0.616	-0.467	1.700	0.265
Blackbird-Starling - Fall Migration				
Intercept	-2.658	-5.585	0.270	0.075
Study Year (vs. Year 1)				
Year 2	0.600	-0.954	2.155	0.449
Year 3	-0.494	-2.370	1.382	0.606
Site (vs. Lakehurst)				
PRNAS	0.169	-2.249	2.586	0.891
WARB	0.316	-2.068	2.700	0.795
Time (vs. Morning)				
Evening	-17.952	-3281.875	3245.971	0.991
%Shrub Cover	-0.126	-0.291	0.039	0.135
% Grass Cover	-3.068	-8.230	2.095	0.244
Vegetation Height	0.943	-0.767	2.652	0.280
Mow (vs. Infrequent)				
Frequent	1.335	-1.732	4.401	0.394

Table 14. Parameter estimates depicting the relationship between swallow occurrence, vegetation structure, and mowing history on WARB, Lakehurst, and PRNAS, 2007-2011. Estimates derived from best-performing models (within 2 AIC_c) listed in Table 12.

	Estimate	LCI	UCI	P
Swallow - Breeding Season				
Intercept	1.211	-1.547	3.969	0.389
Study Year (vs. Year 1)				
Year 2	0.854	-0.160	1.867	0.099
Year 3	0.630	-0.380	1.641	0.222
Site (vs. Lakehurst)				
PRNAS	-6.412	-8.849	-3.974	**< 0.001**
WARB	-0.450	-1.404	0.503	0.354
Time (vs. Morning)				
Evening	-2.427	-3.288	-1.566	**< 0.001**
%Shrub Cover	2.613	0.296	4.930	**0.027**
% Grass Cover	2.633	-0.898	6.164	0.144
Vegetation Height	-0.062	-0.197	0.073	0.368
Mow (vs. Infrequent)				
Frequent	-0.338	-1.432	0.756	0.545
Swallow - Spring Migration				
Intercept	0.091	-0.647	0.829	0.809
Study Year (vs. Year 1)				
Year 2	0.455	-0.397	1.308	0.295
Year 3	0.526	-0.322	1.374	0.224
Site (vs. Lakehurst)				
PRNAS	-2.411	-3.561	-1.261	**< 0.001**
WARB	-1.105	-1.909	-0.301	**0.007**
Time (vs. Morning)				
Evening	-1.765	-2.599	-0.931	**< 0.001**
Mow (vs. Infrequent)				
Frequent	0.275	-0.698	1.248	0.580
Swallow - Fall Migration				
Intercept	-19.760	-2239.634	2200.114	0.986
Study Year (vs. Year 1)				
Year 2	18.280	-2201.591	2238.152	0.987
Year 3	18.089	-2201.782	2237.961	0.987
Site (vs. Lakehurst)				
PRNAS	-2.101	-4.197	-0.004	0.050
WARB	-0.450	-1.609	0.710	0.447
Time (vs. Morning)				
Evening	-1.525	-2.564	-0.486	**0.004**
%Shrub Cover	3.856	1.224	6.489	**0.004**
% Grass Cover	0.775	-2.281	3.832	0.619
Vegetation Height	0.037	-0.065	0.139	0.478
Mow (vs. Infrequent)				
Frequent	-1.752	-3.403	-0.102	**0.037**

Table 15. Parameter estimates depicting the relationship between horned lark occurrence, vegetation structure, and mowing history on WARB, Lakehurst, and PRNAS, 2007-2011. Estimates derived from best-performing models (within 2 AIC_c) listed in Table 12.

	Estimate	LCI	UCI	P
Horned Lark - Breeding Season				
Intercept	2.345	0.605	4.173	**0.010**
Study Year (vs. Year 1)				
Year 2	0.394	-0.381	1.180	0.321
Year 3	-0.063	-0.883	0.751	0.879
Site (vs. Lakehurst)				
PRNAS	-0.156	-1.159	0.809	0.754
WARB	-0.393	-1.295	0.484	0.384
Time (vs. Morning)				
Evening	-1.370	-2.087	-0.701	**< 0.001**
%Shrub Cover	-1.594	-3.526	0.149	0.086
% Grass Cover	-0.523	-2.661	1.612	0.629
Vegetation Height	-0.174	-0.281	-0.082	**0.001**
Horned Lark - Spring Migration				
Intercept	-0.985	-1.806	-0.224	**0.014**
Study Year (vs. Year 1)				
Year 2	-0.432	-1.322	0.436	0.332
Year 3	-0.127	-0.966	0.707	0.765
Site (vs. Lakehurst)				
PRNAS	-1.231	-2.551	-0.010	0.056
WARB	0.082	-0.957	1.075	0.874
Time (vs. Morning)				
Evening	-1.699	-2.632	-0.876	**< 0.001**
Mow Frequency (vs. Infrequent)				
Frequent	2.020	1.079	3.073	**< 0.001**
Horned Lark - Fall Migration				
Intercept	0.544	-1.647	2.735	0.626
Study Year (vs. Year 1)				
Year 2	2.135	1.117	3.153	**< 0.001**
Year 3	1.311	0.357	2.265	**0.007**
Site (vs. Lakehurst)				
PRNAS	1.015	-1.892	3.921	0.494
WARB	0.700	-1.149	2.549	0.458
Time (vs. Morning)				
Evening	-1.981	-2.804	-1.158	**< 0.001**
%Shrub Cover	0.184	-1.809	2.177	0.856
% Grass Cover	-1.280	-3.333	0.773	0.222
Vegetation Height	-0.131	-0.254	-0.009	**0.035**
Veg. Height x Site (PRNAS)	-0.184	-0.443	0.074	0.163
Veg. Height x Site (WARB)	0.015	-0.176	0.205	0.881

Table 16. Parameter estimates depicting the relationship between grasshopper sparrow density, vegetation structure, and mowing history on WARB, Lakehurst, and PRNAS, during breeding season, 2008, 2009, and 2011. Estimates derived from best-performing model listed in Table 12.

	Estimate	LCI	UCI	P
Grasshopper Sparrow - Breeding Season				
Intercept	0.314	0.111	0.517	**0.003**
Study Year (vs. Year 1)				
Year 2	-0.014	-0.094	0.067	0.737
Year 3	-0.001	-0.085	0.083	0.974
Site (vs. Lakehurst)				
PRNAS	0.183	-0.031	0.396	0.093
WARB	0.044	-0.191	0.278	0.715
Time (vs. Morning)				
Evening	-0.235	-0.299	-0.171	**< 0.001**
%Shrub Cover	0.226	0.078	0.375	**0.003**
% Grass Cover	-0.086	-0.299	0.128	0.429
Vegetation Height	0.025	0.010	0.040	**0.001**
Veg. Height x Site (PRNAS)	-0.024	-0.040	-0.008	**0.004**
Veg. Height x Site (WARB)	0.001	-0.019	0.022	0.887

Table 17. Model comparisons and fit statistics for candidate models depicting bird density association with landscape characteristics. Bird density estimates derived from a reduced subset of line-transect surveys conducted at WARB (239 transects), Lakehurst (287 surveys), and PRNAS (195 transects) during fall migration, spring migration and breeding, 2007-2009. Bolded models represent those that best fit the data.

Model ID	***k*** *	**(-)2 Log-Likelihood**	***AICc***	**Δ AIC_c**	***w_i***	**R^2**	***P***
Total Density							
Base Model	9	471.90	490.6	15.1	0.00		
Landcover Model	**12**	**450.21**	**475.5**	**0.0**	**1.00**	**0.23**	**< 0.001**
Land Configuration Model	12	470.12	495.4	19.9	0.00		
Strike-risk species							
Base Model	9	343.99	362.7	55.3	0.00		
Landcover Model	**12**	**282.15**	**307.5**	**0.0**	**1.00**	**0.28**	**< 0.001**
Land Configuration Model	12	343.09	368.4	60.9	0.00		
Conservation-value species							
Base Model	9	136.21	155.0	6.4	0.04		
Landcover Model	12	128.00	153.3	4.7	0.08		
Landscape Configuration Model	**12**	**123.28**	**148.6**	**0.0**	**0.88**	**0.27**	**< 0.001**

* The number of estimable parameters in the model including intercept and error term.

Table 18. Parameter estimates from General Linear Models depicting the relationship between landscape characteristics and mean seasonal bird density (Total, Conservation-Value, and Strike-Risk) among transects. Bird density estimates derived from best-performing models listed in Table 17.

Model Parameters	Estimate	SE	*P*	Lower CI	Upper CI
Total Density					
Intercept	1.09	0.22	**< 0.001**	0.65	1.53
Study Year (vs. Year 1)					
Year 2	0.037	0.092	0.685	-0.144	0.219
Year 3	-0.191	0.092	**0.039**	-0.372	-0.010
Site (vs. Lakehurst)					
PRNAS	0.021	0.102	0.837	-0.180	0.222
WARB	0.131	0.119	0.271	-0.103	0.365
Season (vs. Breeding)					
Fall Migration	0.025	0.090	0.779	-0.151	0.202
Spring Migration	-0.176	0.093	0.060	-0.360	0.008
Evening (vs. Day)	-0.383	0.076	**< 0.001**	-0.532	-0.233
Grassland	-0.003	0.004	0.484	-0.010	0.005
Developed	0.014	0.004	**0.001**	0.006	0.022
Water/Wetland	-0.005	0.004	0.265	-0.013	0.004
Strike-risk species					
Intercept	-0.015	0.162	0.926	-0.333	0.303
Study Year (vs. Year 1)					
Year 2	0.189	0.066	**0.005**	0.058	0.319
Year 3	0.043	0.066	0.520	-0.088	0.173
Site (vs. Lakehurst)					
PRNAS	-0.133	0.073	0.071	-0.277	0.011
WARB	-0.188	0.085	**0.029**	-0.356	-0.019
Season (vs. Breeding)					
Fall Migration	-0.173	0.064	**0.008**	-0.300	-0.046
Spring Migration	-0.005	0.067	0.943	-0.137	0.127
Evening (vs. Day)	-0.109	0.055	**0.046**	-0.217	-0.002
Grassland	0.001	0.003	0.806	-0.004	0.006
Developed	0.020	0.003	**< 0.001**	0.014	0.025
Water	-0.003	0.003	0.392	-0.009	0.003
Conservation-value species					
Intercept	0.829	0.189	**< 0.001**	0.456	1.202
Study Year (vs. Year 1)					
Year 2	0.020	0.048	0.686	-0.076	0.115
Year 3	-0.044	0.048	0.359	-0.140	0.051
Site (vs. Lakehurst)					
PRNAS	-0.202	0.060	0.001	-0.320	-0.083
WARB	0.058	0.063	0.355	-0.066	0.183
Season (vs. Breeding)					
Fall Migration	-0.300	0.047	**< 0.001**	-0.393	-0.208
Spring Migration	-0.290	0.049	**< 0.001**	-0.387	-0.193
Evening (vs. Day)	-0.191	0.040	**< 0.001**	-0.270	-0.112
Landscape Diversity (Simpson)	0.160	0.239	0.505	-0.312	0.632
Edge Density	-0.001	0.001	0.566	-0.002	0.001
% Core Area	-0.010	0.003	**0.003**	-0.016	-0.003

Table 19. Characteristics of runway crossings by strike-risk species groups (see Table 2) observed during 15 minute behavioral observation surveys. Surveys were conducted between 0600 and 1800 in spring migration and breeding season (2008, 2009, and 2011), and fall migration (2007, 2008, and 2010). Crossings include the total number of individuals flying over or landing on a runway surface. Mean flock size and height are based on the number and height for each runway crossing event (i.e., flock or individual). Species groups with crossing rates ≥ 1 per 15 minutes at a site are bolded.

Species Group	Mean crossings per 15 min (± SE)	Total no. individuals	Mean flock size	Mean flock height (m)	Mean crossings per 15 min (± SE)	Total no. individuals	Mean flock size	Mean flock height (m)	Mean crossings per 15 min (± SE)	Total no. individuals	Mean flock size	Mean flock height (m)
WARB	Spring (n = 108 surveys)				Breeding (n = 144 surveys)				Fall (n = 216 surveys)			
Vulture	0.10 ± 0.04	11	1.2	111	0.25 ± 0.06	36	1.6	129	0.07 ± 0.02	15	1.3	110
Goose	0.32 ± 0.16	35	3.2	97	0.10 ± 0.09	14	7.0	20	0.38 ± 0.21	81	9.0	191
Blackbird-Starling	0.59 ± 0.29	64	4.0	38	0.83 ± 0.25	119	2.5	30	**7.19 ± 5.41**	**1552**	**103.5**	**78**
Buteo	0.12 ± 0.03	13	1.1	119	0.16 ± 0.04	23	1.2	89	0.26 ± 0.04	56	1.2	96
Horned Lark	0.27 ± 0.06	29	1.3	11	0.28 ± 0.06	41	1.5	14	**1.08 ± 0.24**	**233**	**5.3**	**34**
Swallow	0.60 ± 0.20	65	2.6	48	**5.65 ± 1.50**	**813**	**5.8**	**25**	0.88 ± 0.33	189	5.7	38
Gull	0.01 ± 0.01	1	1.0	210	0.00 ± 0.00	0	--	--	0.12 ± 0.10	26	5.2	210
Duck	0.00 ± 0.00	0	--	--	0.00 ± 0.00	0	--	--	0.21 ± 0.21	45	45.0	250
Kestrel	0.38 ± 0.06	41	1.1	29	0.17 ± 0.04	24	1.0	18	0.35 ± 0.06	76	1.2	15
All Strike-Risk	**2.40 ± 0.39**	**259**	**2.0**	**51**	**7.43 ± 1.51**	**1070**	**3.8**	**37**	**10.52 ± 5.41**	**2273**	**10.0**	**61**
All Species	**4.13 ± 0.49**	**446**	**1.9**	**55**	**9.62 ± 1.56**	**1385**	**3.0**	**38**	**17.45 ± 5.75**	**3770**	**8.7**	**62**
Lakehurst	Spring (n = 108 surveys)				Breeding (n = 144 surveys)				Fall (n = 215 surveys)			
Vulture	**2.04 ± 0.24**	**220**	**1.9**	**97**	**1.66 ± 0.18**	**239**	**1.6**	**104**	0.99 ± 0.14	212	1.8	114
Goose	0.34 ± 0.14	37	4.1	70	0.08 ± 0.05	11	2.8	23	0.59 ± 0.28	127	18.1	159
Blackbird-Starling	0.18 ± 0.07	19	1.7	46	0.19 ± 0.06	28	1.6	47	0.04 ± 0.02	9	2.3	66
Buteo	0.06 ± 0.03	7	1.0	90	0.13 ± 0.03	19	1.1	118	0.06 ± 0.02	12	1.0	62
Horned Lark	0.27 ± 0.08	29	1.8	12	0.29 ± 0.05	42	1.2	18	0.73 ± 0.17	157	6.3	26
Swallow	0.76 ± 0.13	82	1.6	16	**1.35 ± 0.24**	**194**	**1.9**	**23**	**1.40 ± 0.41**	**300**	**5.6**	**32**
Gull	**1.86 ± 0.90**	**201**	**10.6**	**154**	0.44 ± 0.22	63	7.9	202	0.61 ± 0.22	132	4.3	205
Duck	0.06 ± 0.04	6	3.0	105	0.00 ± 0.00	0	--	--	0.00 ± 0.00	0	--	--
Kestrel	0.37 ± 0.06	41	1.0	22	0.03 ± 0.02	5	1.3	27	0.30 ± 0.05	66	1.2	17
All Strike-Risk	**5.94 ± 0.93**	**642**	**2.4**	**67**	**4.17 ± 0.36**	**601**	**1.8**	**68**	**4.72 ± 0.57**	**1015**	**3.3**	**83**
All Species	**7.88 ± 0.99**	**851**	**2.2**	**60**	**6.97 ± 0.40**	**1003**	**1.7**	**56**	**8.18 ± 0.82**	**1758**	**3.5**	**75**
PRNAS	Spring (n = 111 surveys)				Breeding (n = 139 surveys)				Fall (n = 191 surveys)			
Vulture	0.77 ± 0.18	86	2.0	38	0.24 ± 0.06	33	1.3	49	0.97 ± 0.27	186	2.4	60
Goose	0.07 ± 0.06	8	2.7	74	0.17 ± 0.12	23	11.5	13	0.30 ± 0.22	58	14.5	53
Blackbird-Starling	0.34 ± 0.11	38	2.0	9	**1.62 ± 0.58**	**225**	**5.6**	**11**	**4.64 ± 1.55**	**887**	**21.6**	**19**
Buteo	0.09 ± 0.03	10	1.0	36	0.04 ± 0.02	6	1.2	23	0.06 ± 0.02	11	1.0	103
Horned Lark	0.03 ± 0.02	3	1.5	5	0.01 ± 0.01	1	1.0	8	0.01 ± 0.01	1	1.0	20
Swallow	0.69 ± 0.17	77	2.3	13	0.24 ± 0.08	33	1.9	11	0.17 ± 0.08	33	6.6	17
Gull	**2.11 ± 1.82**	**234**	**39.0**	**19**	0.08 ± 0.05	11	2.2	36	**1.25 ± 0.49**	**239**	**10.4**	**28**
Duck	0.03 ± 0.02	3	1.5	17	0.00 ± 0.00	0	--	--	0.02 ± 0.02	4	4.0	20
Kestrel	0.05 ± 0.02	5	1.3	26	0.00 ± 0.00	0	--	--	0.02 ± 0.01	3	1.0	12
All Strike-Risk	**4.18 ± 1.82**	**464**	**3.8**	**25**	**2.39 ± 0.59**	**332**	**3.5**	**23**	**7.45 ± 1.73**	**1422**	**8.6**	**45**
All Species	**6.26 ± 1.85**	**695**	**2.9**	**20**	**3.81 ± 0.67**	**530**	**2.7**	**19**	**11.80 ± 1.94**	**2253**	**5.5**	**33**

Table 20. Model ranking results for the number of birds crossing runways during 15-minute behavioral observation surveys (n = 1376). Strike risk species included species with a risk score greater than 1.06, plus American Kestrel (see Table 2).

Model	ΔAIC_c	w_i	k	R^2
All Species (min AIC_c = 3991.7)				
Base Model	23.7	0.00	10	
Water	25.2	0.00	11	
Wetland	22.7	0.00	11	
Pavement	**0.0**	**1.00**	**11**	**0.11**
Grassland	22.8	0.00	11	
Mowed Grassland	25.7	0.00	11	
Forest	18.7	0.00	11	
Landscape Diversity	24.9	0.00	11	
Strike-Risk Species (min AIC_c = 3896.5)				
Base Model	23.2	0.00	10	
Water	23.6	0.00	11	
Wetland	23.6	0.00	11	
Pavement	**0.0**	**1.00**	**11**	**0.11**
Grassland	23.7	0.00	11	
Mowed Grassland	24.8	0.00	11	
Forest	19.8	0.00	11	
Landscape Diversity	25.2	0.00	11	

Table 21. Parameter estimates from the best performing models (Table 20) for the number of birds crossing runways during 15-minute behavioral observation surveys (n = 1376).

Model Parameters	Estimate	SE	*P*
All Species			
Intercept	1.155	0.092	**< 0.001**
Study Year (vs. Year 1)			
Year 2	0.183	0.068	**0.008**
Year 3	0.325	0.069	**< 0.001**
Site (vs. Lakehurst)			
PRNAS	-0.674	0.086	**< 0.001**
WARB	-0.549	0.093	**< 0.001**
Time (vs. Evening)			
Mid-Day)	0.232	0.072	**0.001**
Morning	0.516	0.066	**< 0.001**
Season (vs. Breeding)			
Fall Migration	0.011	0.065	0.860
Spring Migration	-0.023	0.076	0.764
% Paved Area	0.023	0.005	**< 0.001**
Strike-Risk Species			
Intercept	0.765	0.089	**< 0.001**
Study Year (vs. Year 1)			
Year 2	0.253	0.066	**< 0.001**
Year 3	0.382	0.066	**< 0.001**
Site (vs. Lakehurst)			
PRNAS	-0.719	0.083	**< 0.001**
WARB	-0.594	0.090	**< 0.001**
Time (vs. Evening)			
Mid-Day)	0.284	0.069	**< 0.001**
Morning	0.287	0.064	**< 0.001**
Season (vs. Breeding)			
Fall Migration	-0.119	0.062	0.056
Spring Migration	0.035	0.073	0.628
% Paved Area	0.022	0.004	**< 0.001**

Appendix A. Survey locations.

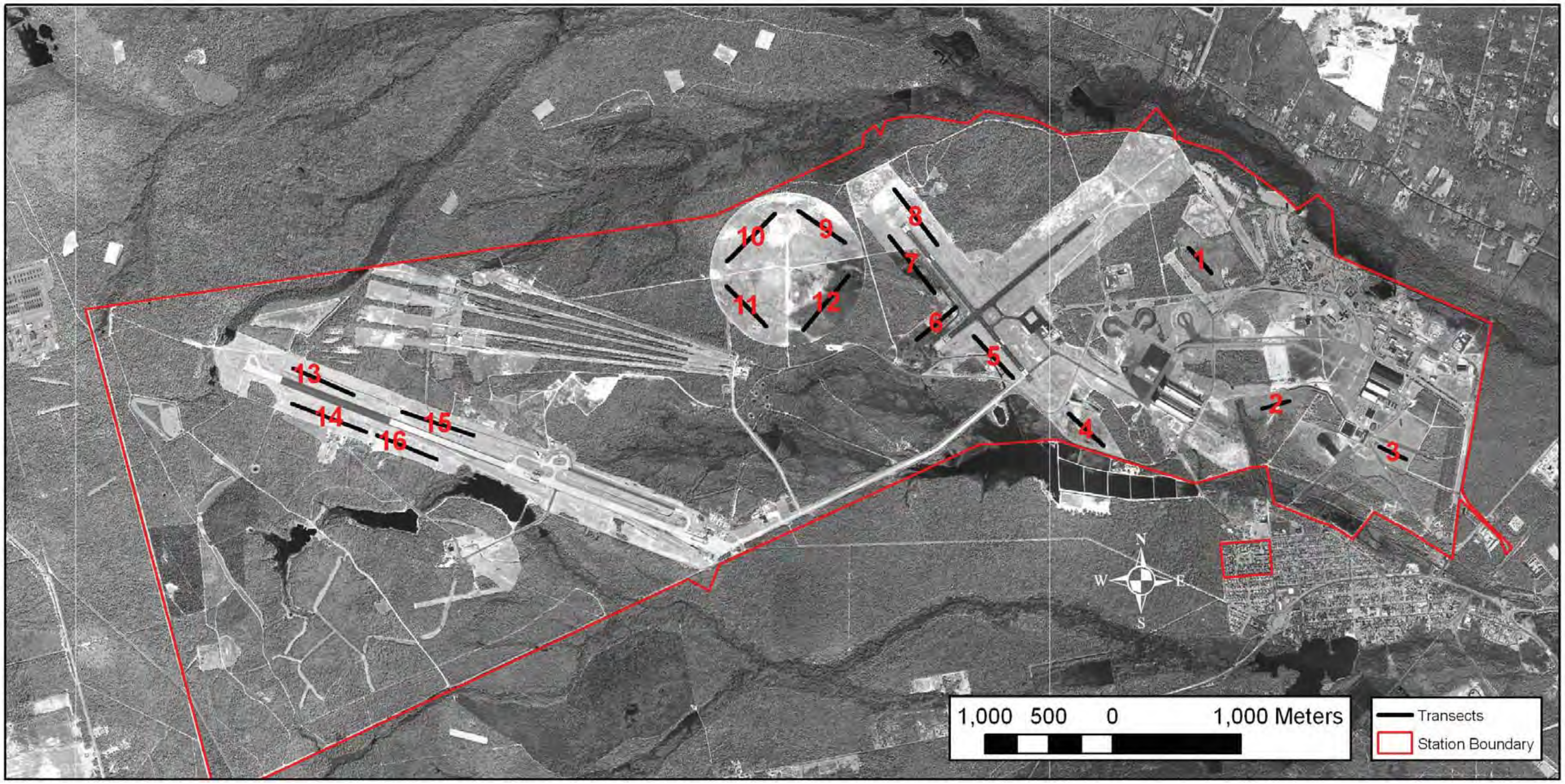


Figure A1. Locations of avian monitoring transects at Joint Base McGuire-Dix-Lakehurst (Lakehurst section), Lakehurst, New Jersey.

Appendix A. Survey locations.

Figure A2. Locations of avian monitoring transects at Patuxent River Naval Air Station, Patuxent River, MD.

Appendix A. Survey locations.

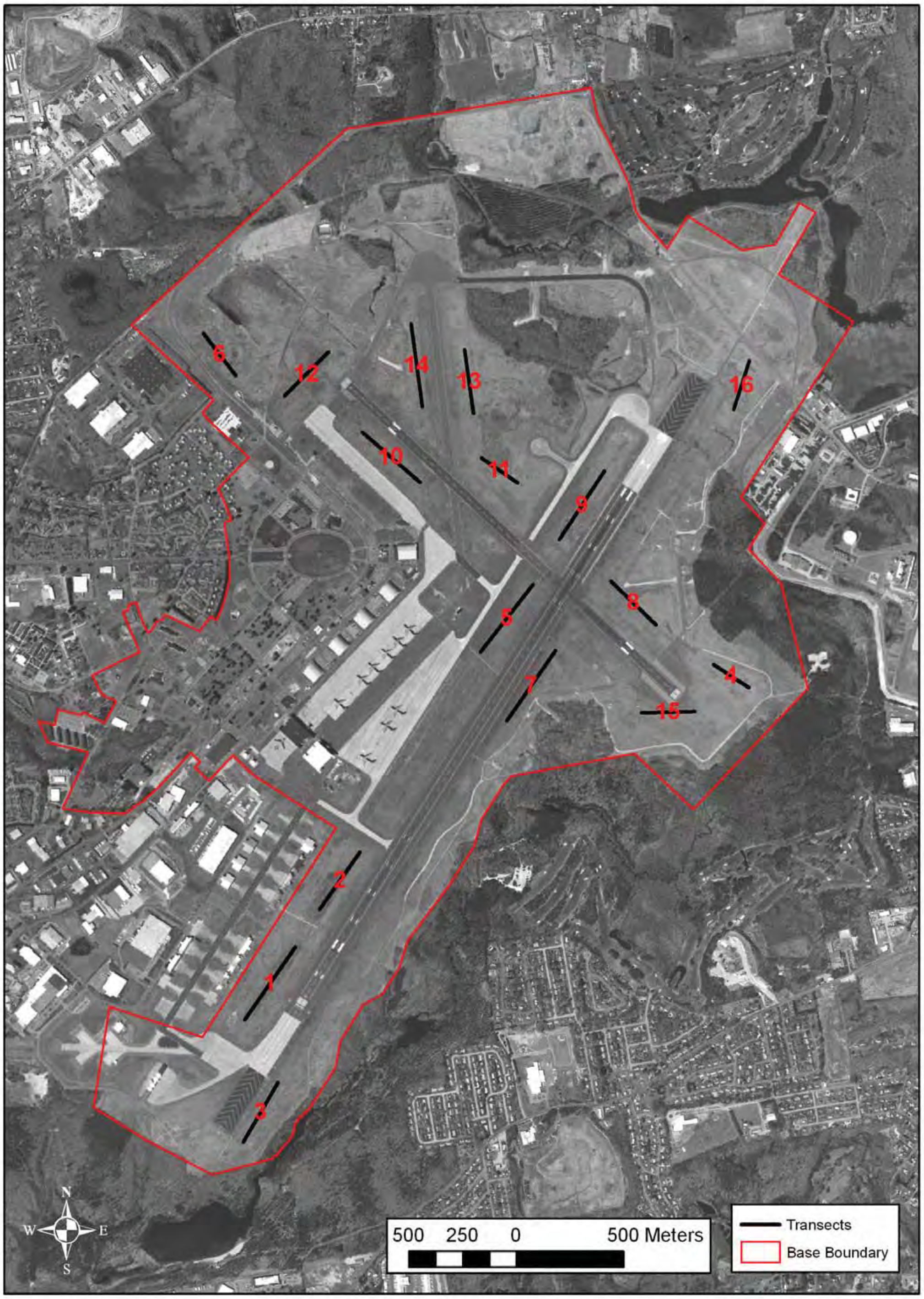


Figure A . Locations of avian monitoring transects at estover Air Reserve ase, ico ee, MA.

Appendix A. Survey locations.

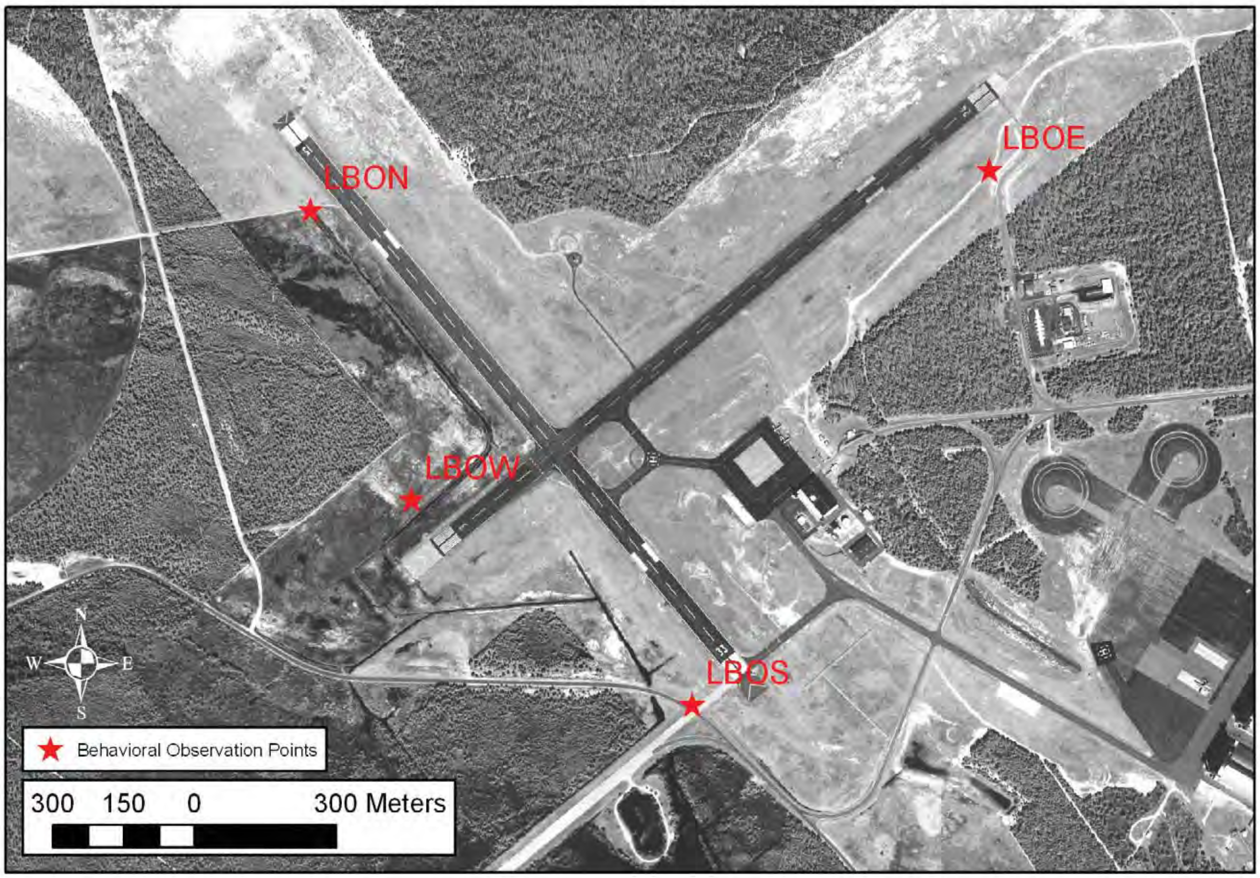


Figure A . Locations of avian e avioral o servation oints at oint ase Mc uire Dix La e urst La e urst section , La e urst, N .

Appendix A. Survey locations.

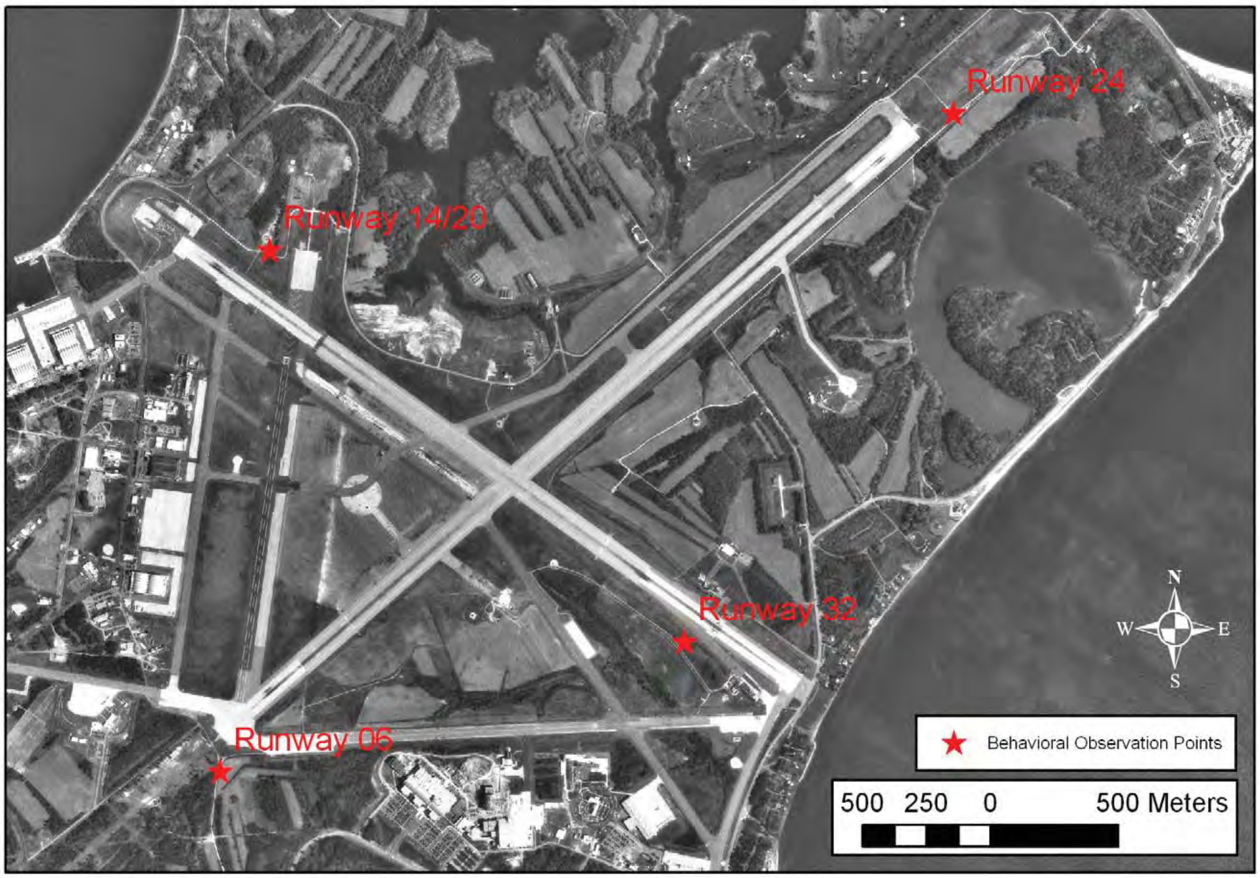


Figure A . Locations of avian e avioral o servation oints at Patuxent River Naval Air Station, Patuxent River, MD.

Appendix A. Survey locations.

Figure A . Locations of avian e avioral o servation oints at estover Air Reserve ase, ico ee, MA.

**Appendix . **Avian istri ution an ensity ma s.

Figure . Density contours generate for all ir o servations at oint ase Mc uire Dix La urst La e urst section , Ne ersey. Data ere collecte uring morning transect surveys in fall migration August to Novem er . ontours escri e t e s atial extent an relative ensity of occurrences for all s ecies. Dar er contours re resent ig er avian ensities.

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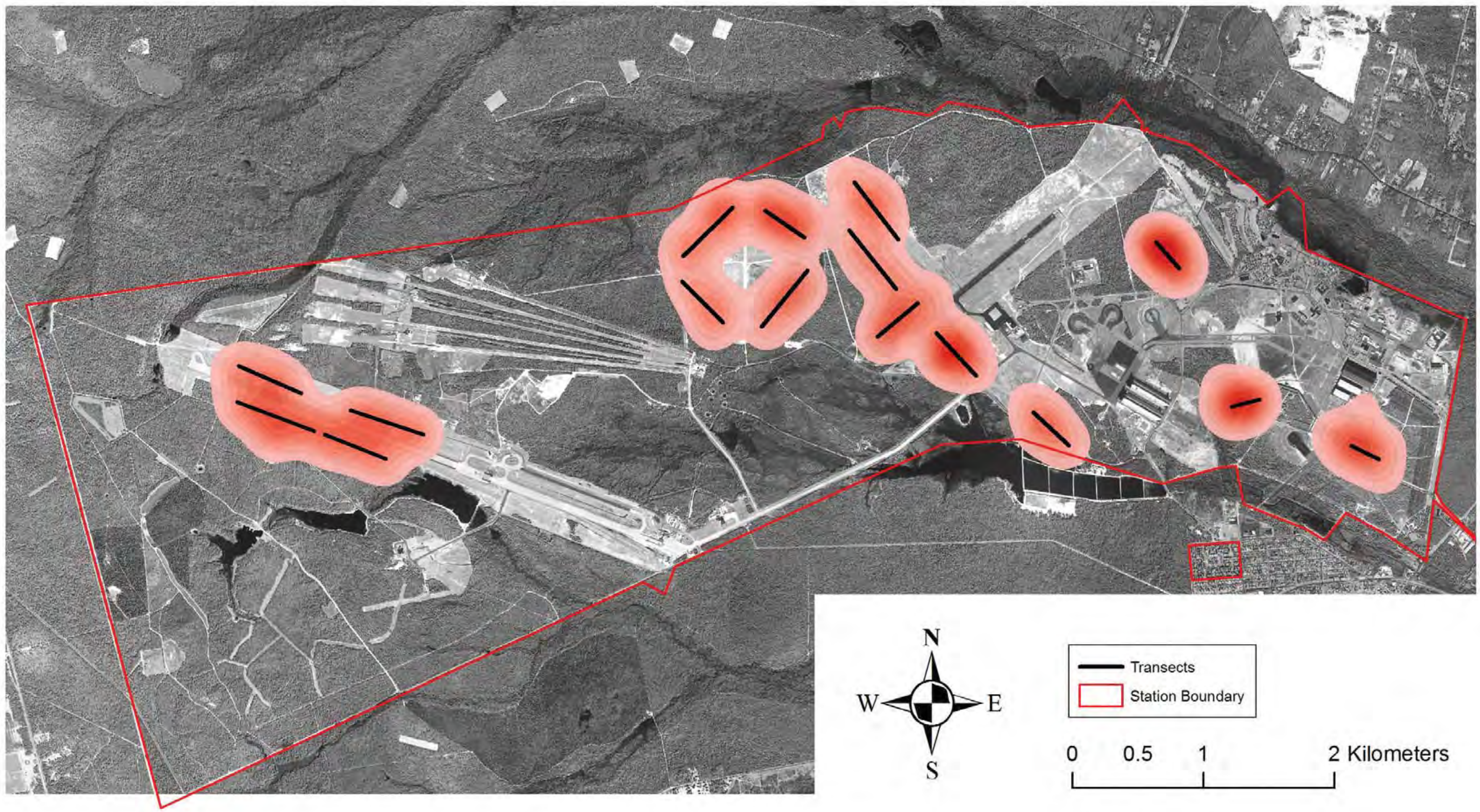

Figure 2. Density contours generate for all ir o servations at oint ase Mc uire Dix La urst La e urst section , Ne ersey. Data ere collecte uring morning transect surveys in fall migration , , an August to Novem er . ontours escri e t e s atial extent an relative ensity of occurrences for all s ecies. Dar er contours re resent ig er avian ensities.

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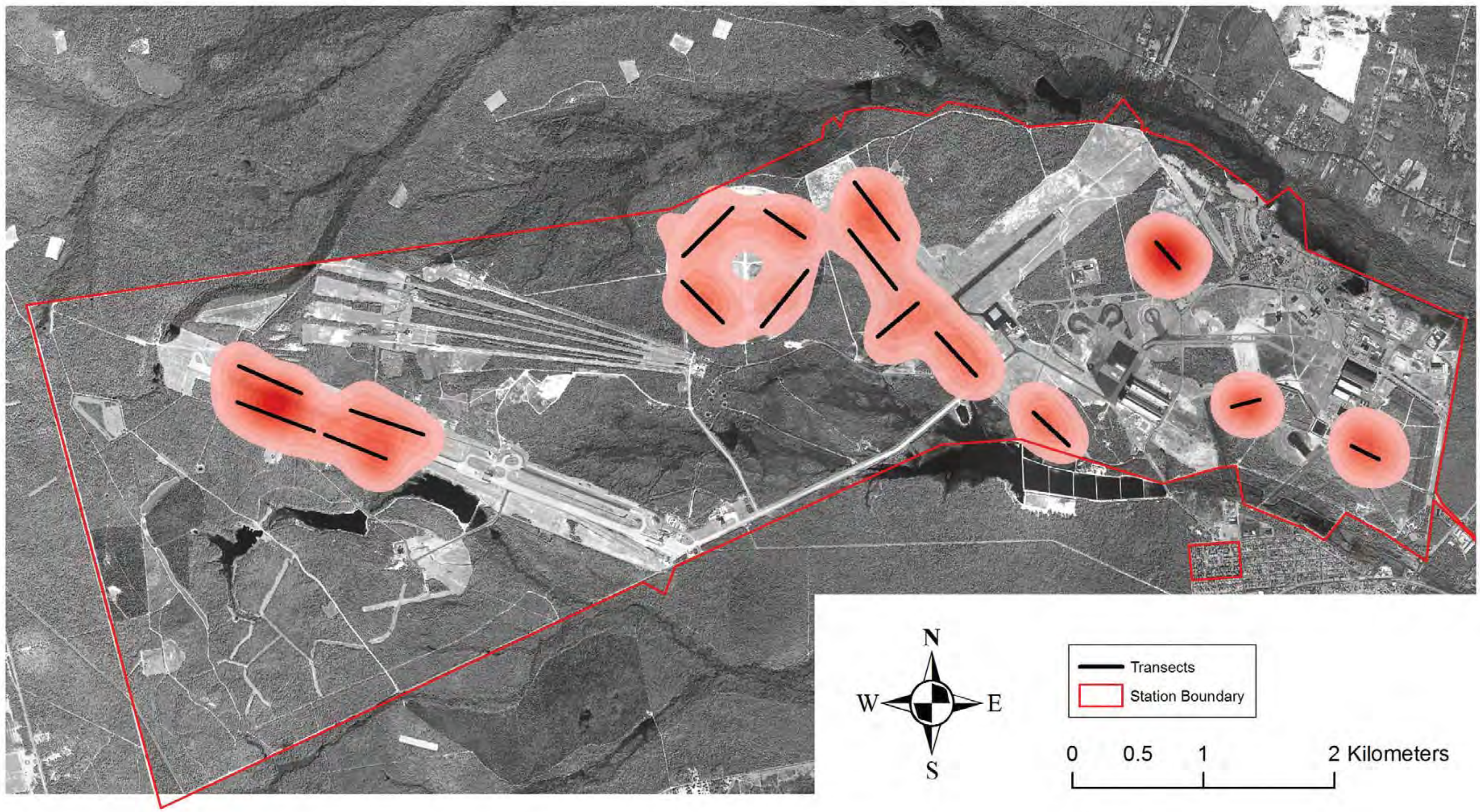

Figure . Density contours generate for all ir o servations at oint ase Mc uire Dix La urst La e urst section , Ne ersey. Data ere collecte uring morning transect surveys in s ring migration A ril to May . ontours escri e t e s atial extent an relative ensity of occurrences for all s ecies. Dar er contours re resent ig er avian ensities.

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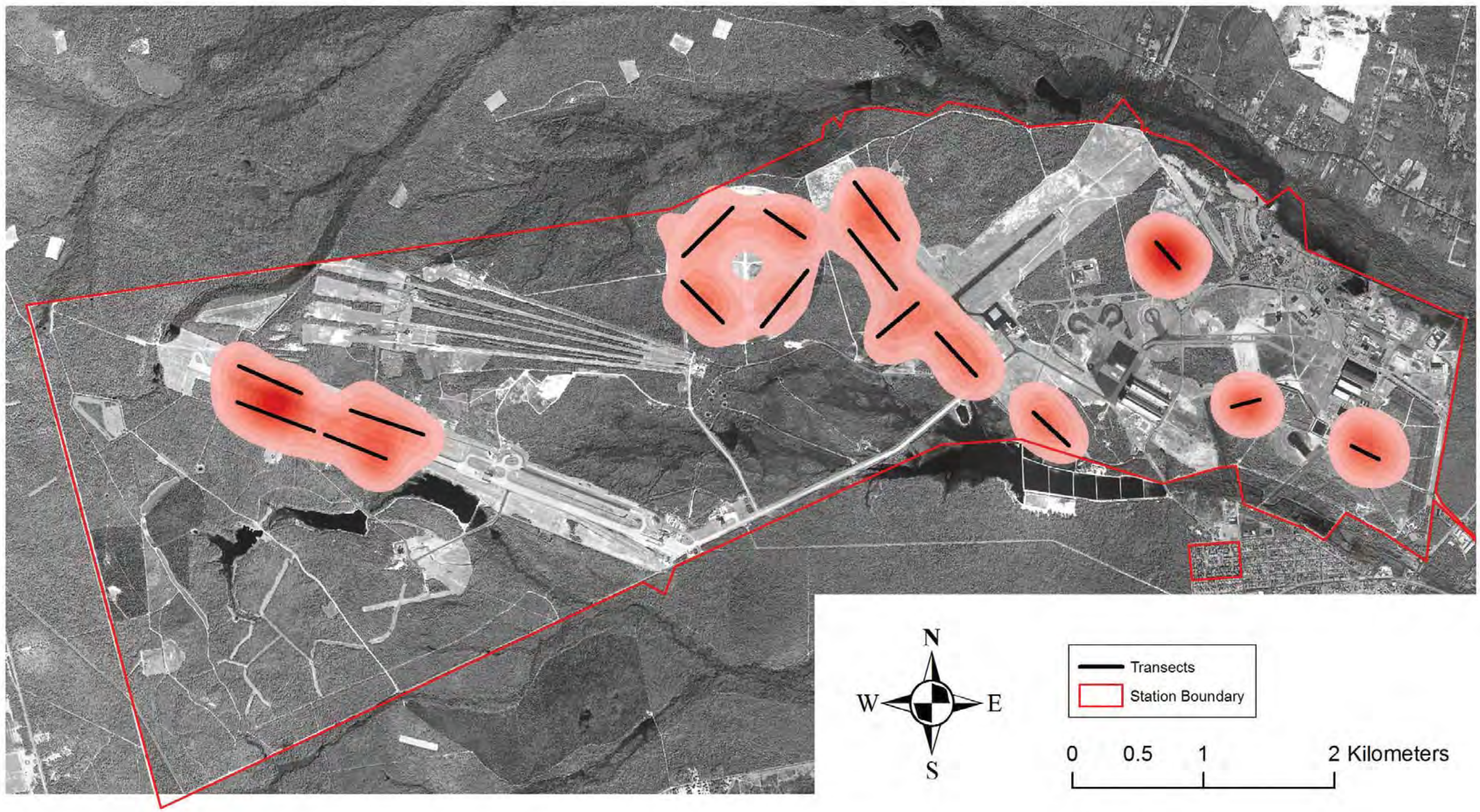

Figure . Density contours generate for all ir o servations at oint ase Mc uire Dix La urst La e urst section , Ne ersey. Data ere collecte uring morning transect surveys in s ring migration , , an A ril to May . ontours escri e t e s atial extent an relative ensity of occurrences for all s ecies. Dar er contours re resent ig er avian ensities.

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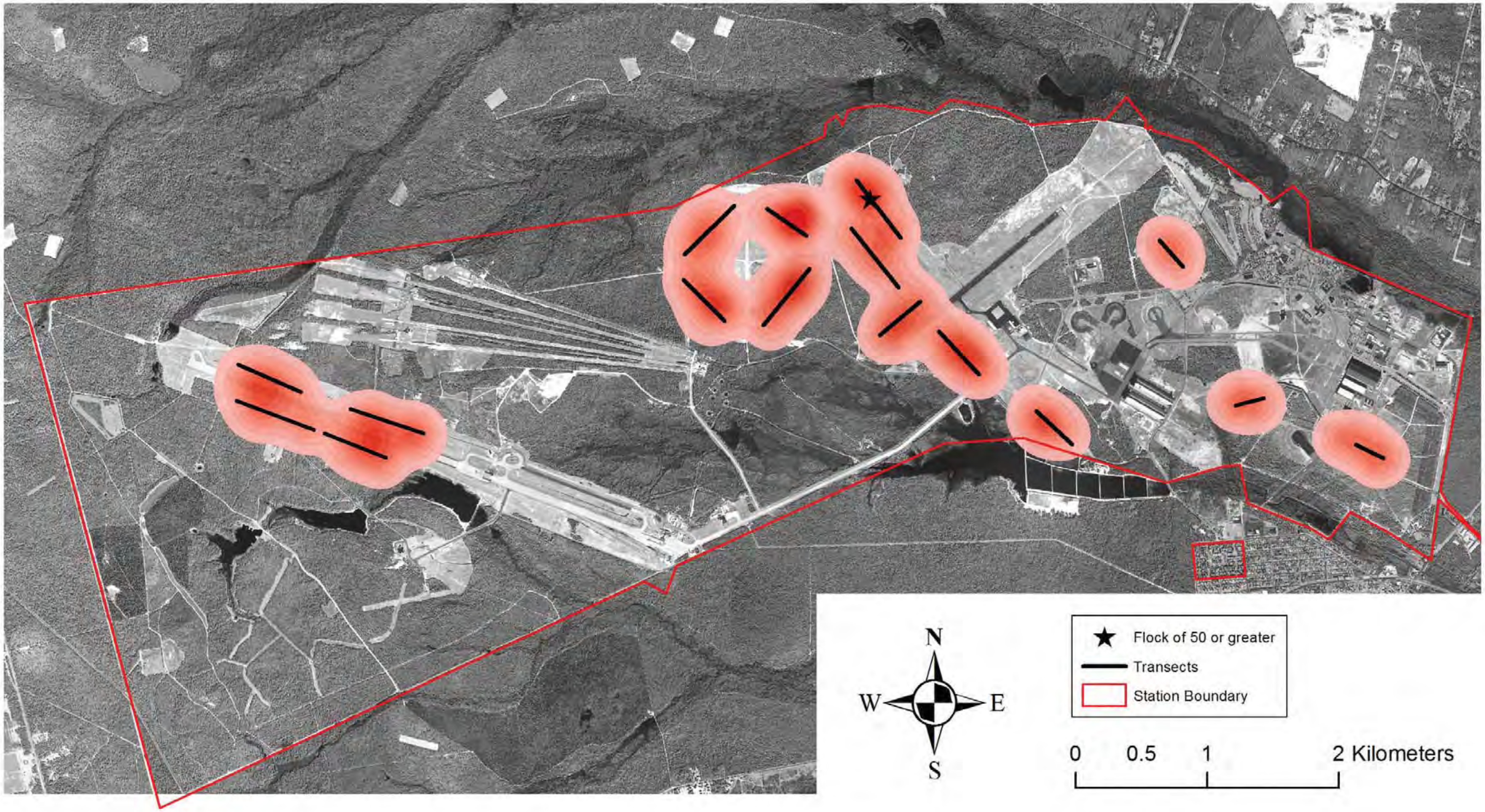

Figure . Density contours generate for all ir o servations at oint ase Mc uire Dix La urst La e urst section , Ne ersey. Data ere collecte uring morning transect surveys in ree ing season May to uly . ontours escri e t e s atial extent an relative ensity of occurrences for all s ecies. Dar er contours re resent ig er avian ensities. e star re resents a floc of mourning oves.

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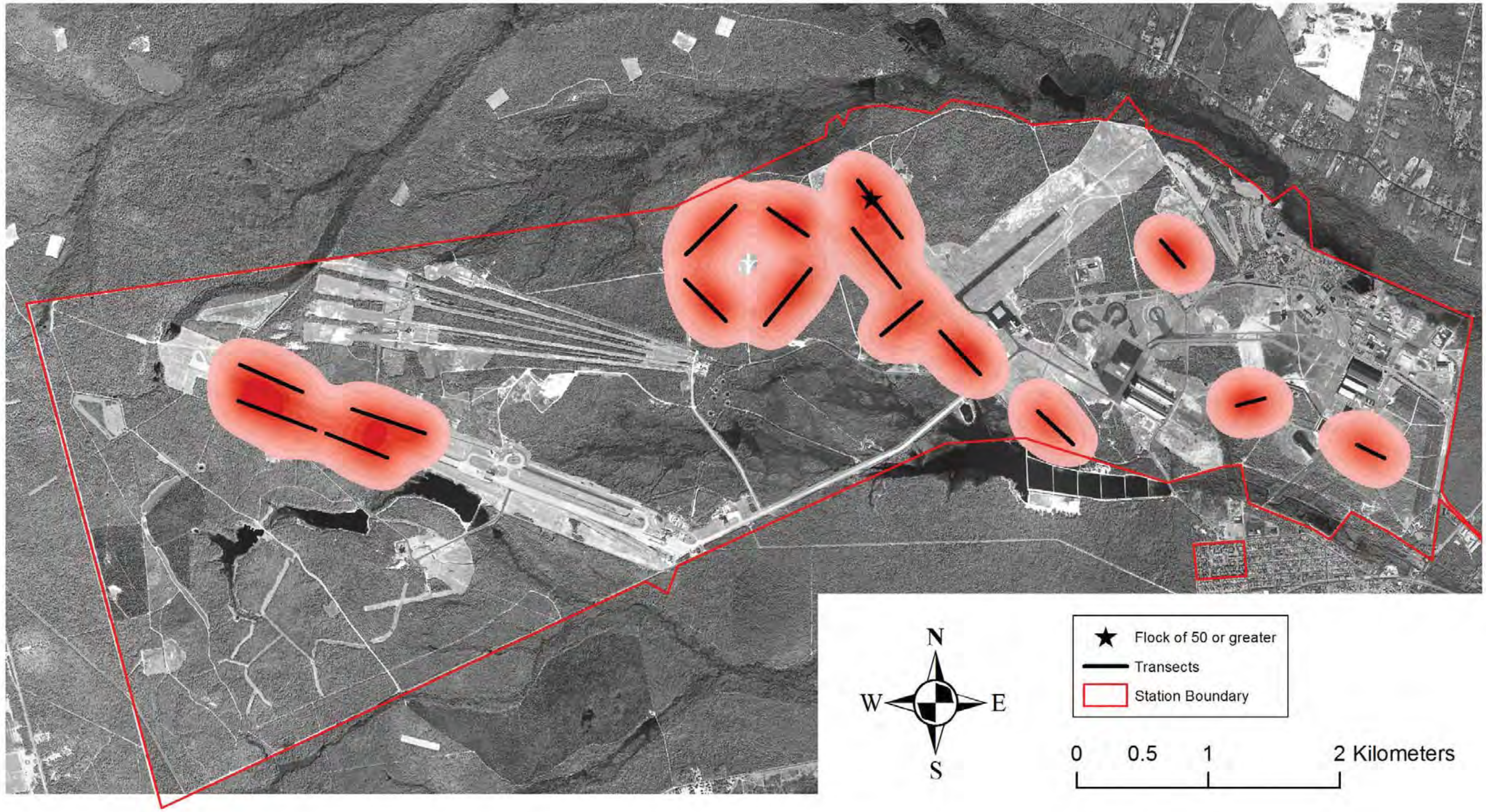


Figure . Density contours generate for all ir o servations at oint ase Mc uire Dix La urst La e urst section , Ne ersey. Data ere collecte uring morning transect surveys in ree ing season , , an May to uly . ontours escri e t e s atial extent an relative ensity of occurrences for all s ecies. Dar er contours re resent ig er avian ensities. e star re resents a floc of mourning oves.

Appendix . Avian istri ution an ensity ma s.

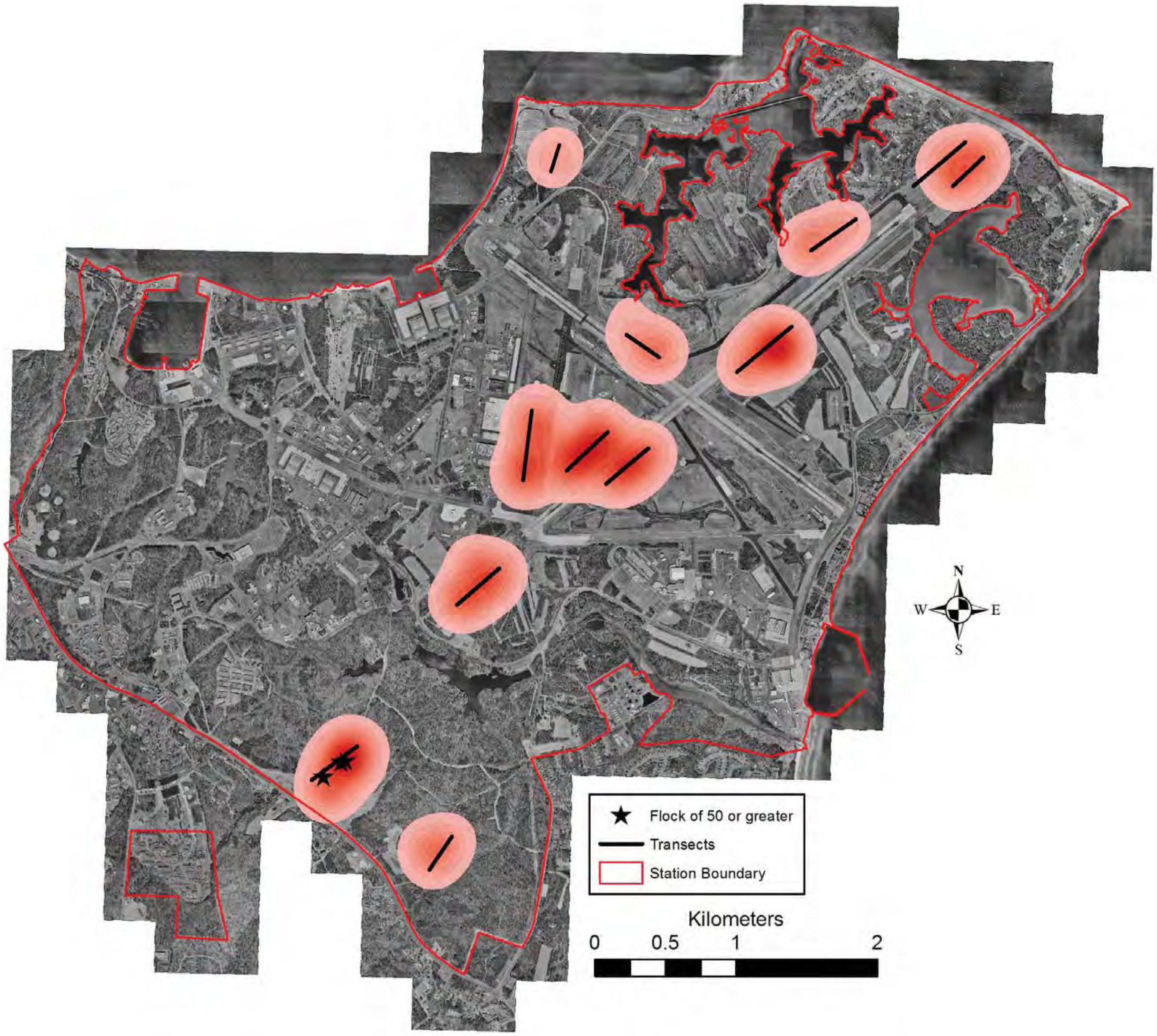
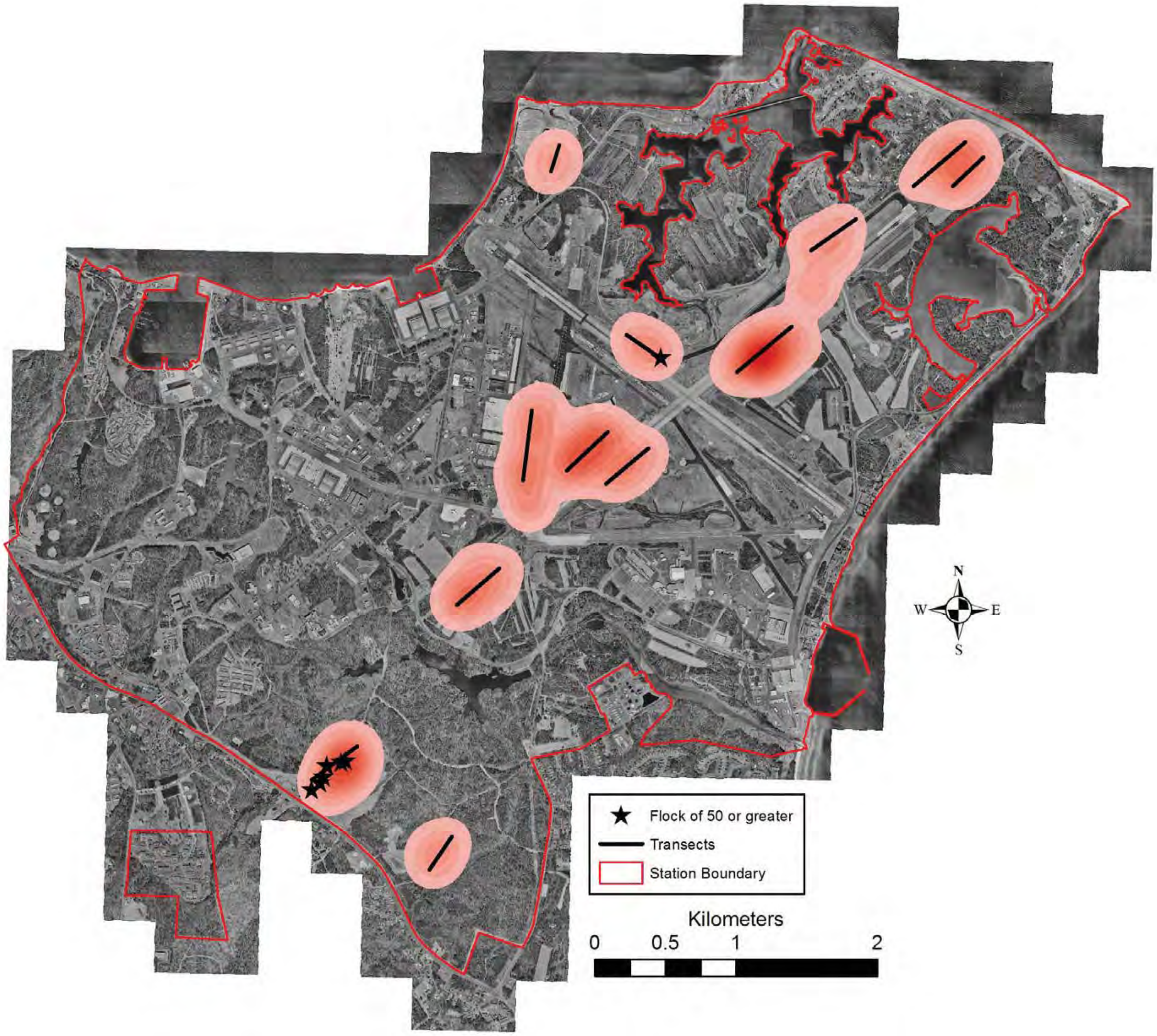


Figure . Density contours generate for all ir o servations at Patuxent River Naval Air Station, Marylan . Data ere collecte uring morning transect surveys in fall migration August to Novem er . ontours escri e t e s atial extent an relative ensity of occurrences for all s ecies. Dar er contours re resent ig er avian ensities. Stars from nort to sout re resent floc s of , , an uro ean starlings, res ectively.

**Appendix . ** Avian istri ution an ensity ma s.



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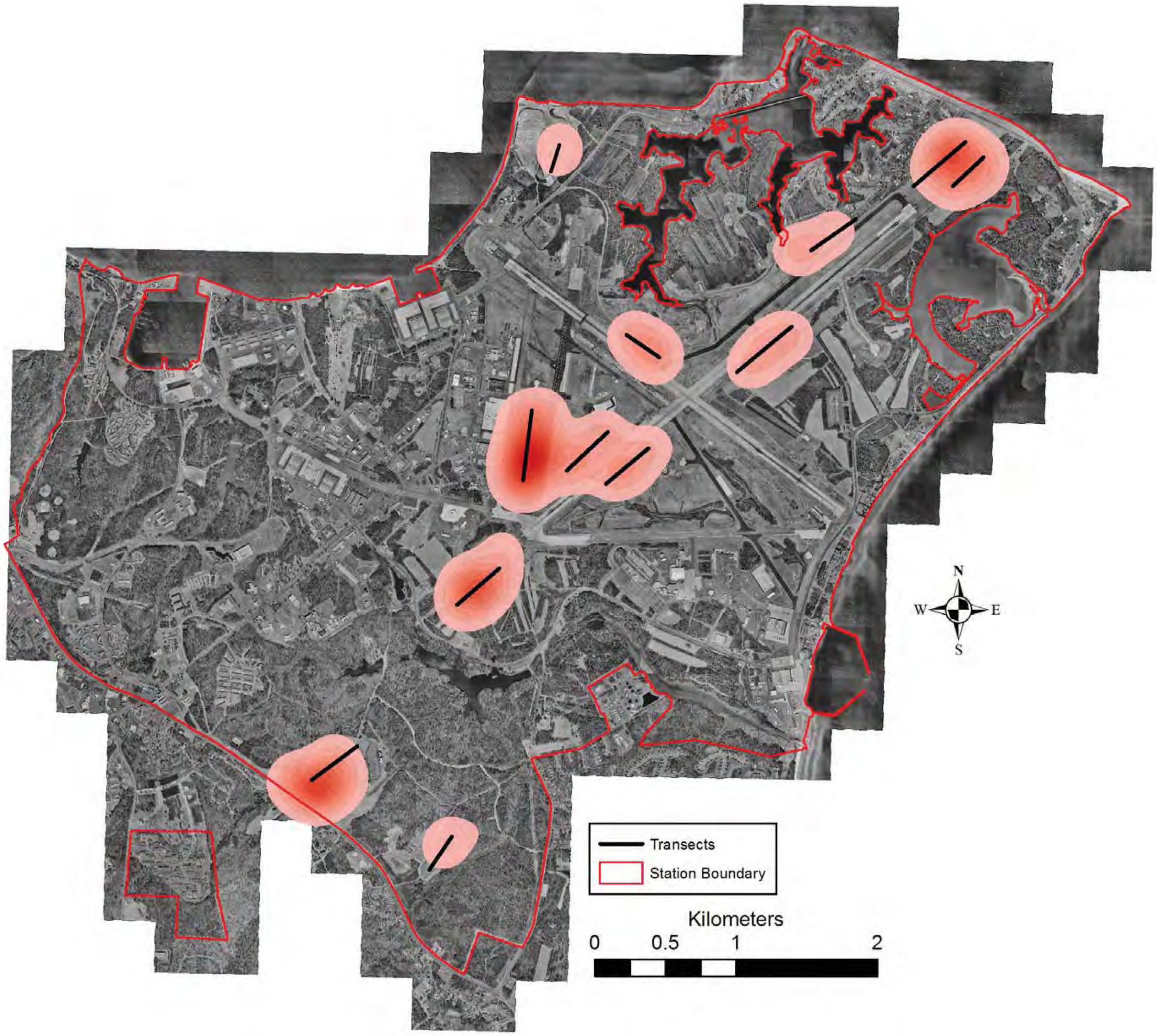

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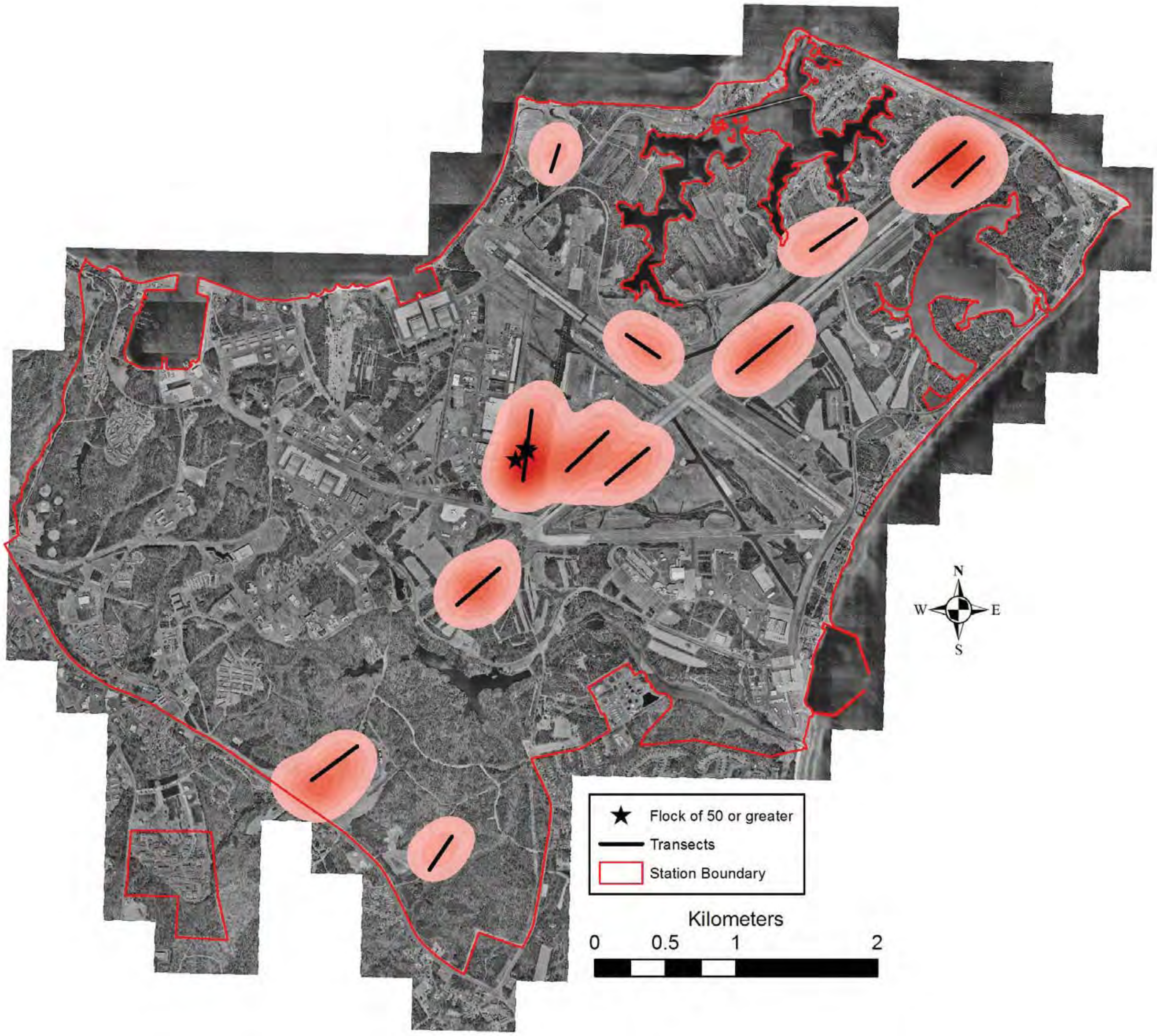

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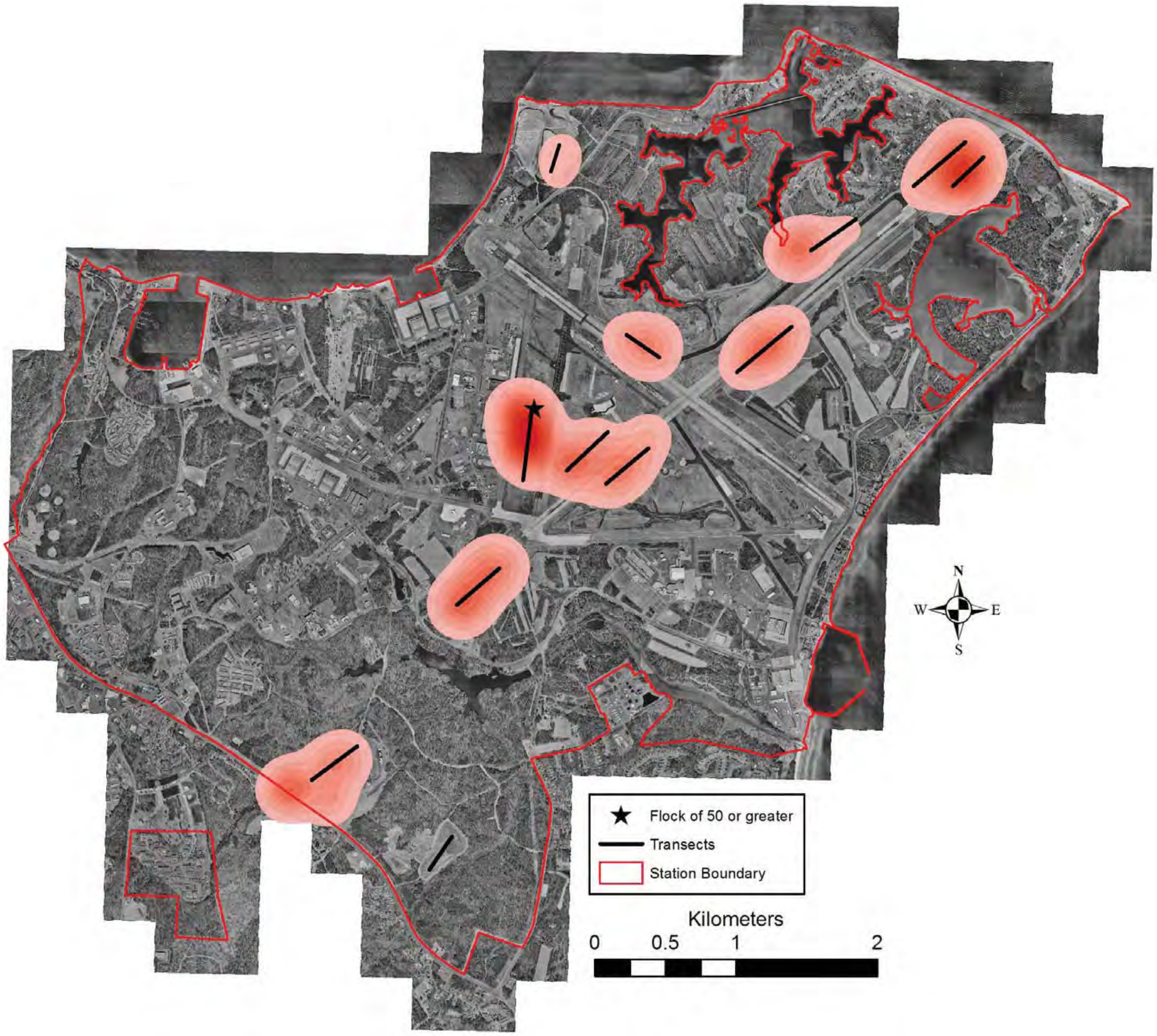

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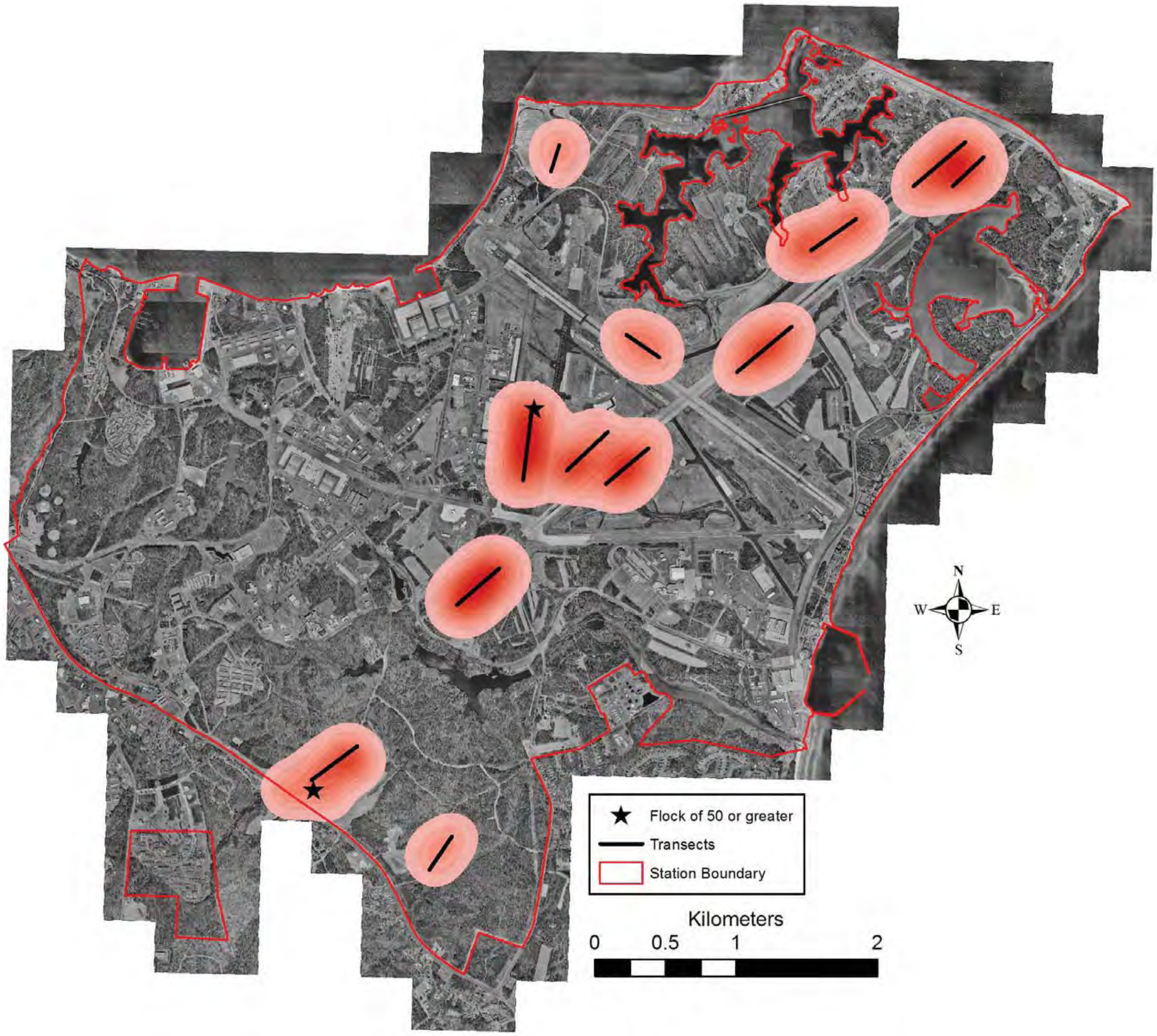

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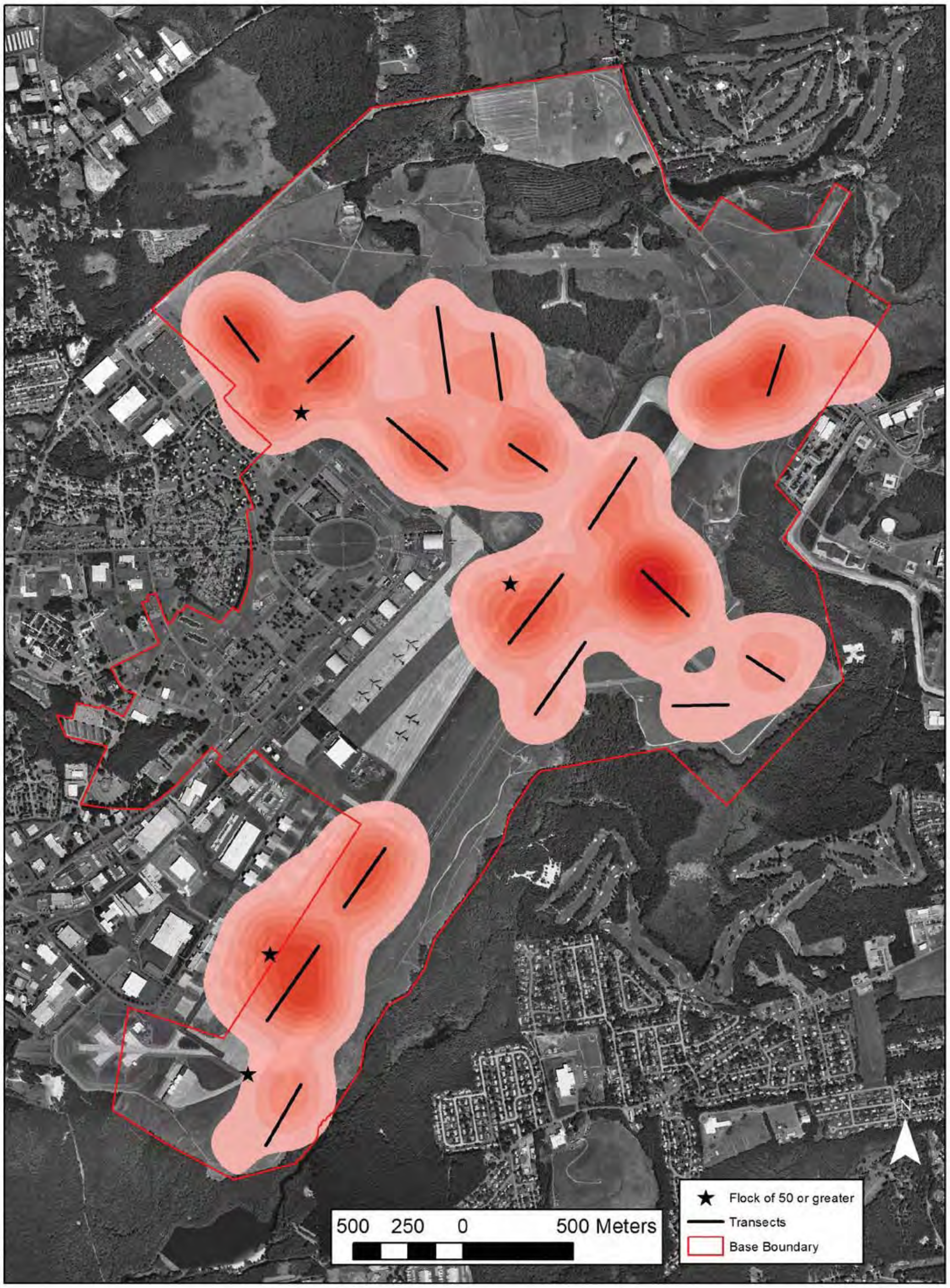

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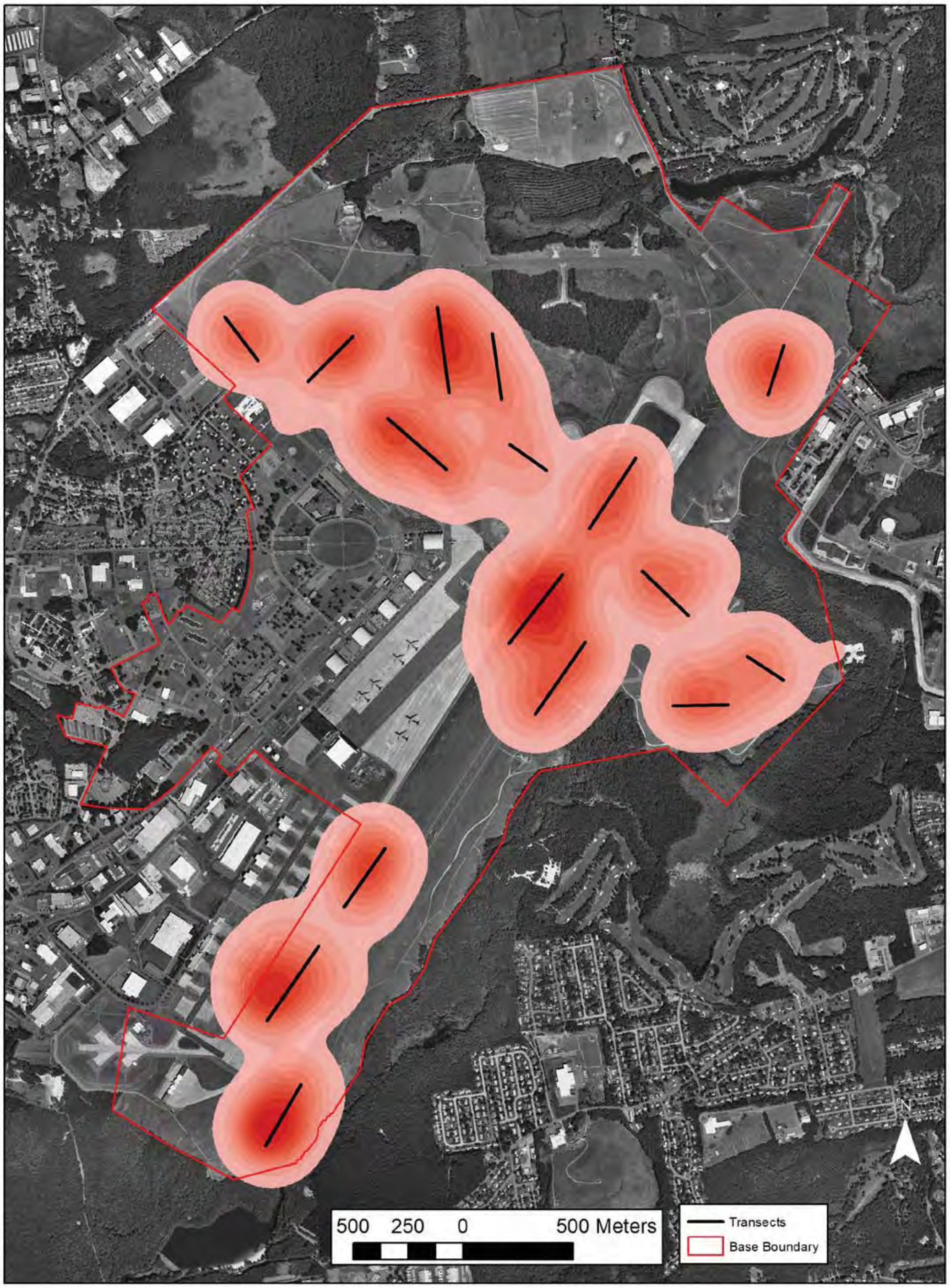

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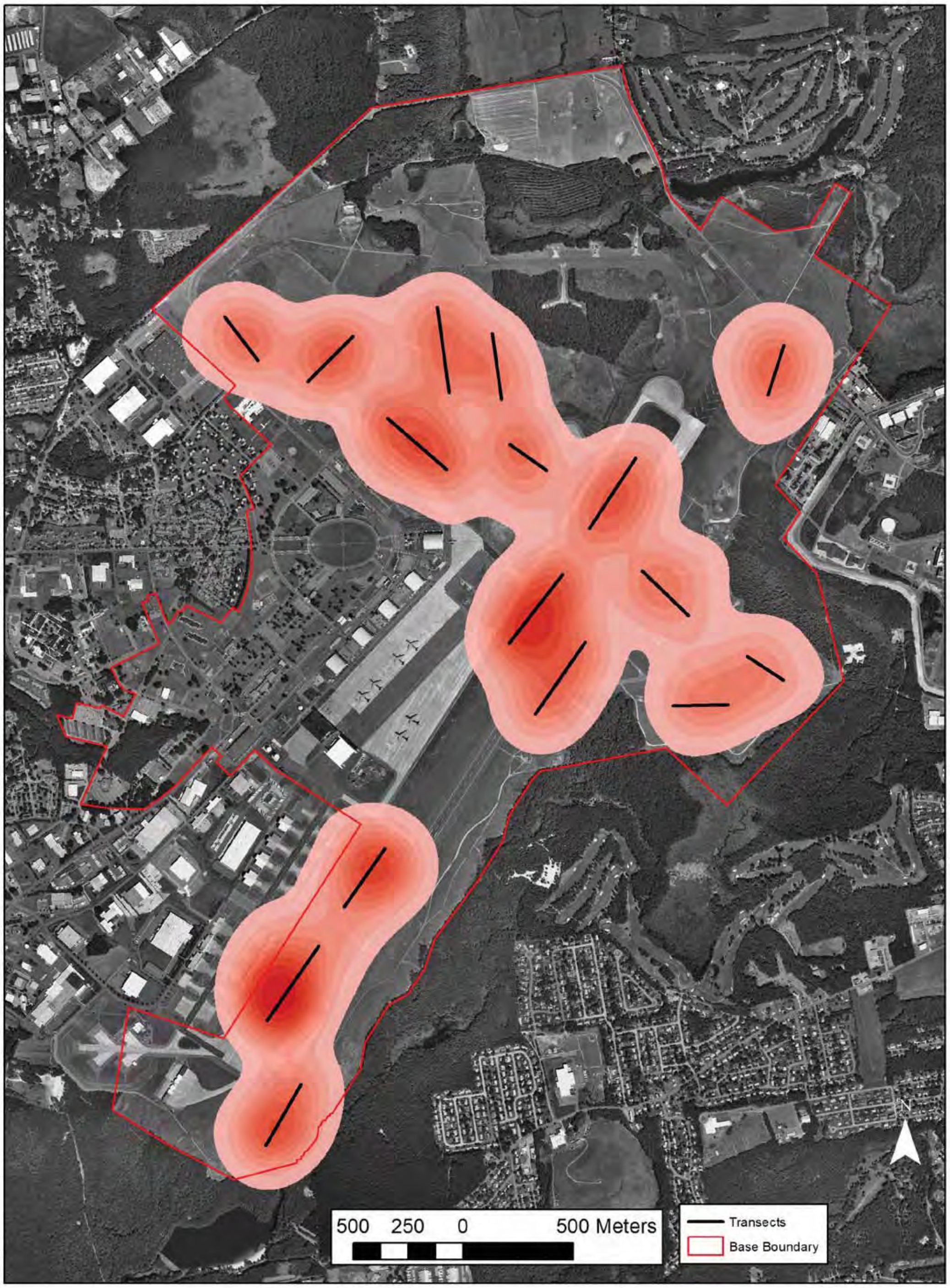

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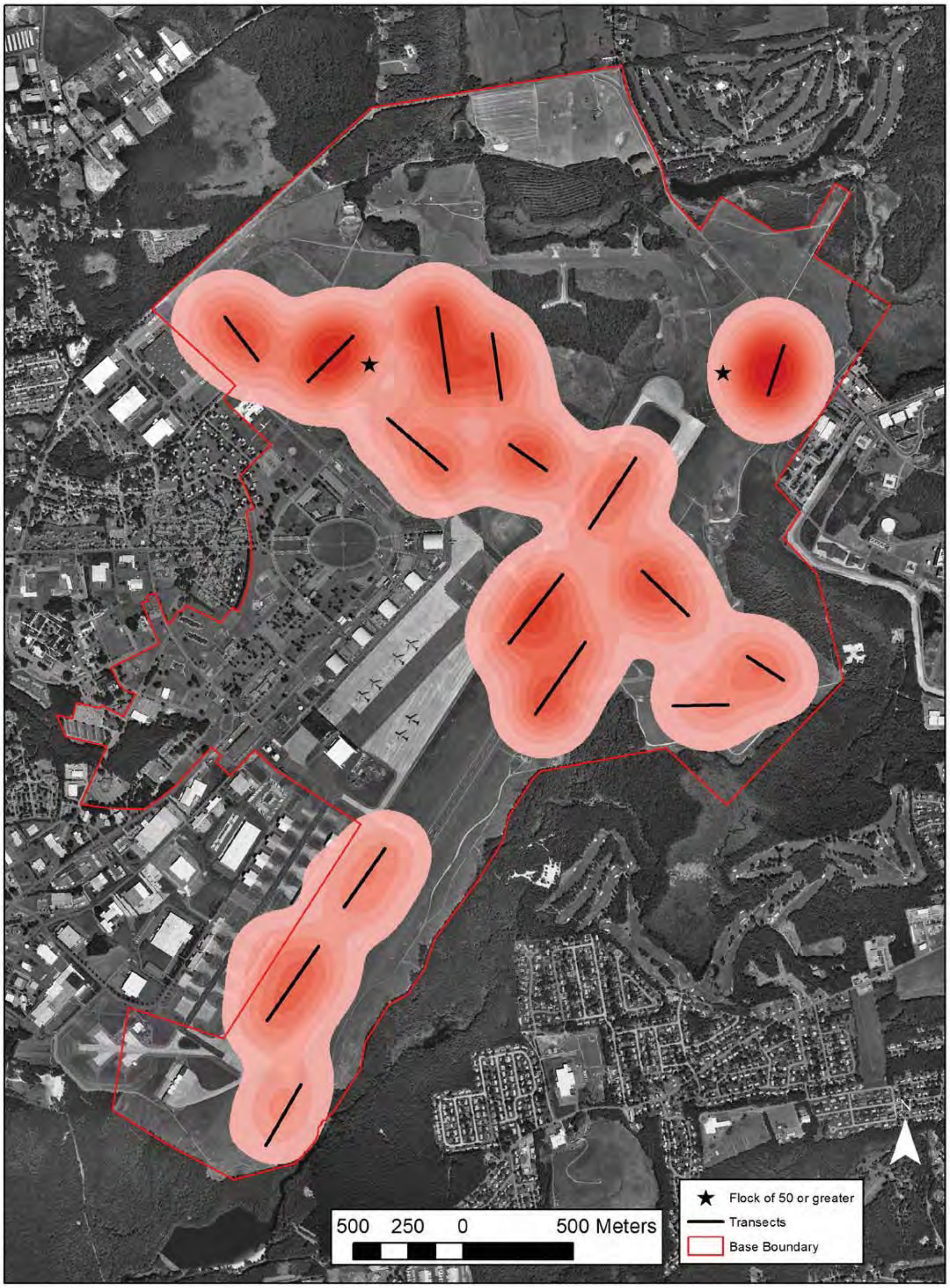

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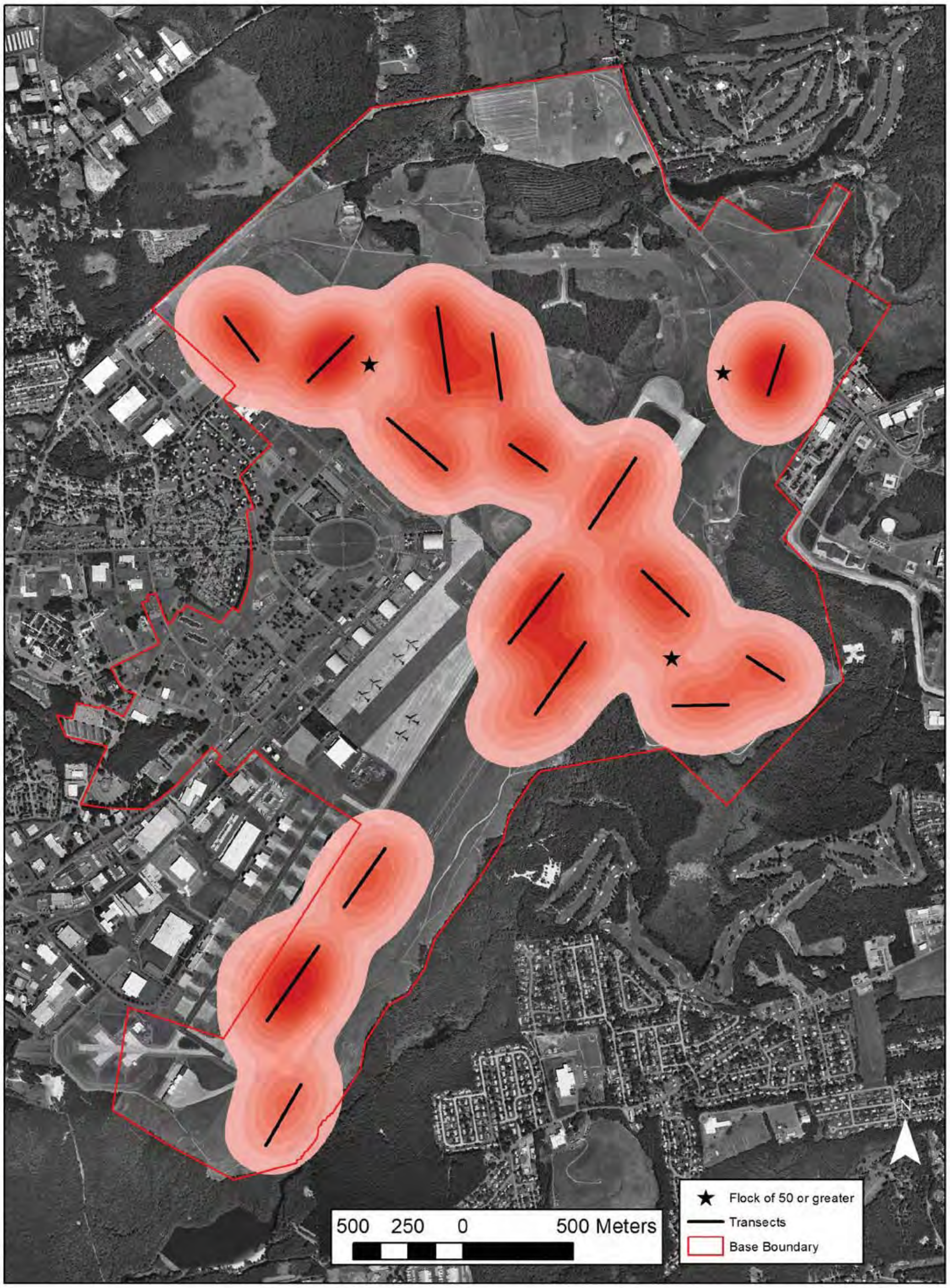

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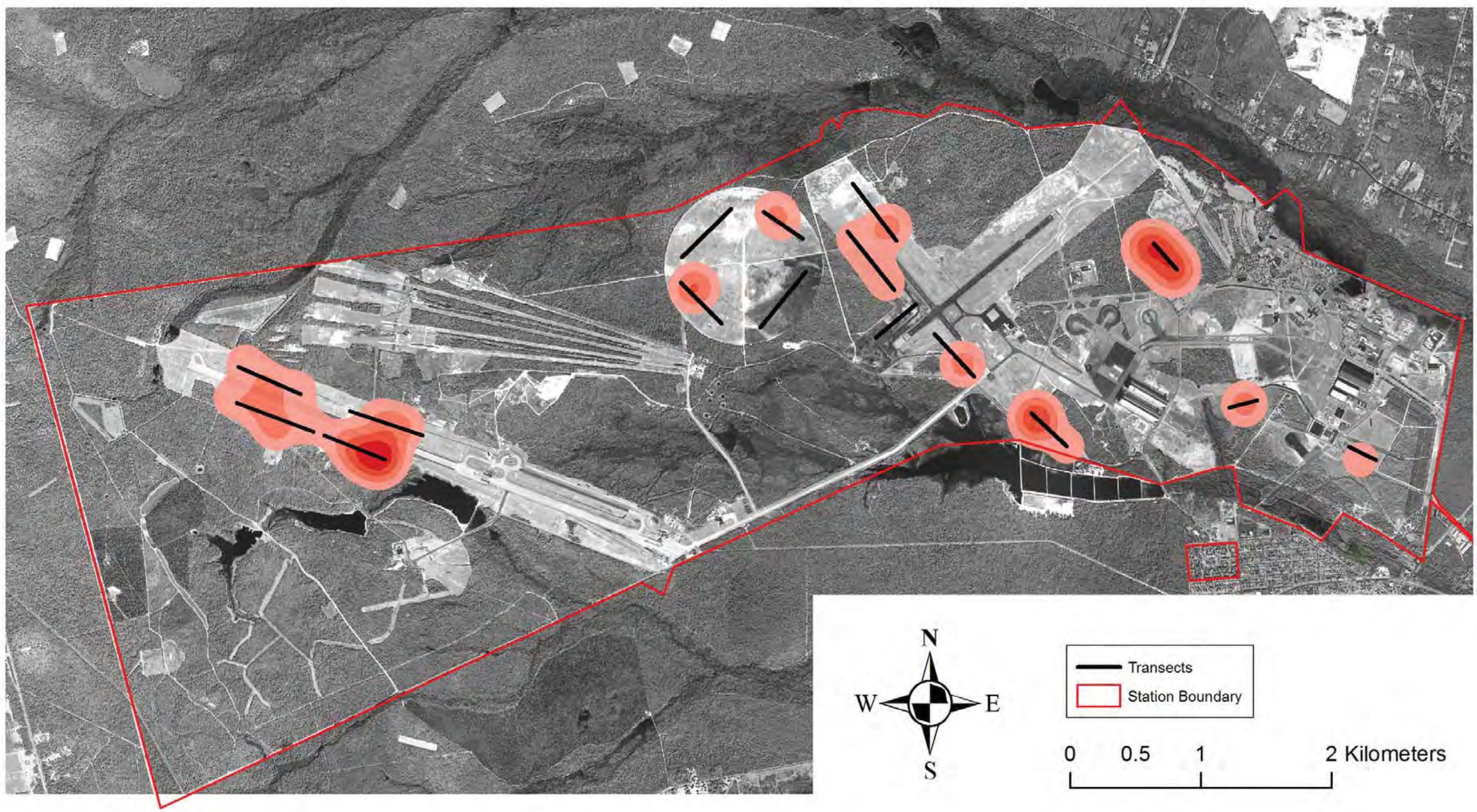

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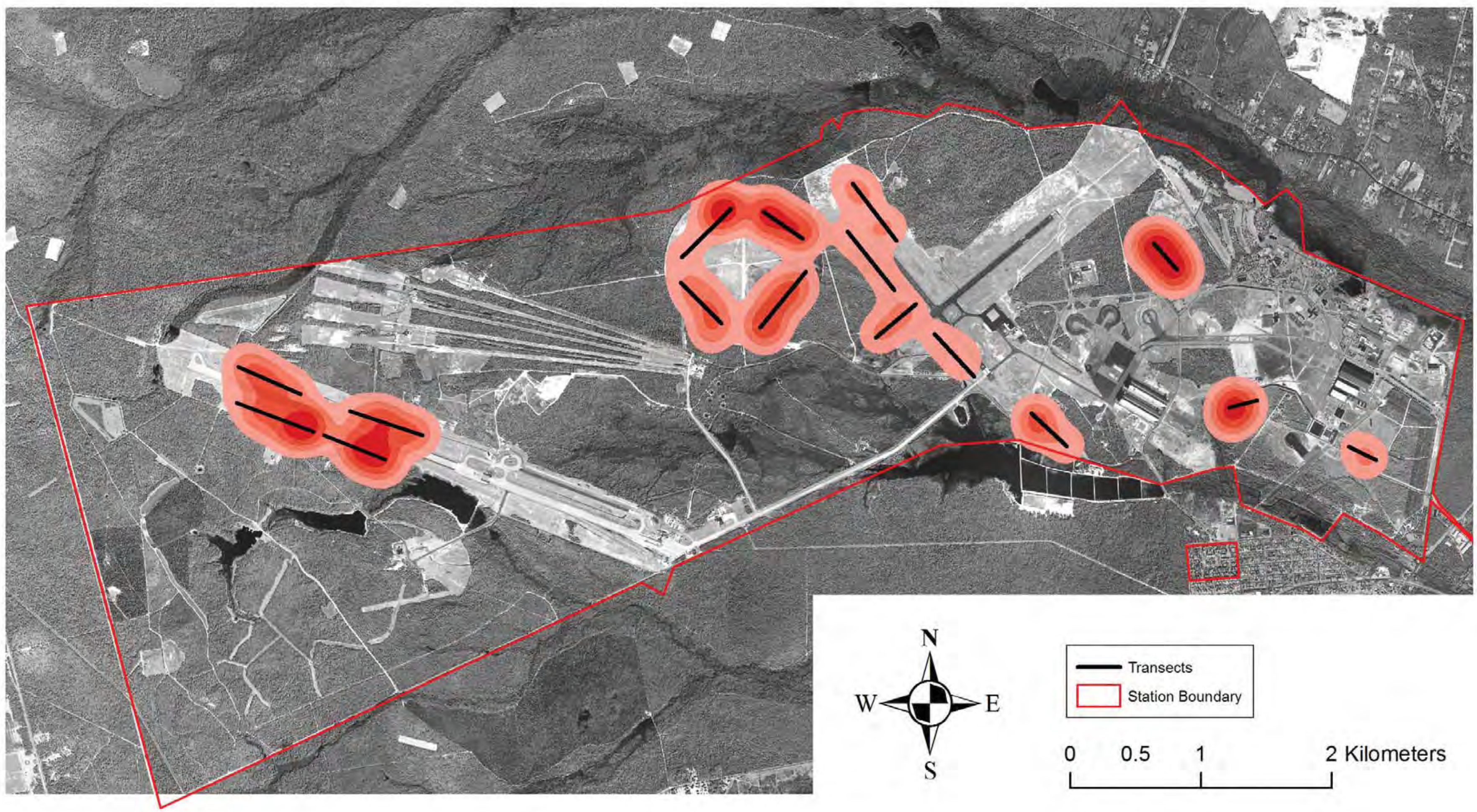

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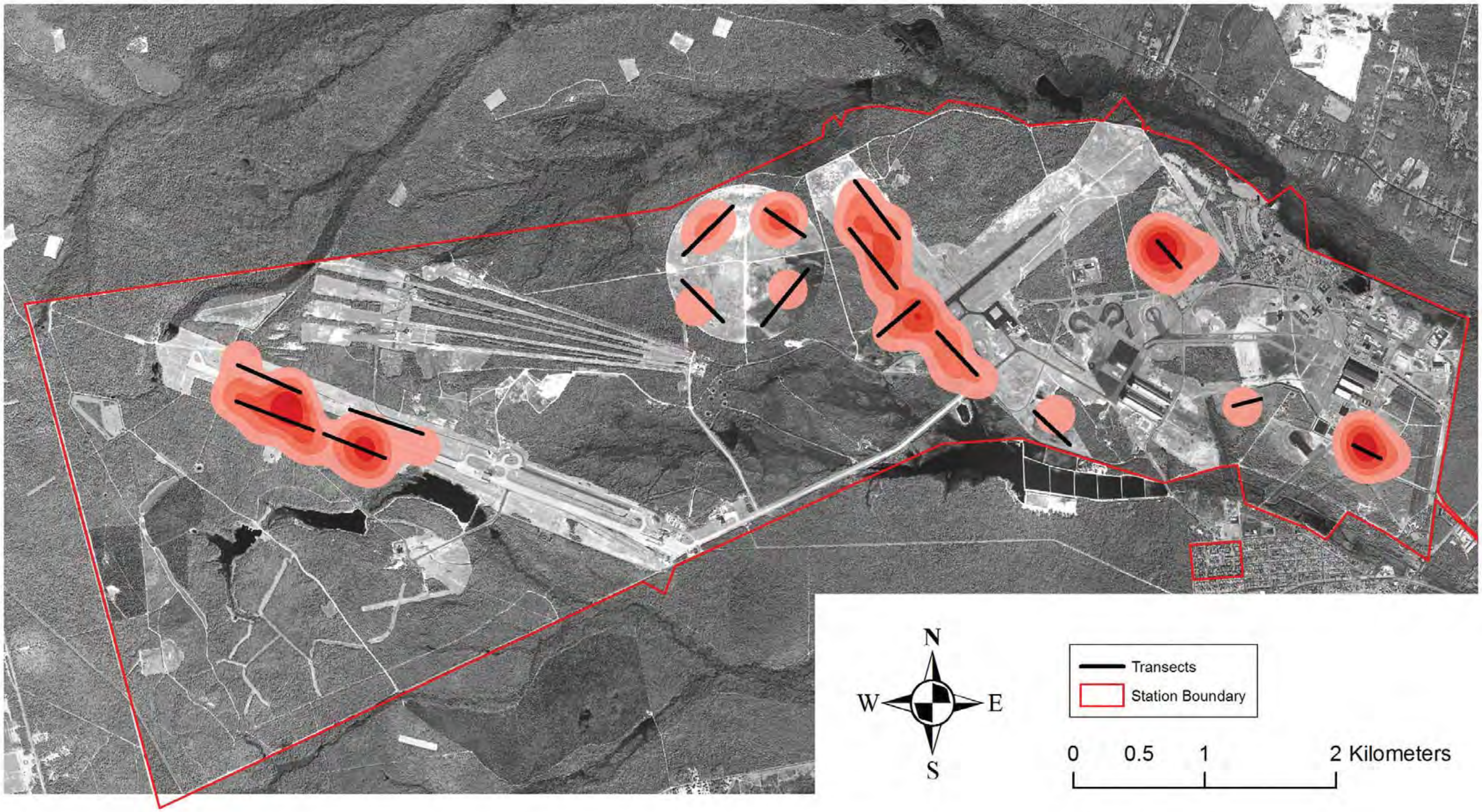

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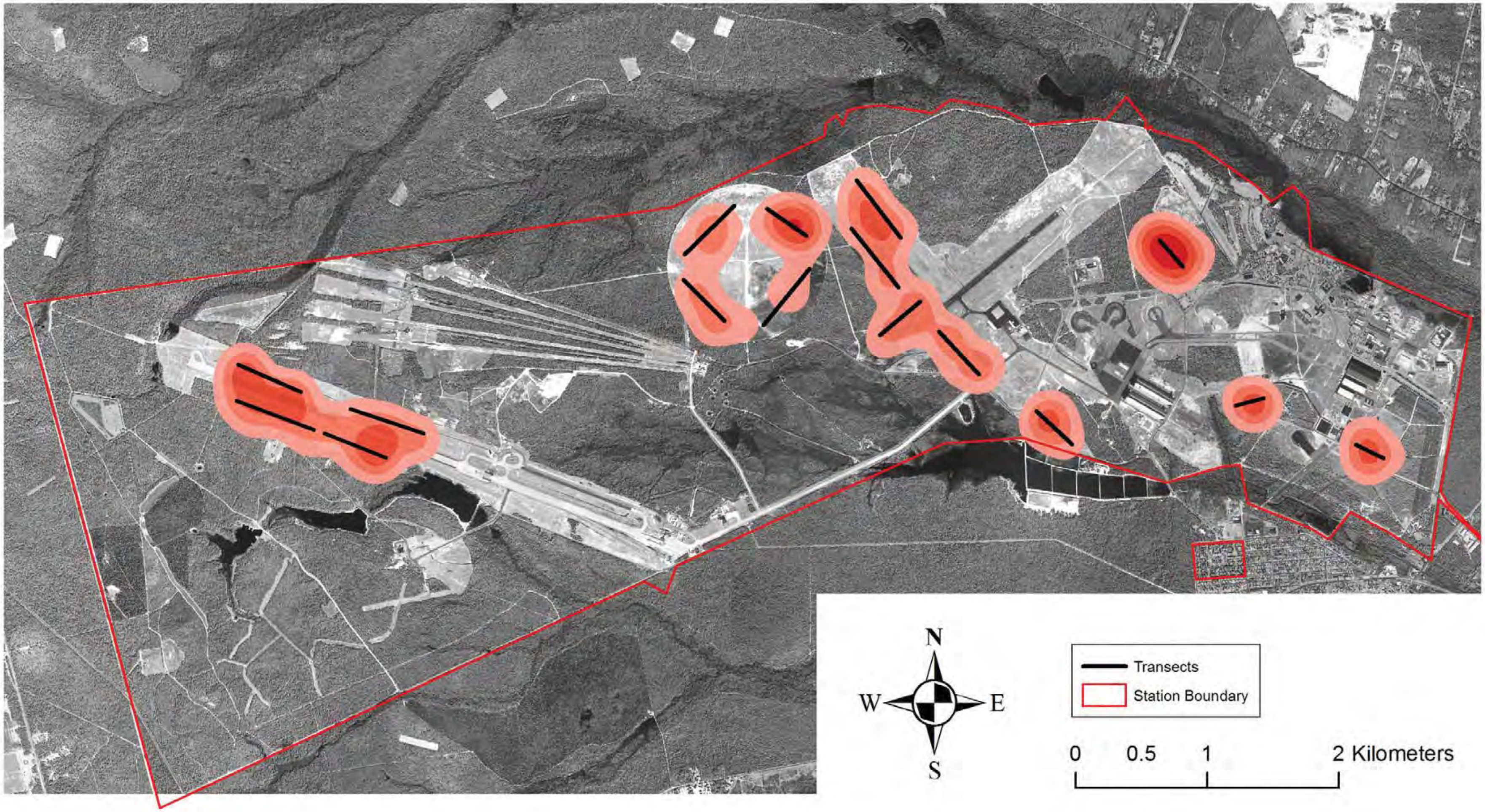

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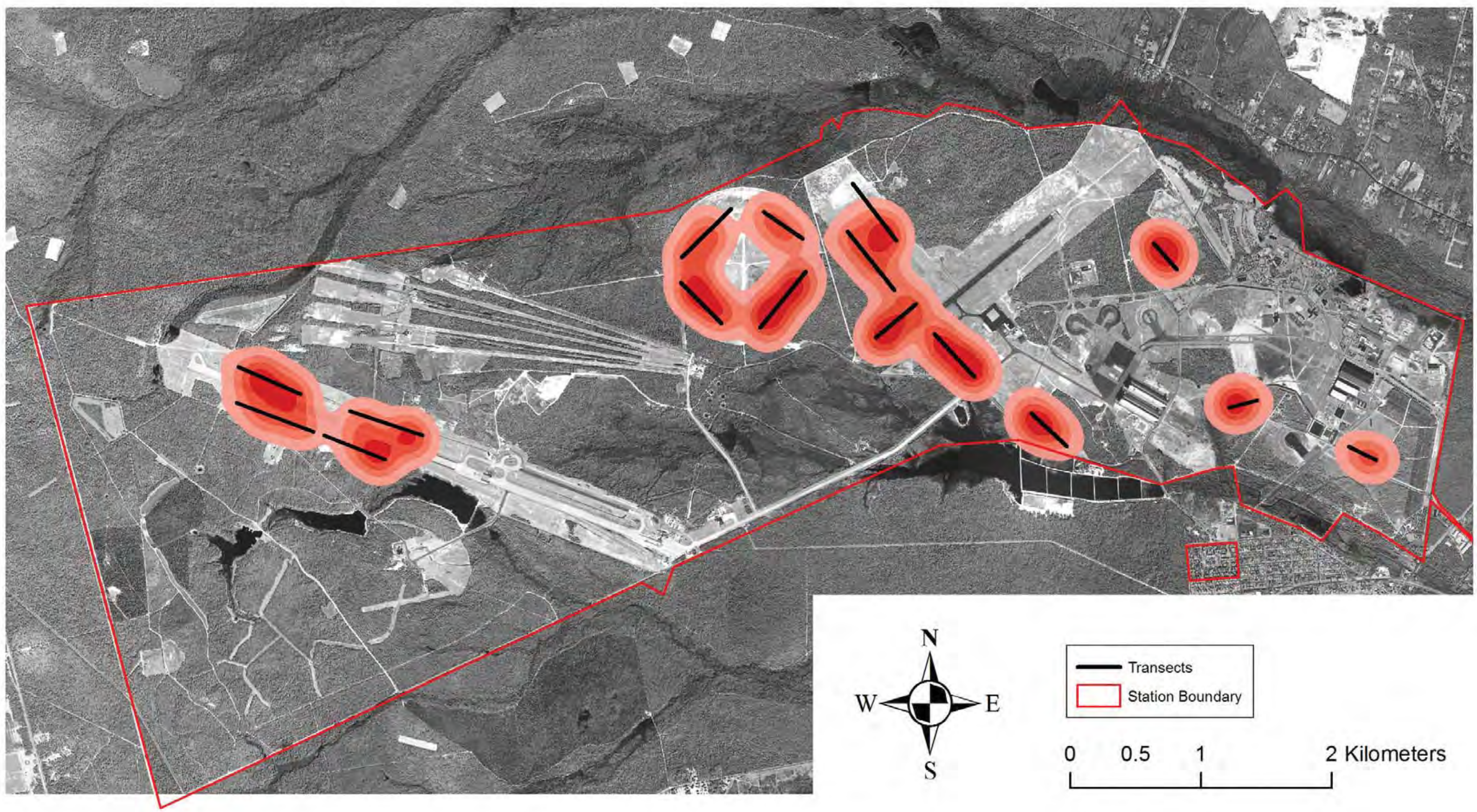

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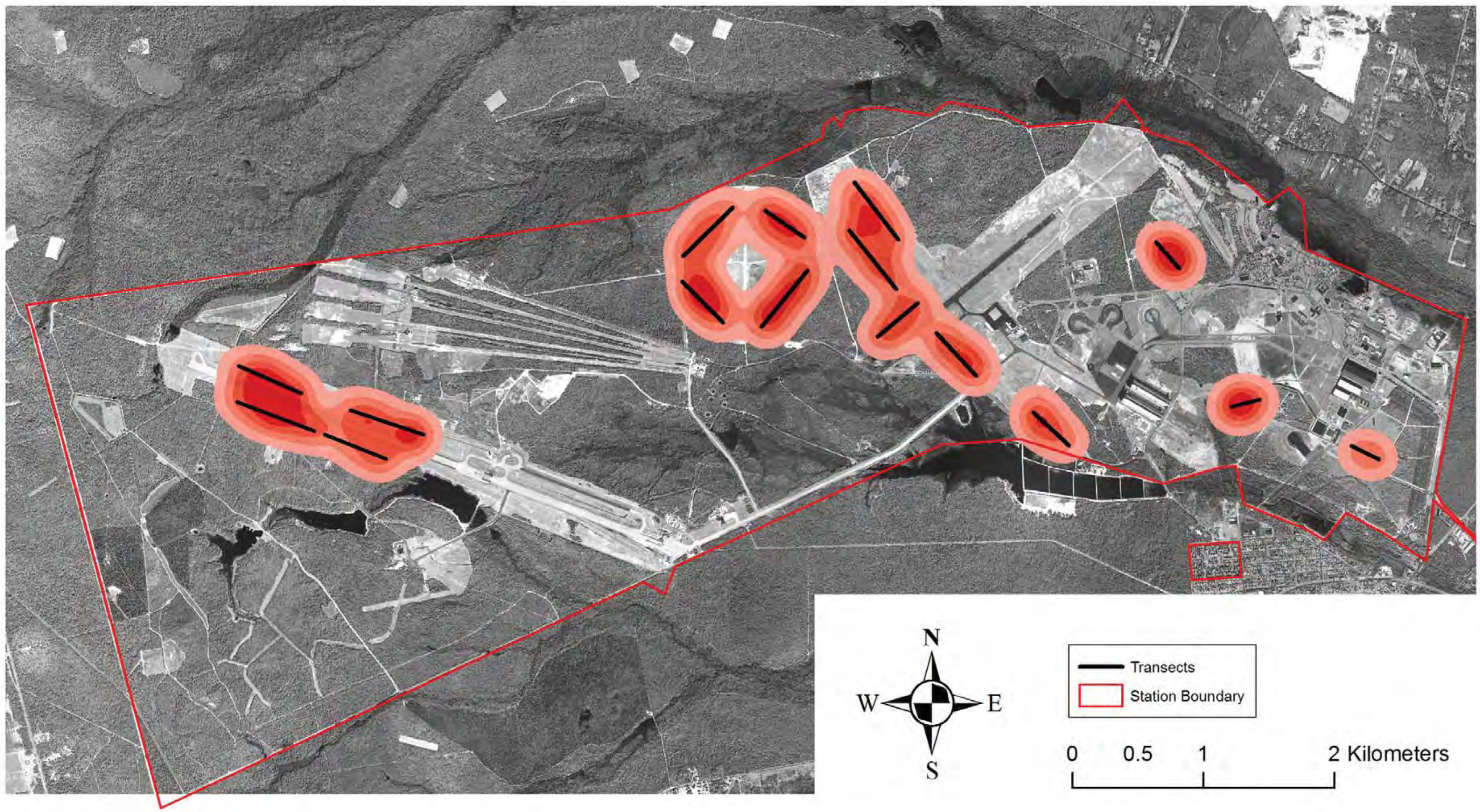

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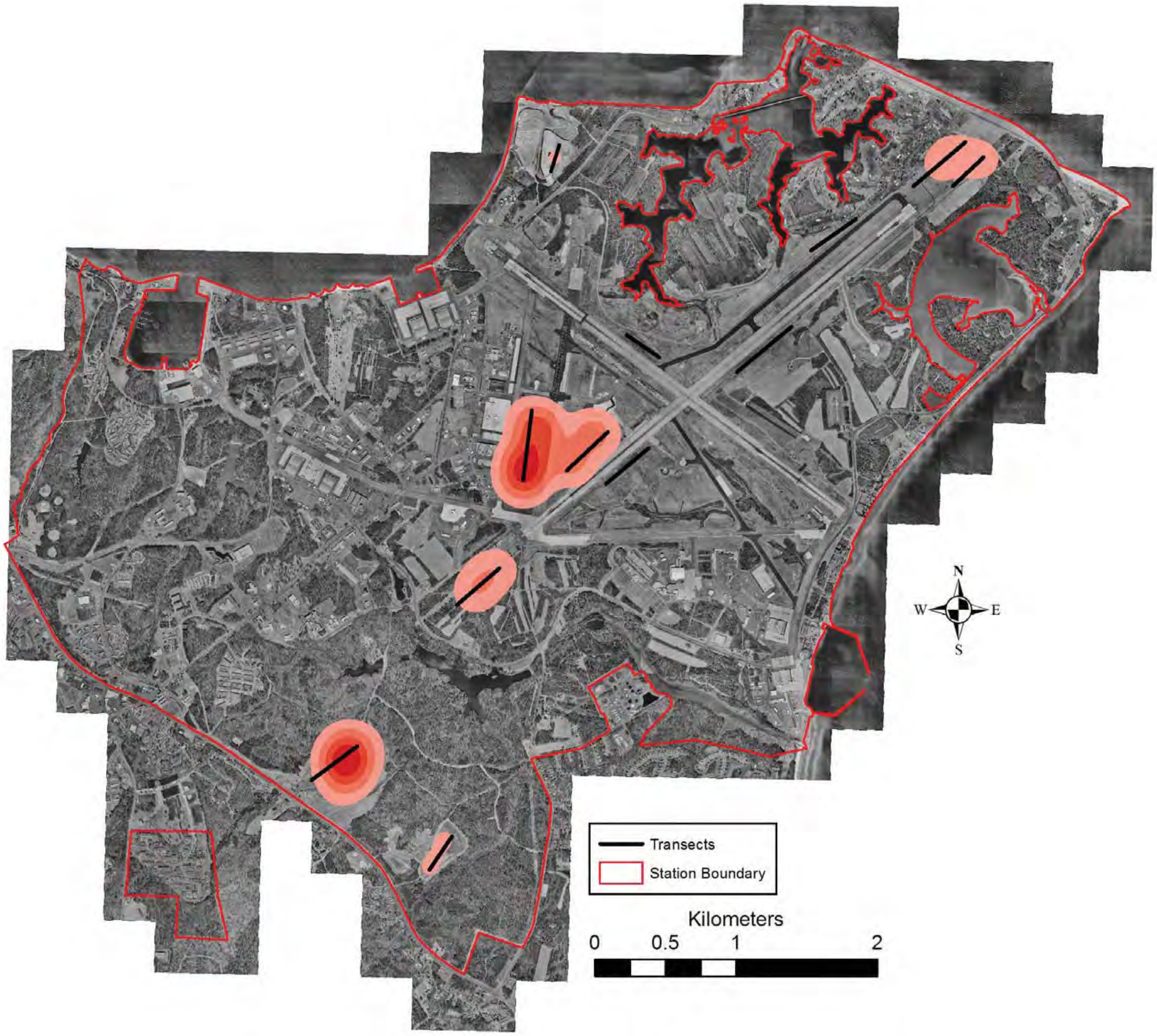

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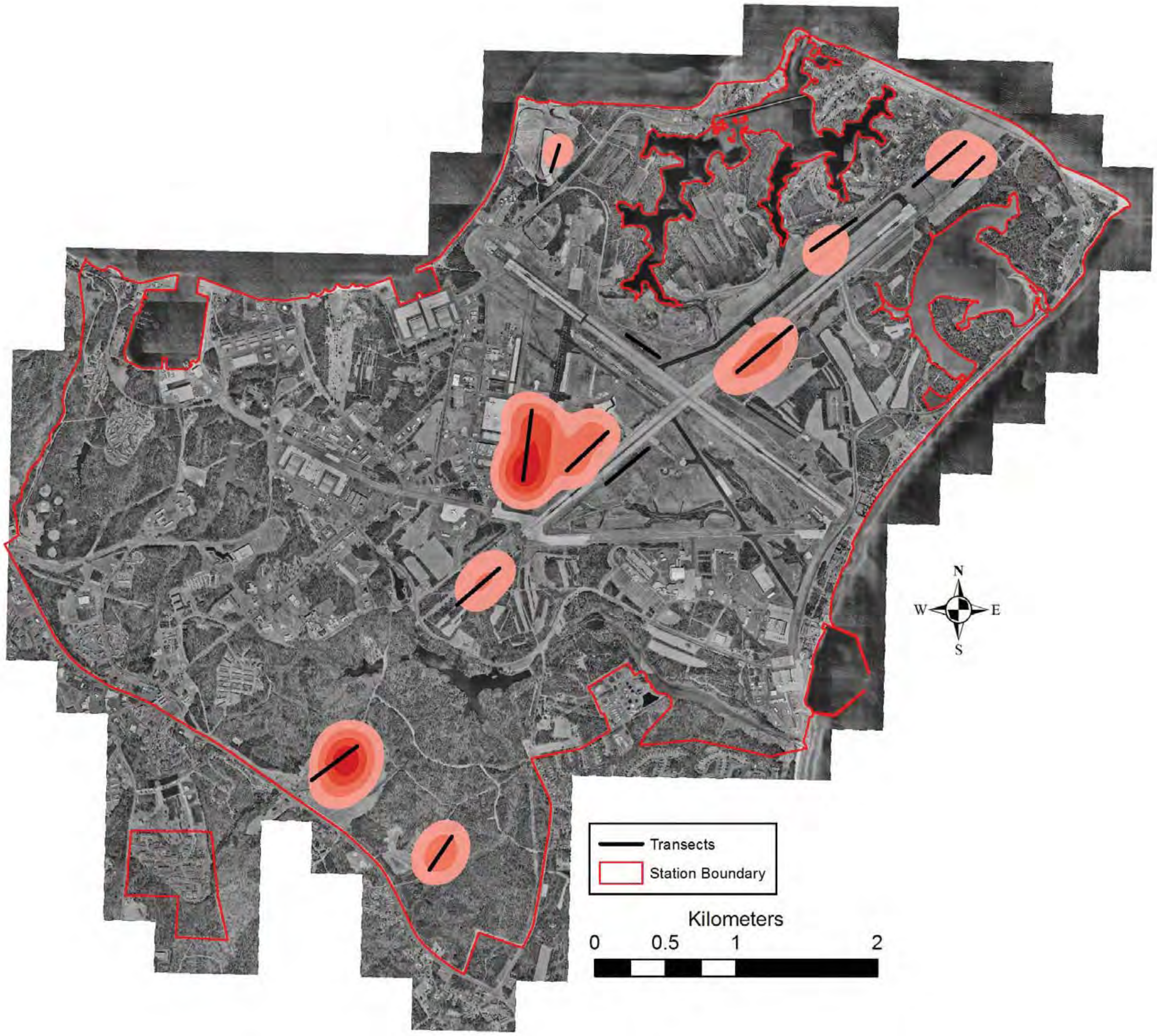

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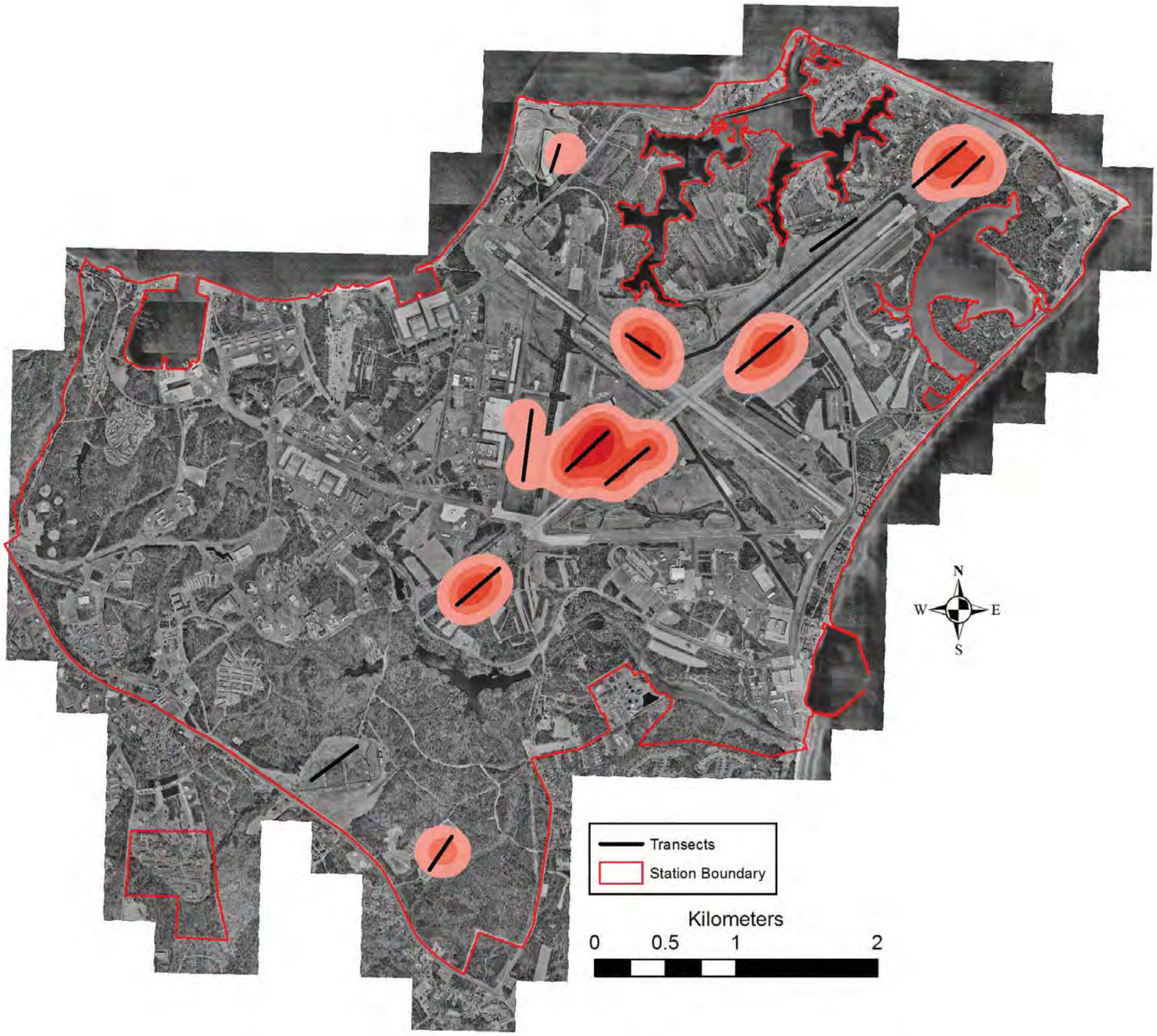

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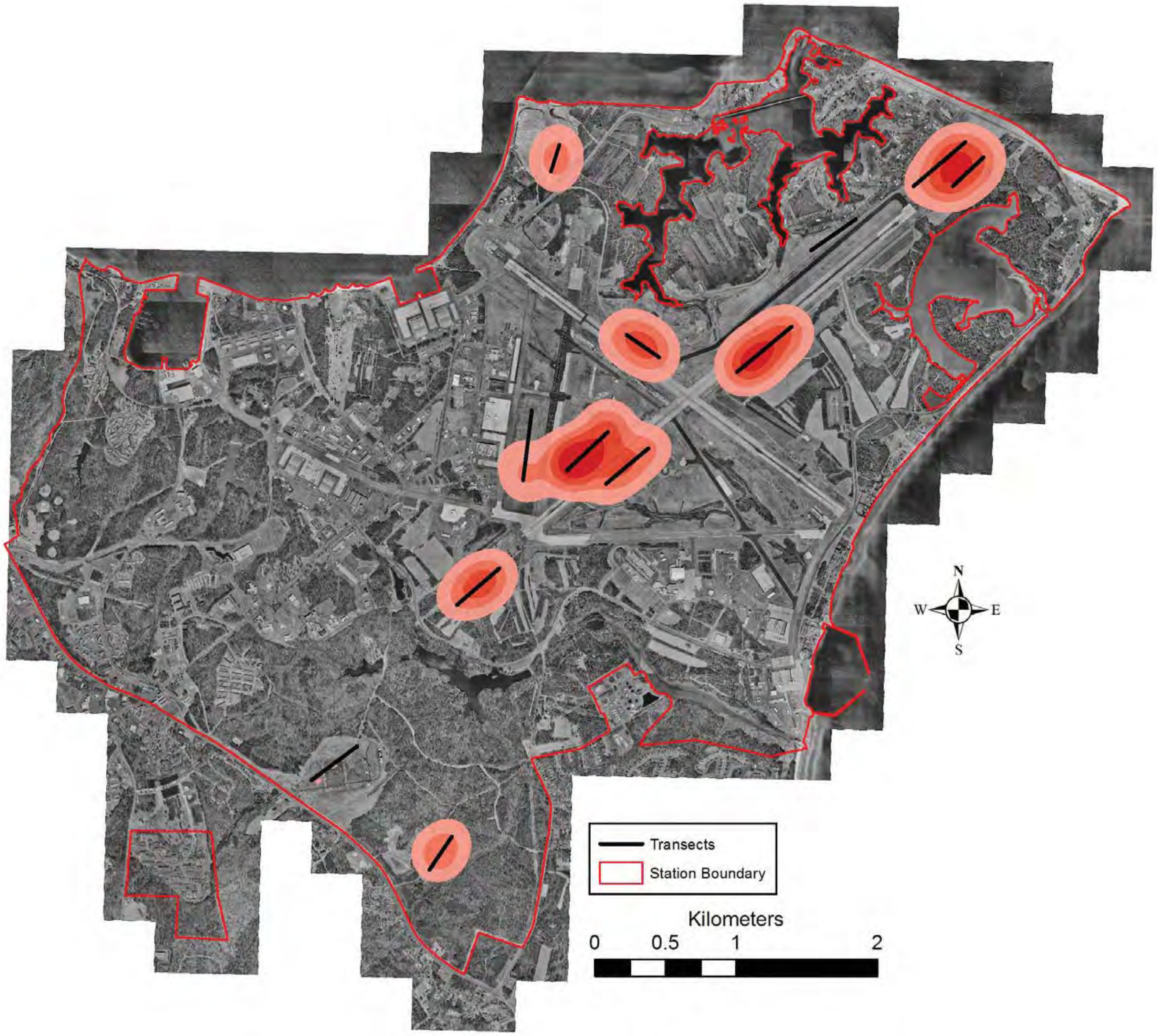

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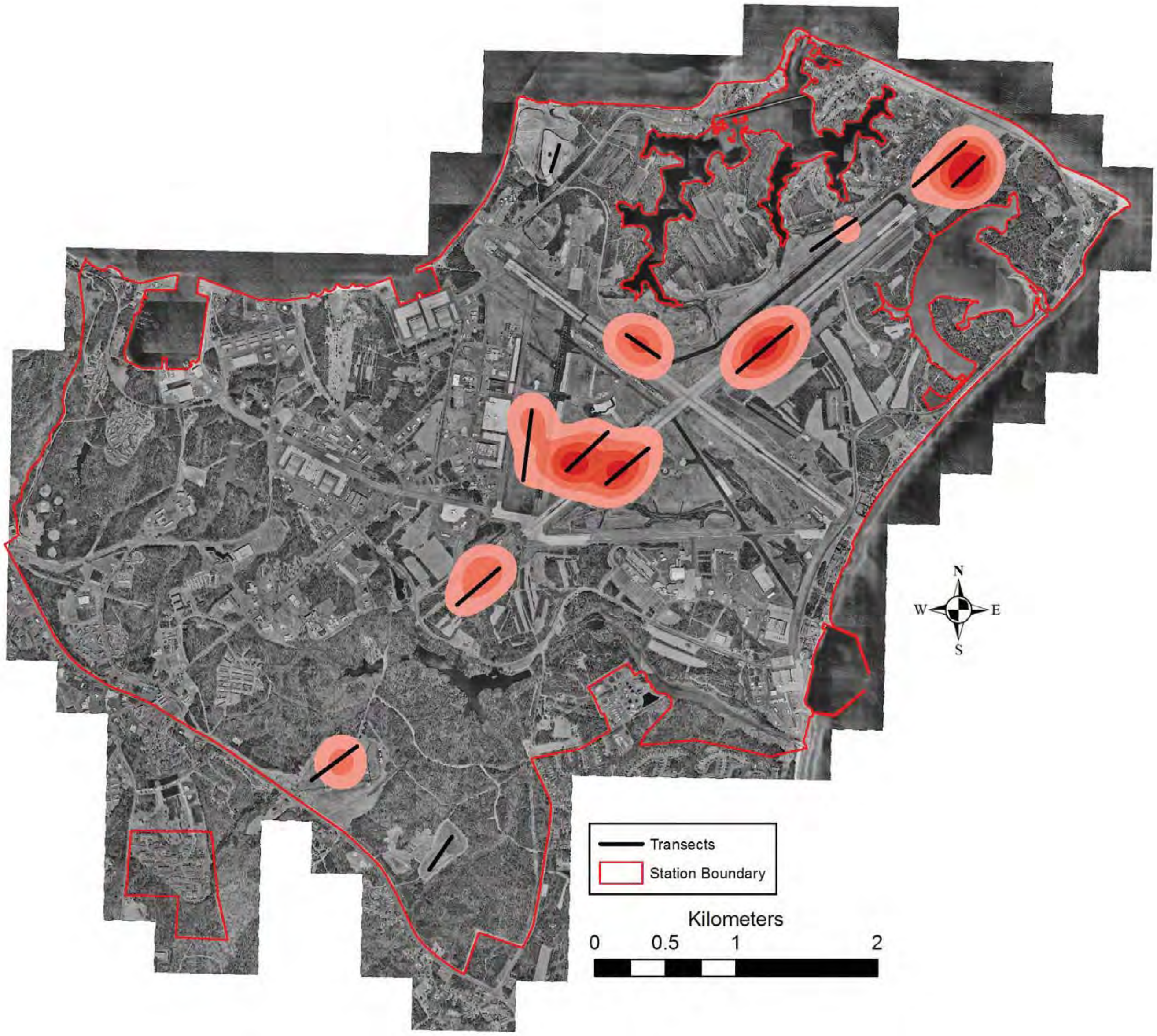

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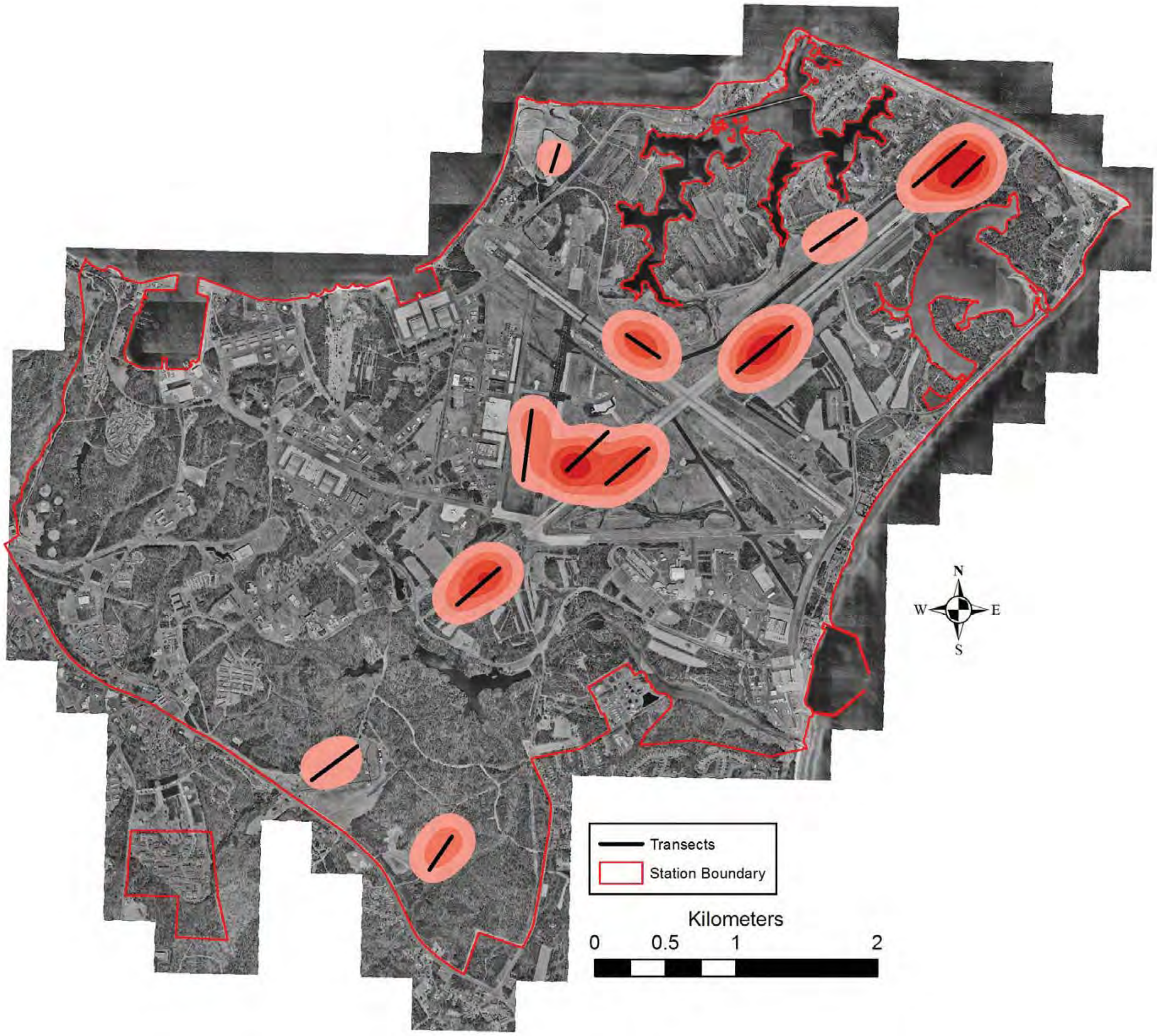

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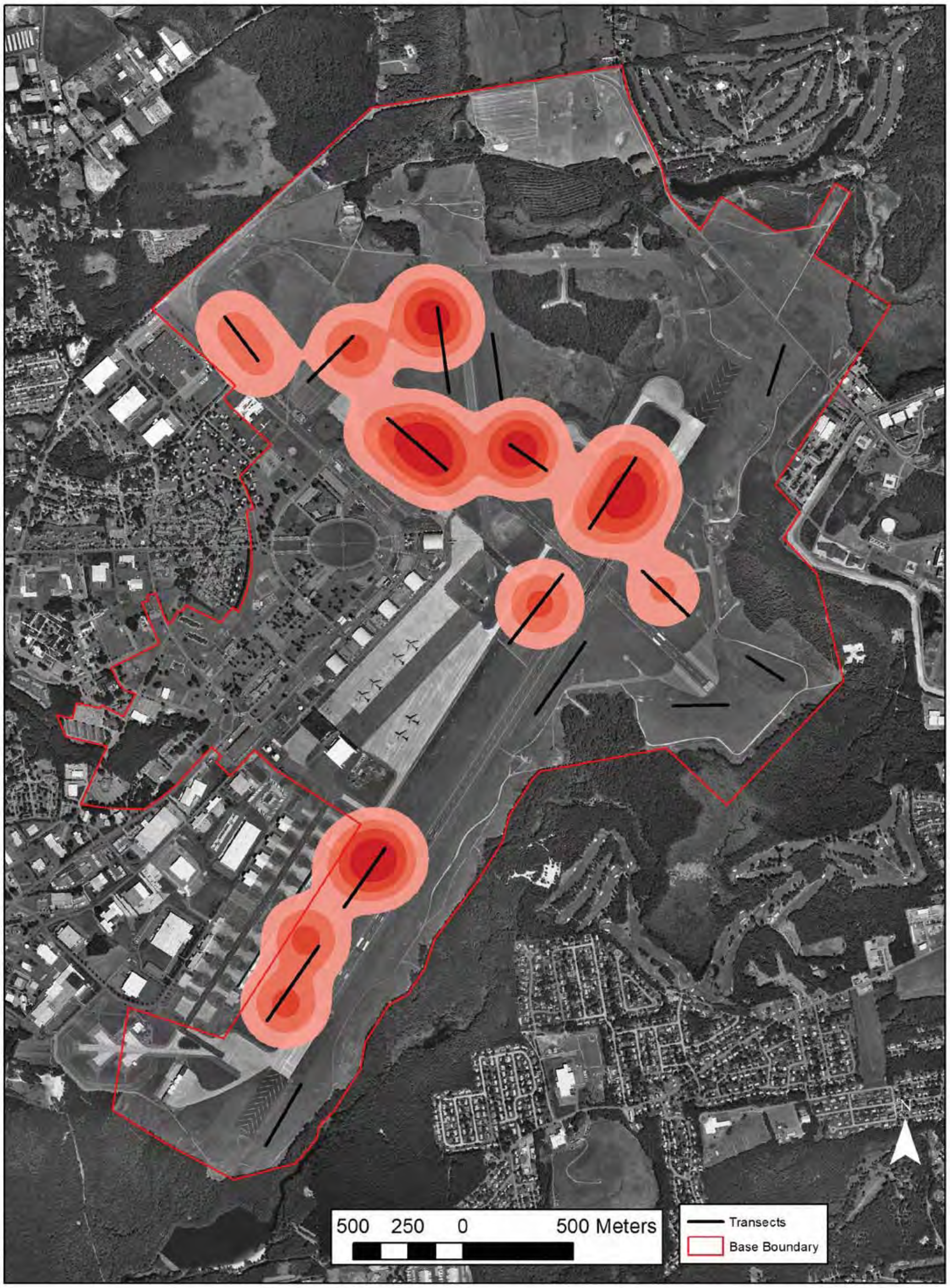

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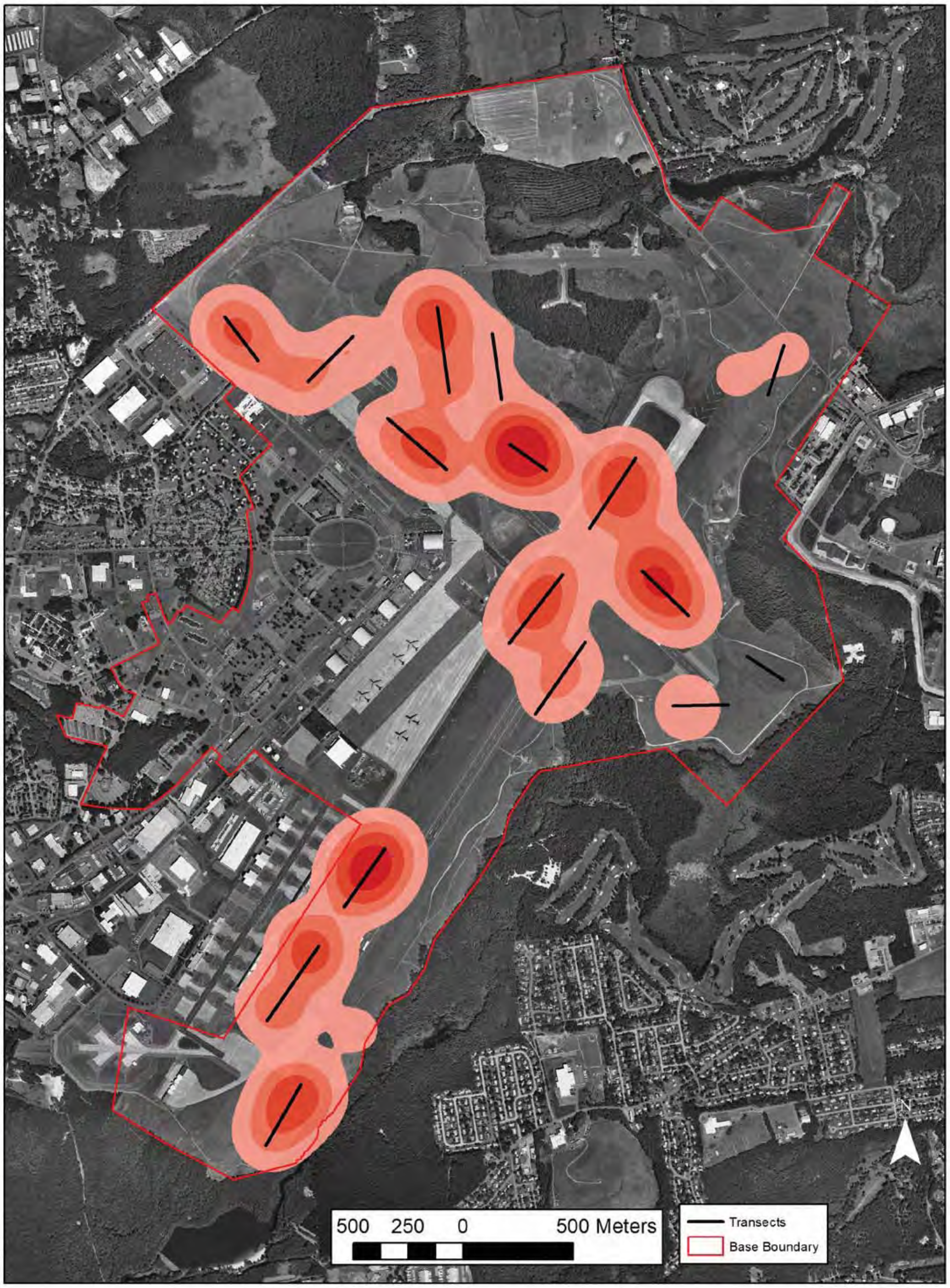

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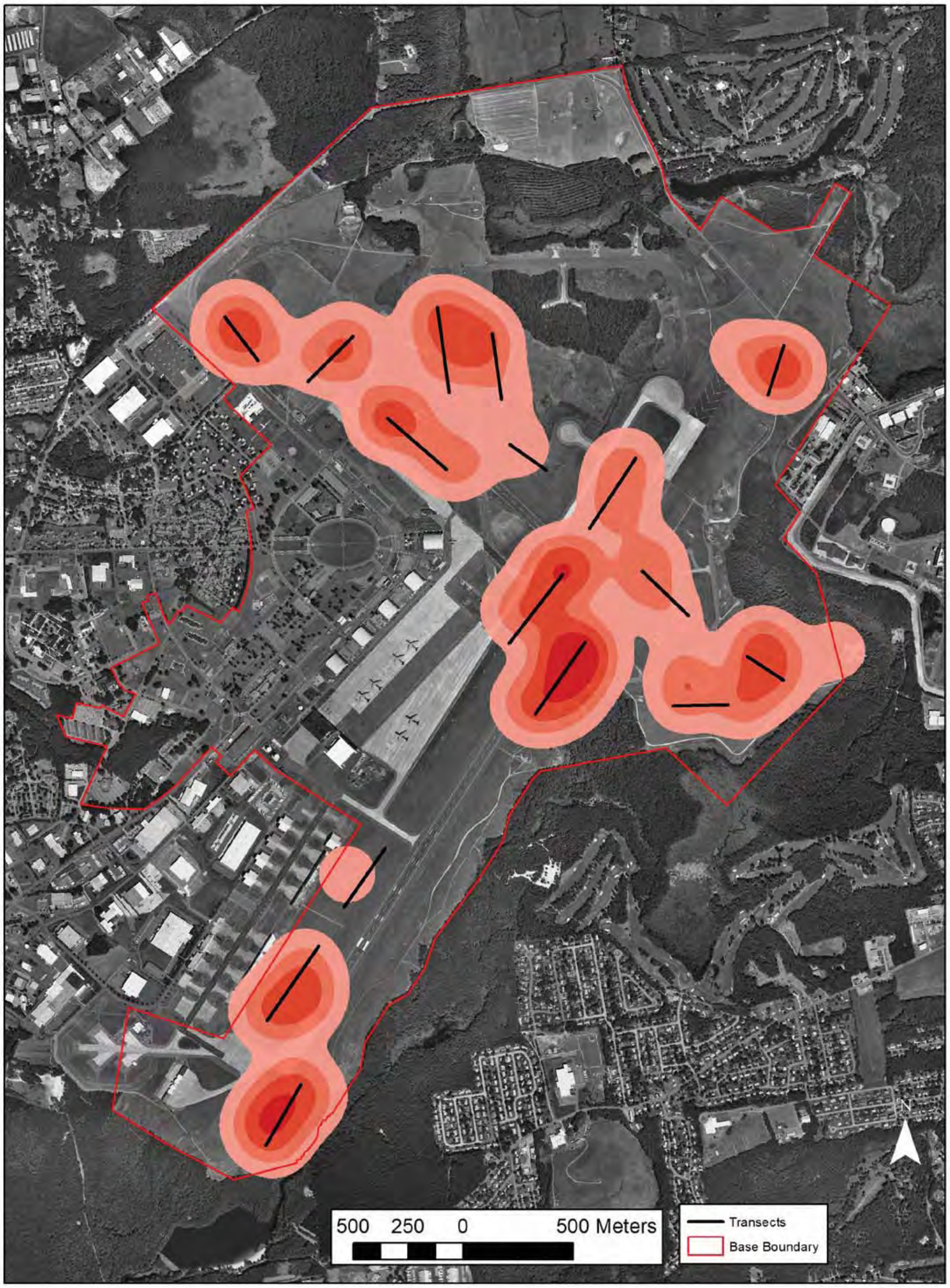

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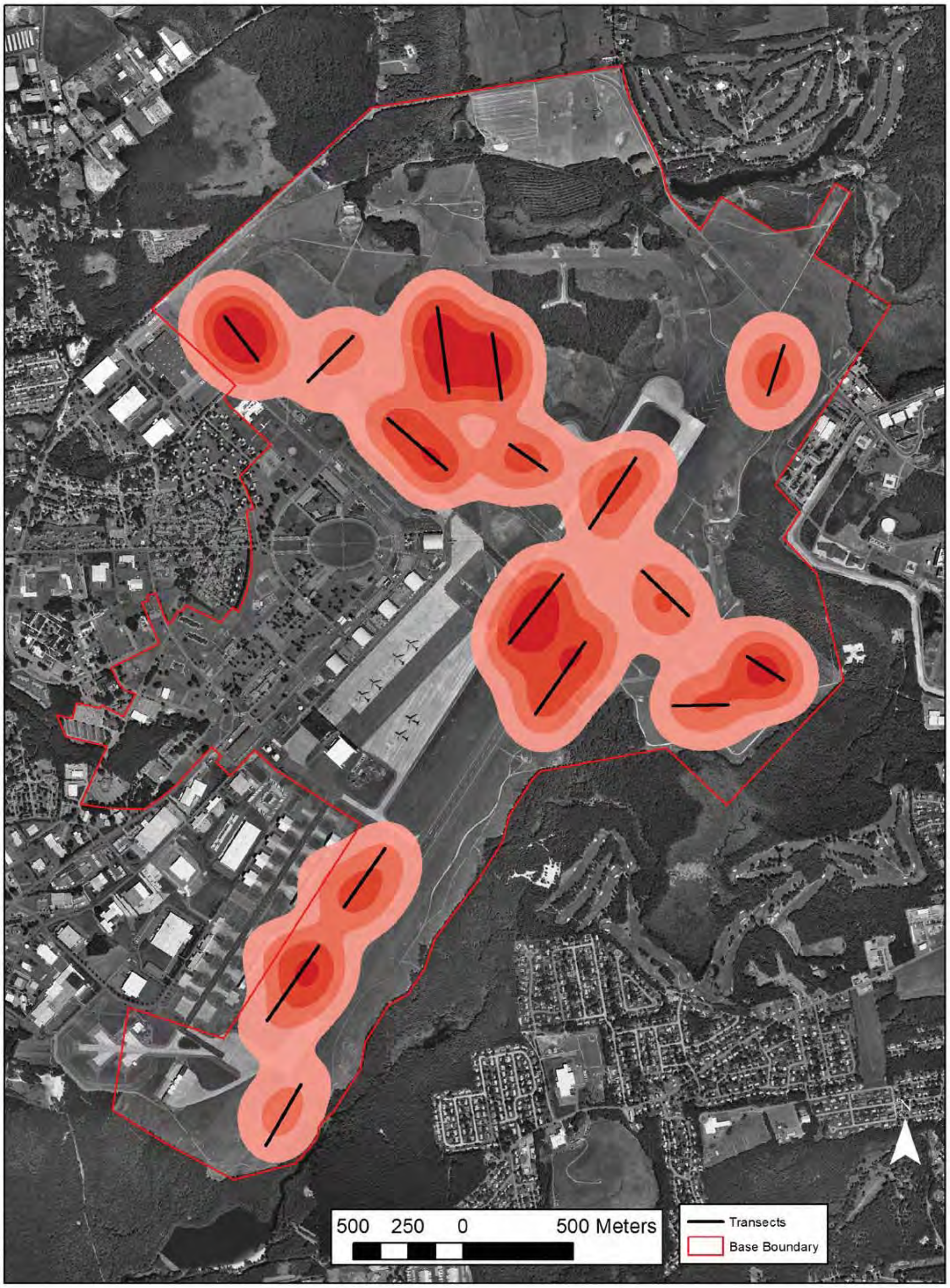

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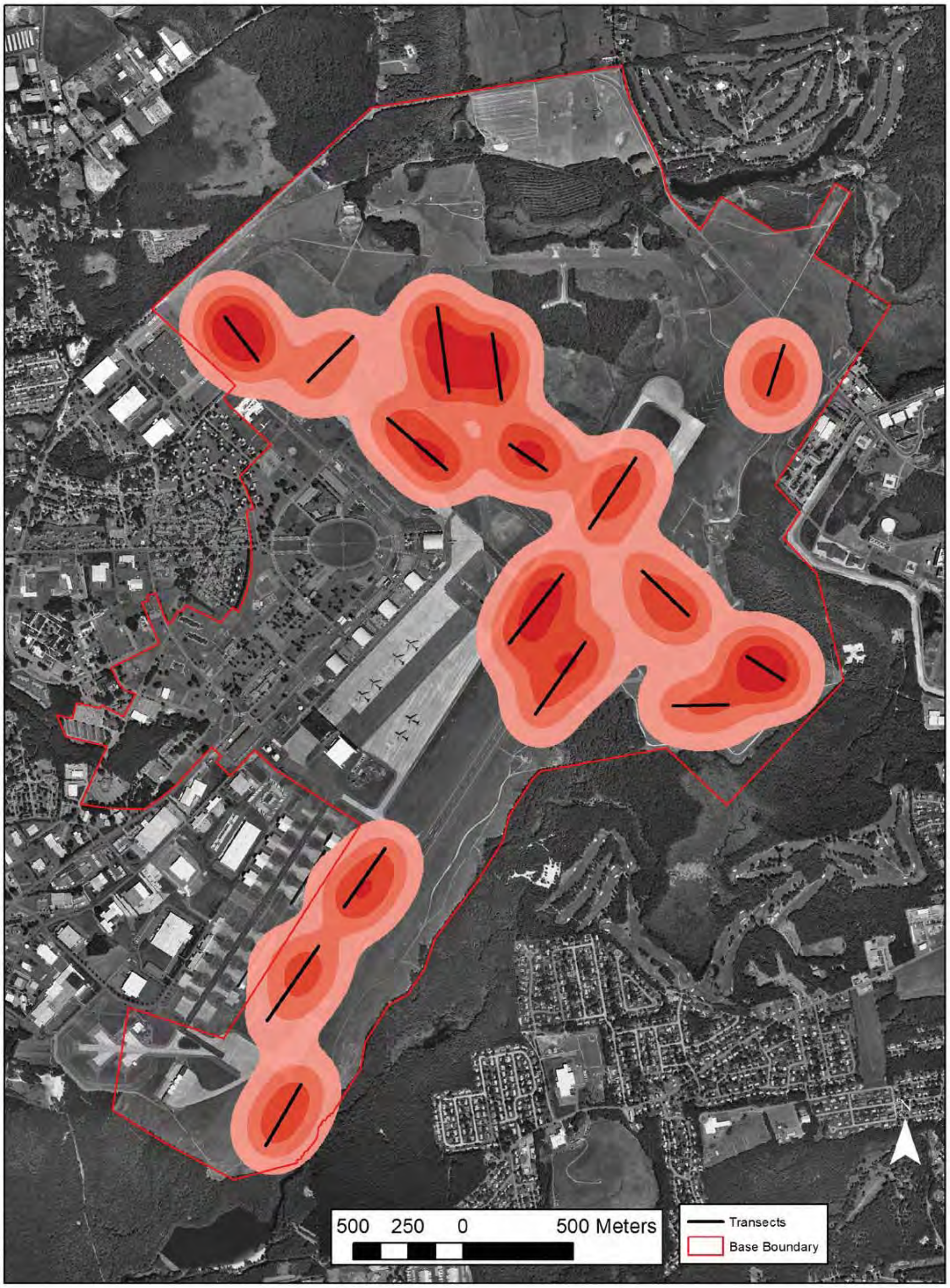

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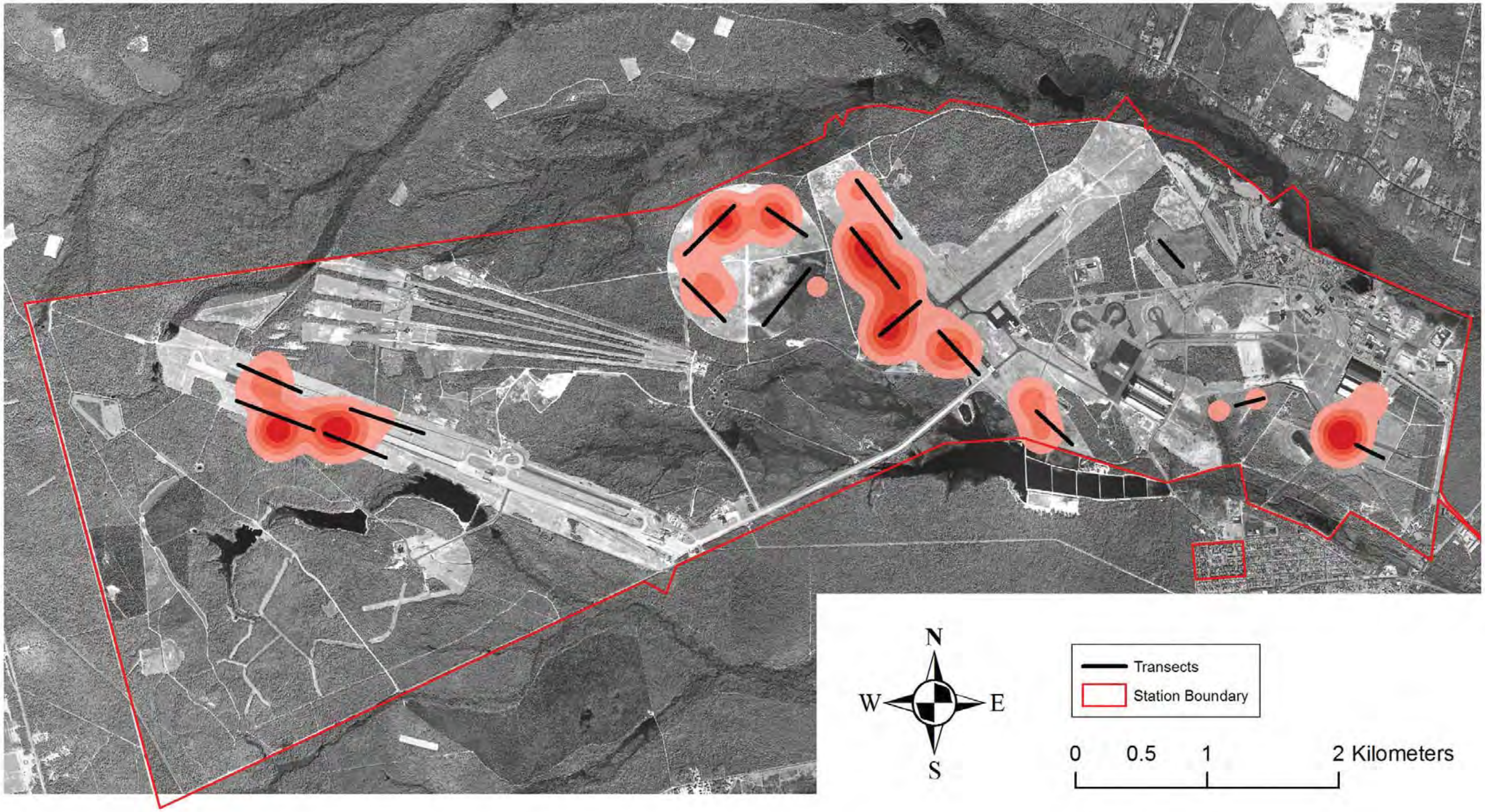

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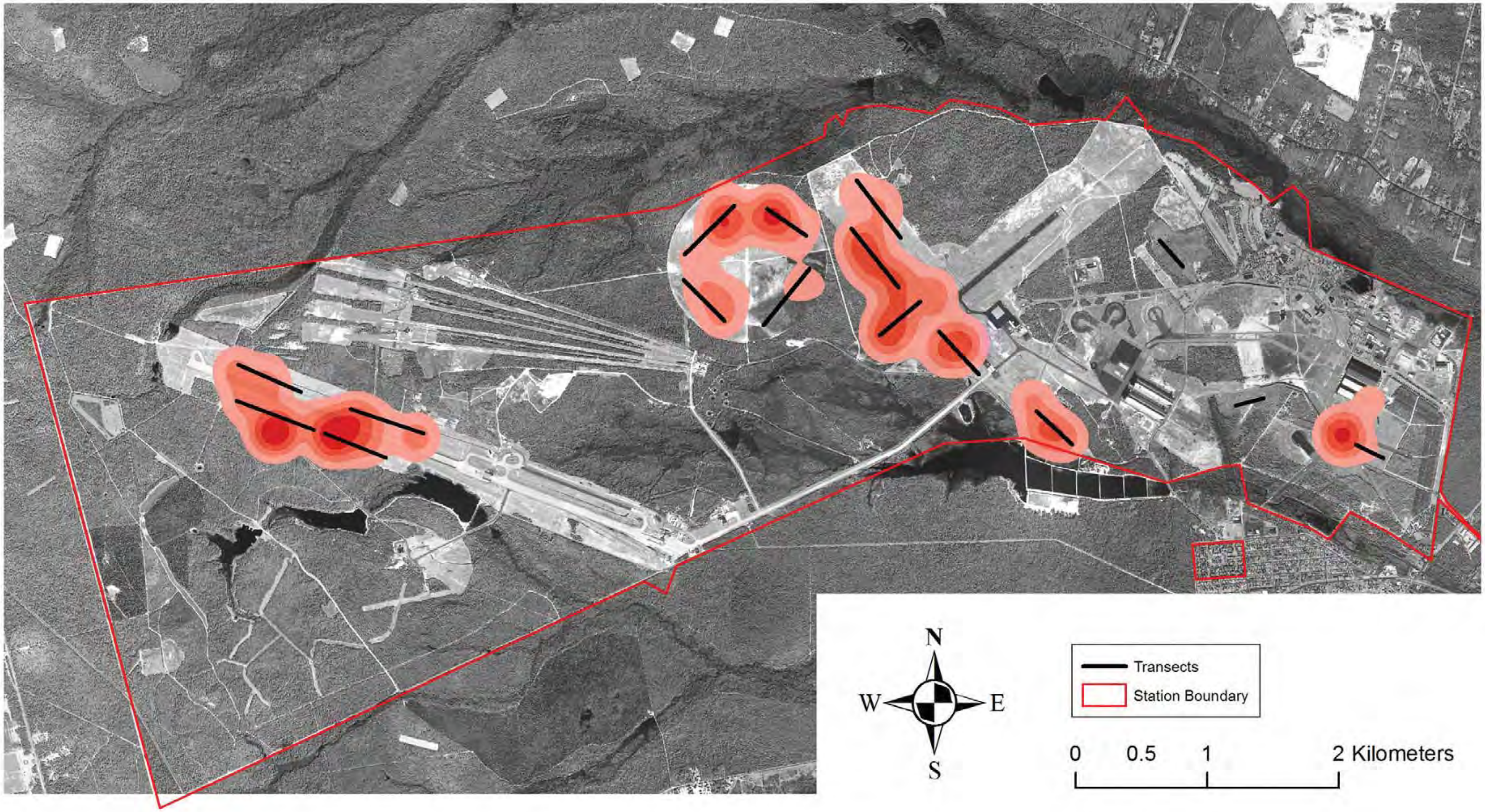

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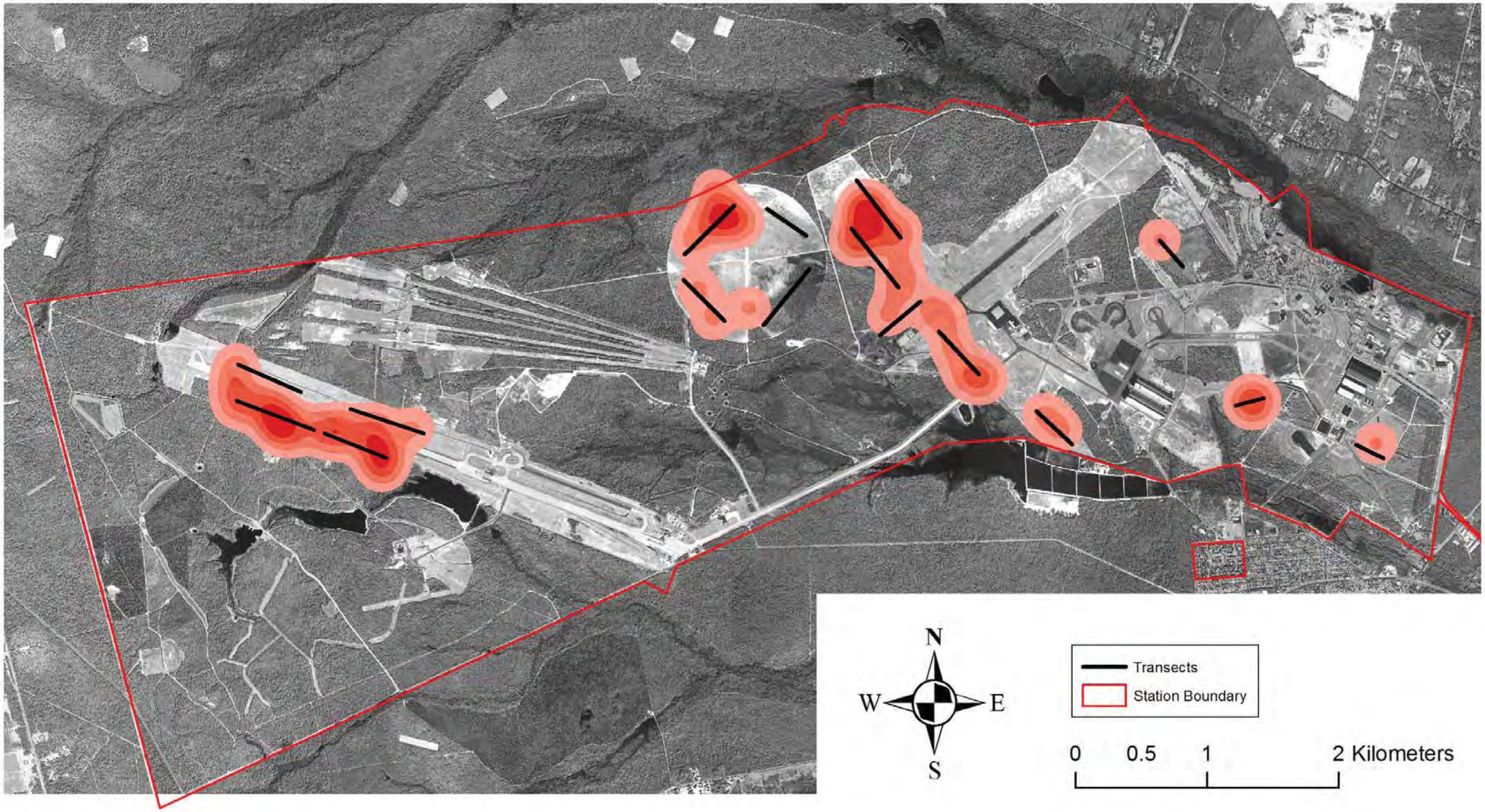

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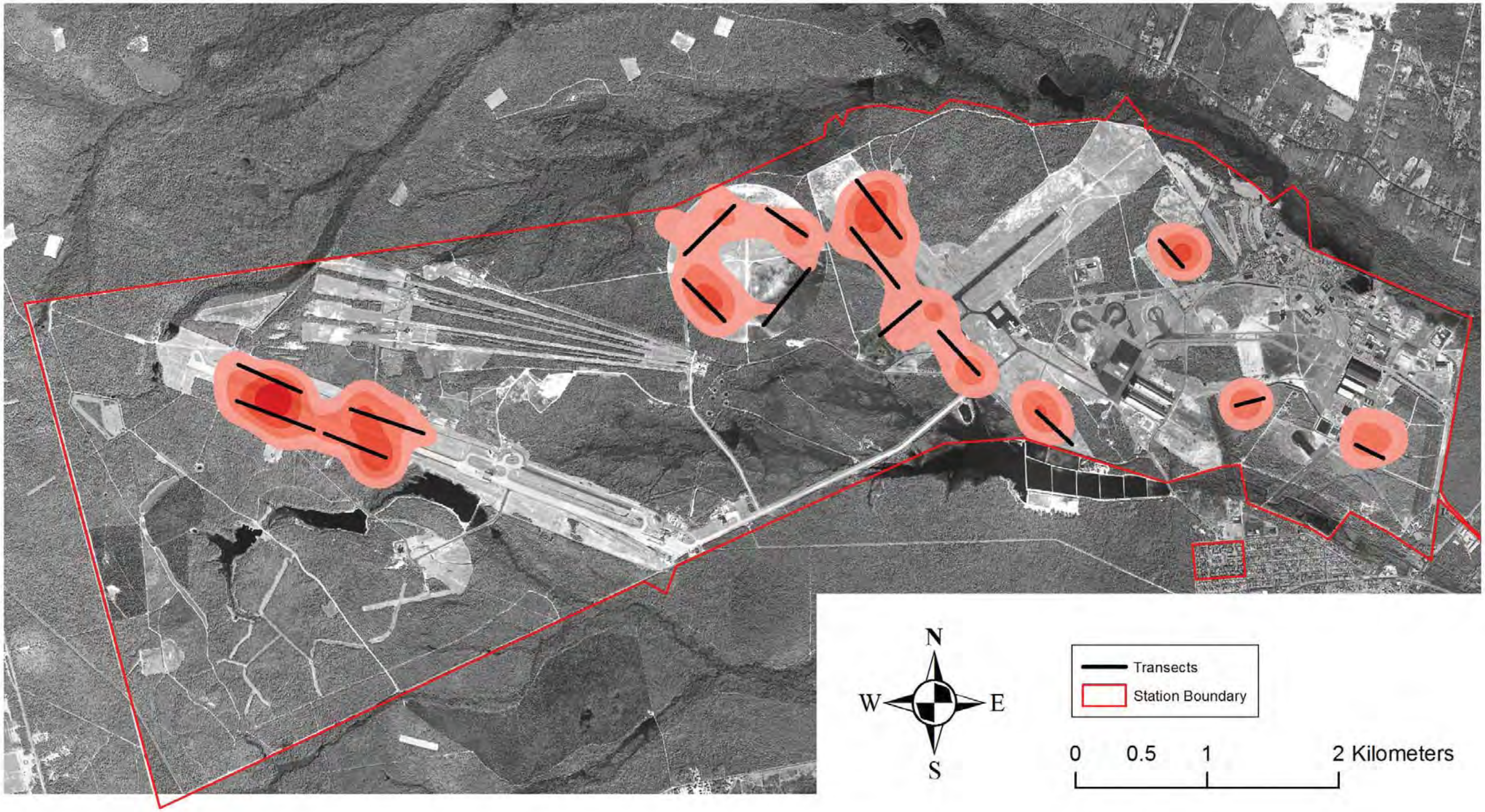

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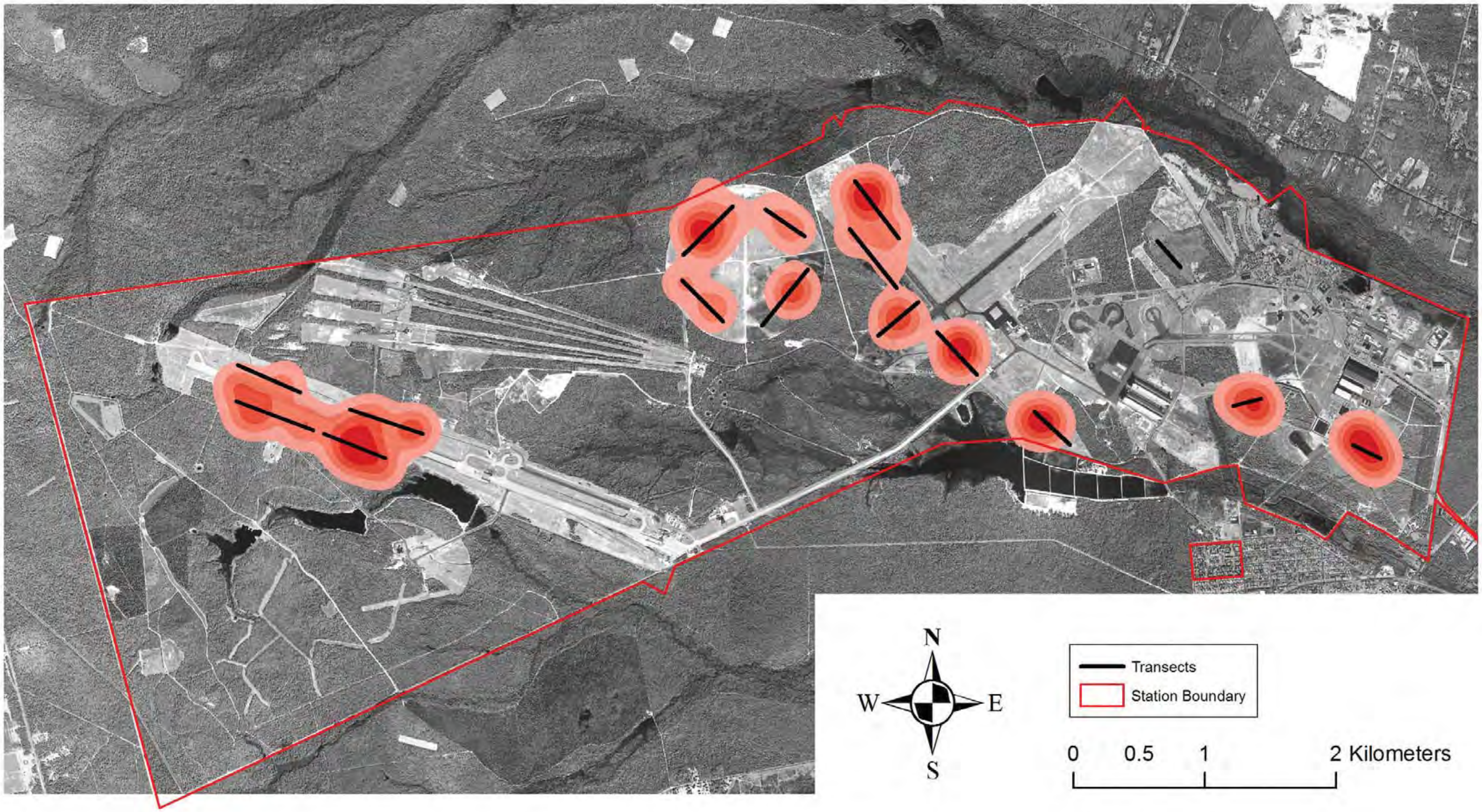

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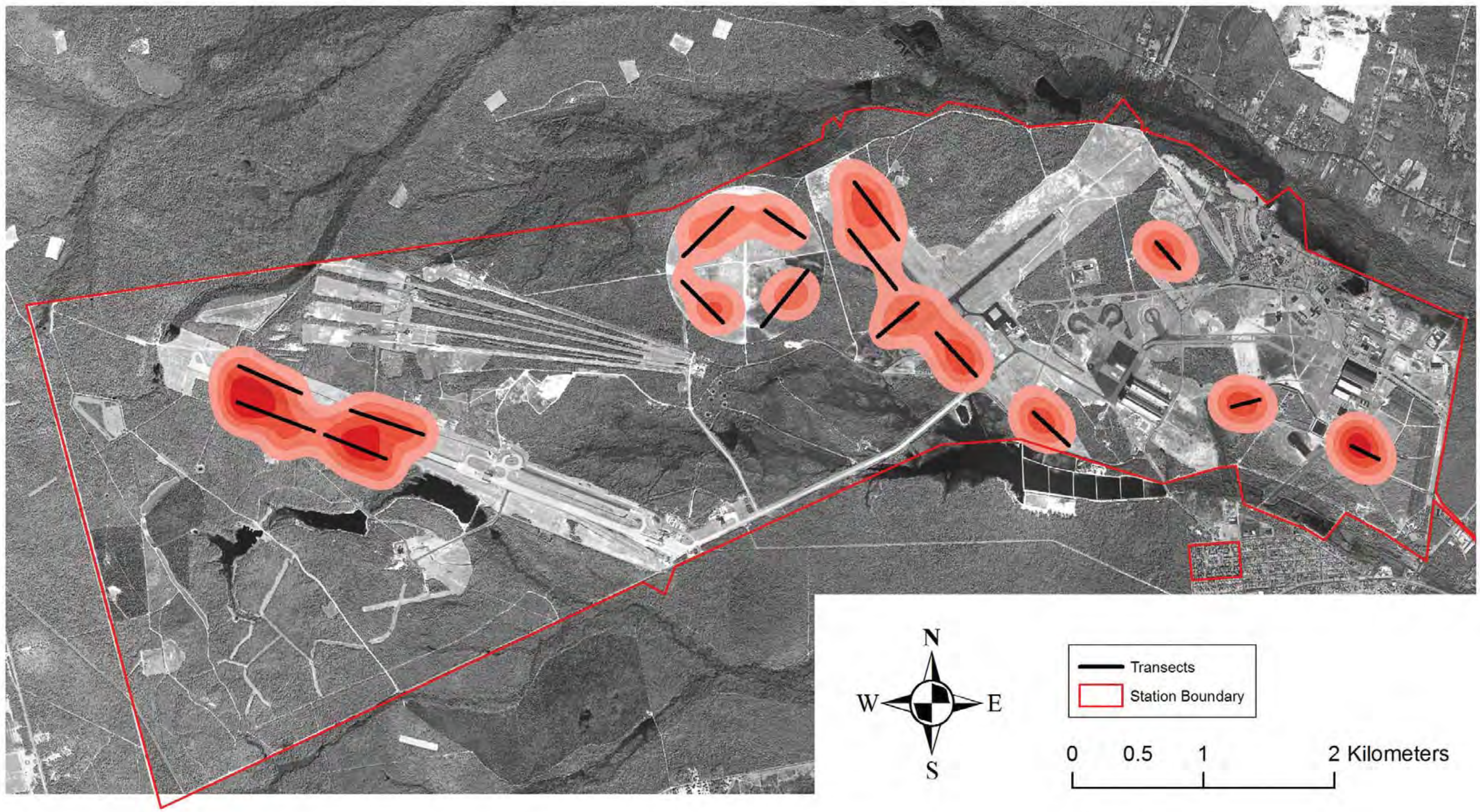

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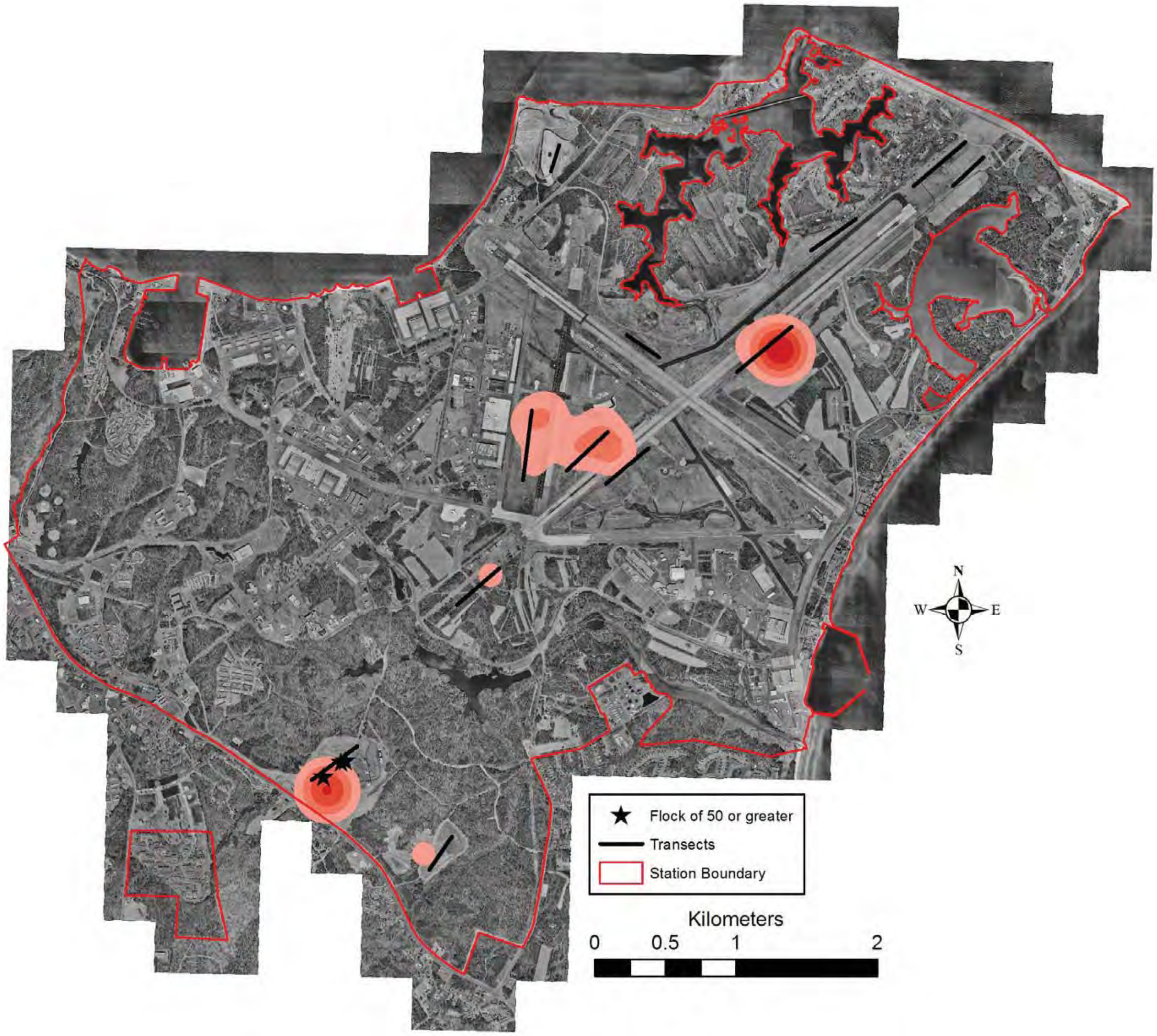

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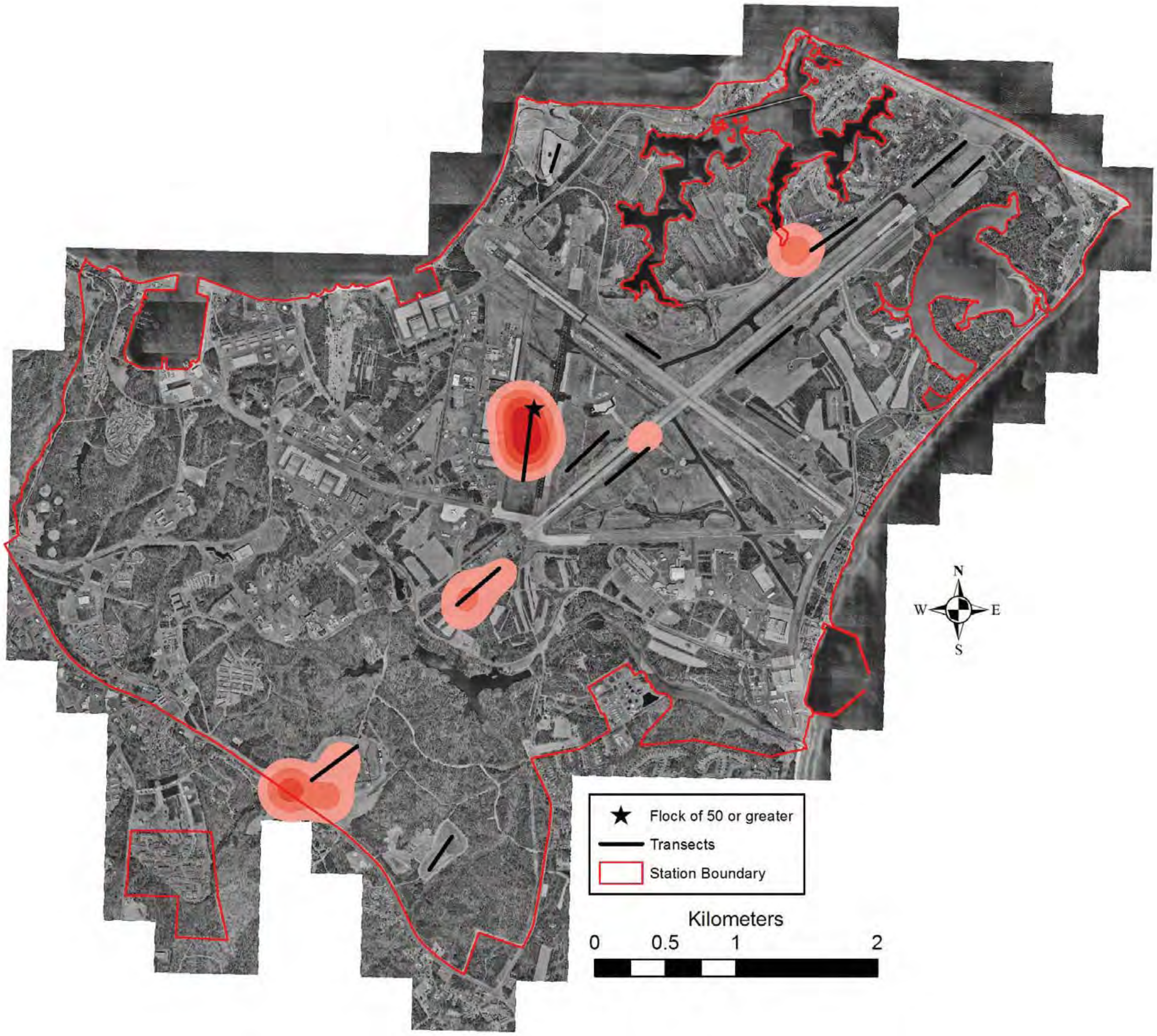

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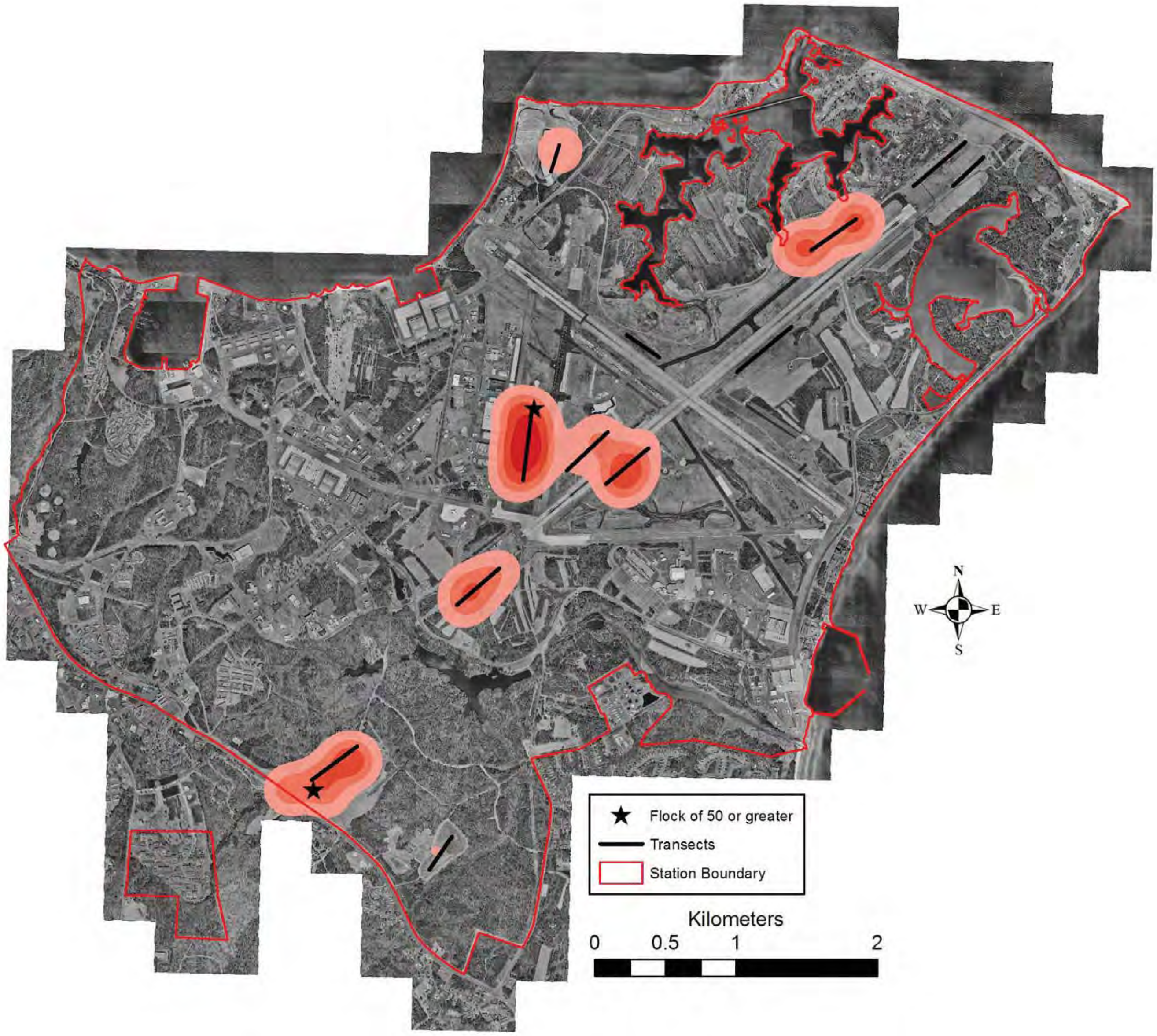

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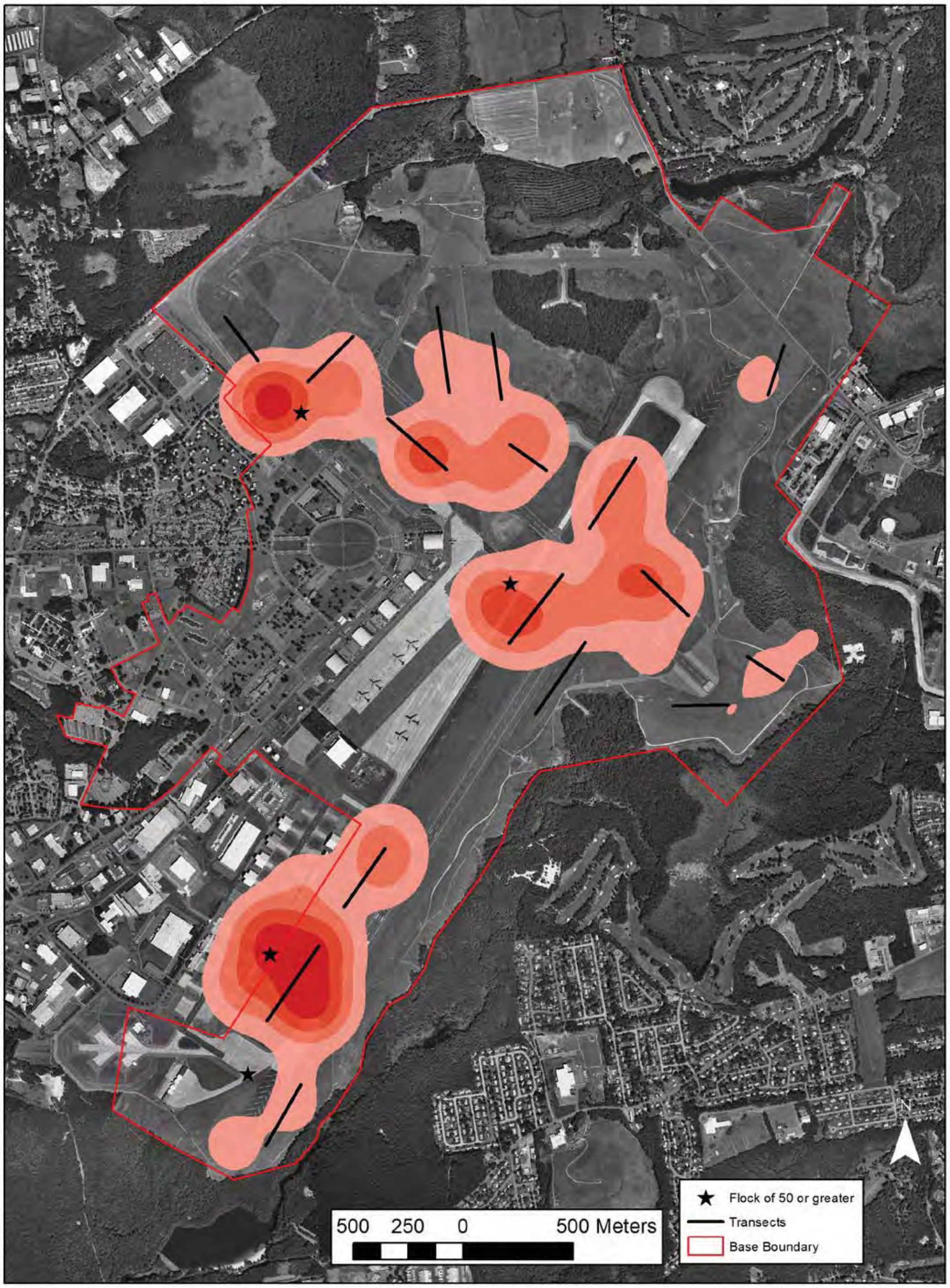

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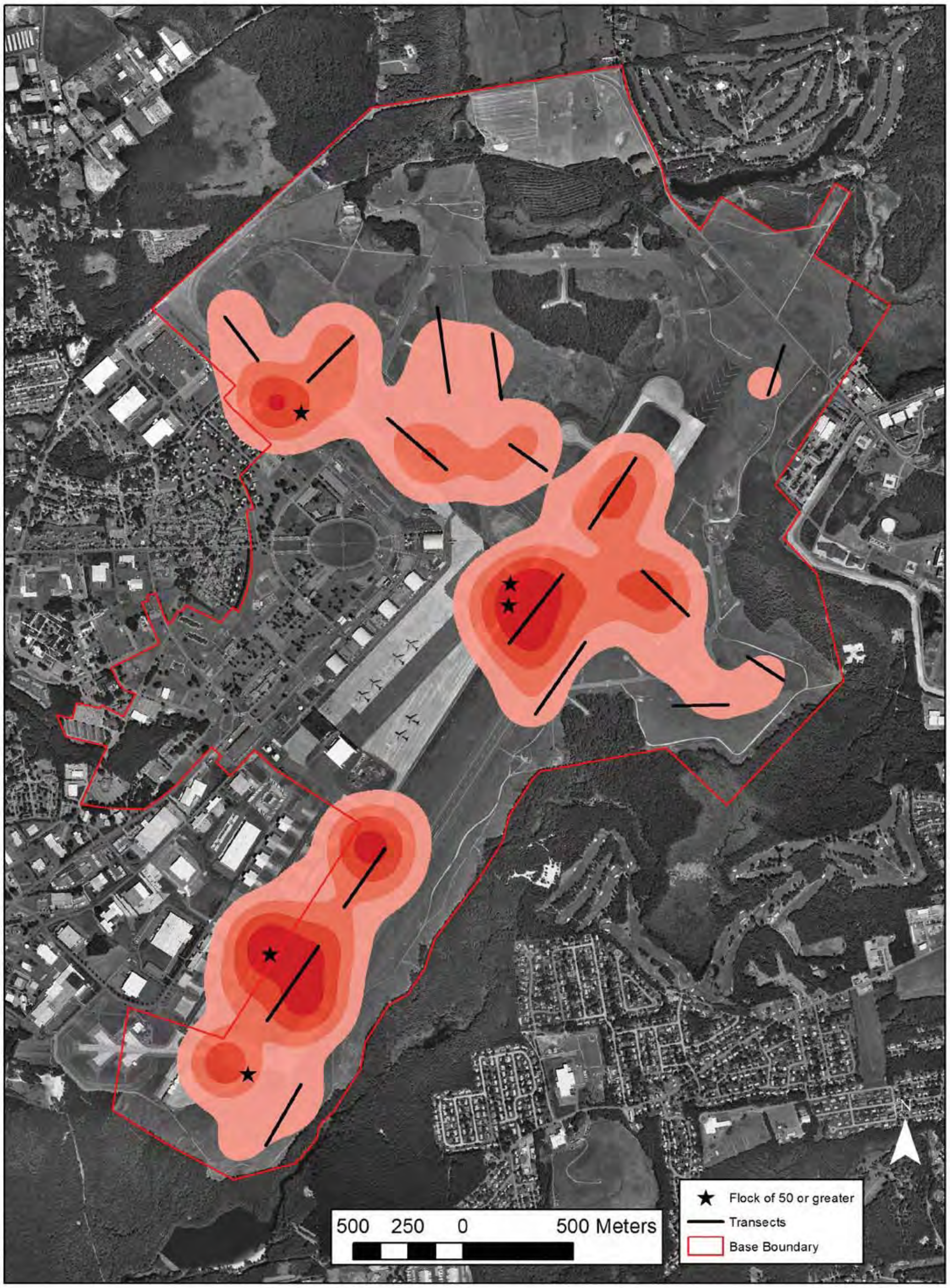

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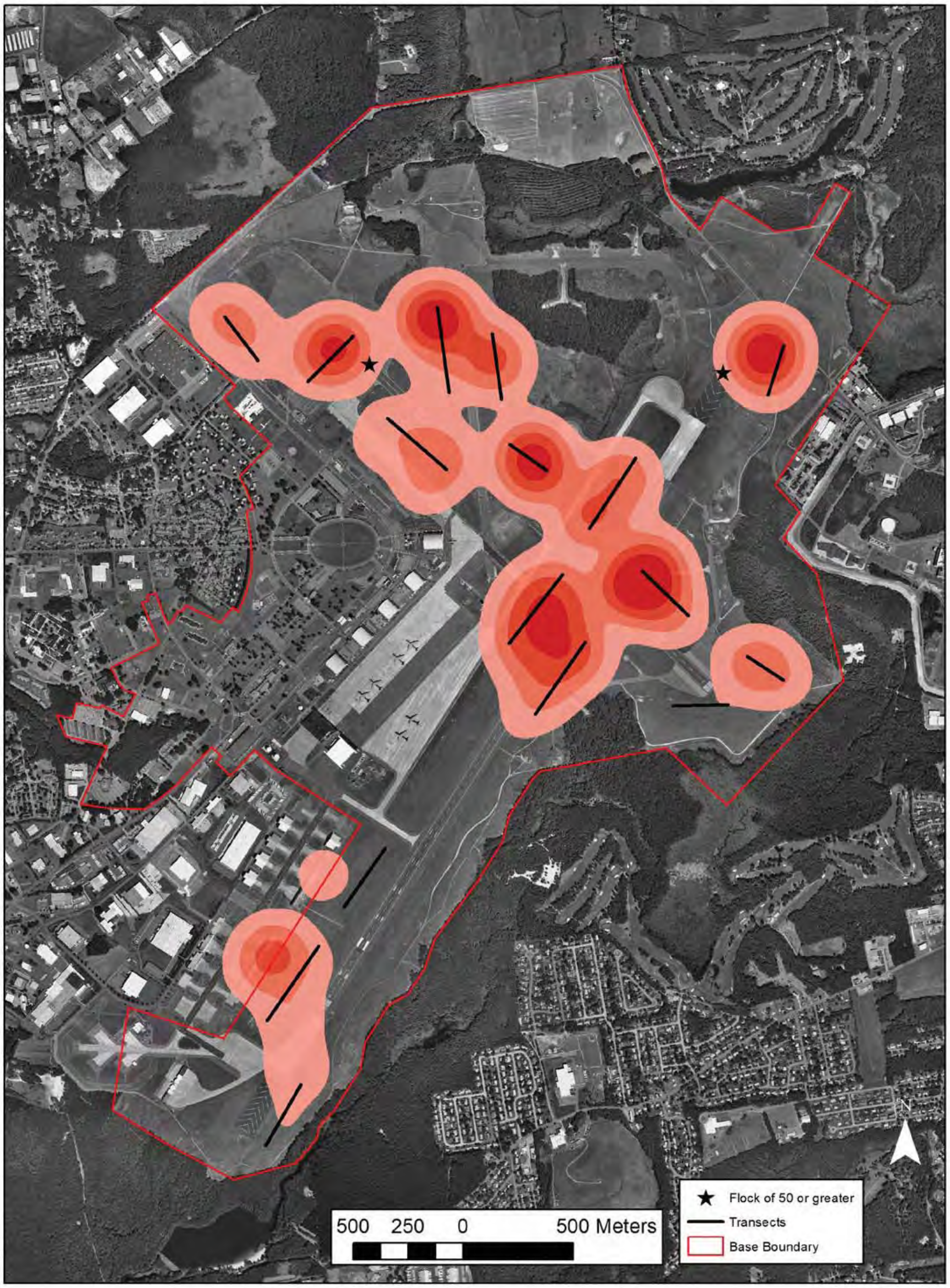

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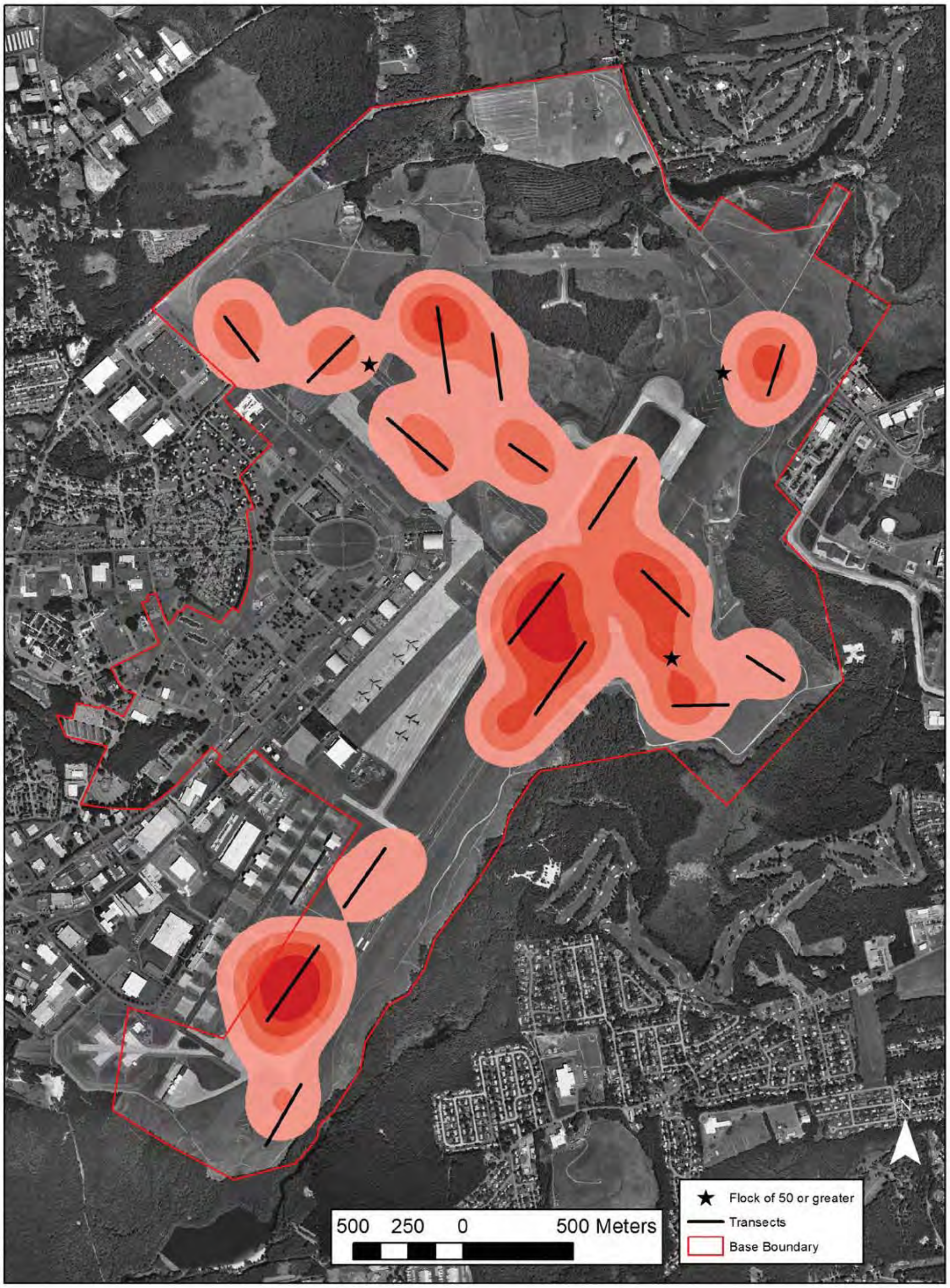

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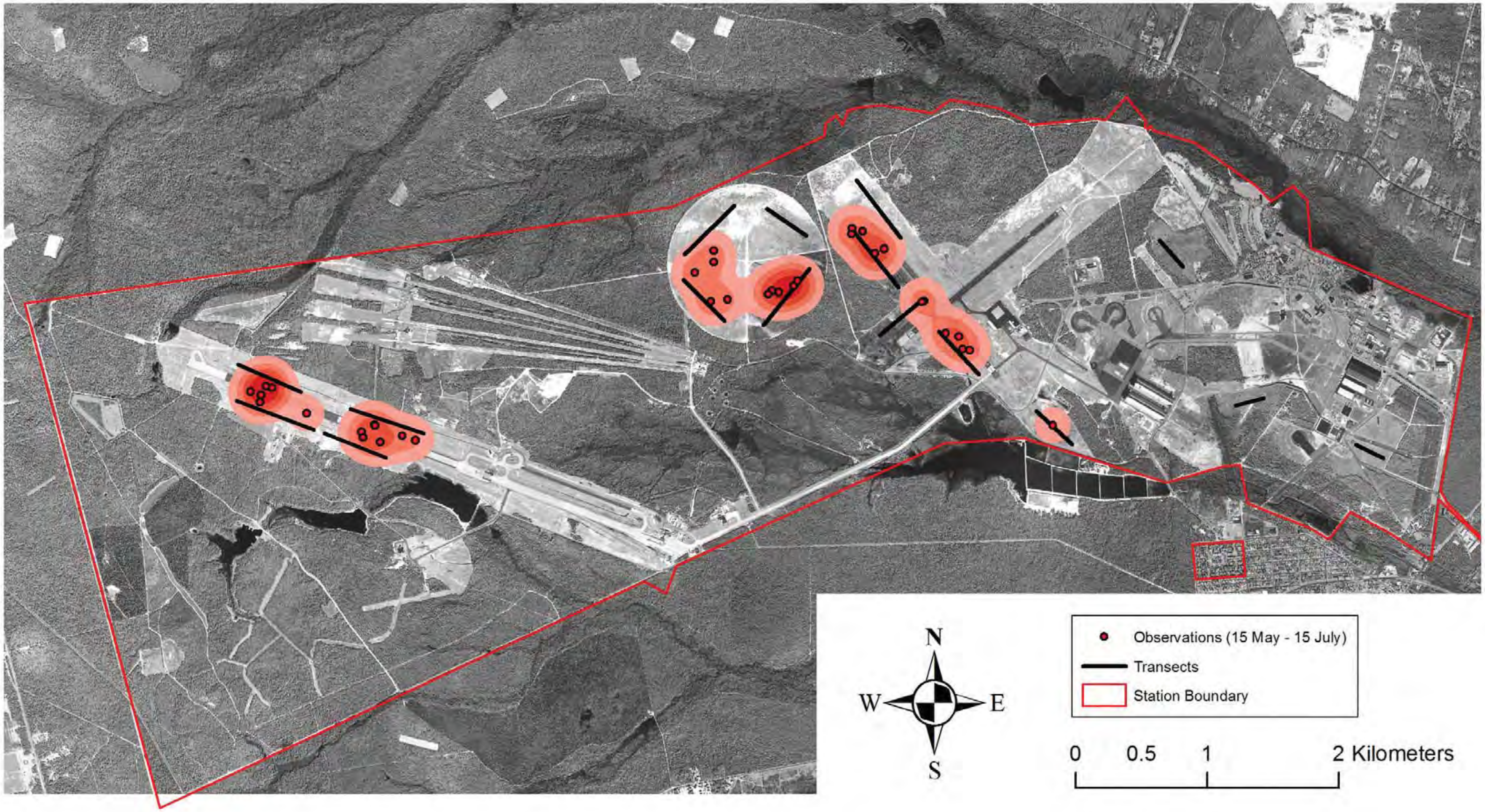

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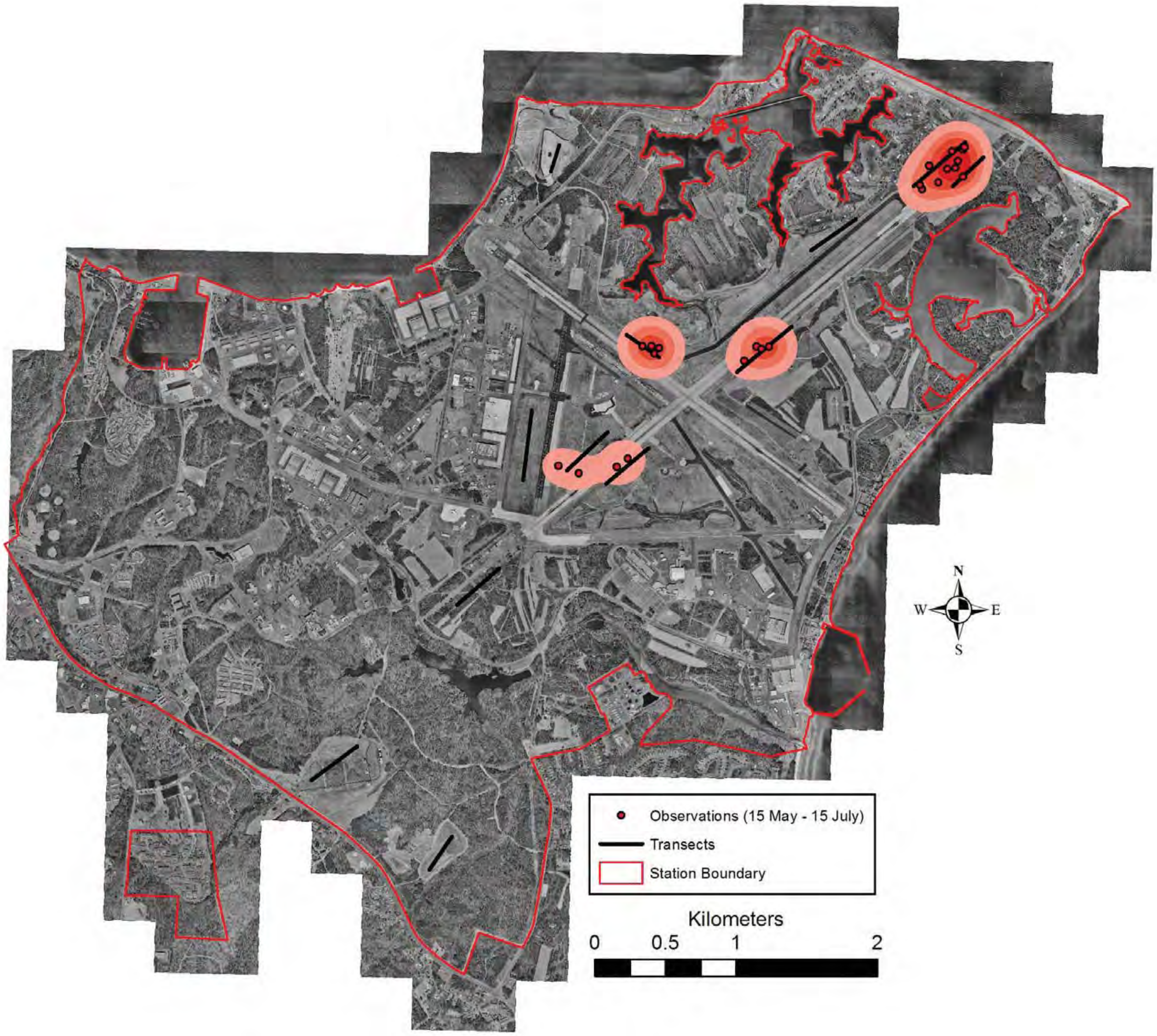

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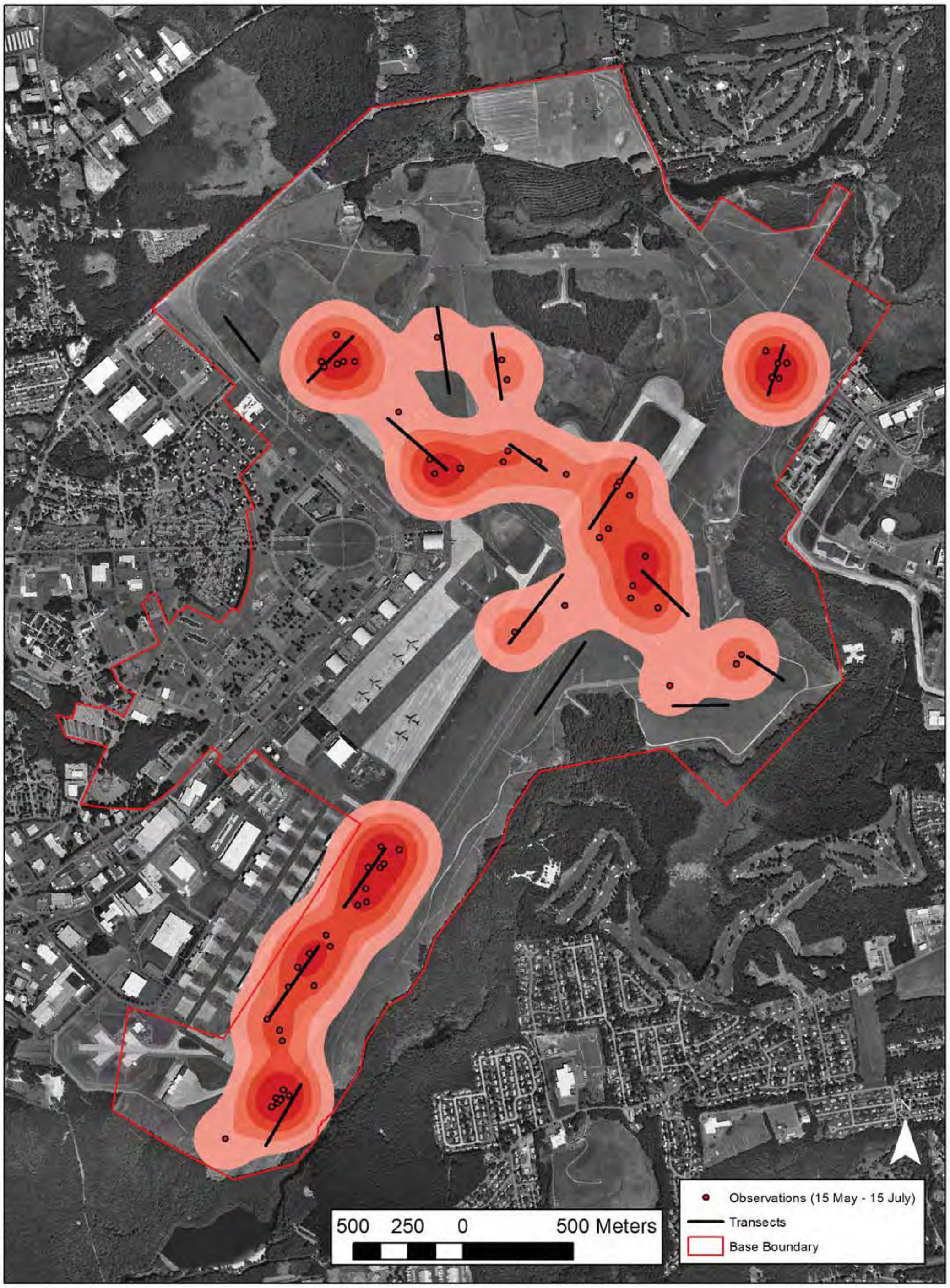

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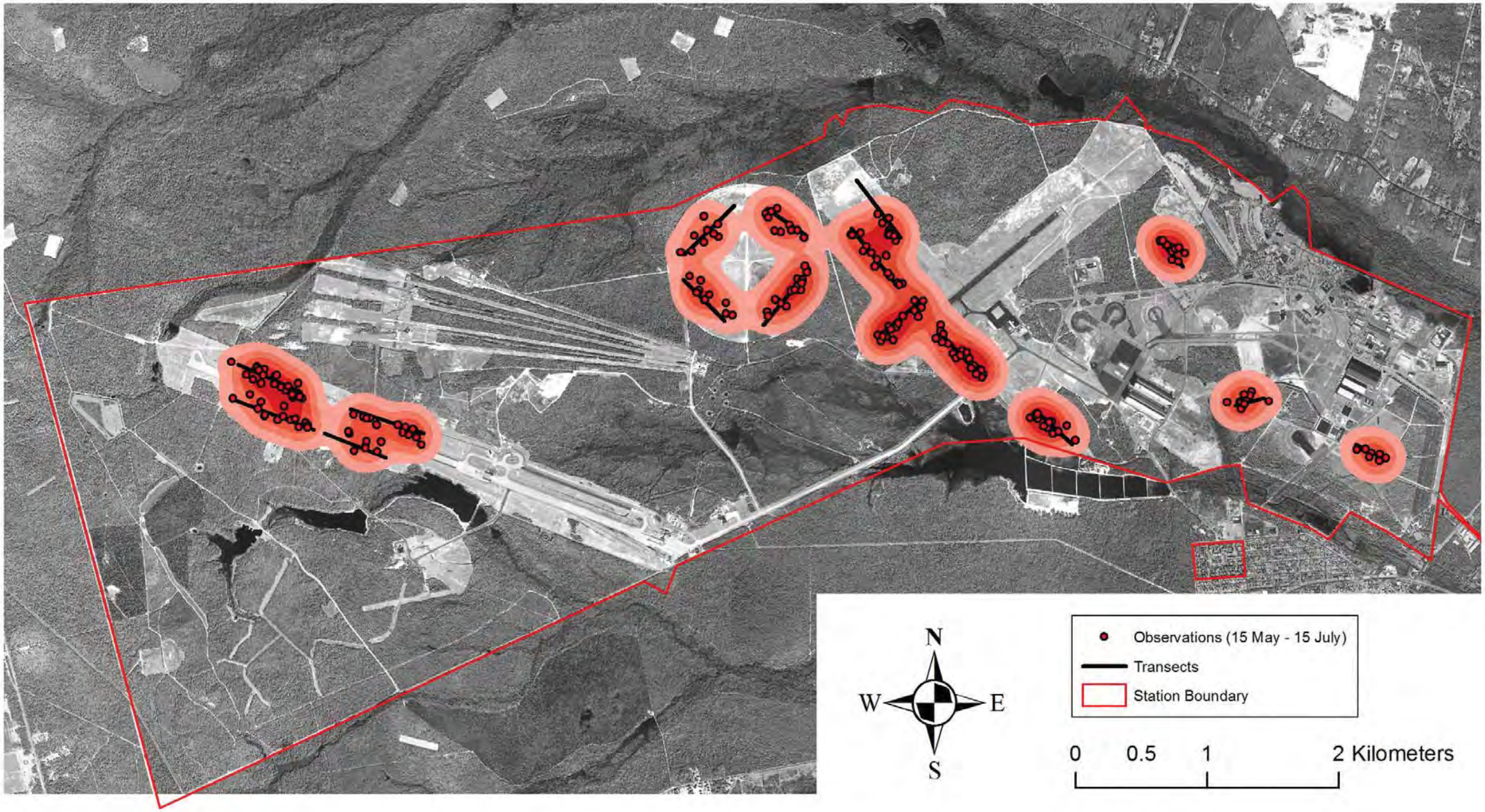

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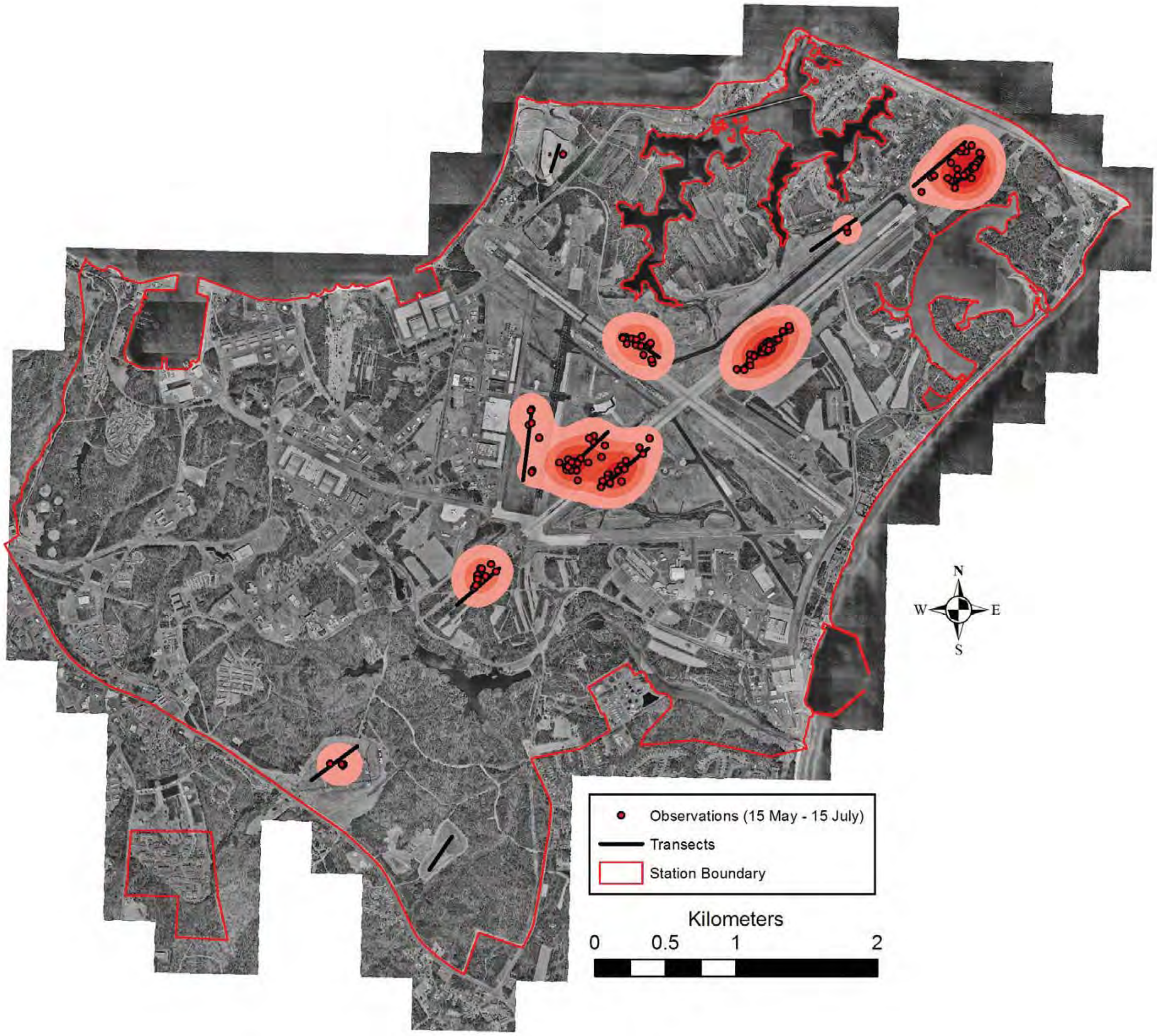

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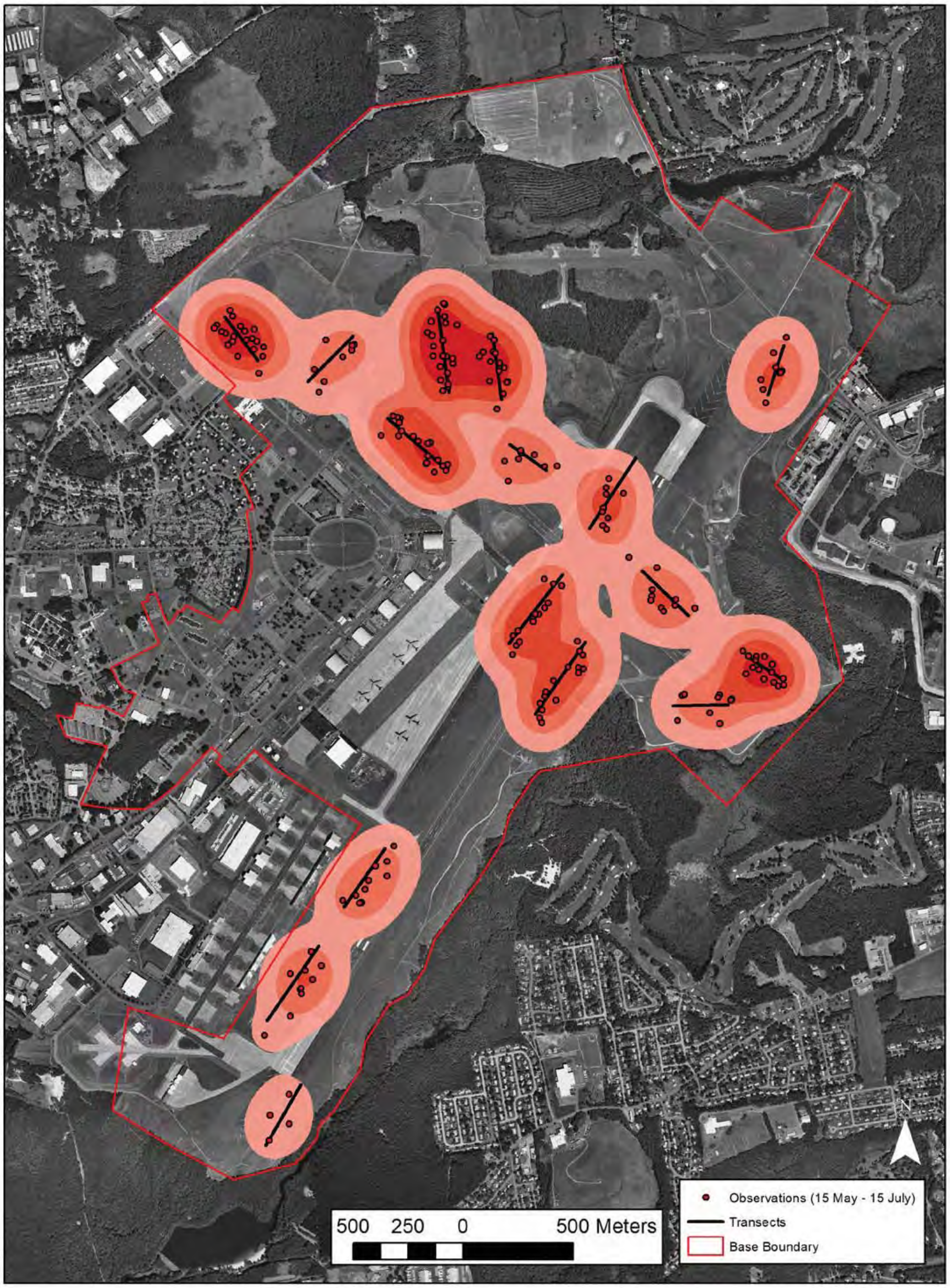

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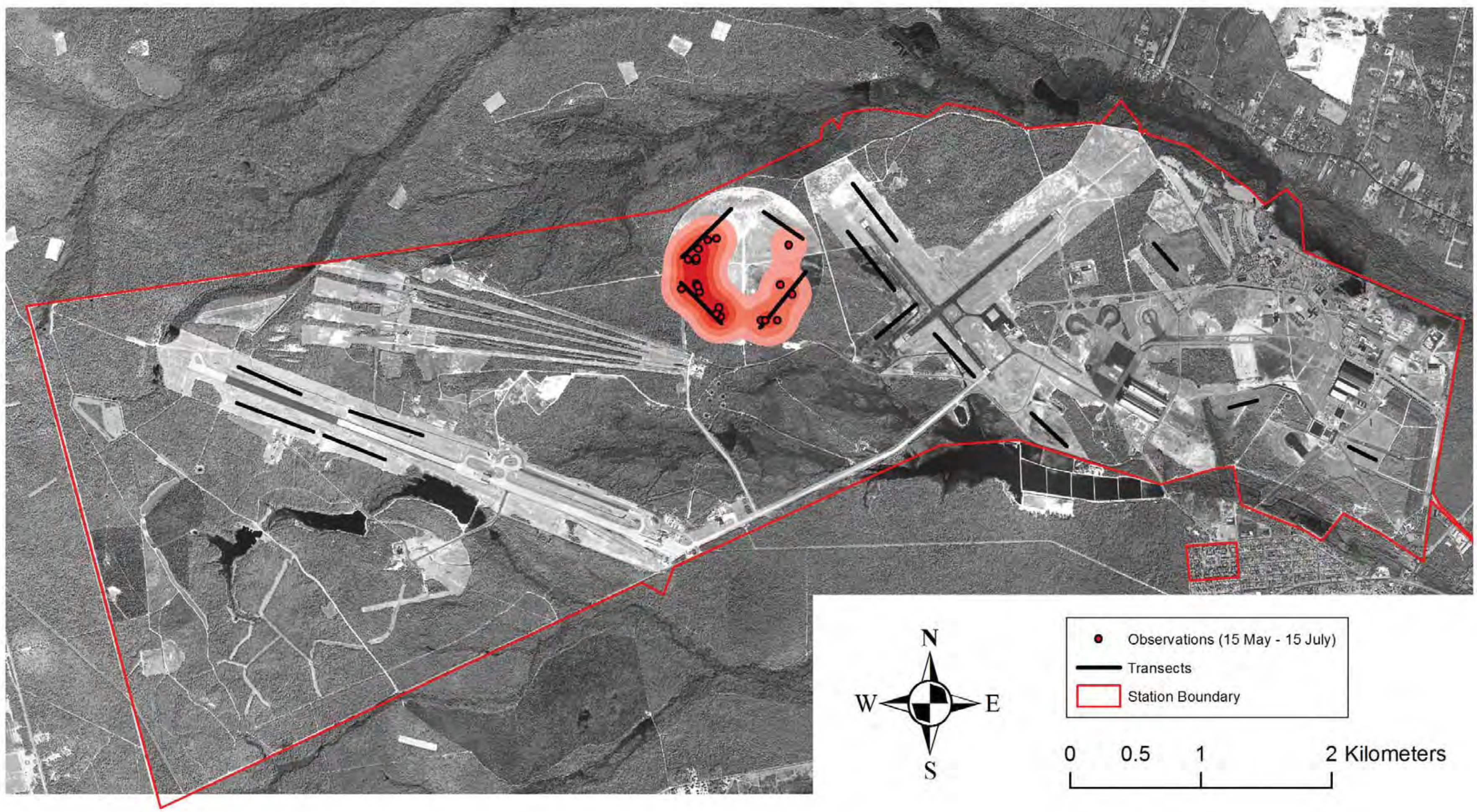

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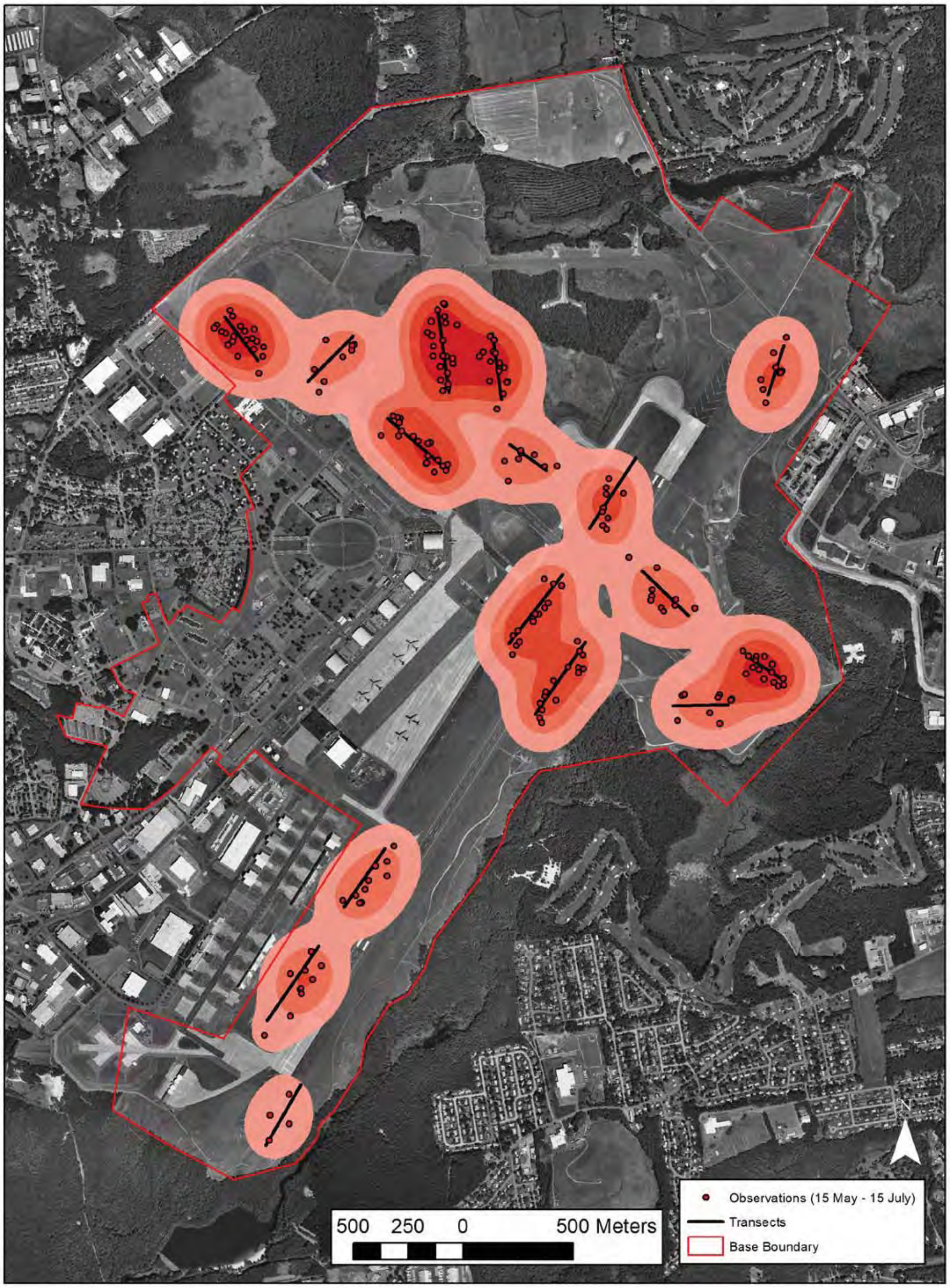

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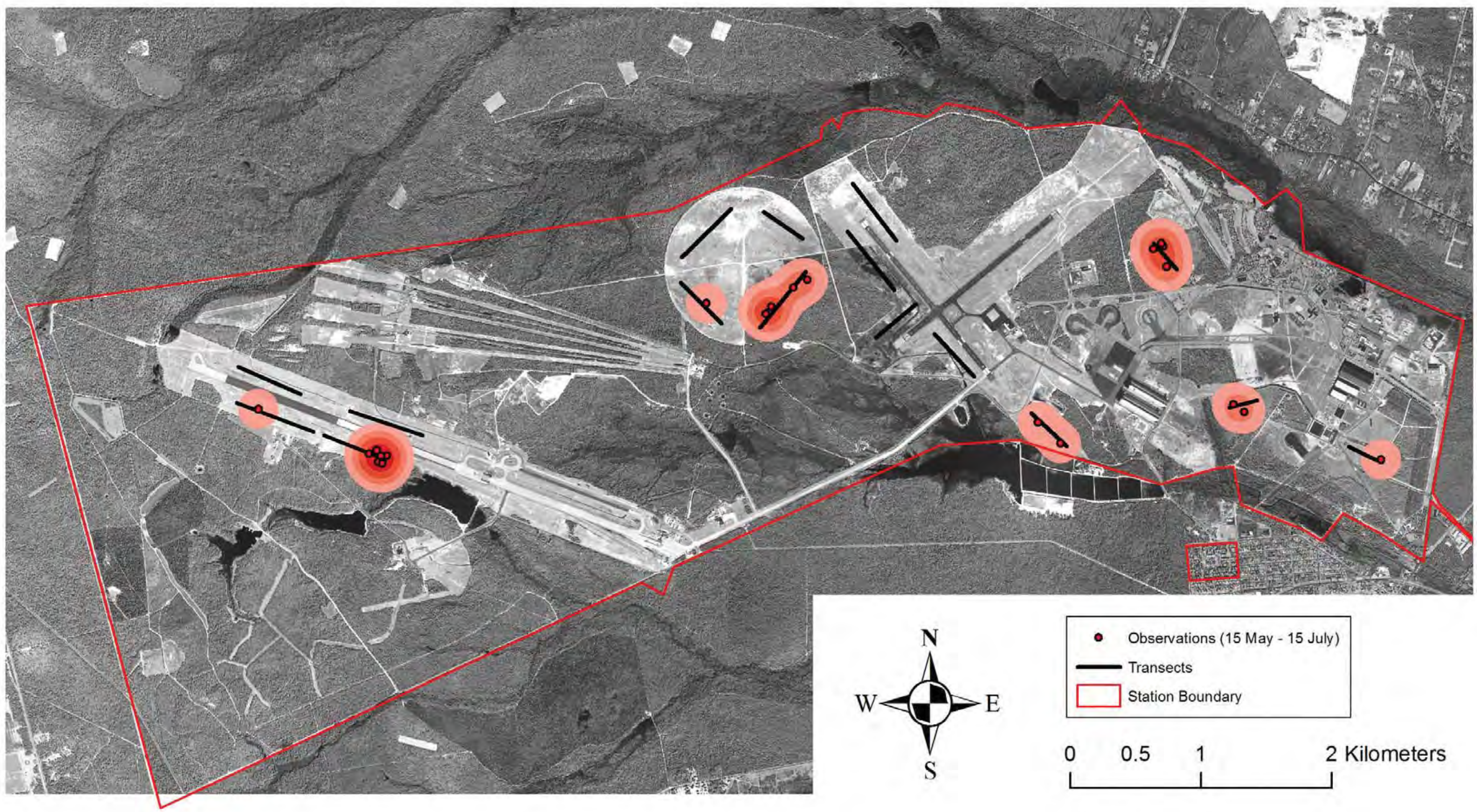

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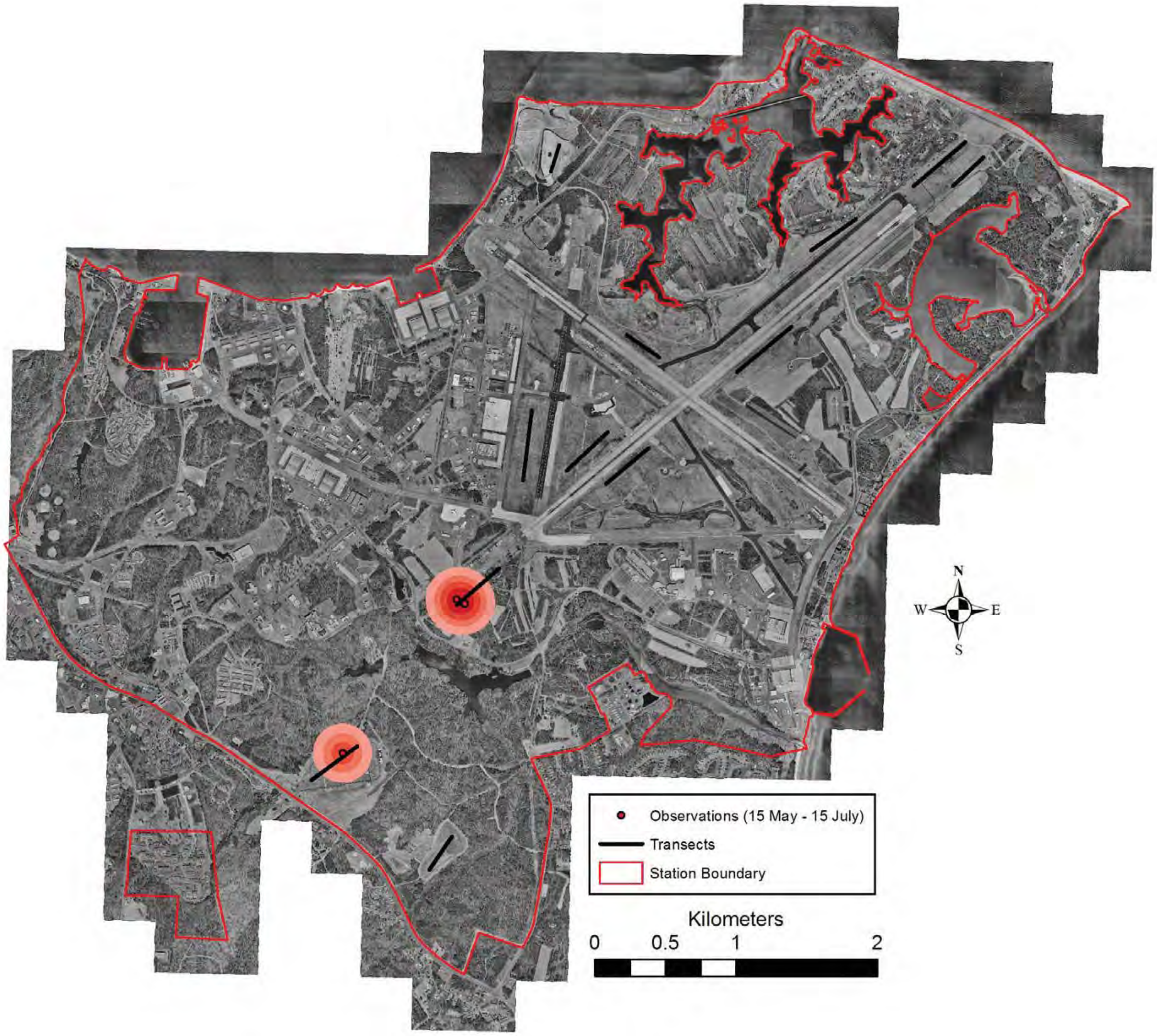

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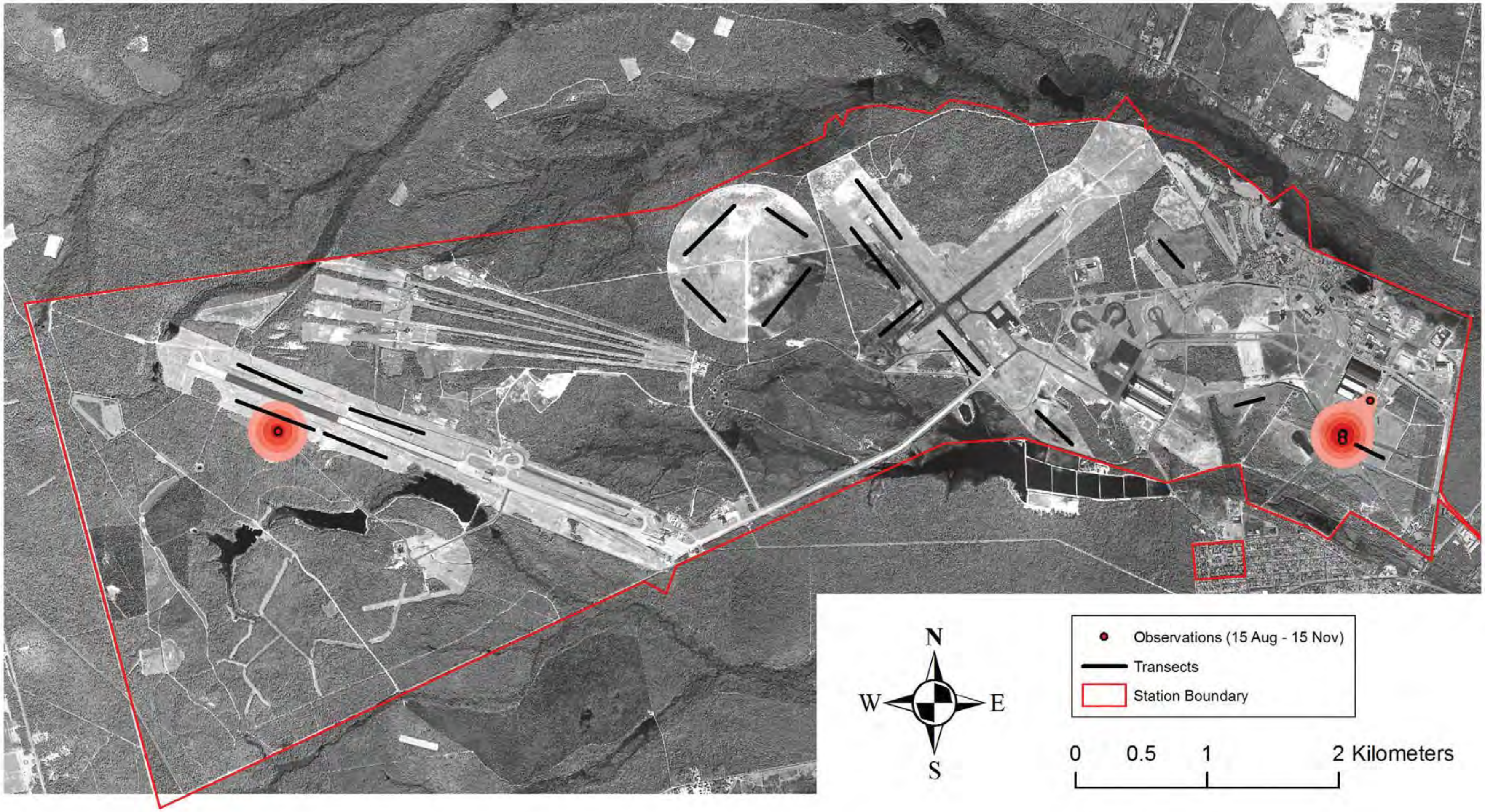

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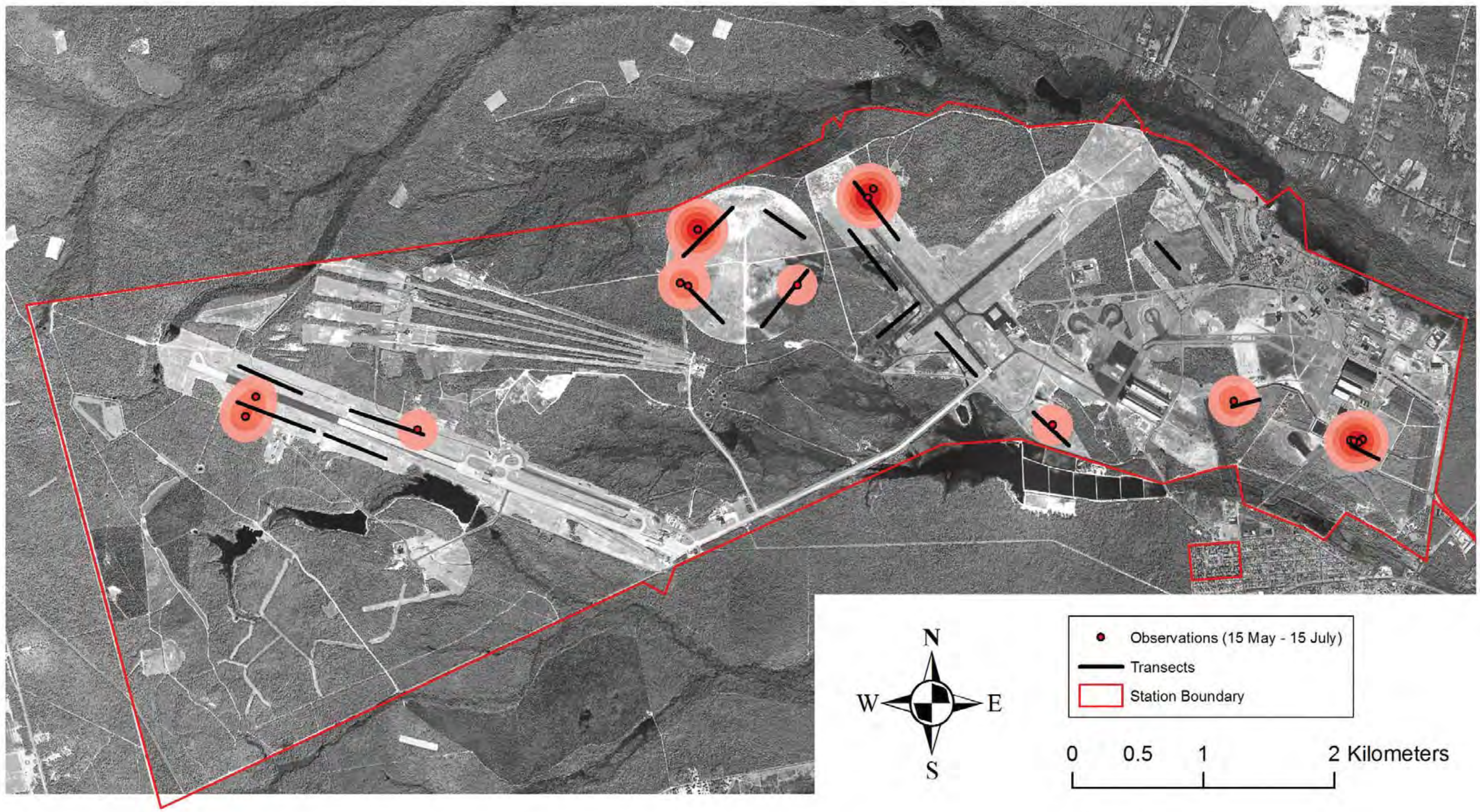

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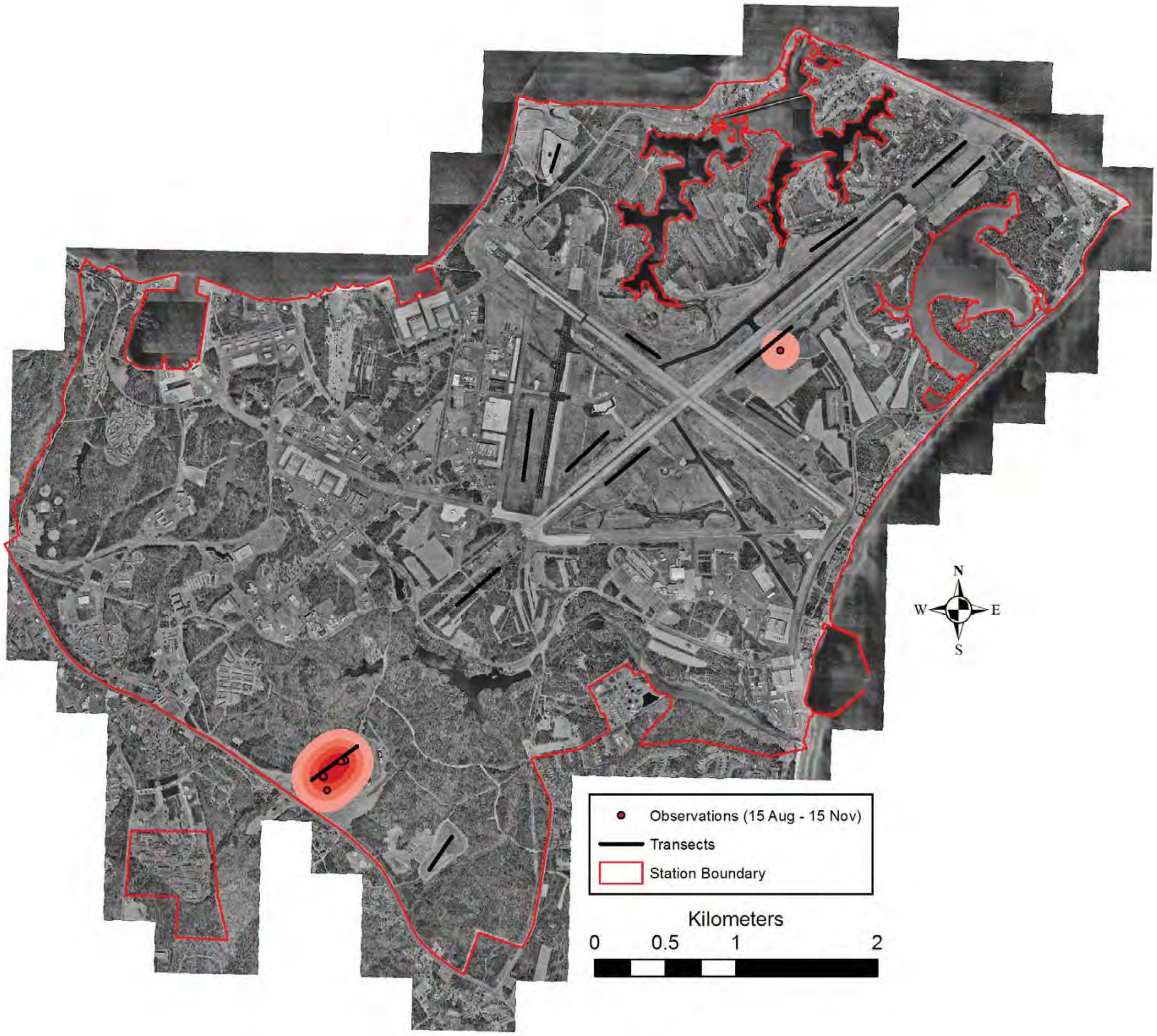

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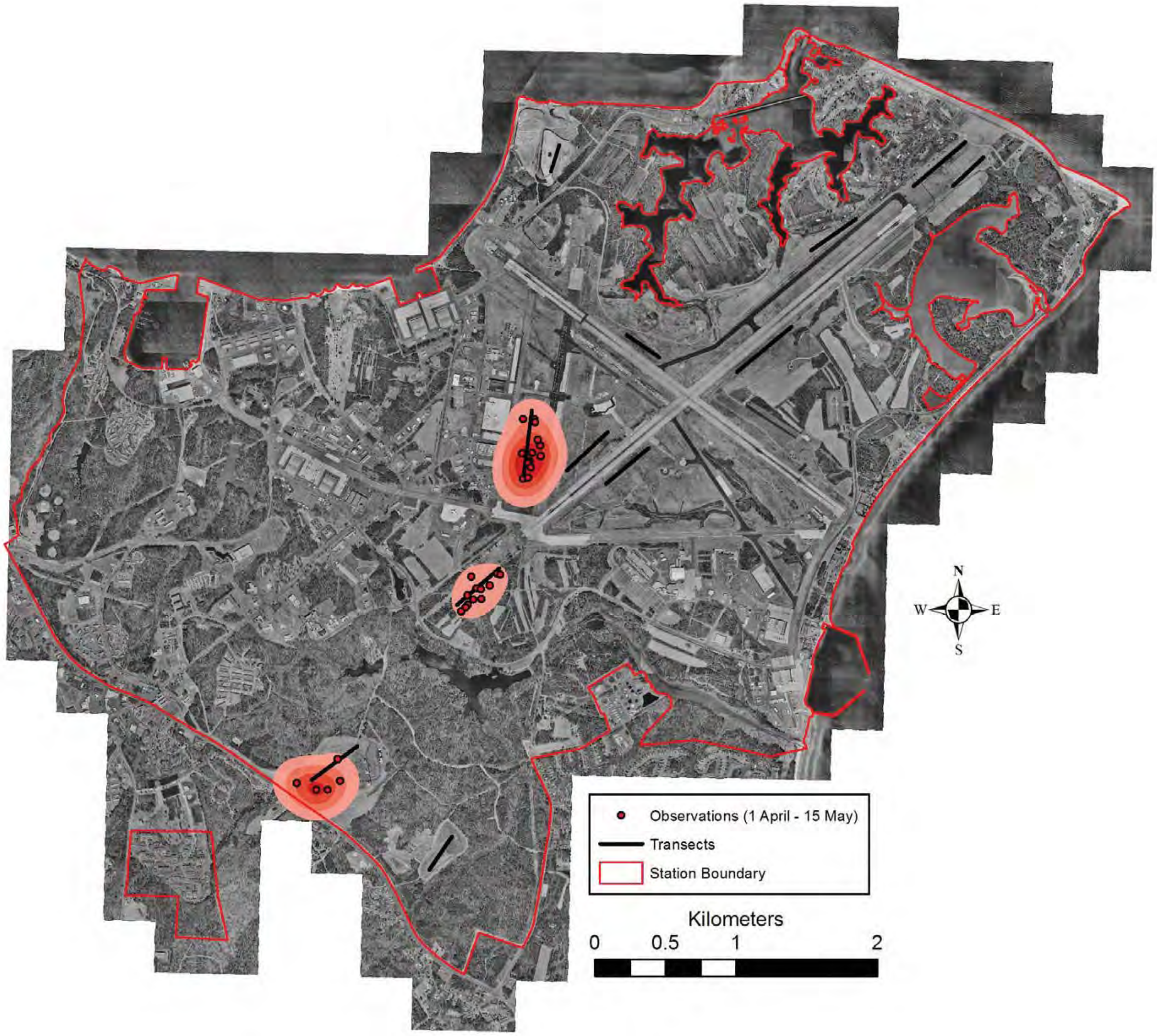

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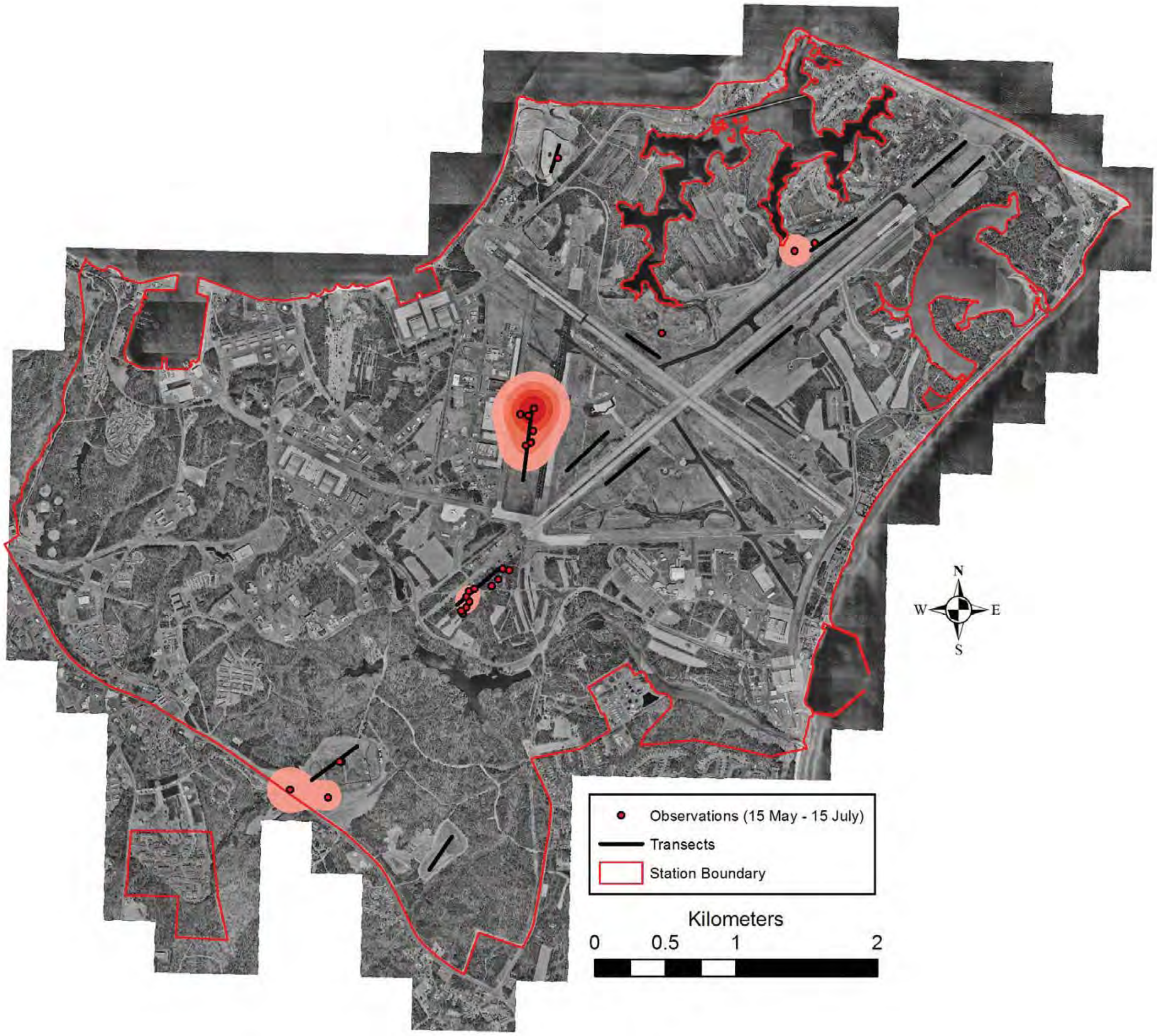

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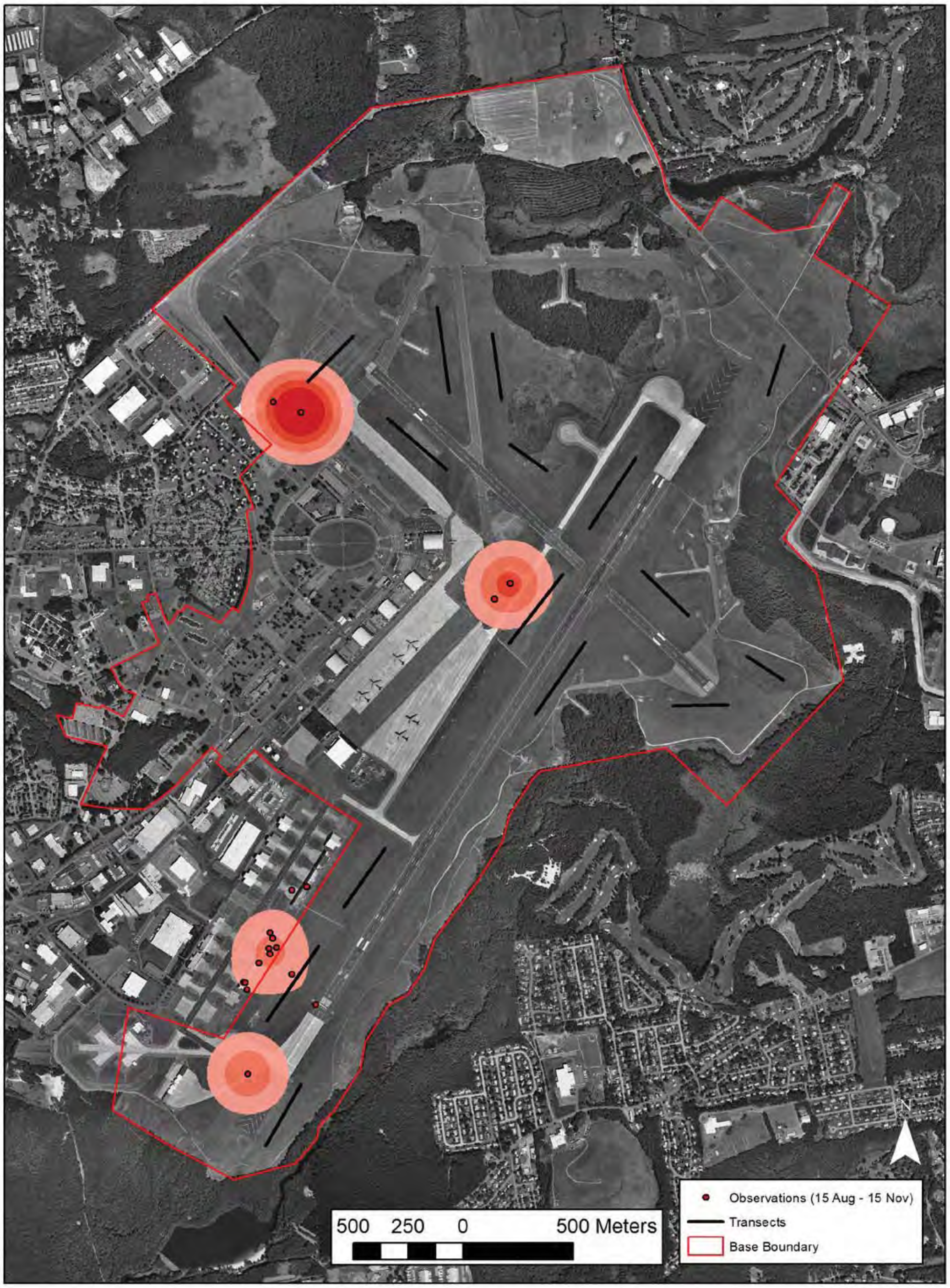

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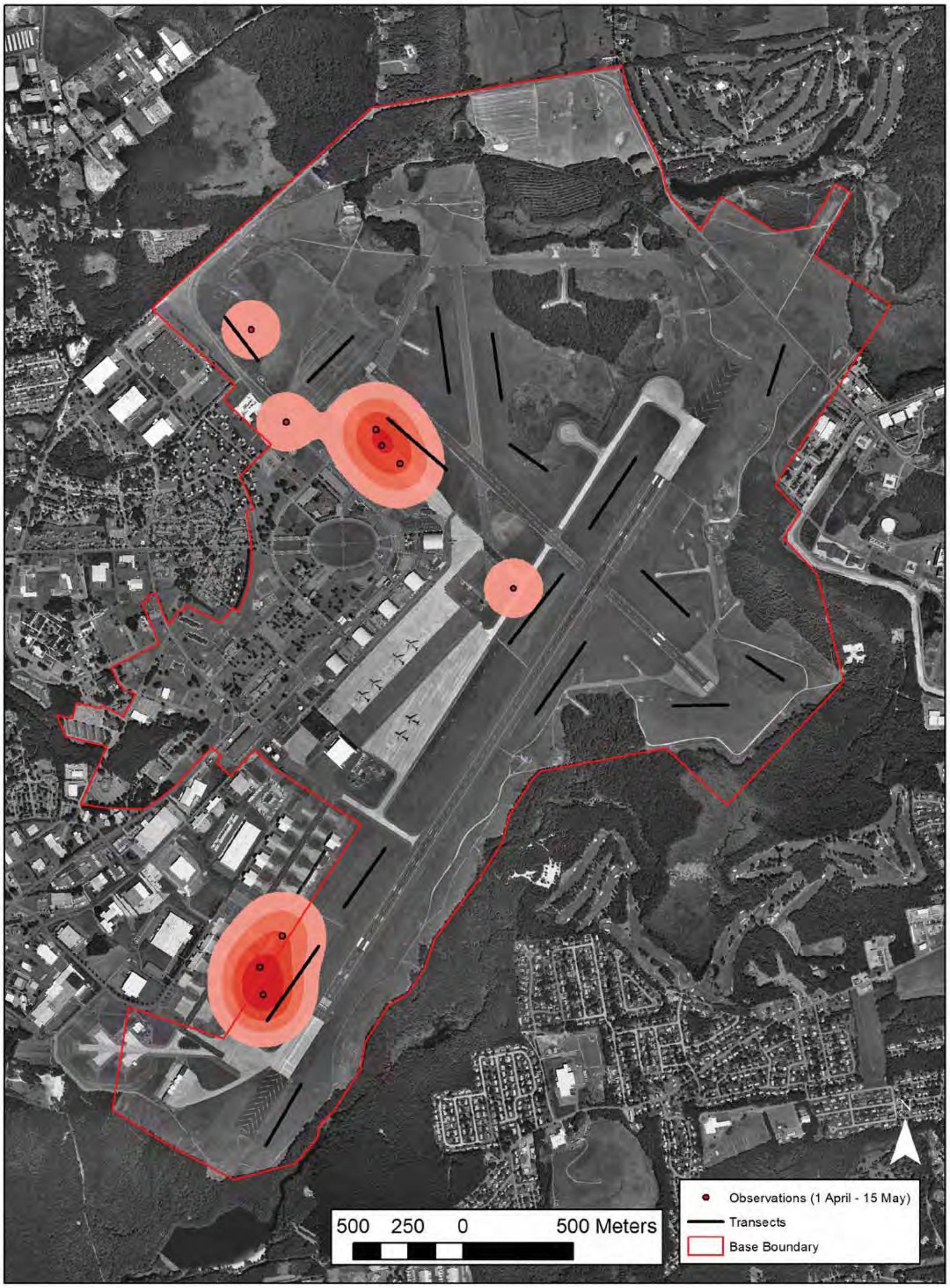

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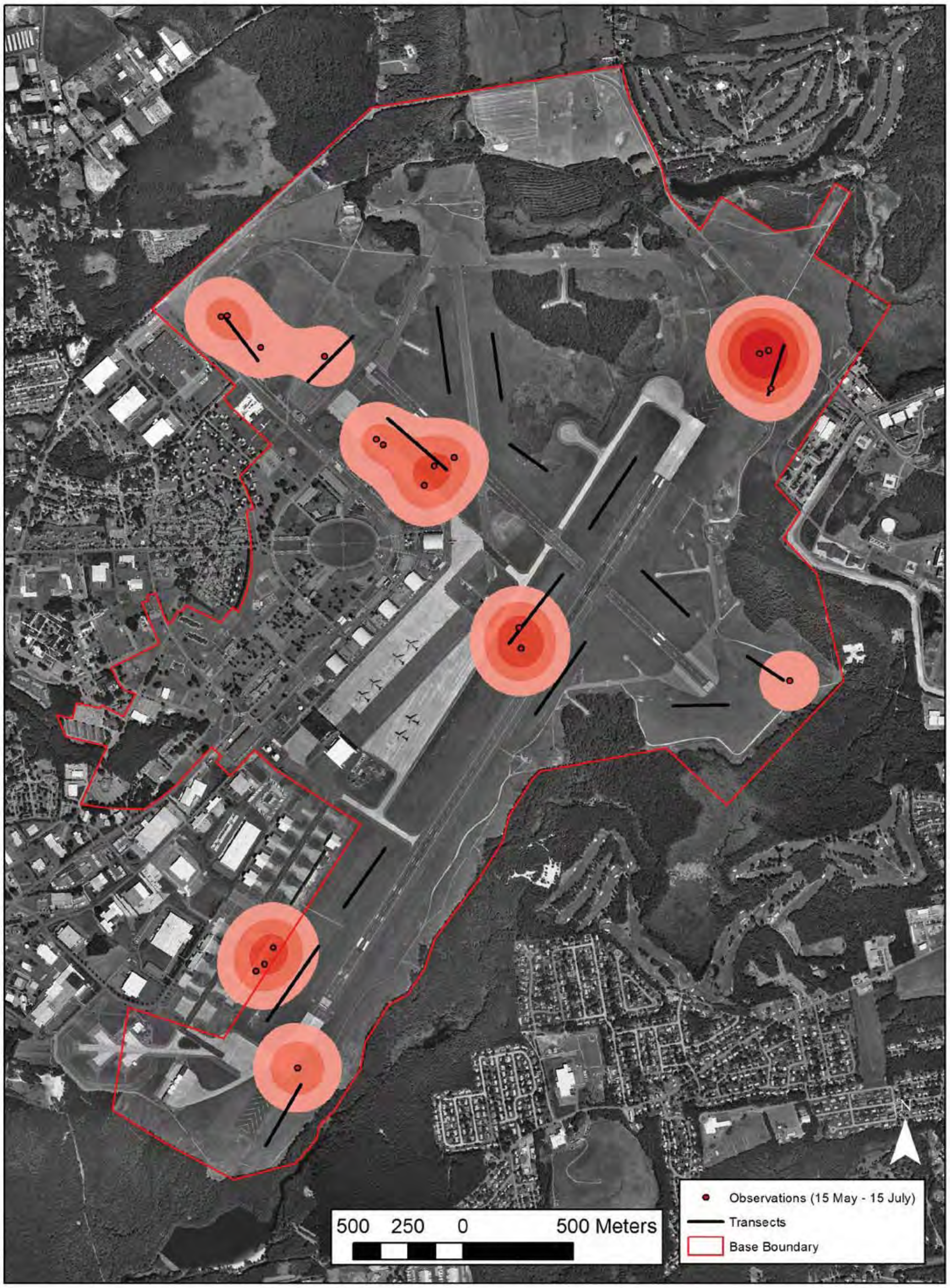

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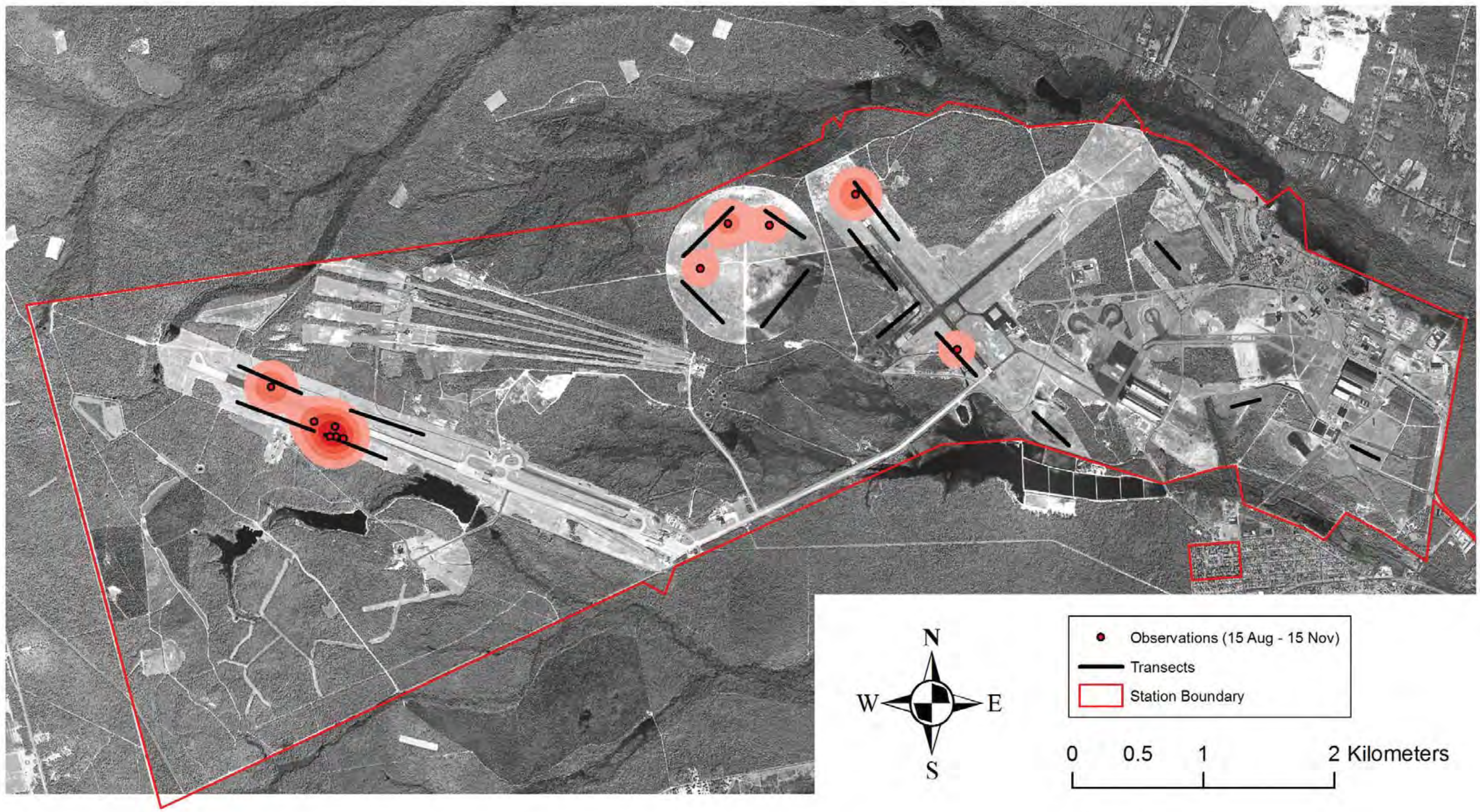

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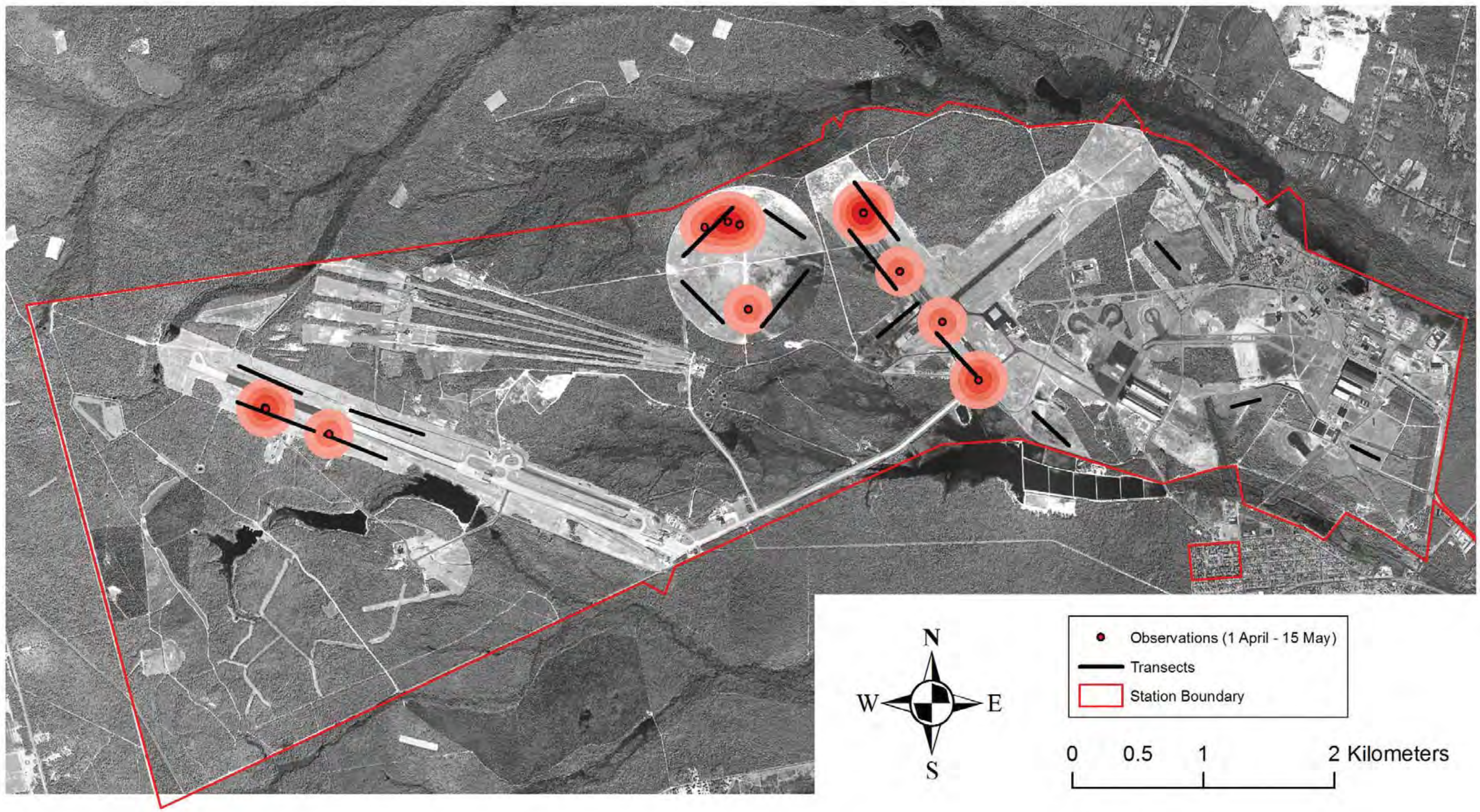

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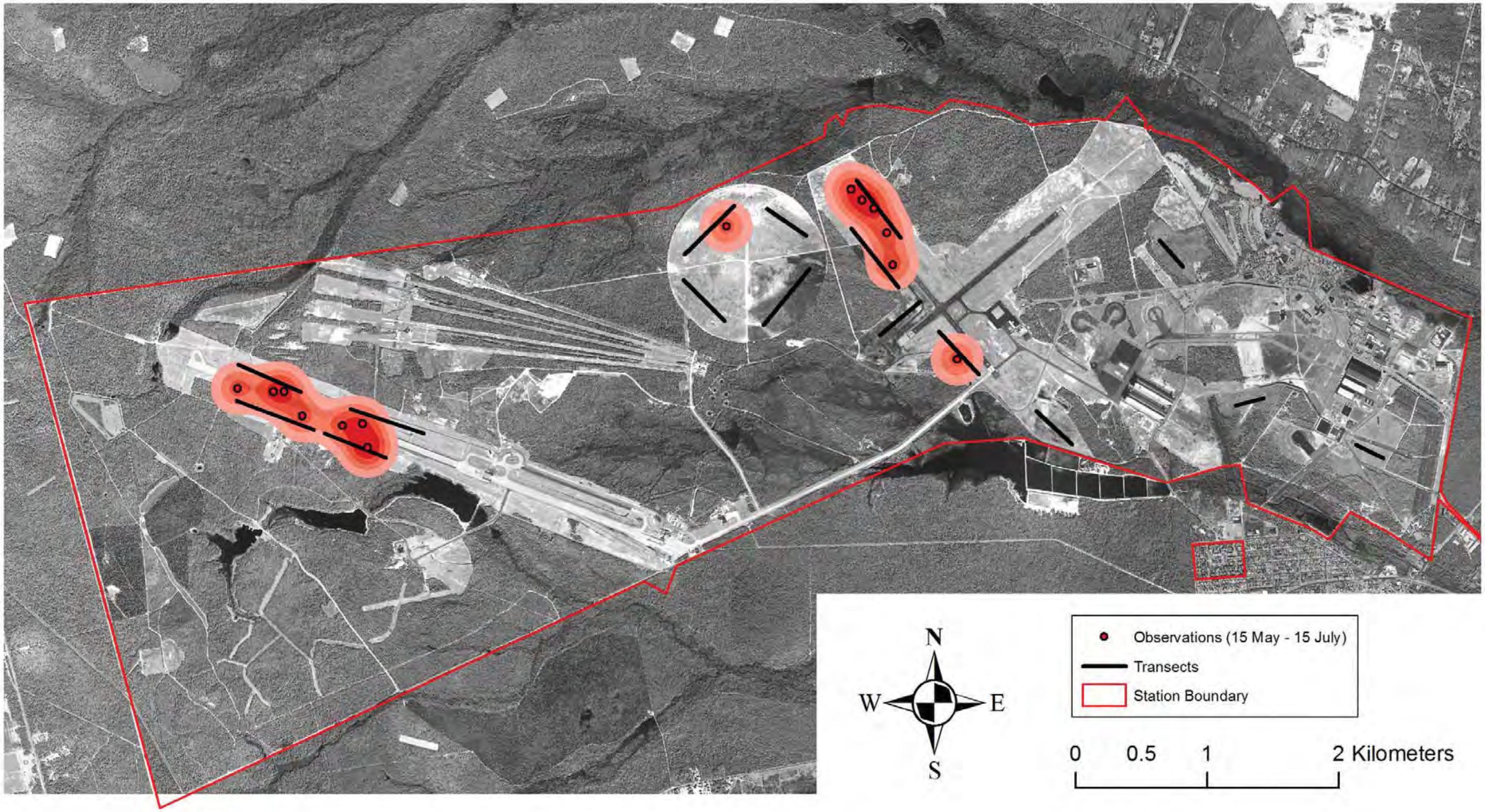

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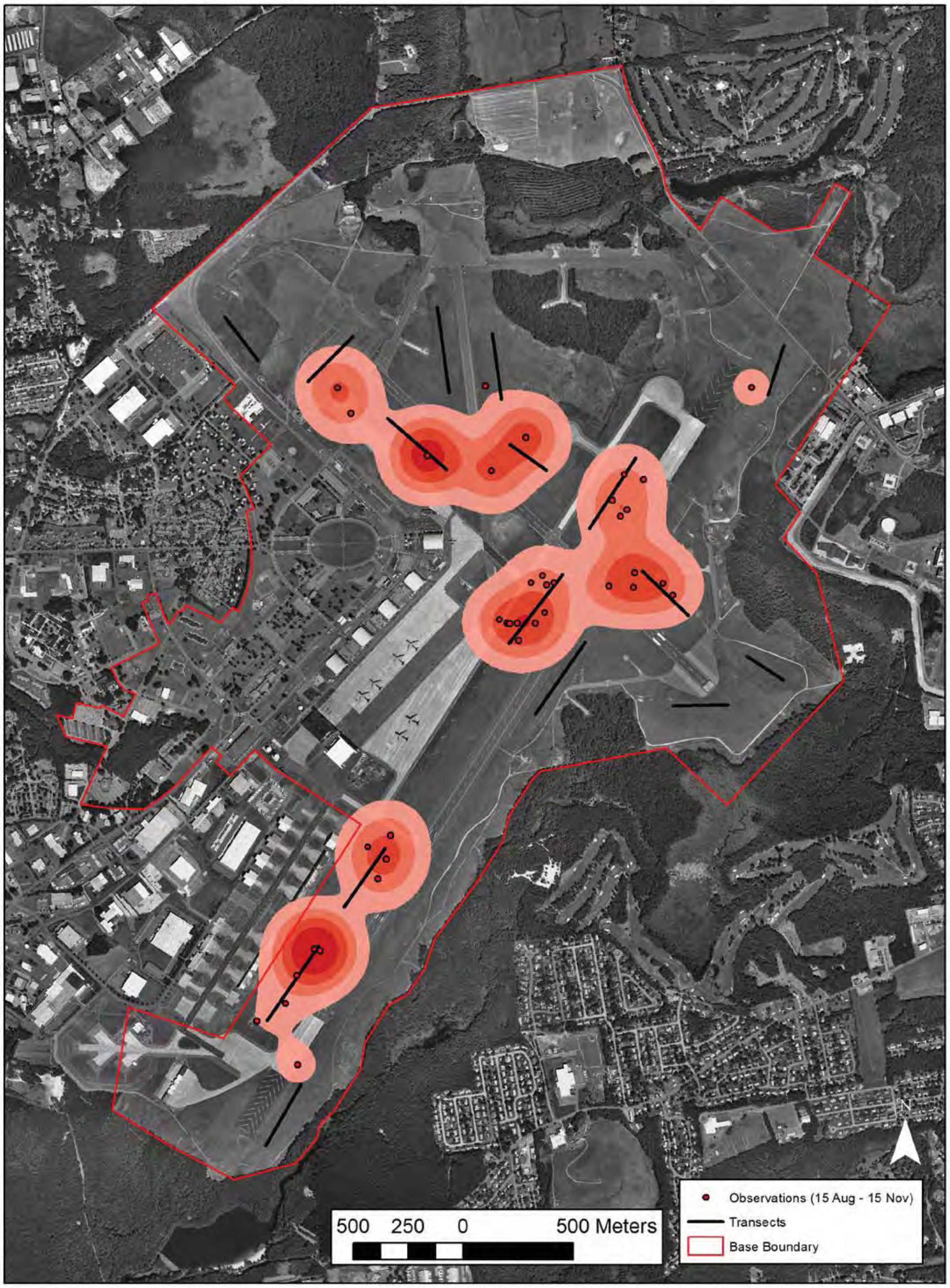

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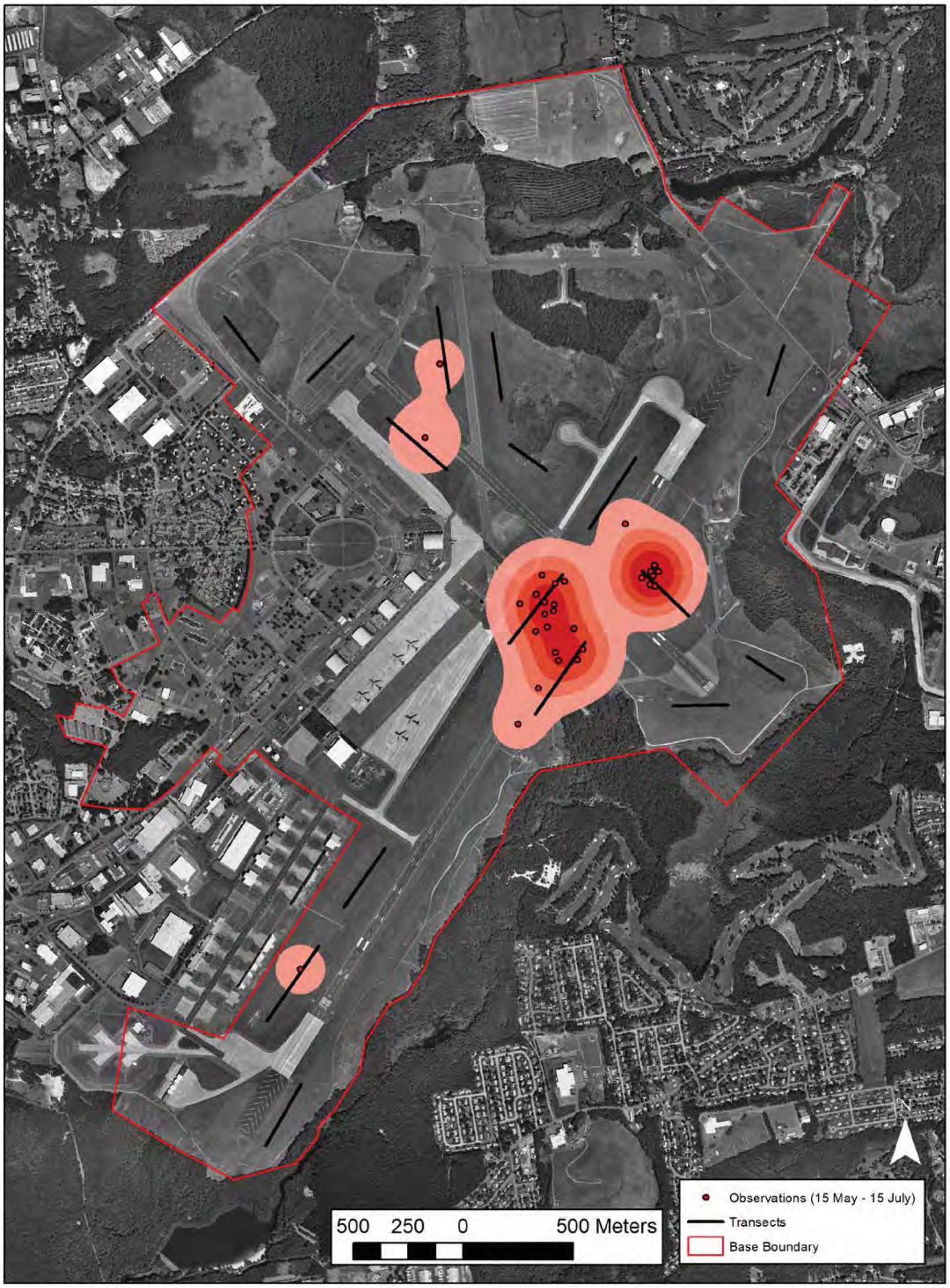

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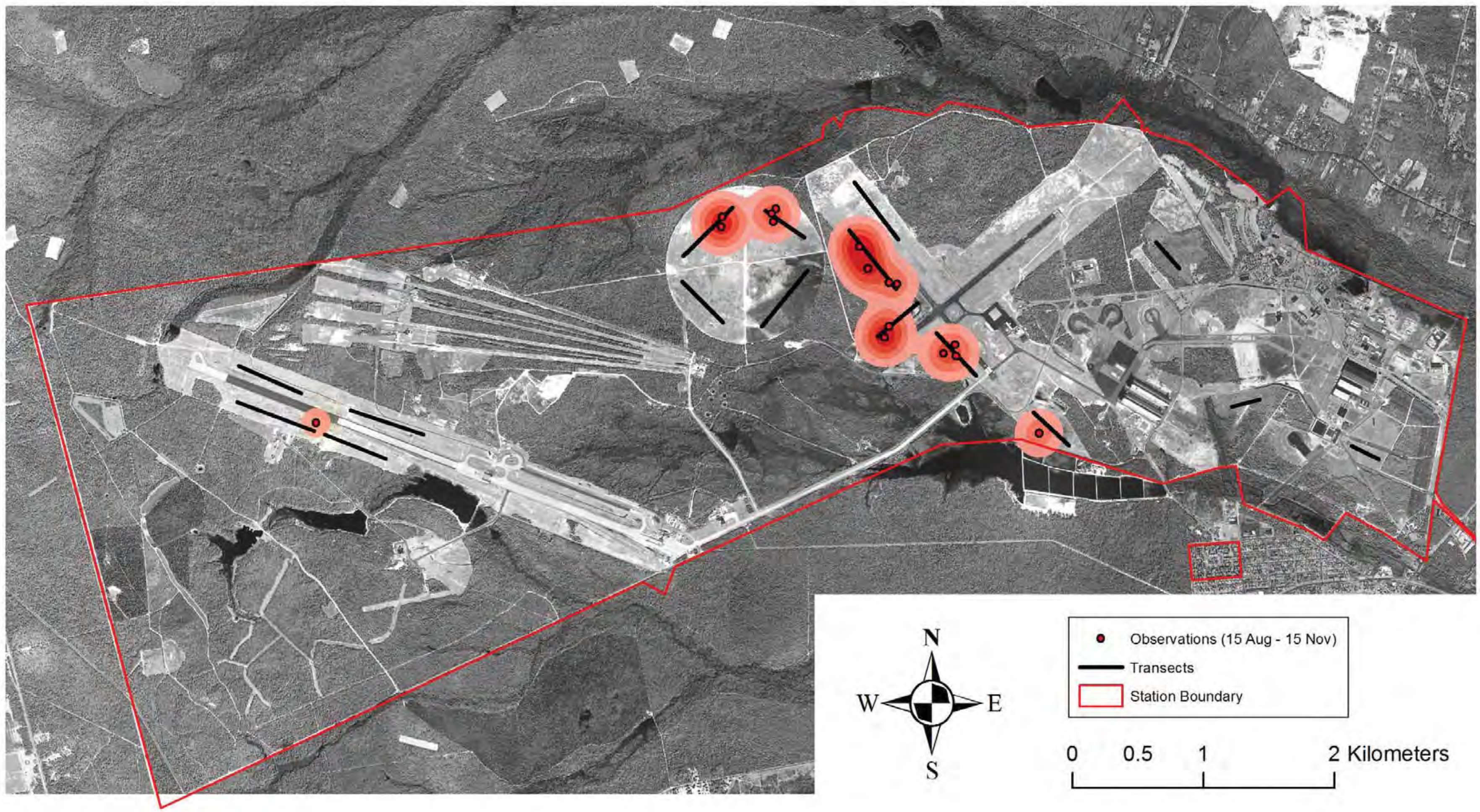

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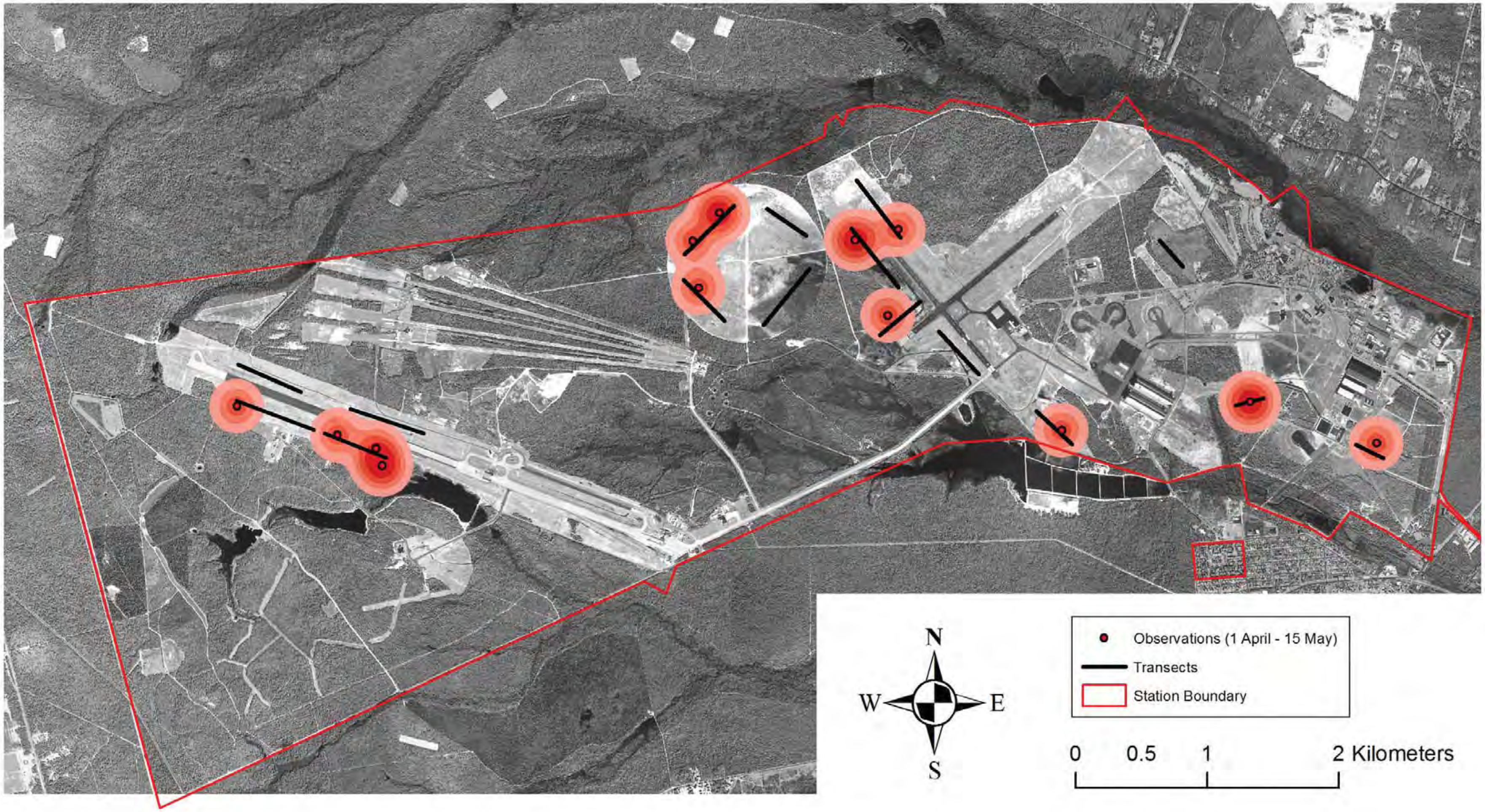

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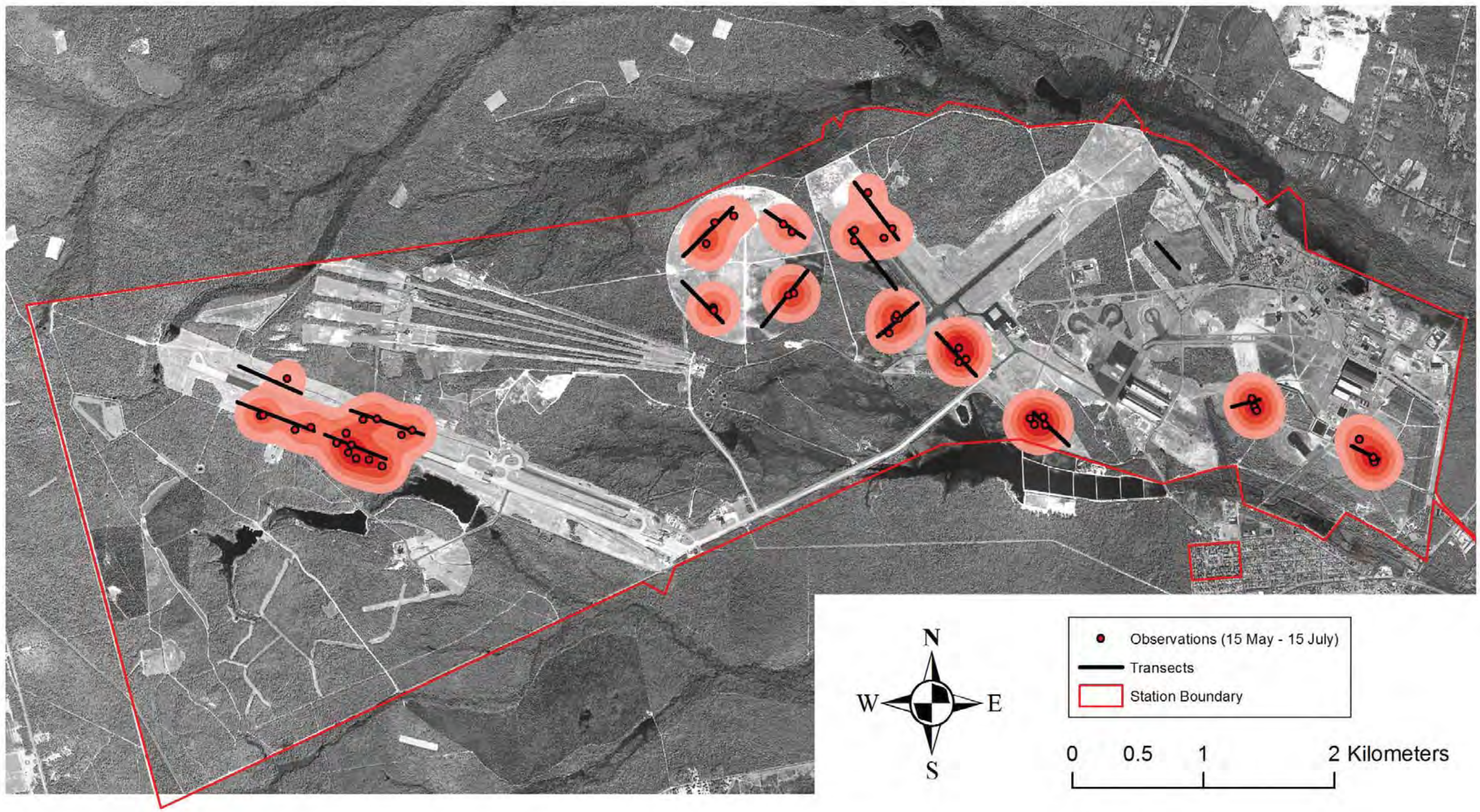

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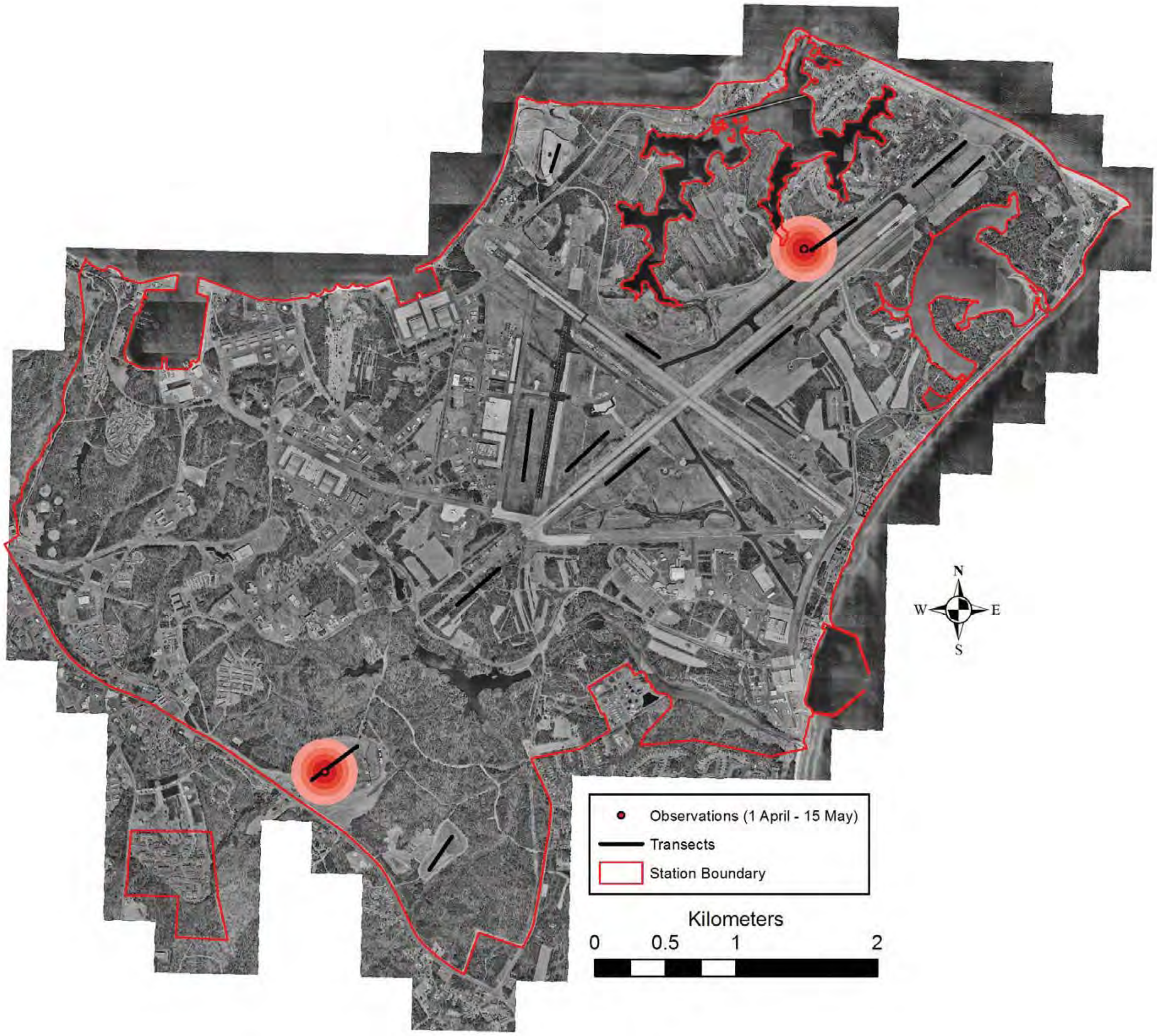

Figure . Density contours generate for s allo s ift o servations at Patuxent River Naval Air Station, Marylan . Data ere collecte uring morning transect surveys in s ring migration A ril to May . ontours escri e t e s atial extent an relative ensity of occurrences. Dar er contours re resent ig er avian ensities.

Appendix . Avian istri ution an ensity ma s.

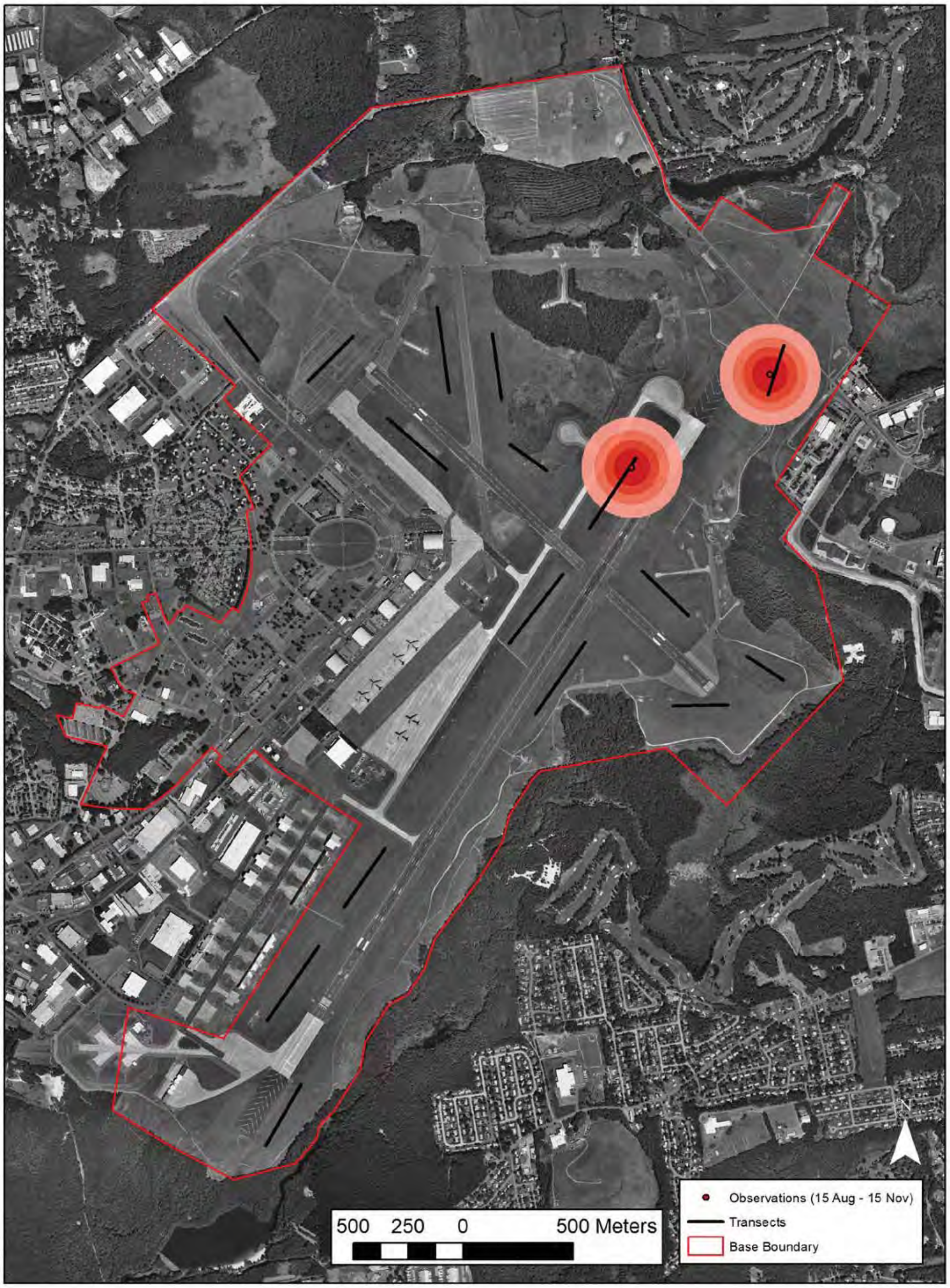

Figure . Density contours generate for s allo s ift o servations at estover Air Reserve ase, Massac usetts. Data ere collecte uring morning transect surveys in fall migration August to Novem er . ontours escri e t e s atial extent an relative ensity of occurrences. Dar er contours re resent ig er avian ensities.

Appendix **.** Avian istri ution an ensity ma s.

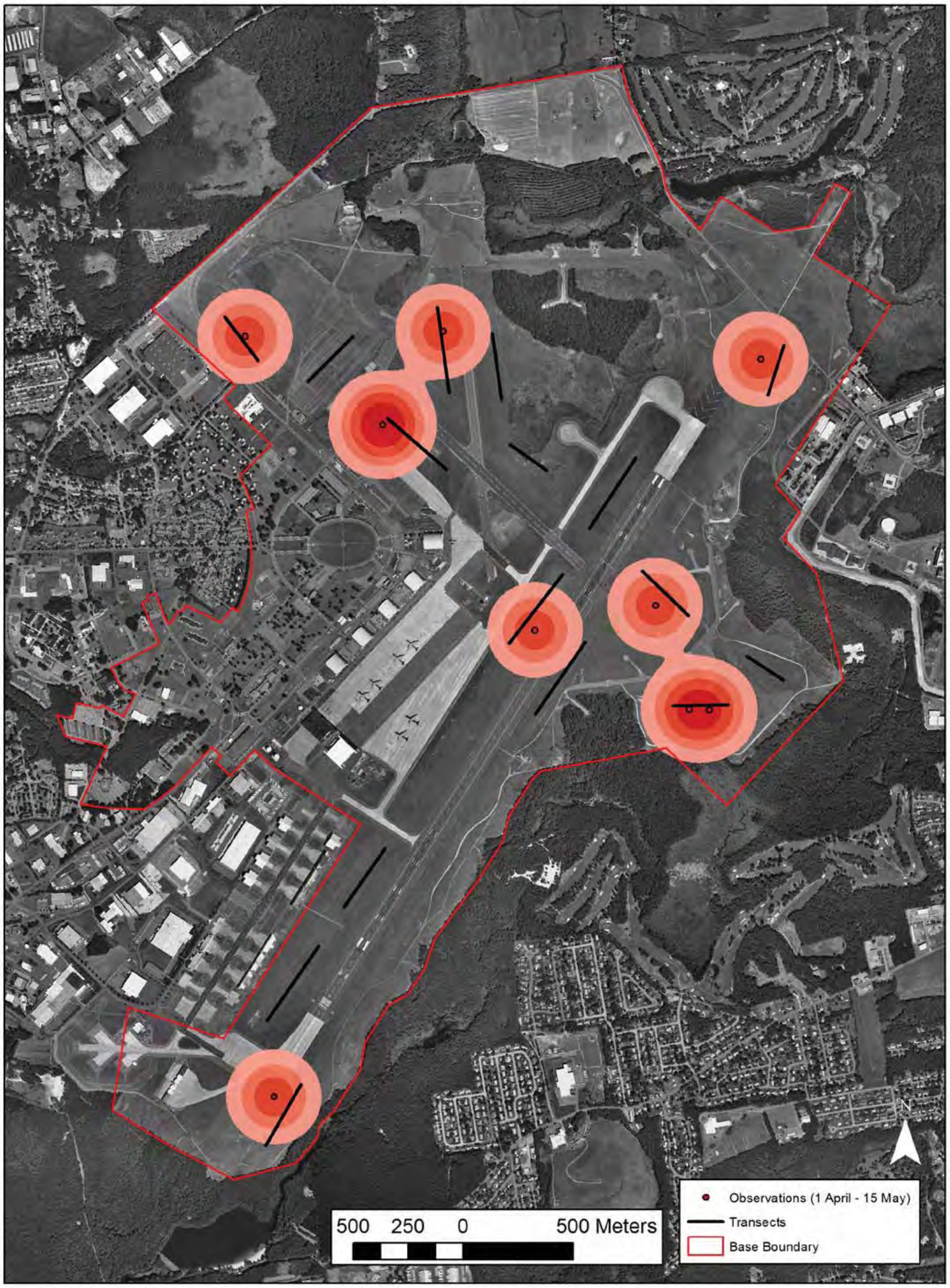

Figure **.** Density contours generate for s allo s ift o servations at estover Air Reserve ase, Massac usetts. Data ere collecte uring morning transect surveys in s ring migration A ril to May . ontours escri e t e s atial extent an relative ensity of occurrences. Dar er contours re resent ig er avian ensities.

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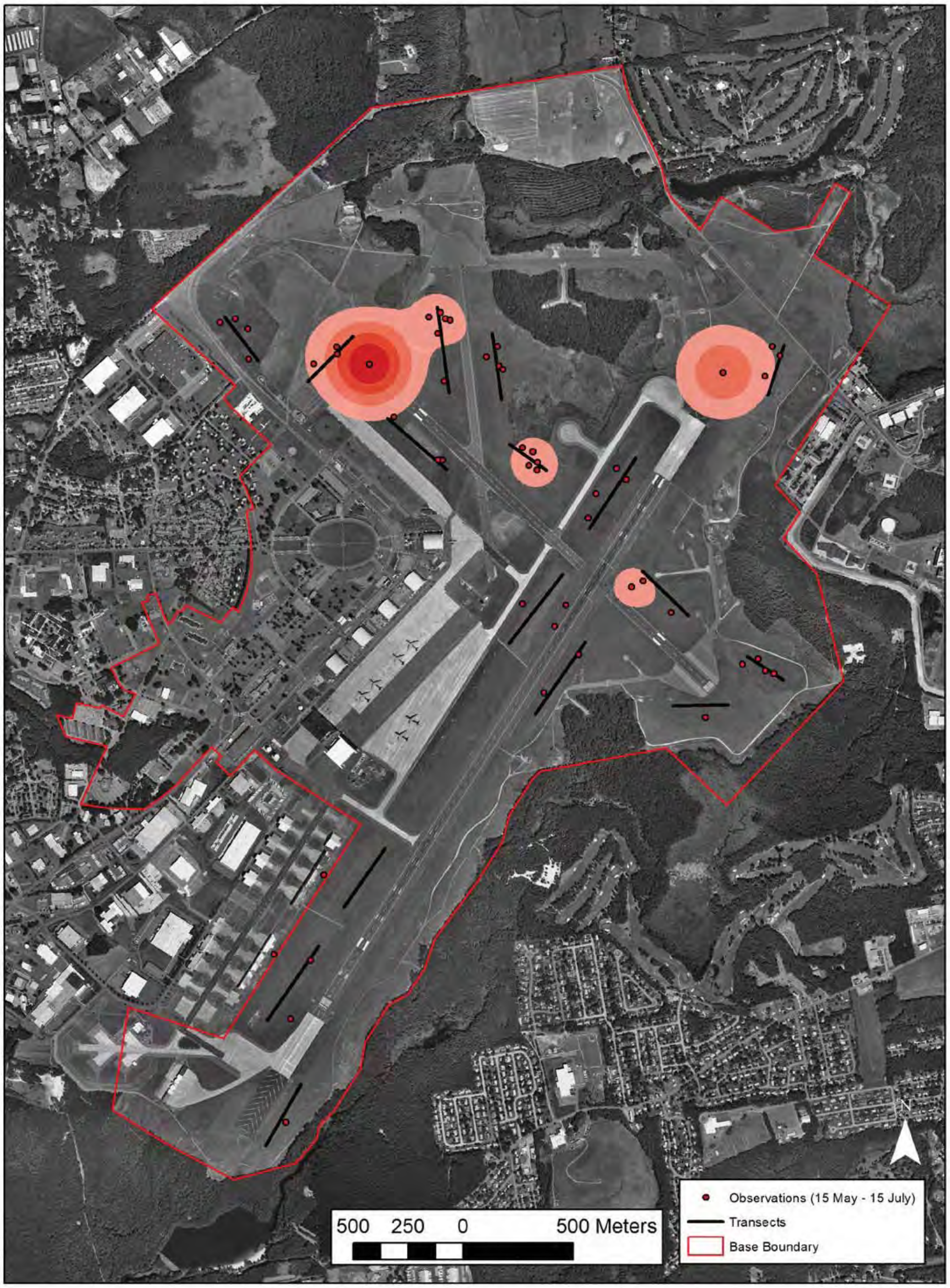

Figure . Density contours generate for s allo s ift o servations at estover Air Reserve ase, Massac usetts. Data ere collecte uring morning transect surveys in ree ing season May to uly . ontours escri e t e s atial extent an relative ensity of occurrences. Dar er contours re resent ig er avian ensities.

**Appendix . ** Avian istri ution an ensity ma s.

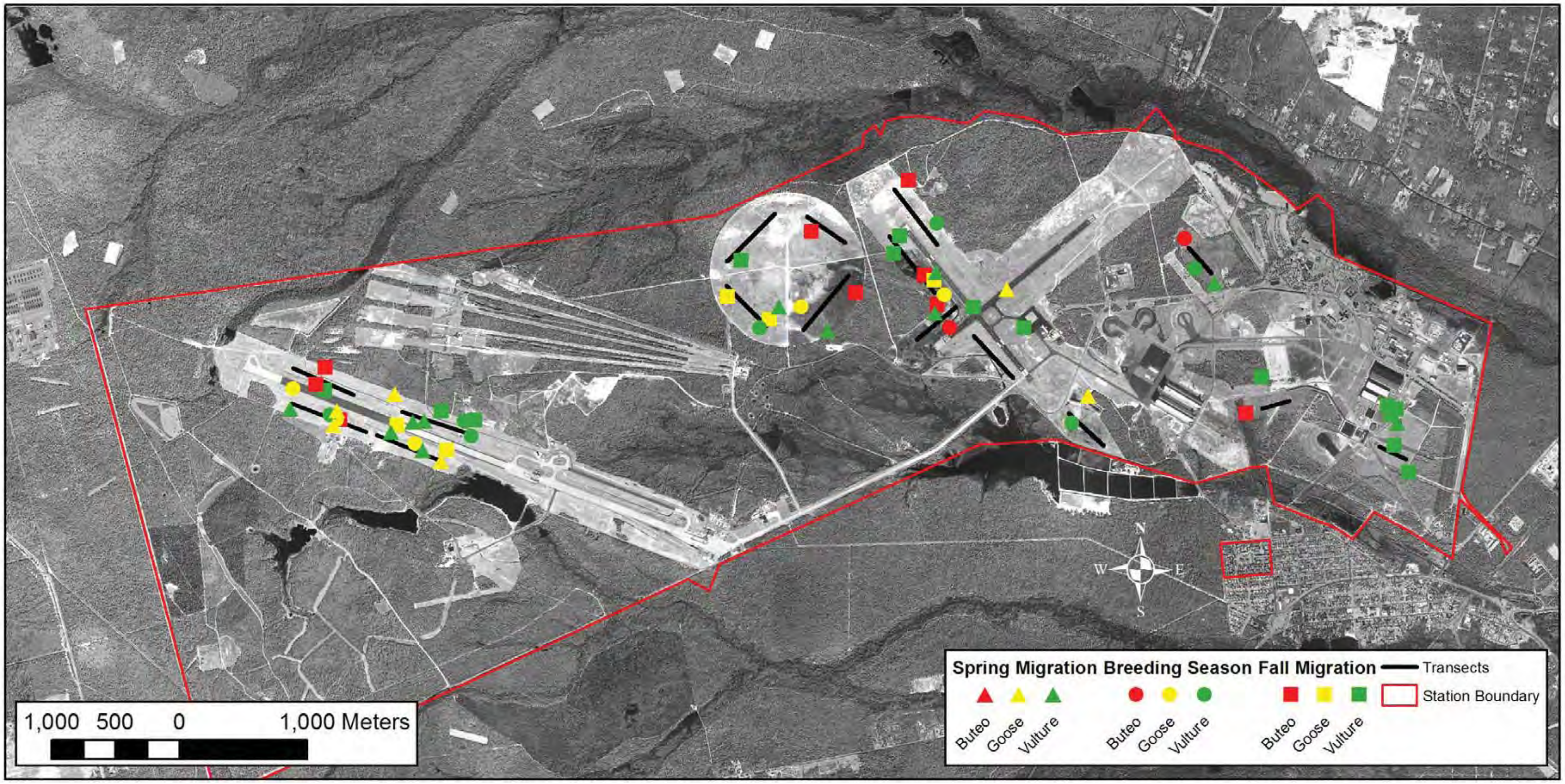

**Figure . ** S atial locations of uteo, goose, an vulture o servations inclu ing fly overs at oint ase Mc uire Dix La e urst La e urst section , Ne ersey. Data ere collecte uring morning an evening transect surveys uring fall migration August to Novem er , s ring migration A ril to May , an ree ing season May to uly .

Appendix . Avian istri ution an ensity ma s.

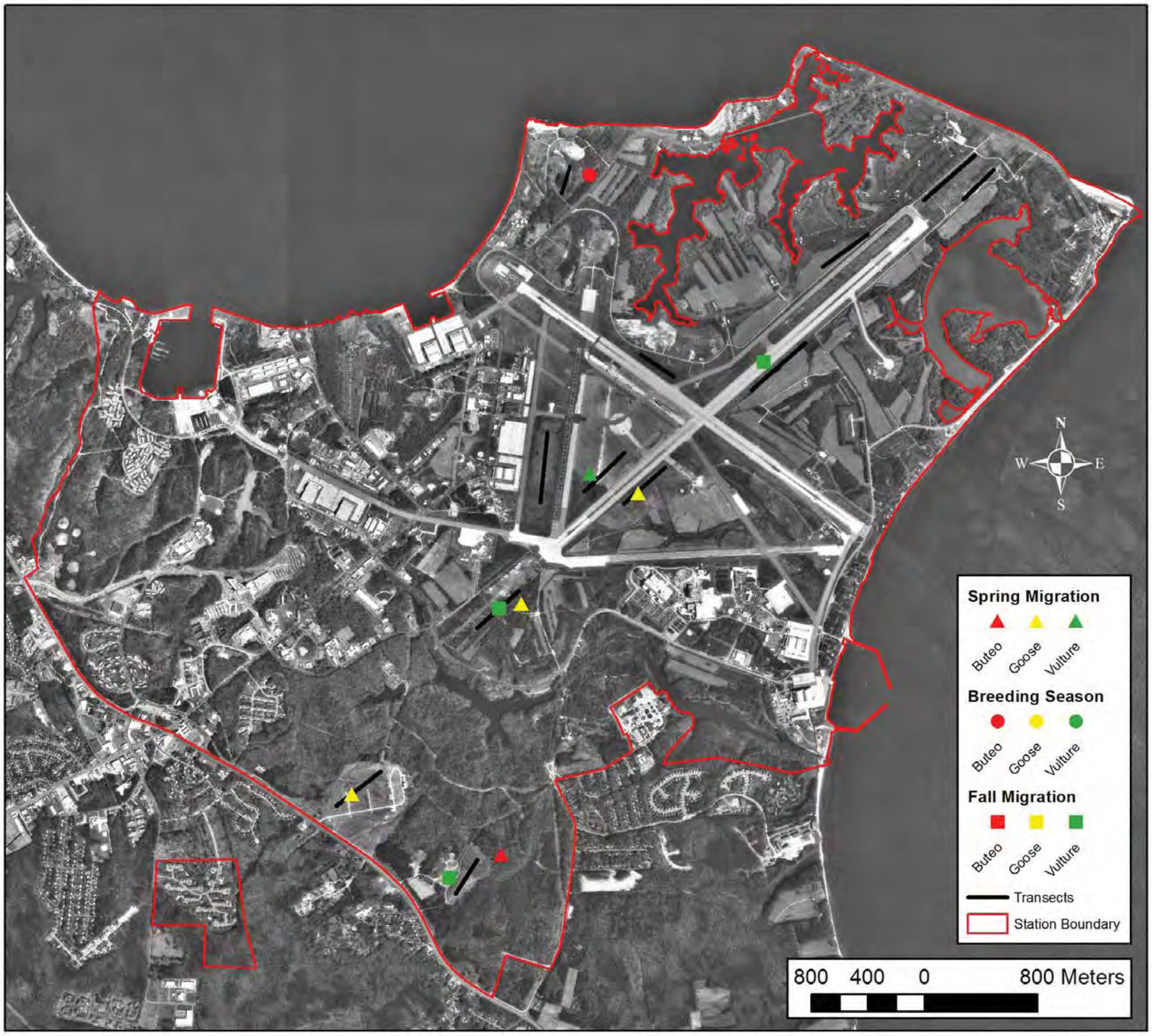

Figure . S atial locations of uteo, goose, an vulture o servations inclu ing fly overs at t e Patuxent River Naval Air Station. Data ere collecte uring morning an evening transect surveys in fall migration August to Novem er , s ring migration A ril to May , an ree ing season May to uly . ly overs at t is site are un erre resente as t ey ere not al ays georeference .

Appendix . Avian istri ution an ensity ma s.

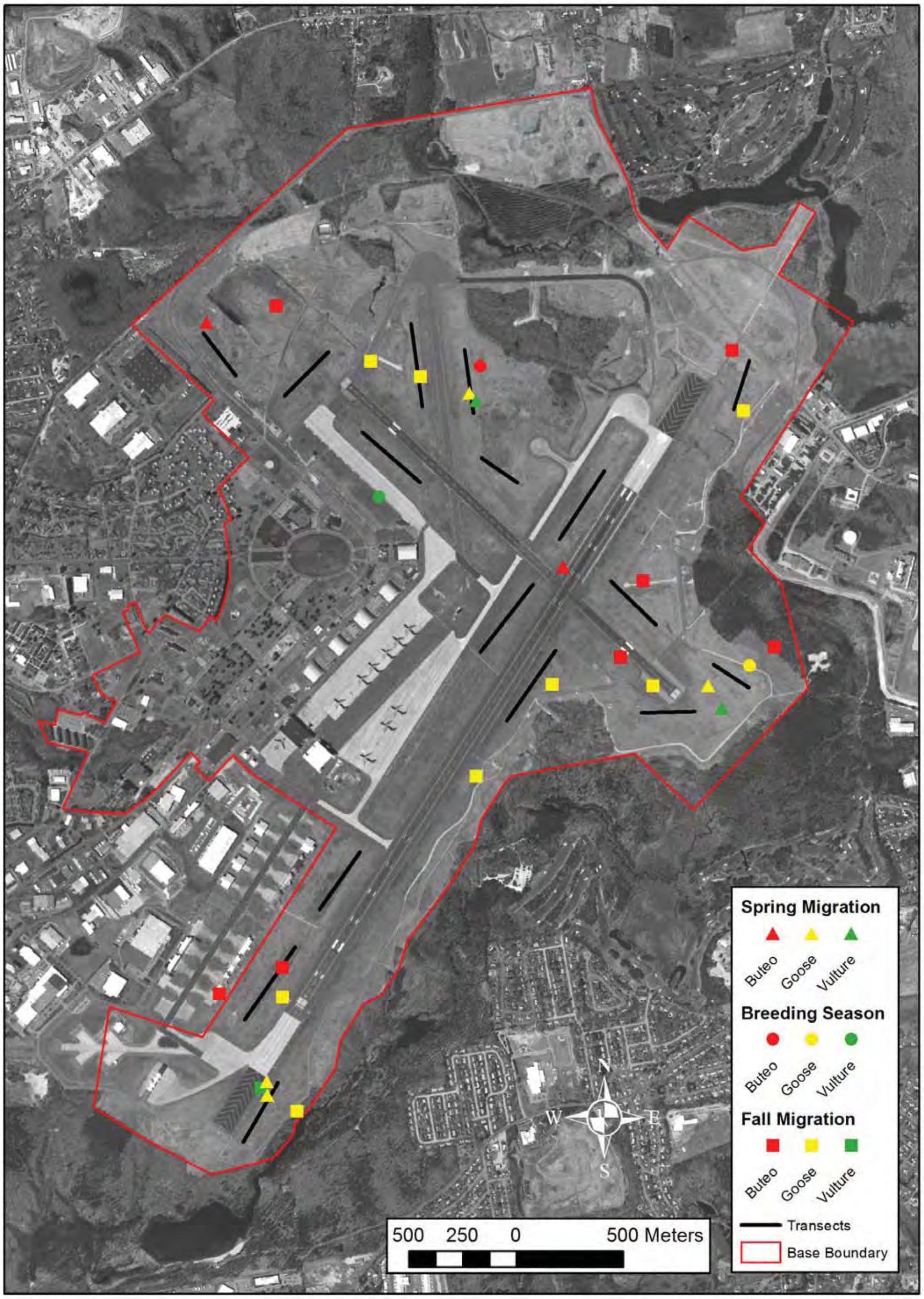

Figure . S atial locations of uteo, goose, an vulture o servations inclu ing fly overs at estover Air Reserve ase. Data ere collecte uring morning an evening transect surveys in fall migration August to Novem er , s ring migration A ril to May , an ree ing season May to uly .

Appendix C. Sampling effort for transects at Patuxent River Naval Air Station (PRNAS) from fall 2007 to breeding season 2011 (morning transects only). At WARB and Lakehurst, transects were surveyed six times each in fall, three times in spring, and four times during the breeding season.

	Number of Times Surveyed								
	Year 1 (2007-2008)			Year 2 (2008-2009)			Year 3 (2010-2011)		
Transect Number	Fall Migration	Spring Migration	Breeding Season	Fall Migration	Spring Migration	Breeding Season	Fall Migration	Spring Migration	Breeding Season
1	4	3	3	5	2	4	6	3	4
2	2	3	3	6	2	4	6	3	4
3	5	3	3	3	2	4	6	3	4
4	3	2	3	6	2	4	6	3	4
5	2	3	3	5	2	4	6	3	4
6	5	3	3	6	2	4	6	3	4
7	5	3	3	6	2	4	6	3	4
8	2	3	3	6	2	4	6	3	4
9	4	3	3	6	2	4	6	3	4
10	5	3	3	6	2	3	6	3	4
11	4	2	2	6	2	4	5	3	4
12	0	3	3	6	2	4	6	3	4

Appendix . Lan sca e analysis uffers.

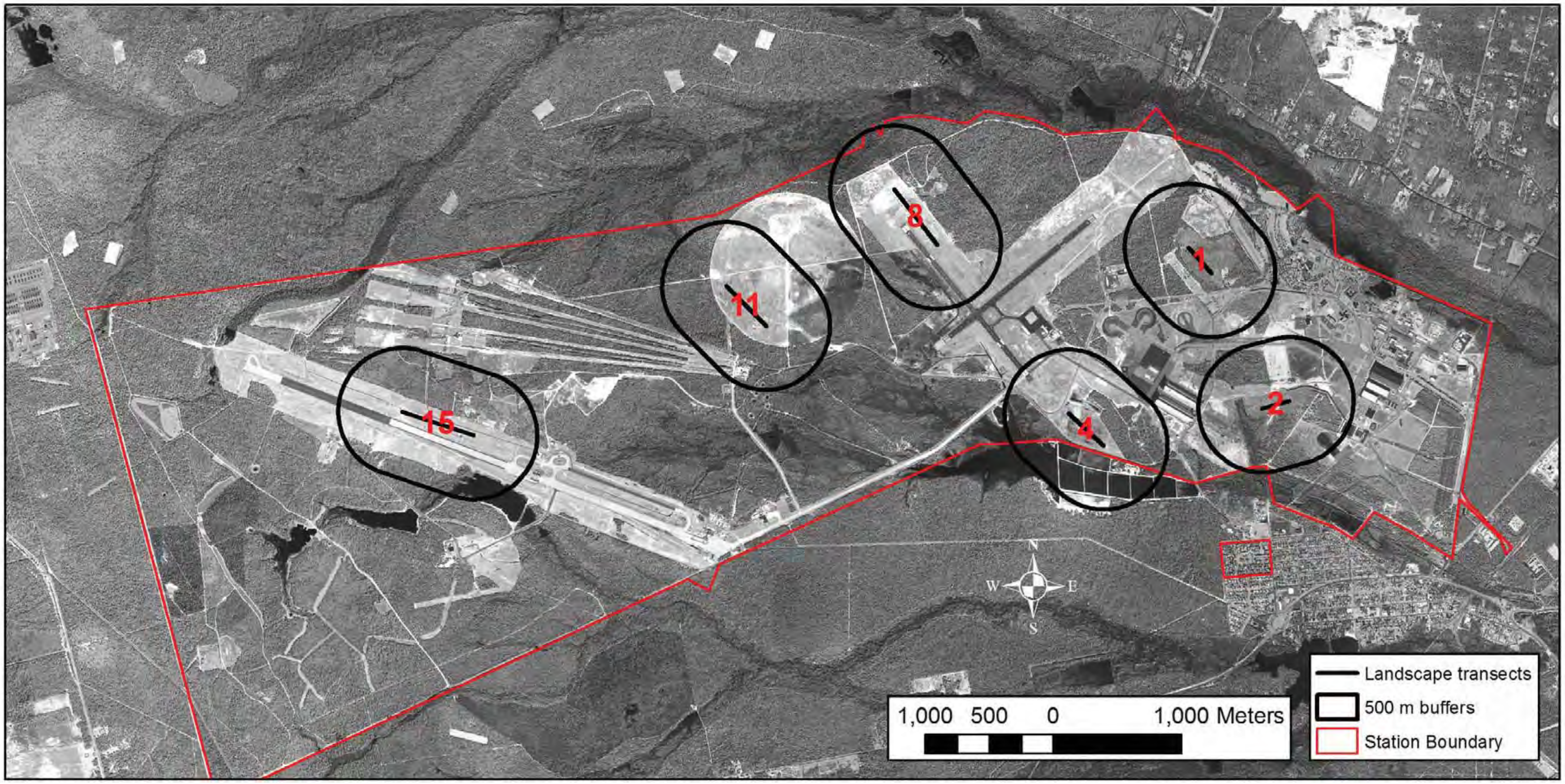

Figure . Locations of transects an uffers use for lan sca e scale analyses at oint ase Mc uire Dix La e urst La e urst section , La e urst, N .

Appendix **.** Lan sca e analysis uffers.

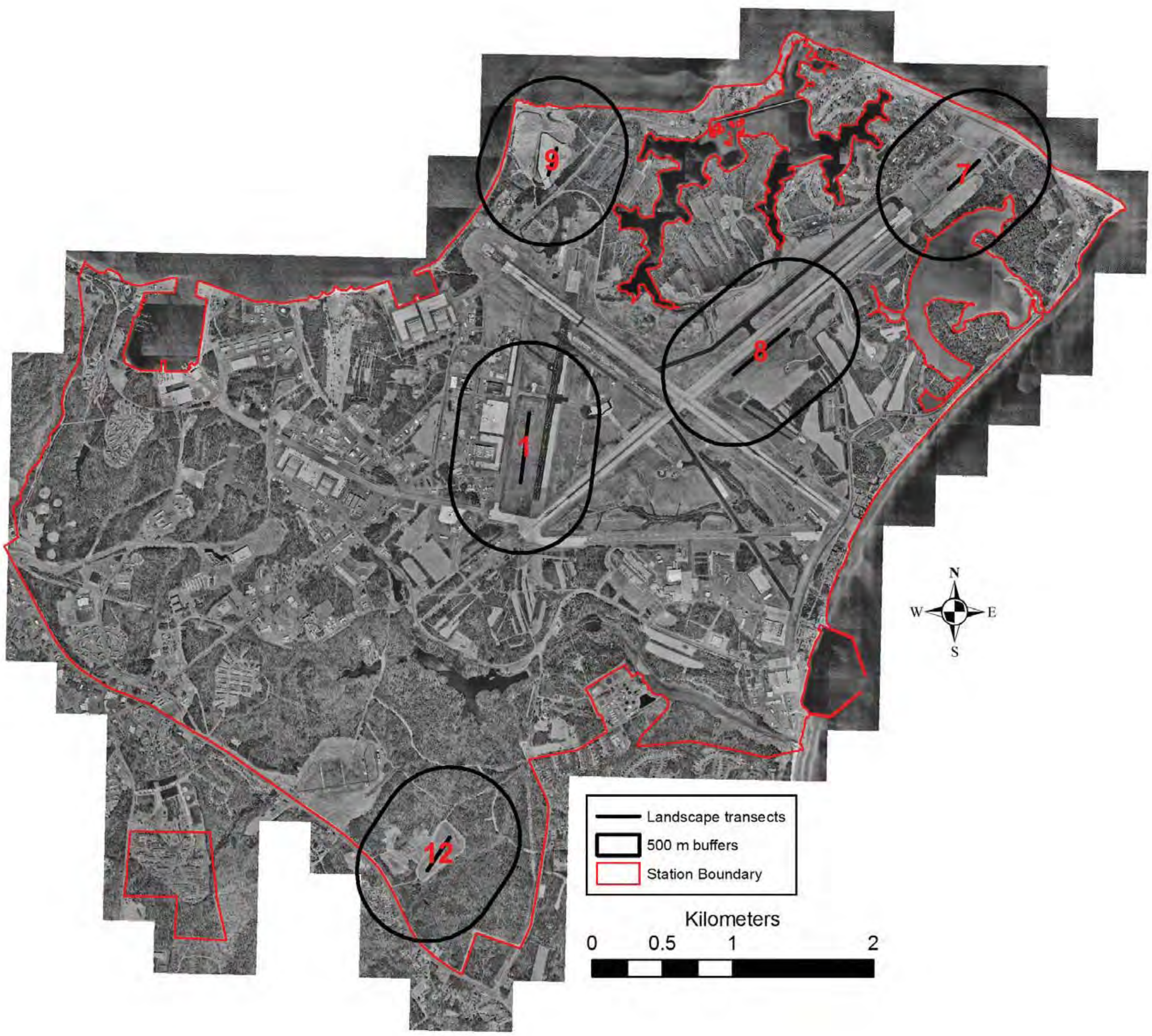

Figure 2. Locations of transects an uffers use for lan sca e scale analyses at Patuxent River Naval Air Station, Patuxent River, MD.

Appendix . Lan sca e analysis uffers.

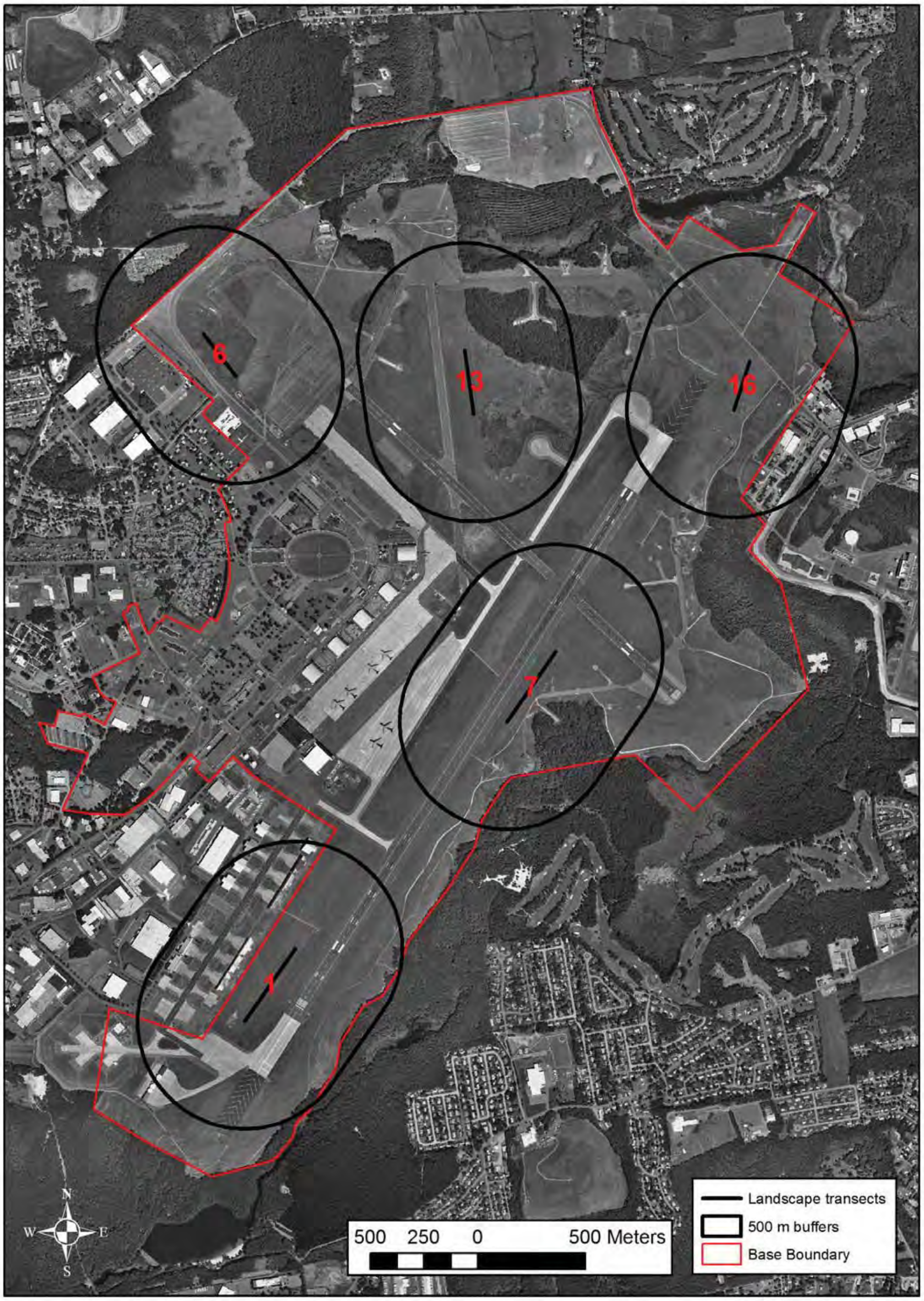

Figure . Locations of transects an uffers use for lan sca e scale analyses at estover Air Reserve ase, ico ee, MA.

Appendix . Lan sca e analysis   uffers.

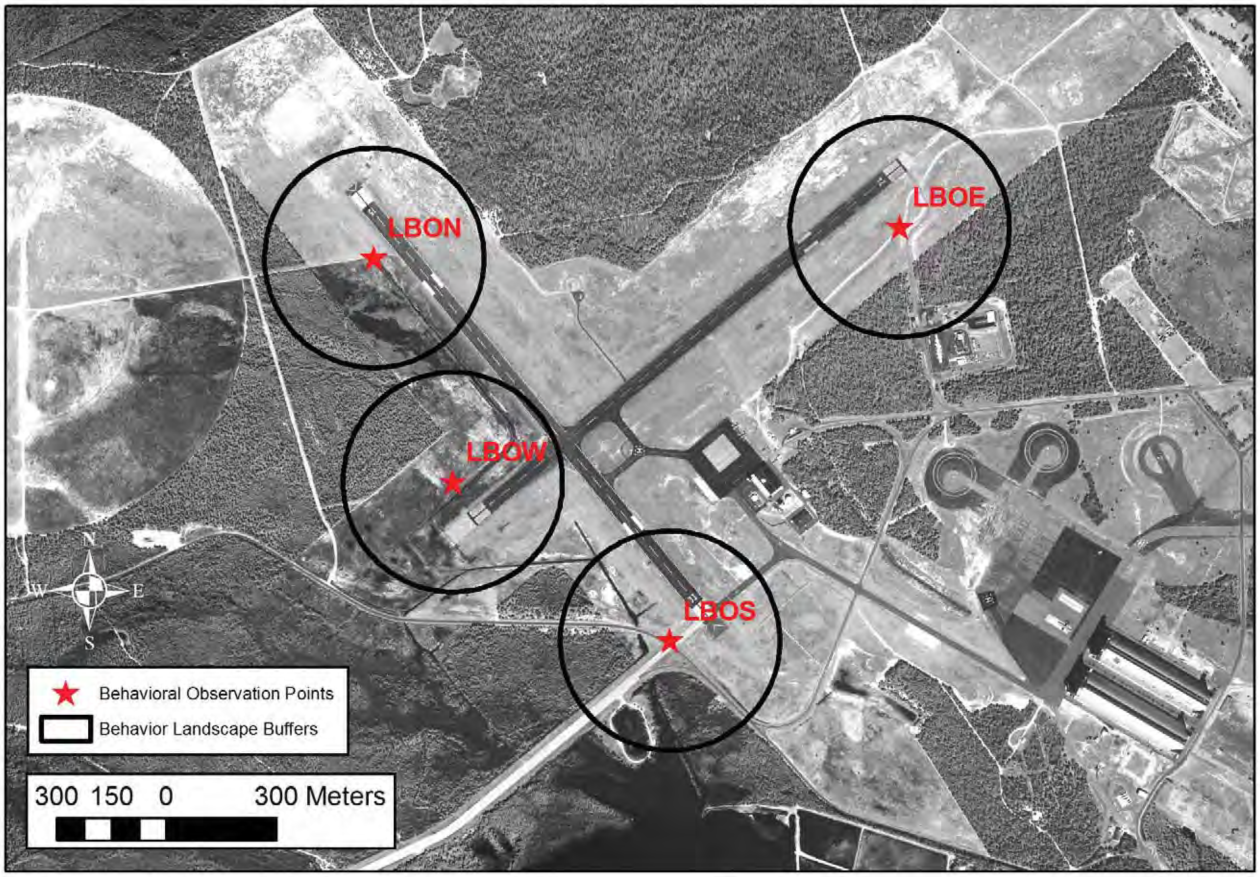

Figure . Locations of e avioral o servation oints an   m uffers use for lan sca e analysis at oint ase Mc uire Dix La e urst La e urst section , La e urst, N .

Appendix . Lan sca e analysis uffers.

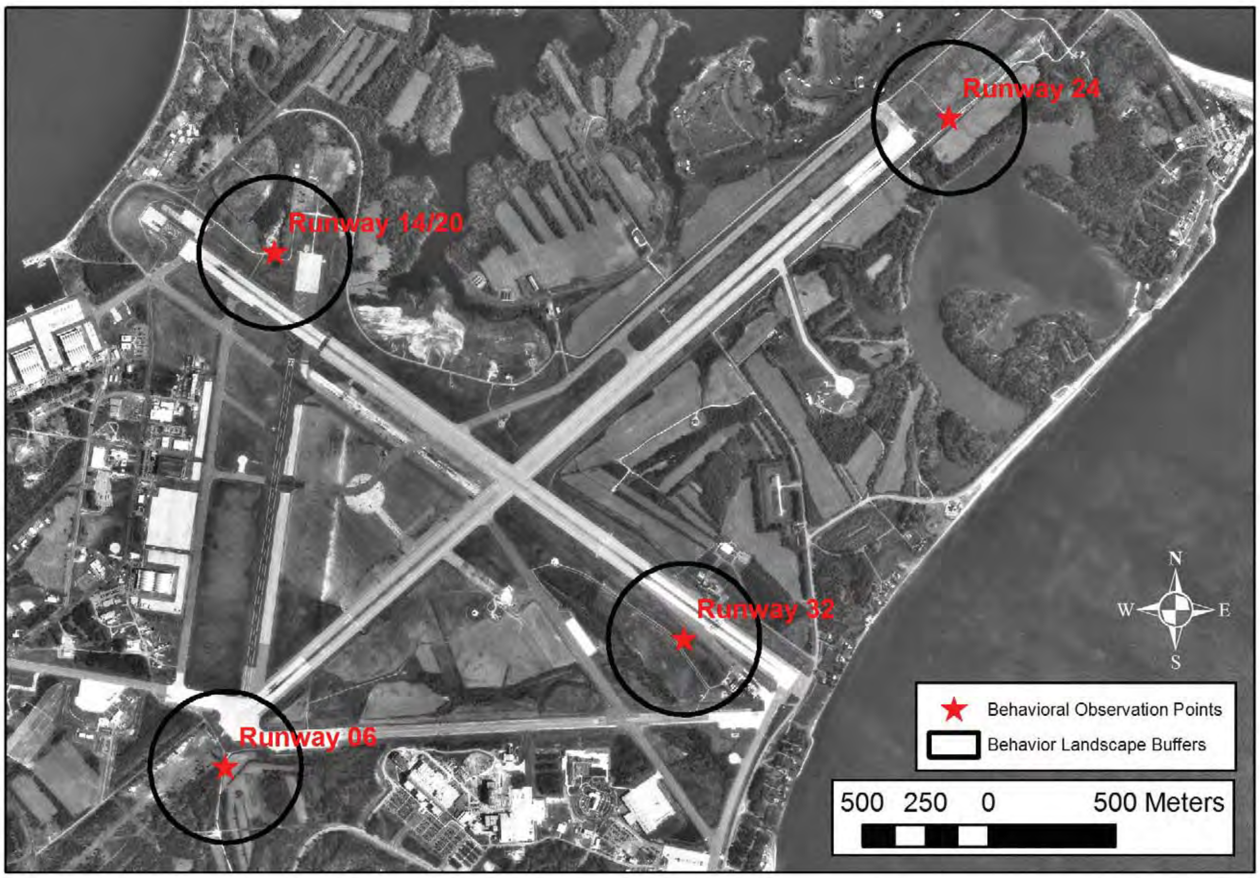

Figure . Locations of e avioral o servation oints an m uffers use for lan sca e analysis at Patuxent River Naval Air Station, Patuxent River, MD.

**Appendix . **Lan sca e analysis uffers.

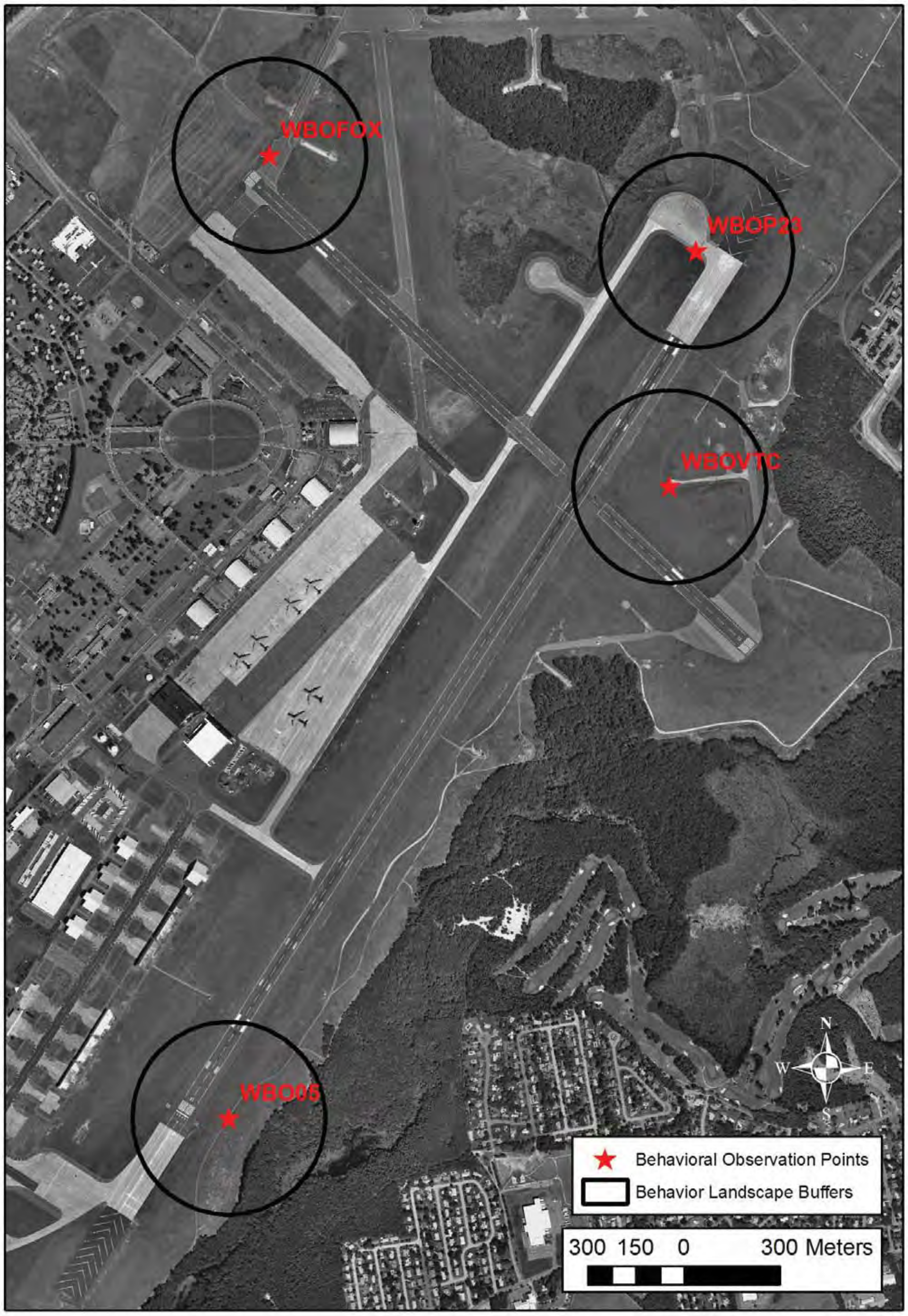

**Figure . **Locations of e avioral o servation oints an m uffers use for lan sca e analysis at estover Air Reserve ase, ico ee, MA.