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SERDP Project SI-1439

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Final report

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Abstract

Military lands and waters may be particularly valuable for migrating birds requiring stopover habitat to rest and refuel en route to very distant seasonal ranges. Recent developments in radar technology have provided powerful tools for investigating on a broad scale migrant use of military installations; thus providing an opportunity to improve both conservation and flight safety measures. In this study, spring and fall migrant use of 40 military installations across the United States were qualitatively investigated. These times of year were selected since they are the periods when BASH is of most concern. Migratory patterns on three installations (Eglin Air Force Base, FL; Ft. Polk, LA; and Yuma Proving Ground, AZ) were then closely examined and migration forecast models for those locations were developed with the goal of providing a tool for reducing the probability of collisions between birds and military aircraft. A comparison was also made between radar estimates of migrant densities aloft during exodus events and more traditional ground-based surveys to evaluate the effectiveness of estimating migrant abundance in stopover habitat with radar data. At Fort Polk, movement ecology and migrant-habitat relations of the Red-eyed Vireo were investigated during migratory stopover. Lastly, migrant use of diverse riparian habitats was compared along water courses near the Yuma Proving Ground. Results indicated that approximately half of the installations examined with radar data contained migrant stopover "hotspots," reaffirming the fact that military installations are important to migrating birds. Interestingly, migrant abundances, and species turnover as estimated by ground-based surveys, were found to poorly reflect migrant densities estimated with radar data. Migrant abundance, species richness, and community composition were all also found to be influenced by riparian vegetation composition. This information collectively suggested that radar data can be used to identify migratory hotspots on military installations and improve flight safety on installations with an aviation mission. However, radar data may not be sufficient to distinguish fine-scale differences in habitat use by migrants within an installation's boundaries.

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Preface

This report was prepared by Drs. Richard A. Fischer and Michael P. Guilfoyle, U.S. Army Engineer Research and Development Center–Environmental Laboratory (ERDC-EL); Jonathon J. Valente, Bowhead Inc., Vicksburg, MS; Dr. Sidney A. Gauthreaux, Jr., Carroll G. Belser, Donald Van Blaricom, and John W. Livingston, Clemson University Radar Ornithology Laboratory; and Drs. Emily Cohen and Frank R. Moore, University of Southern Mississippi (USM), Department of Biological Sciences. The authors wish to thank the Strategic Environmental Research and Development Program (SERDP) for providing the financial assistance for the project. Appreciation for technical assistance is extended to Mr. Bradley Smith and Dr. Jeffrey Marqusee, SERDP Executive Directors, former and present, and Drs. Robert Holst and John Hall, Sustainable Infrastructure Program Managers, former and present, and to the HydroGeoLogic, Inc., staff for their administrative assistance. The research would also not have been possible without the assistance of military base personnel granting access to the bases, helping to identify study sites, and providing site information, including Mr. Bruce Hagedorn and Ms. Kathleen Gault (Eglin Air Force Base, FL); Mr. Danny Hudson (Fort Polk, LA), and Mr. Randy English (Yuma Proving Ground, AZ). Thanks to Mr. Jim Johnson and Mr. Lynn Bennett for their logistical support and to Dr. Robb Diehl and Eben Paxton, USM, for help with analyses. The authors gratefully acknowledge field crew personnel who provided outstanding avian sampling during the course of the project: Archer Larned, Dr. Cliff Cordy, and Thomas Auer in Arizona; Beth Wright, Harley Winfrey, Sarah Winfrey, Kristina Baker, and Jordan Smith in Florida; and Phil Heavin, Emily Lain, Jaclyn Smolinsky, Kristin Comolli, Brian Wilson, Christine Roy, Christopher Nicholson, Shanna Everett, Lainie LaHaye, Dana Ripper, Christine Roy, Amy Scarpignato, Dave Haines, Mason Cline, Megan Hughes, Zoltan Nemeth, Clay Graham, Lisa Vormvold, Brian Bielfelt, and Pete Hosner in Louisiana.

The report was reviewed by Drs. Eric R. Britzke and Nathan R. Beane, ERDC-EL.

The study was conducted under the direct supervision of Tisa Webb, Branch Chief, Ecological Resources Branch, Dr. Edmond J. Russo, Chief, Environmental Evaluation and Engineering Division, EL; and Dr. Beth C. Fleming, Director, ERDC-EL.

COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. Jeffery P. Holland was Director.

Acronyms

AAC	All-American Canal
AFB	Air Force Base
AHAS	Avian Hazard Advisory System
AIC_C	Akaike's information criterion corrected for small sample size
ALCR	Alaqua Creek
BACR	Basin Creek
BAM	Bird Avoidance Model
BASH	Bird-Wildlife/Aircraft Strike Hazard
BPCKM	Birds per cubic kilometer
BUCR	Bundick Creek
CUROL	Clemson University Radar Ornithology Laboratory
dBZ	Decibels of reflectivity
DoD	Department of Defense
DRCR	Drakes Creek
eBIRDRAD	Enhanced Bird Radar
EL	Environmental Laboratory
ERDC	Engineer Research and Development Center
GIS	Geographic Information System

GPS	Global Positioning System
hr	hour
IMP	Imperial Valley
INRMP	Integrated Natural Resources Management Plan
km	kilometer
m	meter
min	minute
NCDC	National Climatic Data Center
NEXRAD	NEXt generation RADar (same as WSR-88D)
ND	Native-dominated with non-natives
NND	Non-native/invasive dominated with some natives
NNI	Non-native/invasive shrub and tree community
NS	Native shrubs
NT	Native trees
PIF	Partners in Flight
SE	Standard error
SERDP	Strategic Environmental Research and Development Program
SMCR	Six-mile Creek
TMCR	Ten-mile Creek
UPTR	Upland Transect

USM	University of Southern Mississippi
WHCH	Whiskey Chitto
WSR-88D	Weather Surveillance Radar- 1988 Doppler
YUMA	Yuma transect site
Z	Absolute reflectivity

1 Objectives

This research project was performed with support from the Department of Defense (DoD) Strategic Environmental Research and Development Program (SERDP) to develop a radar-based monitoring strategy for migratory birds on military lands. The broad goal was to investigate migrant use of military installations as stopover habitat using ground-based surveys and Doppler weather surveillance radar (WSR-88D, also known as next generation radar [NEXRAD]) data. Specific objectives were to:

1. use WSR-88D radar data to identify military installations that consistently support large migrant populations;
2. examine the timing of migration on two eastern military installations and one western installation;
3. develop migration forecast models for those three installations by combining migrant density estimates with weather variables;
4. compare radar-based estimates of migrant density with more traditional ground-based bird surveys on the three installations;
5. examine how vegetation influences migrant habitat use along riparian systems in the Southwest; and
6. investigate movement ecology and habitat use by migrant Red-eyed Vireos in the spring within stopover habitat on Ft. Polk, Louisiana (Appendix A).

Radar information showing bird migration on and near military installations is critically important for the protection of habitats used by migratory birds during stopover periods. This information is vital to DoD land managers who protect stopover areas on military lands. Similarly, radar data are particularly important to land managers of military air stations where bird-wildlife/aircraft collisions threaten lives and cost millions of dollars in damages to aircraft infrastructure every year. By identifying where, when, how long, and in what concentrations migratory birds inhabit temporary stopover sites or pass above military training airspace, affected installations will be able to improve both military readiness and species conservation. The work described in this document meets several of the objectives outlined in the DoD Partners in Flight (PIF) Strategic Plan (2002), including determining the current status of neotropical migratory bird populations on DoD lands, identifying and maintaining priority habitats on DOD lands for neotropical migratory bird populations, using radar technology as a BASH tool, improving communication with Air Operations personnel, improving hazard detection technology for pre-flight planning, and using information collected by partners to better support DoD mission requirements.

2 Background

Approximately half of all bird species that nest in the United States are classified as neotropical migratory birds. These species, which include about 340 species of songbirds, shorebirds, waterfowl, and birds of prey, move annually between their breeding grounds in North America and wintering areas in Mexico, Central America, South America, and the Caribbean. Seasonal bird migration is a time-consuming, energetically expensive behavior that imposes numerous risks on the survival of individuals, with potential implications for long-term viability of populations (Alerstam 2003, Moore et al. 1995). Migrants are often under pressure to complete the migratory passage quickly to procure suitable breeding opportunities or high quality over-winter territories (Greenberg 1980, Francis and Cooke 1986). Although many landbird migrants are capable of making spectacular, nonstop flights over ecological barriers, few migrants actually engage in nonstop flights between points of origin and destination. Instead, migration is divided into alternating phases of flight and stopover, with each stopover lasting a few hours to a few days. In fact, the cumulative amount of time spent at stopover sites far exceeds time spent in flight and largely determines the total duration of migration (Alerstam 2003). Thus, migrants are highly dependent on the availability of high quality stopover habitats with sufficient food and cover resources for refueling and avoiding predators (Morrison et al. 1992, Moore et al. 1995, 2005).

Complicating — and potentially compromising — this already complex process, are decades of urban growth and agricultural expansion that are fragmenting and eliminating key migratory stopover habitats, such as riparian areas (e.g., Askins et al. 1990, Askins 1993, Rich 2002), for many species of birds. In particular, over 90% of western riparian areas have been lost (Dahl and Johnson 1991, Noss et al. 1995). Coastal areas in general, and the Northern Gulf Coast in particular (Moore et al. 1995), are critical for many trans-Gulf neotropical migrants. Yet human coastal populations were projected to increase over 60% from 1990 to 2010 (Cullitan et al. 1990). Loss and degradation of migratory stopover areas are frequently cited as key contributors to the observed long-term declines of migratory landbirds (Hutto 1985, Askins et al. 1990, Moore et al. 1995). Conservation organizations (e.g., National Audubon Society, Nature Conservancy) rank protection of important migration stopover areas in the United States as a very high priority. Furthermore, Donovan et al. (2002) suggested that mapping migration stopover areas should be one of the highest research priorities for the conservation of migratory birds.

Objective 1: Migrant Use of Military Installations

DoD military installations, which include nearly 30 million acres of land and water in relatively large unfragmented tracts, provide a diversity of high-quality habitats (e.g., grasslands, wetlands, riparian areas, early successional habitats, and mature forests) for millions of en route migratory birds annually, including a large number of threatened, endangered, and otherwise sensitive species (Martin et al. 2000). Collectively and individually, military installations represent unique and important resources that likely play a critical role in the health and viability of migratory bird populations within and beyond the installation boundaries in all regions of the country. In recognition of this, the DoD has become an active member of the Partners in Flight (PIF) initiative, a voluntary, international coalition of government agencies, conservation groups, academic institutions, private businesses, and everyday citizens dedicated to "keeping common birds common." The main goal of PIF is to direct resources toward the conservation of birds and their habitats through cooperative efforts in North America and the neotropics. The DoD PIF program has been instrumental in assisting installations with conservation planning, facilitating avian inventories, and providing critical information from the various bird conservation initiatives to DoD land managers. In addition, the DoD PIF Strategic Plan (2002) clearly provides DoD natural resources managers with information about how to integrate bird conservation into Integrated Natural Resources Management Plans (INRMPs).

Unfortunately, very little is known about specific stopover sites on military lands that provide critical in-transit habitats for migrating birds. Because of the potential conflicts between the conservation of migratory birds and mission readiness, natural resource managers need to know if their base occurs along a major bird migration flyway or serves as an important bird migration stopover area. Since the early 1940s, radar has been used to monitor bird migration. Most bird migration occurs under the cover of darkness, and radar is one of the few means of detecting and quantifying such movements (Gauthreaux 1970). Recent technological advances in radar systems have proven invaluable for improving knowledge of migratory bird movements. The newest weather surveillance radar, WSR-88D or NEXRAD (NEXt generation RADar), is ideal for studies of migratory bird movements. This sophisticated radar system can be used to map geographical areas of high bird activity (e.g., stopover, roosting and feeding, and colonial breeding areas). It also provides information on the quantity, general direction, and altitudinal distribution of birds aloft.

From 1990 through 1997, nearly 150 new Doppler weather surveillance radars were installed in the United States (Figure 1), providing nearly complete NEXRAD coverage. Some of these units are on DoD installations, providing an opportunity to collect site-specific data on bird movements and use of DoD lands. Since 1993, the Clemson University Radar Ornithology Laboratory (CUROL) has examined the effectiveness of using these radars to detect, quantify, and monitor flying birds (Gauthreaux and Belser 1998, 1999, 2003a and b). Research at the CUROL has shown that radar data can greatly enhance the ability to monitor broad-level migration patterns, assess annual trends of migratory bird passage, determine geographical areas of high stopover use, and gather information on the quantity, speed, and altitude of flying birds (Gauthreaux and Belser 1998, 2003b; Diehl and Larkin 2004). By combining classified Landsat imagery and data from WSR-88D radar images, CUROL is mapping the geographical distribution of critical migratory stopover areas and is characterizing the habitat of these areas (Gauthreaux and Belser 2003b). The first objective was to use geographic information systems (GIS) as a screening tool to identify all military installations within 120 km of NEXRAD stations, and then use NEXRAD data to identify installations that serve as migration stopover hotspots in the spring and fall.

Objectives 2 and 3: Quantifying Migration and Developing Migration Forecast Models

In addition to conservation obligations, the DoD also has safety and financial incentives to be concerned with migratory bird populations on military installations. Reduction of bird-wildlife/aircraft strike hazards (BASH) is a critically important issue on installations that have an aviation mission. Military aircraft are subject to potential bird strikes, especially during takeoff/landing and during low-level missions, and the problem is particularly acute during period of dense bird migration in spring and fall. Collisions between birds and aircraft pose a serious threat to the safety of passengers and flight crews on both civilian and military flights. Since 1985, nearly 38,000 bird-military aircraft collisions have been reported. These collisions have killed 33 pilots, destroyed 30 aircraft, and resulted in over $500 million in damage (Lovell and Dolbeer 1999). Between 1988

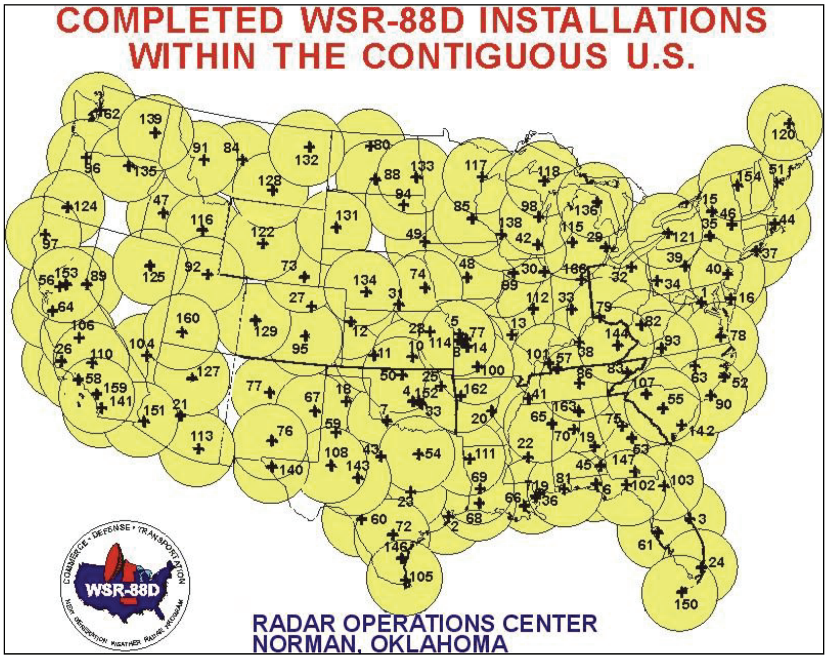

Figure 1. WSR-88D stations in the contiguous United States. Edges of the circles are at 124 nautical mile range (230 km).

and 2004, approximately 194 people were killed from bird-aircraft strikes (Dolbeer 2006). In the United States, collisions between aircraft and wildlife cost the aviation industry over $600 million annually (Cleary et al. 2007), while global costs are estimated at $1.2 billion (Allan and Orosz 2001). On average, the U.S. Air Force (USAF) experiences costs of $35 million annually on bird-aircraft collisions, while over the past 20 years, total costs of $98 million have been estimated for aircraft collisions with Turkey Vultures (*Cathartes aura*) alone (Kelly and Wilkens 2006). The number of wildlife-aircraft strikes has increased from 1,700 in 1990 to over 7,000 in 2006; total reported collisions during this period exceed 70,000 (Cleary et al. 2007). The number of bird-aircraft collisions have increased recently due to increased air traffic and population increases of several large birds, particularly the Canada Goose (*Branta canadensis*) (Dolbeer and Eschenfelder 2005). This situation was recently highlighted by the well-publicized story of a commercial passenger aircraft that landed in the Hudson River (U.S. Airways Flight 1549) in January 2009 after colliding with several Canada Geese (Langer 2009).

Bird migration is a dynamic process. Although predictable in terms of general timing, the specific times for determining peaks in activity often depend on current weather conditions. Migrants are known to respond to frontal systems (Alerstam 2003) during both the spring and the fall. During spring, radar data suggests that during peak migration, as many as 80,000 birds per mile may pass northward over some sections of U.S. coastlines each day. After a stopover along the coastline to replenish energy reserves expended during long-distance flight, these migrants slowly filter northward to their breeding grounds, sometimes taking as long as six weeks to reach breeding sites. Typically, these migrants travel in large flocks that emerge from stopover sites shortly after dusk. From late-summer to fall, southward migration back to wintering grounds often includes large flocks of young birds and adults.

Currently, two tools are available to DoD airfield personnel to assess bird strike risk during flight planning: the U.S. Bird Avoidance Model (BAM) and the Avian Hazard Advisory System (AHAS). The BAM, which is based on 30 years of historical bird activity data (primarily Audubon Society Christmas Bird Count, U.S. Biologic Survey Breeding Bird Survey, and bird refuge arrival and departure data for the conterminous U.S.), is used as a tool for analysis, predictability, and correlation of bird habitat, migration, and breeding characteristics, combined with key environmental and geographic data (USBAM 2004). The AHAS is an online, near real-time, tool based in a geographic information system (GIS) platform. This system also uses WSR-88D weather radars and models developed to predict bird movement, monitor bird activity, and forecast bird strike risk. When radar data indicate bird activity in a particular area, AHAS uses the BAM to assess risk for a particular time period. Yet, in addition to the BAM, AHAS also looks at migration and soaring bird data to determine if the risk should be higher than that indicated by the BAM. Although the BAM and AHAS are useful tools currently used by the military to reduce BASH incidences, there is need for an improved system that can more accurately predict timing and volume of migrating birds on specific installations. CUROL has also conducted preliminary work that suggests multivariate statistical analyses of forecast weather variables and bird migration density measures can be used to develop statistical models that accurately predict the density of migration events (http://www.birdsource.org/BirdCast/home.html). Thus, the temporal pattern of migration was first examined on three installations, and then constructed models that can be implemented through a desktop computer spreadsheet to predict migrant densities over those installations on any given evening.

Objective 4: Comparison of Migrant Survey Techniques

The Engineer Research and Development Center (ERDC), Environmental Laboratory (EL), has conducted numerous intensive inventory and monitoring efforts to document the distribution, abundance, and diversity of avian populations on numerous military installations throughout the country. These surveys typically have been done on a seasonal basis (i.e., winter, spring migration, summer breeding, and fall migration). Typically, migration surveys are conducted by personnel on the ground either walking transects or sampling from fixed points. Ideally, sampling during migration seasons should be conducted over the course of many weeks, but this is often difficult to accomplish with limited personnel and funding. Investigators often use best professional judgment to determine when peaks in migration are likely to occur in an area, and when to conduct field surveys for migrants. For these ground-based surveys, however, timing may be such that peak passage of birds is missed or the approach may overlook some important areas or habitats that are used heavily by stopover migrants. Radar data can be a significant tool to assist in improving the timing and location of ground-based migration surveys, and in identifying the importance of military lands to migrant birds. While WSR-88D data are limited in resolution and complex in interpretation, the technology allows users to investigate migratory patterns on spatial and temporal scales that are not logistically or economically feasible with field surveys. Still, WSR-88D data have the potential to be a more efficient method than field survey data due to a number of biases associated with the former (Diehl and Larkin 2004).

Few studies have actually compared indices of bird abundance on the ground with data from radar observations, and those that have done so have yielded mixed results. Buler and Diehl (2009) actually found a strong positive correlation between radar estimated bird densities and densities observed on the ground along transect surveys. A number of other investigations have shown a similar relationship between mist-net data and radar observations (Simons et al 2004, Peckford and Taylor 2008, Buler and Diehl 2009). However, mist-net capture data from multiple sites in California failed to detect significant relationships with radar data (DiGaudio et al. 2008). A lack of consistent correlation between on-the-ground field observations and radar may reflect a disparity in the resolution of the methods (see Diehl and Larkin 2004, Buler and Diehl 2009) and warrants further investigation. Thus, the investigation consisted of the relationship between abundance of transient migrants detected on the ground and measures of bird density in the atmosphere as determined through WRS-88D radar on or within the vicinity of three military installations. The results provide an opportunity compare and contrast the two methods of monitoring migrants to ultimately improve future sampling efforts on military installations.

Objective 5: Avian Habitat Use in Southwestern Riparian Systems

Lastly, in the arid southwestern United States, the DoD manages nearly a third of its total acreage (9 million ac). Much of this acreage is covered with a network of perennial, intermittent and ephemeral streams and drainages with relatively high-quality riparian habitat. Riparian areas typically comprise a small component of landscapes, especially in the southwestern United States where they are less than 1 percent of the total land area. However, they are used by more species of breeding birds than any other habitat in North America (Knopf et al. 1988, Stevens et al. 1977). The broad importance of riparian areas in providing stopover habitat, especially in the arid Southwest, is well documented (Yong and Finch 1997; Skagen et al. 1998; Kelly et al. 2000). While width of riparian areas can strongly influence breeding bird community composition (though little information is available from the Southwest; Fischer 2000), research suggests that riparian habitats in this region are extremely important as stopover habitat, regardless of width or extent (Skagen et al. 1998). Some species may even adjust their migratory routes in order to maintain proximity to riparian habitats (Skagen et al. 2005). However, there is far less information available as to how migrants respond to finer scale differences in habitat variables within riparian areas such as vegetation structure and community composition (Carlisle et al. 2009). It is especially important to understand the influence of such variables on migrant communities in this region where human effects have, more often than not, heavily impacted riparian systems.

Historically, riparian plant communities in the arid and semi-arid western United States were dominated by native willow (*Salix* spp.) and cottonwood (*Populus* spp.) trees. However, most riparian ecosystems in the West have been significantly degraded, with losses approaching 99 percent in some areas (Briggs 1996). Hydrologic modifications such as dams and water withdrawals for irrigation on most rivers and streams have heavily altered the natural functions and processes on these systems. Complicating the matter is the invasion of Saltcedar (*Tamarix* sp.), which possesses a number of weedy qualities that allow it to quickly out-compete native vegetation. In a study of riparian plant communities in the Gila and lower Colorado drainage basins of Arizona, Stromberg et al. (2007) found that reaches with a natural flood regime were dominated by willow and cottonwood, while those where natural spring flood pulses had been eliminated had some of the highest abundances of Saltcedar. Saltcedar is native to Eurasia and was introduced into the U.S. in the 1800s as a firewood source and for erosion control; it is now the second most dominant woody riparian tree in the western U.S. In the Lower Colorado River, Saltcedar has become the dominant riparian plant species, having replaced native vegetation in approximately 500,000 ha of riparian habitat (Zavaleta 2000; Friedman et al. 2005) and is expanding within western riparian areas at the rate of 50,000 to 60,000 acres per year (Laccinole 2009).

Research has thus far yielded little evidence that Saltcedar-dominated riparian corridors negatively impact breeding birds in comparison to those dominated by native vegetation (Fleishman et al. 2003; Durst 2004). Sogge et al. (2008) identified 49 different bird species that have been documented utilizing saltcedar during the breeding season in the U.S. and Sogge et al. (2005) actually showed a positive link between saltcedar coverage and the abundance and diversity of breeding bird communities. While bird abundance and density can be higher in riparian corridors dominated by native willow and cottonwood trees (Hunter et al. 1988), several researchers have suggested that these plants are no longer viable in the region due to widespread alterations in river hydrology, and thus riparian areas would actually have less value for breeding birds were it not for the presence of Saltcedar (Livingston and Schemnitz 1996; Sogge et al. 2008).

Less is known about the value of various riparian plant communities as migratory bird stopover habitat. Skagen et al. (1998) deduced from their findings that all riparian areas dominated by native trees were important for migrants regardless of patch size or degree of isolation, yet they did not compare these areas to those dominated by other vegetation types. Hardy et al. (2004) showed that an overwhelming proportion (97%) of the migrants passing through a riparian system in the Sonoran Desert were utilizing xeroriparian vegetation over creosote bush (*Larrea tridentata*)-bursage (*Ambrosia* sp.), mixed cacti, or rock and cliff communities. However, Paxton et al. (2008) showed that Wilson's Warblers (*Wilsonia pusilla*) actually base their selection of stopover sites on the flowering phenology of plants, rather than on the plant species themselves. Still other southwestern U.S. work has documented that migrant abundance is strongly associated with riparian species composition and that the highest abundances were recorded in areas dominated by saltcedar (Walker 2008).

To meet this objective, this study also investigated how communities of spring migrants utilizing riparian stopover habitat near the U.S. Army Yuma Proving Ground in southwestern Arizona respond to differences in plant community composition. Specifically, differences in migrant abundance and richness among plant communities were identified, as were differences in migrant use of areas dominated by saltcedar versus native vegetation. The results will help natural resources managers develop management objectives and prioritize important migrant stopover habitats for conservation on southwestern military installations.

Objective 6: Movement Ecology and Habitat Use of a Neotropical Migrant during Spring Migratory Stopover

Due to the hazardous nature of migratory journeys, neotropical migrants require high-quality stopover habitat where they may rest and forage safely to refuel their energy stores. To date, little is known about how migrants identify, select, and move among habitats with varying resource availability. Understanding how migrants identify stopover areas and when or why they choose to move among habitat types is critical to improving researchers' ability to provide quality stopover sites on DoD lands. To meet this objective, migrating Red-eyed Vireos were translocated (*Vireo olivaceous*) to stopover sites on Ft. Polk during the spring of 2007 and 2008 and four hypotheses were investigated: 1) migrants stopping over in a heterogeneous landscape move to select high-quality habitat; 2) movement within a habitat type is related to the quality of that habitat type; 3) movement during stopover is related to the energetic condition of the bird; and 4) the duration of stay at a stopover site is related to the time of the season and the energetic condition of the bird. The effects of conspecific social cues on Red-eyed Vireo stopover site selection on Ft. Polk in the spring of 2009 were also investigated. Due to the uniqueness of this part of the project, these experiments are detailed separately in Appendix A.

3 Materials and Methods

Objective 1: Migrant Use of Military Installations

The easiest way to identify migratory stopover hotspots with radar is to examine exodus data collected in the early evening (from 45 minutes to 2 hours after sunset). When large, high density exodus events are recorded consistently in a location, that area is assumed to provide important stopover habitat. Because WSR-88D radars only reliably record exodus events within a 120 km radius, the first step was to identify all military installations within the effective survey area of NEXRAD stations. Using ArcView 3.2, shapefiles were overlaid outlining all military installations in the United States, and 120 km buffer regions around all NEXRAD stations. On 26 May 2005, Dr. Richard Fischer visited the CUROL and reviewed the output of this analysis. Smaller installations (< 200 sq. km) were eliminated from the potential base pool to concentrate on potential stopover habitats on larger installations. Drs. Fischer and Gauthreaux selected the 40 largest installations that met these criteria for generating preliminary stopover areas in relation to base boundaries (see results). For each of these 40 installations, the CUROL used archived radar data for the spring migration periods of 2000 and 2001, and the fall migration periods of 2003 and 2004 to characterize patterns of bird migration. All data were downloaded from the National Climatic Data Center (NCDC) in Ashville, North Carolina.

To determine whether birds were responsible for the reflectivity in the display of the WSR-88D, the methods described in Gauthreaux and Belser (1998, 1999, 2003a) and Gauthreaux et al. (2008) were followed. First, the base reflectivity and velocity files were examined for each night and those with precipitation in the sample area or with other issues such as excessive strobes and anomalous propagation of the radar beam were eliminated. In each case, it was noted whether migration could be observed outside the sample area where precipitation was not occurring. All information was recorded in a spreadsheet with a row for each evening. The series of saved base reflectivity and base velocity files without precipitation in the sample area was examined for each evening and the files showing peak density were selected and those with excessive insect contamination and other aerial reflectors were eliminated (e.g., smoke and dust particles). The last task was accomplished by comparing winds aloft with the mean speeds of targets in the base velocity images. The winds aloft data were obtained from the archive of the Department of Atmospheric Science at the University of Wyoming. This dataset is from the Universal RAwinsonde OBservation program (RAOB; Environmental Research Services, Matamoras, Pennsylvania) sounding plots and is available from 1973 to present for sounding plot locations. These atmospheric observations are measured by radiosonde near the beginning (00:00 Universal Time Coordinate [UTC]) and the end of the night (12:00 UTC). Text files were saved and converted into Excel spreadsheet files containing: date, time (UTC), altitude (m), wind speed (m per second [sec-1], and wind direction (from).

If the maximum mean radial velocity of the targets was within 5 m sec^{-1} (18 km per hour [hr^{-1}]) of the velocity of following winds aloft, the associated base reflectivity file was eliminated from additional analysis because of the likelihood of insect contamination. Likewise, if winds aloft were calm and the base velocity file showed no mean radial velocities in keeping with velocities of songbirds (32.4 to 54 km hr^{-1} [17.5 knots to 29.2 knots], Bruderer and Boldt 2001), the associated base reflectivity file was eliminated. If the maximum mean radial velocity of the targets was in keeping with birds and the direction of flight was not in the direction of the winds aloft, the base reflectivity file was saved for further analysis. Surviving mean base velocity information at least 5 m sec^{-1} above wind speed was used to determine the direction of flight and to determine the relative reflectivity values (decibels of reflectivity [dBZ]) in associated relative reflectivity pixels (1° x 1 km pulse volumes or resolution cells). Taking this conservative approach made it possible to measure the difference between the maximum relative reflectivity in a reflectivity file and the maximum relative reflectivity of the pixels that had velocities in keeping with bird flight speeds. The former is generally greater than the latter, but in some cases, the two measures are the same. A difference between the two measures indicates that insects and other particulates in the atmosphere are contributing to the relative reflectivity. Base reflectivity files with little or no reflectivity from insects or other particulates in the atmosphere were processed with an algorithm designed to measure the base reflectivity of each surviving pixel. The base reflectivity values were converted to Z values (absolute reflectivity) and then used to compute birds per cubic kilometer [km^{-3}] (Z-value multiplied by 1.84, Gauthreaux et al. 2008). The conical beam of the WSR-88D is 1° in diameter and the center of the beam is tilted 0.5° above the horizontal for the lowest scan. Bats and migrating birds are very similar in size and shape. They are essentially indistinguishable from one another on reflectivity returns of the 88-D radar. However, there is little to no contamination of bird migration by bats in the reflectivity images used for analyses. Bats comprise <2% of the total number of individuals that pass through the disk of the moon during migration observation periods (Gauthreaux, unpublished data). Most of the bats that are observed during moon watching are actually foraging; thus, they have reflectivity but no radial velocity. Therefore, most bats are actually filtered out with algorithms and probably do not contaminate these estimates of migrating bird densities on radar. Second, the relative number of bats migrating on a given night is likely very small, and again, contributing very little to the reflectivity of migrants aloft. Future technology may allow better discrimination between the two and provide a more quantitative estimate of the relative proportion of bats aloft.

The majority of analyses were completed using level-III data, but level-II data was used where available. Level-III data have a range resolution of 1 km for both reflectivity and radial velocity, while for level-II data, these values are 250 m. With higher resolution Level-II data, it was possible to sample the mean radial velocity of each pulse volume or resolution cell in a volume of atmosphere and discriminate differences in the flight speeds of the different types of reflectors moving through the atmosphere, making it easier to separate birds from other particles. The resulting data from each evening in each location were combined into a rectangular raster for importing into GIS. Once in GIS, the data were mapped and displayed as deviation from the mean. Stopover areas with consistently large densities of migrants show high positive deviations above mean density while areas of lower density show low positive deviation above mean density. Spring and fall composite maps were generated for each of the 40 installations (Appendix B). Migrant exodus densities were qualitatively assessed over each installation in both seasons and identified those that contained stopover hotspots (defined as ≥ 2 standard deviations above mean migrant density). It was not possible to generate appropriate composite maps for some site-by-season combinations due to lack of reliable data (see results).

Objective 2: Quantifying Seasonal Migration

After assessing radar data for each installation, two installations were selected for each detailed spring and fall migration analyses (Fort Polk, Louisiana; and Eglin AFB, Florida for fall migration; Yuma Proving Ground, Arizona; and Fort Polk for spring migration). These installations were selected because of the consistent patterns of exodus events during the respective migration seasons, and the relative ease of access to field sites suitable for establishment of transects within the surveillance area of the nearest radar station (see Objective 4). Originally, it was proposed to examine eastern and western study sites during both fall and spring migration seasons; however, the fall migration data on western military installations examined in this project appeared too dispersed and variable through the season to clearly identify fall migrant hot spots. Instead, a second eastern site (Eglin AFB) was selected for comparison during the fall migration season with data collected from Fort Polk. Past work on Eglin AFB (Tucker et al. 2003) suggested this site was not a significant stopover site for spring migrants; thus, it was only examined during fall.

The first step for each of these individual installations was to investigate seasonal patterns of nocturnal bird migration so that the temporal scope for building forecast models could be limited and ground-based surveys could be conducted. However, rather than examine the same exodus data used to identify these stopover hotspots, peak nightly migration densities over each installation were quantified, as this would be a better indicator of regional migration activity. The data were processed and analyzed as described above for the exodus data.

For the WSR-88D station (KEVX) at Eglin Air Force Base, Florida data for the fall migration period (15 August to 31 October) for the years 2000-2005 were downloaded and used. The archive at NCDC has Level-III data for KEVX from 15 August 1994 to present and Level II data from 1 May 2001 to present. Level-III data were analyzed from the NCDC archive at a 0.5° antenna elevation angle for the fall of 2000 and then analyzed Level-II data for the fall migrations of 2001-2005. Only rarely were scans at 1.5° used when 0.5° scans were not suitable because of beam bending and strobe patterns on the display.

For the WSR-88D station (KPOE) at Fort Polk Army Base, Louisiana, data for the spring and fall migrations periods (15 March-30 May, 15 August-15 November) for the years 2000-2005 were downloaded and used. The archive at NCDC has level-III data for KPOE from 1 May 2001 to present and Level-II data from 28 June 1995 to 13 December 2001. Level-II data for the years 2000 and 2001 were analyzed and Level-III data for the years 2002-2005 were used. Data with antenna elevations of 0.5° were used. When excessive beam bending downward or a strobe pattern in the display occurred, data with a higher antenna elevation were used.

For the WSR-88D station (KYUX) at Yuma, Arizona, data for the spring migrations period (15 March-30 May) for the years 2000-2005 were downloaded and used. The archive at NCDC has level-III data for KYUX from 26 July 1996 to present and Level-II data from 29 July 1996 to present. Level-II data for the years 2000 through 2005 were analyzed and Level-III data for the same years were also used. Data with antenna elevations of 0.5° were used. When excessive beam bending downward or a strobe pattern in the display occurred, data with the next higher antenna elevation (e.g., 1.45°-1.5°) were used. There was topographic blockage of the radar beam at this location that restricted the team's analysis to areas without beam blockage.

Objective 3: Development of Migration Forecast Models

The team used the peak nightly migration data (described above) as the response variables for migration forecast model development, and explanatory variables were collected by downloading archived weather data from either the National Climatic Data Center (NCDC) in Asheville, North Carolina or from Weather Underground (http://www.wunderground.com). The weather data were gathered for 10 PM local time and included the following weather variables: temperature, dew point temperature, humidity, barometric pressure, surface wind direction and speed, 925mb wind direction and speed, precipitation, and cloud cover. These weather variables are commonly forecasted by the National Weather Service and can be entered into a migration forecast model to predict bird migration densities. Because wind direction is a circular variable, the wind direction and speed variables were converted to head wind and cross wind variables using a wind component calculator (http://www.aeroplanner.com/calculators/avcalcdrift.cfm). For fall, the course was entered as 180 (toward the south), and for spring the course was entered as 360 (toward the north). Weather data were downloaded for the period 15 August through 15 November 2001-2005 for Eglin Air Force Base and Ft. Polk and for the period 15 March through 31 May 2001-2005 for Yuma and entered into an Excel spreadsheet.

The statistical software JMP 8 (SAS Institute Inc., Cary, NC) was used to generate the predictions of migration density based on neural nets. Under the "Analyze" tab, Modeling > Neural Net was selected. Bird density (birds per km^3) was entered as the response variable and ordinal date, temperature, dew point temperature, humidity, barometric pressure, surface head wind and cross wind, 925mb head wind and cross wind, amount of precipitation, and cloud cover were loaded as factors (input variables).

Precipitation was not loaded in the neural net analysis for Yuma, because only one date had rain. Five-fold cross validation was selected. This procedure generates a cross-validation R^2 and the closer the Coefficient of Variation (CV) R^2 is to the neural net R^2, the better the prediction ability of the neural net model. In the control panel the following were selected: hidden nodes 3 (H1, H2, and H3 in Figure 2), overfit penalty 0.01 minimizes issues from overfitting and the effects of multicolinearity, number of tours 20, maximum iterations 75, and converge criterion 0.00001. Additional details and explanations for the application of neural net algorithms in JMP 8 can be found in the JMP White Paper by Marie Gaudard (2008).

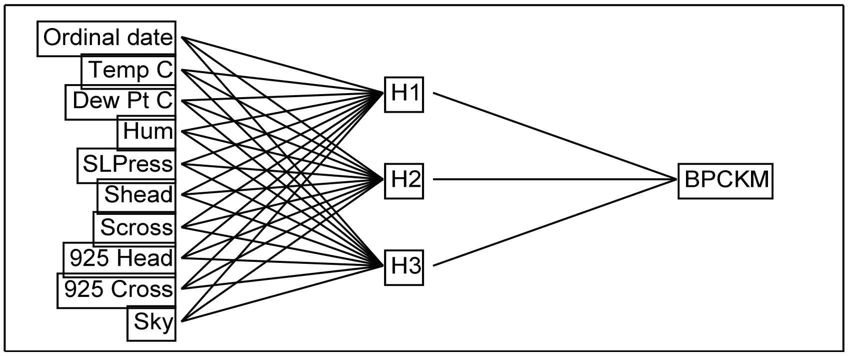

Figure 2. Diagram of neural net showing input variables, three nodes and output variable.

After application of the neural net algorithm, the option “Save Formulas” was selected. This added four new columns to the data table: the formulas for the three hidden nodes and a formula for predicted birds per km^3. When new weather variables are added to the data table, a new prediction of bird density will result when the cursor is in the empty cell in the predicted birds per km^3 column. With JMP software and the data tables, the forecast weather variable can be used to forecast bird migration density.

Objective 4: Comparison of Migrant Survey Techniques

Bird Surveys

Three to five different riparian areas (sites) were identified on or adjacent to each installation (Yuma Proving Ground, Ft. Polk, and Eglin AFB) to be surveyed simultaneously using line-transects. Bird sampling was focused along riparian areas because numerous radar studies and field surveys have shown eastern (Gauthreaux and Belser 1998, 2005) and western (Skagen et al. 1998; Kelly and Hutto 2005) migrants to be highly dependent on riparian habitats during migration. Sites were selected based on radar information indicating stopover hotspots. At each site, 5-7 500m transects were established and each was comprised of a numbered start and end point (i.e., waypoints) (see Figures 3-16).

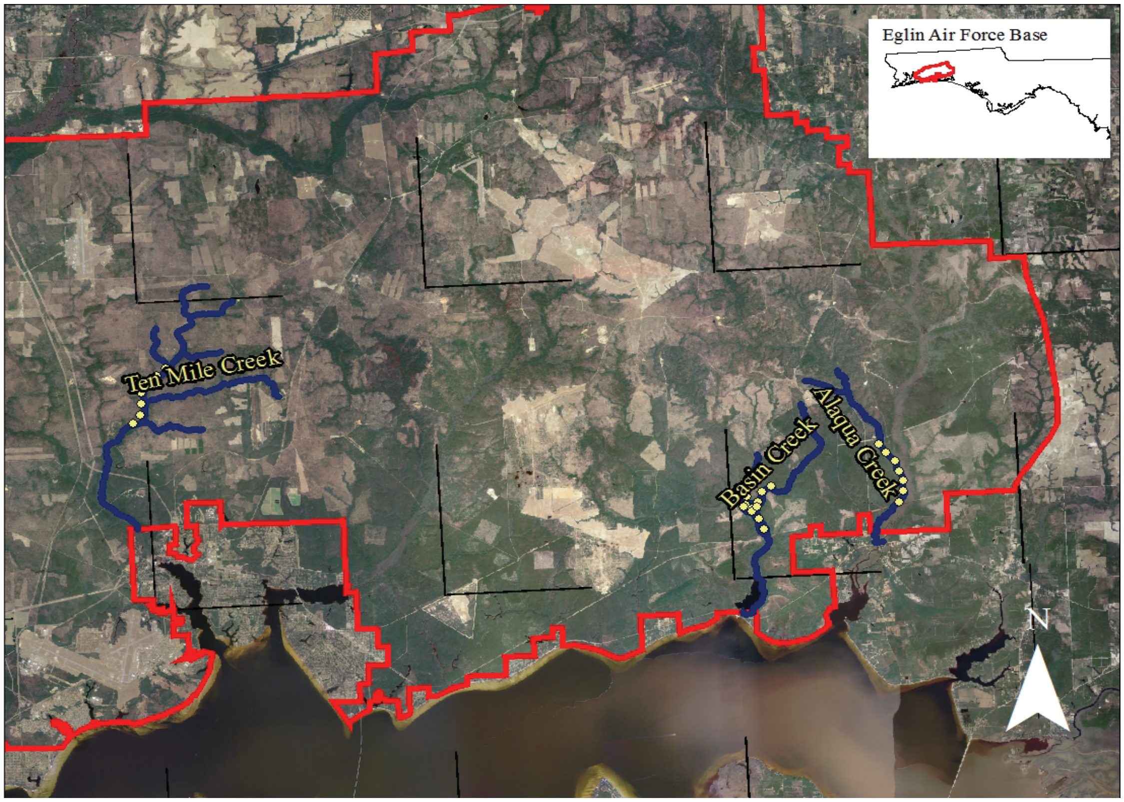

Figure 3. Three riparian transects established in Fall 2005 at Eglin Air Force Base, FL.

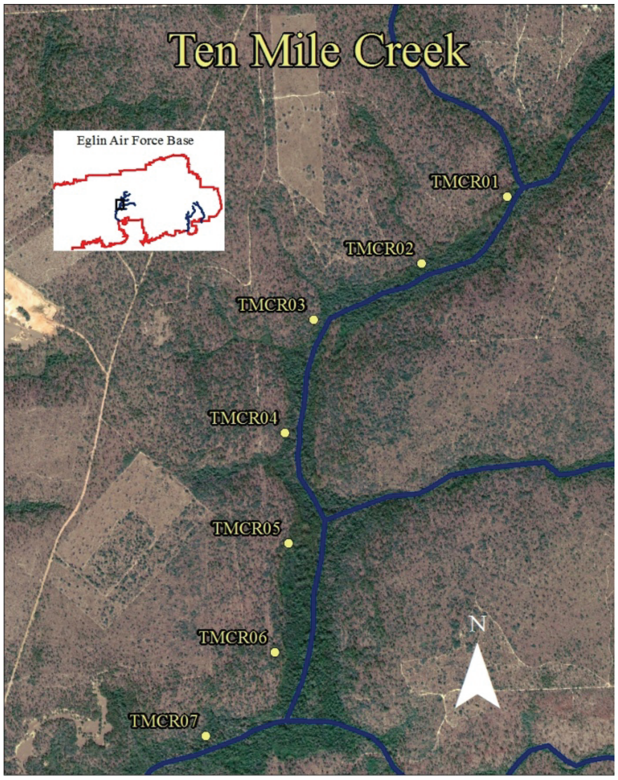

Figure 4. Transect endpoints along Tenmile Creek, Eglin AFB, FL.

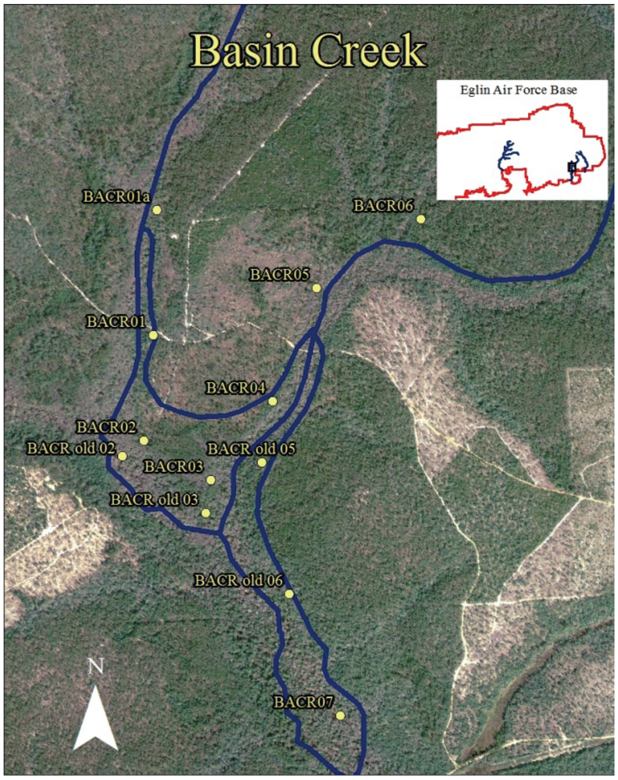

Figure 5. Transect endpoints along Basin Creek, Eglin AFB, FL.

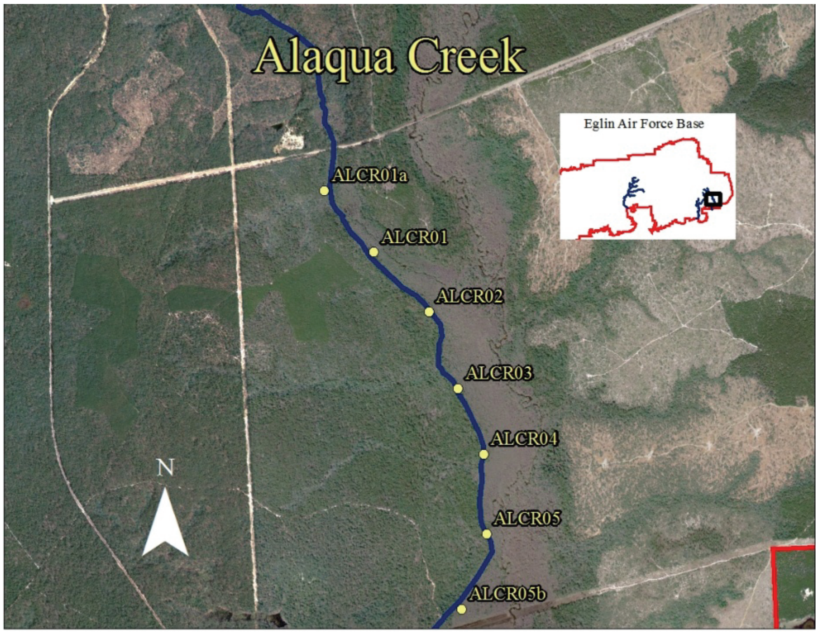

Figure 6. Transect endpoints along Alaqua Creek, Eglin AFB, FL.

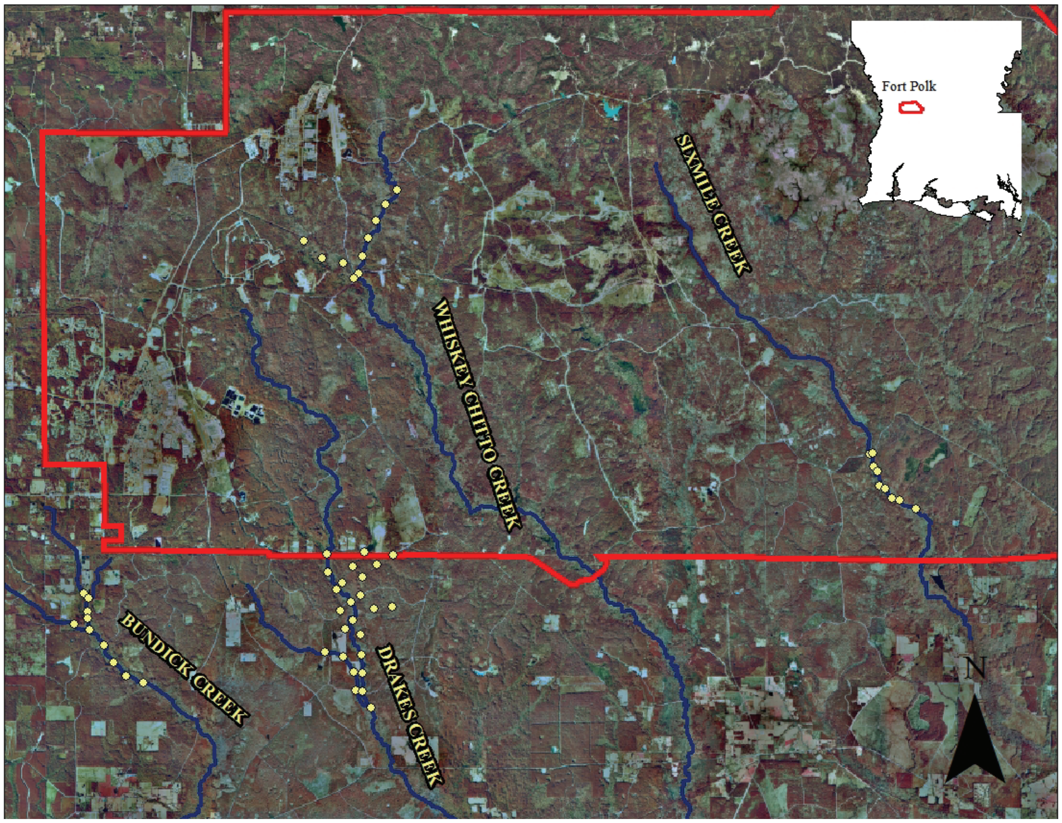

Figure 7. Four riparian transects and one upland transect established in during 2005-2007 at Fort Polk, LA. The upland transect extends northwest from Drakes Creek.

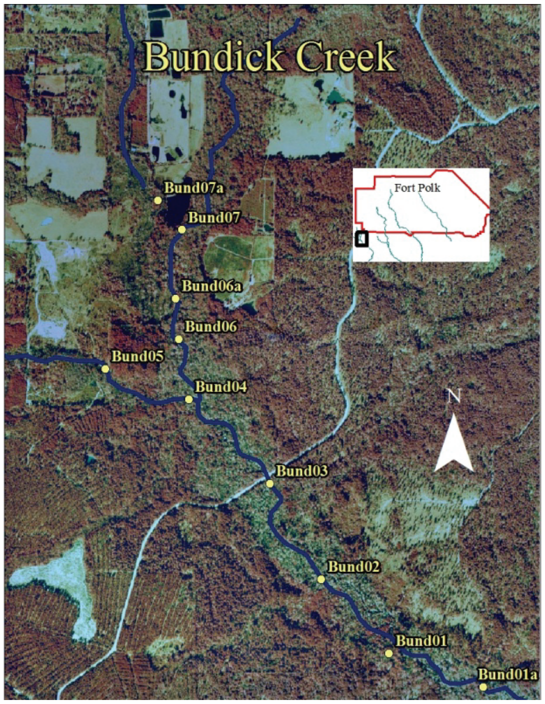

Figure 8. Transect endpoints along Bundick Creek, Fort Polk, LA.

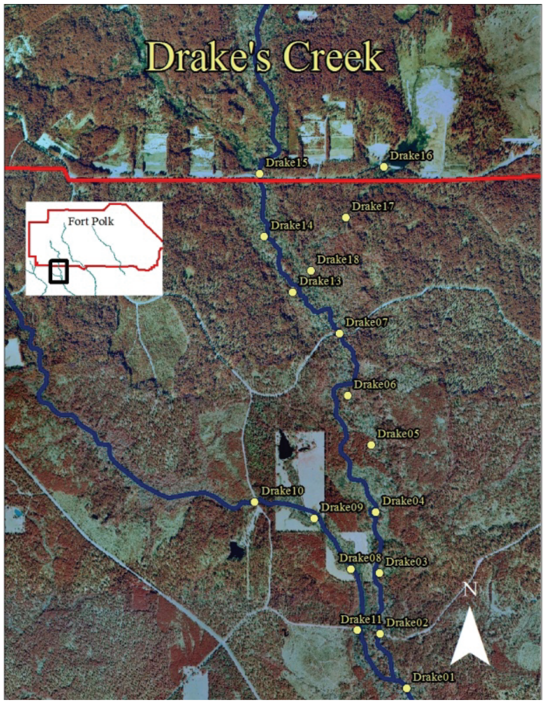

Figure 9. Transect endpoints along Drakes Creek, Fort Polk, LA.

Figure 10. Transect endpoints along Six Mile Creek, Fort Polk, LA.

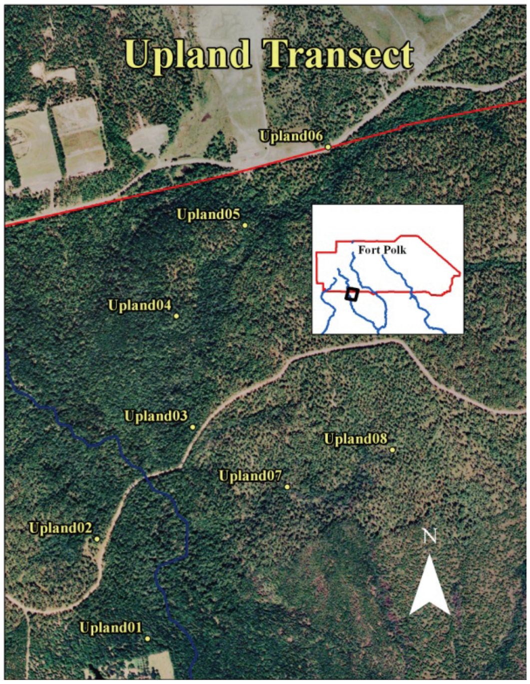

Figure 11. Transect endpoints along the upland transect, Fort Polk, LA.

Figure 12. Transect endpoints along Whiskey Chitto Creek, Fort Polk, LA.

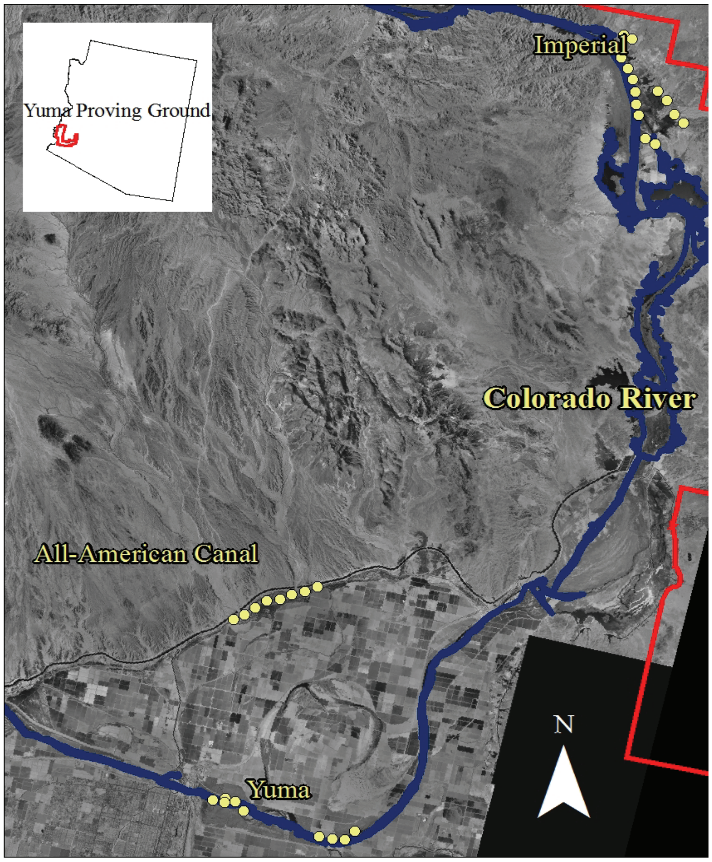

Figure 13. Three riparian transects established in spring 2006 near Yuma, AZ and Imperial National Wildlife Refuge, AZ.

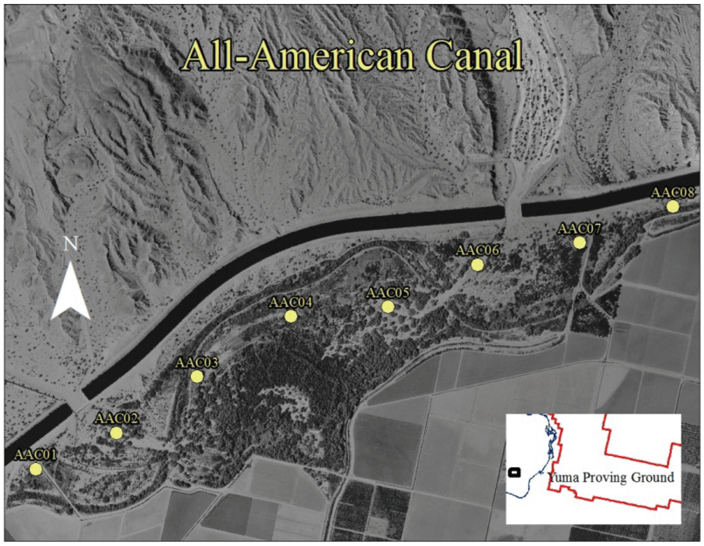

Figure 14. Transect endpoints along All American Canal, Yuma, AZ.

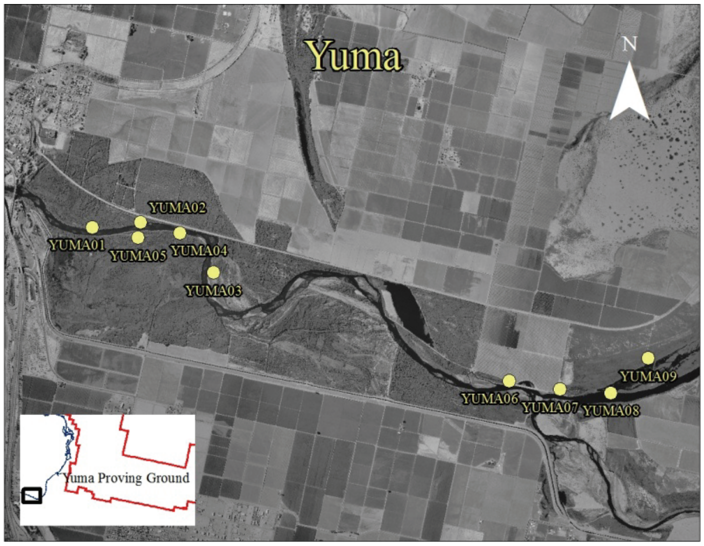

Figure 15. Yuma transect endpoints along the Colorado River, Yuma, AZ.

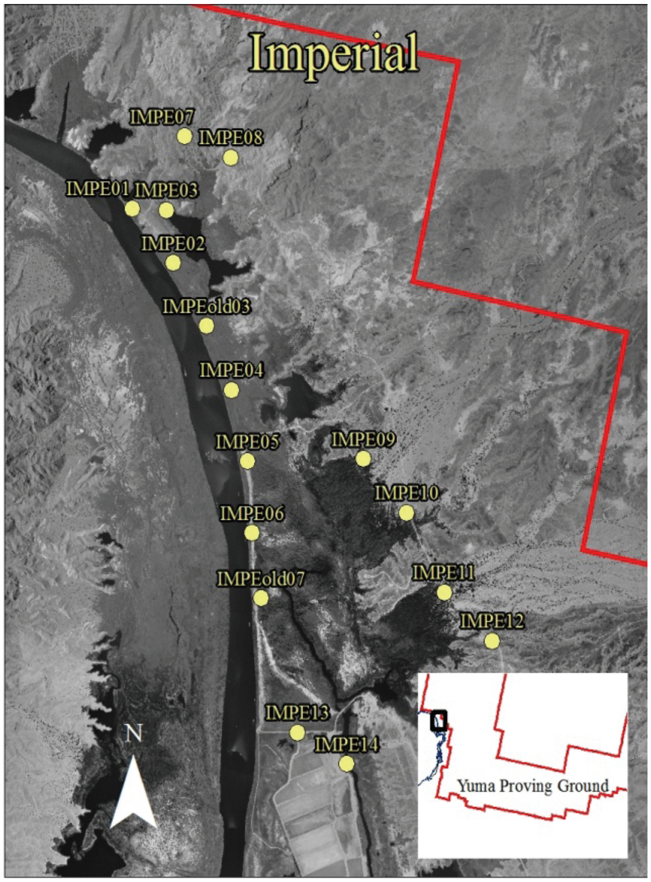

Figure 16. Imperial transect endpoints along the Colorado River, Imperial National Wildlife Refuge, AZ.

Experienced birders conducted simultaneous transect surveys at sites from fall 2005 through spring 2007; however, one technician left early in the 2006 season at Yuma, and one site (Imperial Valley) was not surveyed that year. In addition, one technician left early during the spring 2007 season at Fort Polk; therefore, the surveys were conducted by two birders at Polk during that season. Each morning, field crews began monitoring at or shortly after sunrise, with each surveyor at a different site. Each surveyor used a handheld GPS unit preloaded with numbered waypoints that denoted the beginning and end of each 500 m transect. The team recorded the number and species of all birds detected. If a bird could not be identified to species, it was categorized to the lowest taxonomic level possible in order to separate and assess all potential migrants observed during the surveys. The team used transect data sheets that diagrammatically depicted the transect being surveyed, with beginning and end points indicated, plus a main line to transverse while walking the transect. The approximate location of any birds detected along each transect were noted (e.g., whether the bird was to the left or right of the surveyor, the approximate distance of the bird to the surveyor, and how far along the transect (0-500 m) the bird was detected). Each 500 m transect was completed in approximately 30 minutes; therefore, each site survey could be completed in about three hours (surveys usually ended at approximately 10:00 am local time). Surveys were conducted $\geq$5 days a week (except in cases of inclement weather), and surveyors rotated among sites on a daily basis. A brief description of the areas surveyed on each installation, plus a short history of transects sampled are provided below. Sampling was conducted during a wide range of dates to capture peak bird migration at each site during all migration seasons (Tables 1 and 2).

Eglin Air Force Base, Florida

Three sites were selected along three different drainages on Eglin AFB, including Alaqua Creek (ALCR), Basin Creek (BACR), and Ten-mile Creek (TMCR). All transects at these sites were established in fall 2005 and included seven continuous waypoints each separated by 500m of habitat (see Figures 3-6). All transects on Elgin AFB were placed in drainages with well-defined, transitional habitats between upland and floodplain forests. Uplands were typically dominated by extensive longleaf pine (*Pinus palustris*) sandhills characterized by an open, savanna-like structure with a moderate to tall canopy of longleaf pine, a sparse midstory of oaks and other hardwoods, and a diverse groundcover comprised mainly of grasses, forbs and low stature shrubs (Eglin Air Force Base, 2007). Riparian areas were comprised of a wide variety of hardwood tree species of Magnolia (*Magnolia* spp.), sweet gum (*Liquidambar styraciflua*), poplar (*Populus* spp.), hickory (*Carya* spp.), ash (*Fraxinus* spp.), and maple (*Acer* spp.). Although some minor changes were made in specific locations of some waypoints because of flooding along Basin and Alaqua Creeks, total distance covered and the number of transects remained consistent during the survey period.

Table 1. Dates of fall migration bird surveys conducted at all sites around Eglin Air Force Base and Fort Polk from 2005-2007. Sites at Eglin AFB include Alaqua Creek (ALCR), Basin Creek (BACR) and Ten Mile Creek (TMCR); sites at Fort Polk include Bundick Creek (BUCR), Drakes Creek (DRCR), Six Mile Creek (SMCR), Upland Transect (UPTR), and Whiskey Chitto (WHCH). An “x” indicates that morning surveys were conducted on that date while an “o” indicates that *only* evening surveys were conducted.

Year	Region	Site	September			October																				
			28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
2005	Eglin AFB	ALCR							x	x	x	o	x	x	x	x	x	x	x							
		BACR							x	x	x	o	x	x	x	x	x	x	x							
		TMCR							x	x	x	o	x	x	x	x	x	x	x							
	Fort Polk	BUCR																								
		DRCR	x	x	x					x	x				x	x	x	x	x	x						
		SMCR	x	x	x			x	x	x	x	x				x	x	x	x	x						
		UPTR																								
		WHCH	x		x				x	x	x	x			x		x	x	x	x						
2006	Eglin AFB	ALCR	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
		BACR	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
		TMCR	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x						
	Fort Polk	BUCR	x	x	x	x	x	x	x	x				x	x		x	x	x	x						
		DRCR	x	x	x	x	x	x	x	x	x		x	x	x	x	x		x	x						
		SMCR	x	x	x	x	x	x	x	x	x		x	x	x	x		x	x	x						
		UPTR																								
		WHCH																								
2007	Eglin AFB	ALCR					x	x	x	x	x	x	x	x	x	x	x	x	x	x	o	x		o	x	x
		BACR					x	x	x	x	x	x	x	x	x	x	x	x	x	x	o	x		o	x	x
		TMCR					x	x	x	x	x	x	x	x	x	x	x	x	x	x	o	x				
	Fort Polk	BUCR																								
		DRCR																								
		SMCR																								
		UPTR																								
		WHCH																								

Fort Polk, Louisiana

Throughout the study, the team established transects at five different sites at Fort Polk, Louisiana (see Figures 7-12). Transects at three sites were established in the fall 2005, including Whiskey Chitto (WHCH), Six-mile (SMCR), and Drakes Creeks (DRCR). Numerous logistic difficulties occurred along some of these transects that required modifications. After the fall 2005 season, the Whiskey Chitto Creek site could not be accessed

Table 2. Dates of spring migration bird surveys conducted at all sites around Yuma and Fort Polk from 2006-2007. Sites at Yuma include All-American Canal (AAC), Imperial (IMP) and Yuma (YUMA); sites at Fort Polk include Bundick Creek (BUCR), Drakes Creek (DRCR), Six Mile Creek (SMCR), Upland Transect (UPTR), and Whiskey Chitto (WHCH). An “x” indicates that morning surveys were conducted on that date while an “o” indicates that *only* evening surveys were conducted.

Year	Reg	Site	March							April																														May														
			25	26	27	28	29	30	31	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2006	Yuma	AAC									o	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					
		IMP																																																				
		YUMA										x	x		x	x	x	x	x	x		x	x	x		x		x	x	x	x	x	x	x	x	x	x	x		x	x		x	x	x	x								
	Fort Polk	BUCR	x	x	x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x		x	x	x	x	x		x	x	x		x	x		x	x		x		x	o	x								
		DRCR	x	x	x	x	x	x	x		x	x	x	x	x		x	x	x	x		x	x	x			x	x	x			x			o	x	x		x	x	x	x		x	o	x								
		SMCR	x	x	x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x		x	x	x	x	x		x	x	x		x	x		x	x	x	x		x	o	x								
		UPTR																																																			
		WHCH																																																			
2007	Yuma	AAC										x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		IMP										x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
		YUMA										x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Fort Polk	BUCR			x	x	x	x	x			x		x	x	x	o	x	o	o	x	x		x	x	x	x	x	x	x	x	x	x		x	x	x		x		x	x	x	x					x					
		DRCR			x	x	x		x			x	x	x	x	x	o	x	o	o	x	x	o	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x		x		x	x	x									
		SMCR																																																			
		UPTR			x	x	x	x	x			x		x	x	x	o	x	o																x																		
		WHCH																																																			

because of military training restrictions; therefore, transects were established at Bundick Creek (BUCR) in the spring of 2006 and surveyed for the remaining period of the study. In addition, access along some transects at other sites was prohibited due to private landowner issues or logistic difficulties in accessing the sections (e.g., extensive flooding, downed woody debris, etc.). When this occurred, transects were moved up or down the drainage but always within the same drainage and within the radar-identified hotspot. Occasionally, migrants may use upland habitat disproportionally to riparian habitat (Rodewald and Matthews 2005). In order to assess the relative number of migrants detected outside of riparian transects, the team established an upland transect (UPTR) in the spring of 2007. During this season, transect surveys were conducted on the Upland, Bundick Creek, and Drakes Creek sites. All transects, except those in upland habitat described above, were located in bottomland hardwood floodplains dominated by a variety of oak (*Quercus spp.*), hickory (*Carya* spp.), ash (*Fraxinus* spp.), and other hardwood species.

Yuma Proving Ground, Arizona

Because only xeroriparian (dry washes with very little riparian vegetation) habitat was present on Yuma Proving Ground, the team chose to locate study sites in Yuma outside the installation boundary along and near the Colorado River. In early 2006, three sites were established along two different drainages including the Colorado River and the All-American Canal (see Figures 13-16). The All-American Canal (AAC) site was located within an abandoned channel parallel with the All-American Canal. This site was characterized as having abundant shrub vegetation dominated by Palo Verde (*Parkinsonia* spp.), Creosote Bush (*Larrea tridentata*), and Saltcedar (*Tamarix* spp.). The Yuma transect (YUMA) was located immediately adjacent to the Colorado River and was within the city limits of Yuma, AZ. Vegetation varied in dominance among transects at this site, and most abundant species included Saltcedar, Willow (*Salix* spp.), and Fremont Cottonwood (*Populus fremontii*). The Imperial Valley site (IMP) was located approximately 18 km north of the other two sites and bisected the Imperial National Wildlife Refuge. Vegetation at this site was similar to other sites and was dominated by Mesquite (*Prosopis* spp.), Palo Verde, Creosote Bush, and Saltcedar.

Radar Data

The team downloaded, analyzed, and processed archived migrant exodus data and nightly peak migration data for all days that ground surveys were conducted in all locations. The team used the same process described above (see Objective 1 methods). In some instances there were no usable radar data for a given evening due to the presence of precipitation or high densities of insects, and these were removed from analyses. Two spatially distinct exodus densities were estimated on each night on Eglin AFB and Ft. Polk due to the distance between ground sampling sites, and these two numbers were averaged to calculate a single exodus value. Only one peak migration value was recorded for each installation on each night.

Statistical Analyses

The team first classified all species recorded during transect surveys over the course of the study into migratory categories (Table 3), then eliminated all diurnal migrants and permanent residents from analyses; this ensured that only the relationship between migratory events captured on evening radar scans and changes in abundance of birds which had the potential to be captured by those radar scans was being modeled. For each morning a region was sampled, the team summed the number of spring or fall migrants recorded and divided it by the total distance walked (migrants/km) that morning (this value was not necessarily constant on every morning because observers may have had to avoid or stop sampling transects for any number of logistical reasons). The team then calculated the change in migrant abundance between days by using the formula

$$\Delta\text{migrants} / \text{km}_\text{d} = \text{migrants} / \text{km}_\text{d} - \text{migrants} / \text{km}_{\text{d}-1}$$

where d = the survey date of interest. The team also calculated positive and negative species turnover from one day to the next; positive turnover is defined here as the number of species present on day_d which were not present on $\text{day}_{\text{d-1}}$ and negative turnover as the number of species not present on day_d which were present on $\text{day}_{\text{d-1}}$.

The initial goal was to model changes in migrant abundance and species turnover as a function of migratory events captured on evening radar scans at the site level (i.e., individual riparian sites). However, due to a number of confounding issues, the team opted to combine all data recorded on each date at the regional (i.e., installation) level instead. First, due to the fact that observers at the site level were rotated within a season, it was impossible to determine how much variation in migrant data from one day to the next was attributable to real changes and how much was attributable to differences in

Table 3. Migratory classification for all species recorded on ground transects during migration surveys at Eglin AFB, Fort Polk and Yuma (Poole 2005).

Neotropical Migrants		Nearctic Migrants	Short-Distance Migrants
Acadian Flycatcher	Louisiana Waterthrush	American Pipit	American Crow
Alder Flycatcher	Lucy's Warbler	Brewer's Blackbird	American Goldfinch
American Redstart	MacGillivray's Warbler	Brewer's Sparrow	American Robin
Ash-throated Flycatcher	Magnolia Warbler	Chipping Sparrow	American Woodcock
Baltimore Oriole	Mourning Warbler	Golden-crowned Kinglet	Bachman's Sparrow
Bank Swallow	Nashville Warbler	Green-tailed Towhee	Belted Kingfisher
Barn Swallow	Northern Parula	Hermit Thrush	Bewick's Wren
Bay-breasted Warbler	Northern Rough-winged Swallow	House Wren	Black-chinned Sparrow
Bell's Vireo	Northern Waterthrush	Lincoln's Sparrow	Black-throated Sparrow
Black-and-white Warbler	Olive-sided Flycatcher	Orange-crowned Warbler	Bronzed Cowbird
Black-billed Cuckoo	Orchard Oriole	Palm Warbler	Brown Creeper
Blackburnian Warbler	Ovenbird	Purple Finch	Brown Thrasher
Black-chinned Hummingbird	Pacific-slope Flycatcher	Ruby-crowned Kinglet	Brown-crested Flycatcher
Black-headed Grosbeak	Painted Bunting	Sage Thrasher	Brown-headed Cowbird
Blackpoll Warbler	Philadelphia Vireo	Say's Phoebe	Cedar Waxwing
Black-throated Blue Warbler	Plumbeous Vireo	Sedge Wren	Common Grackle
Black-throated Gray Warbler	Prothonotary Warbler	Swamp Sparrow	Common Poorwill
Black-throated Green Warbler	Purple Martin	Vesper Sparrow	Costa's Hummingbird
Blue Grosbeak	Red-eyed Vireo	White-crowned Sparrow	Dark-eyed Junco
Blue-gray Gnatcatcher	Rose-breasted Grosbeak	White-throated Sparrow	Eastern Bluebird
Blue-headed Vireo	Ruby-throated Hummingbird	Winter Wren	Eastern Meadowlark
Blue-winged Warbler	Rufous Hummingbird	Yellow-bellied Sapsucker	Eastern Phoebe
Bullock's Oriole	Scarlet Tanager	Yellow-headed Blackbird	Eastern Towhee
Calliope Hummingbird	Summer Tanager	Yellow-rumped Warbler	European Starling
Canada Warbler	Swainson's Thrush		Horned Lark
Cassin's Vireo	Swainson's Warbler		Lesser Goldfinch
Cerulean Warbler	Tennessee Warbler		Loggerhead Shrike
Chestnut-sided Warbler	Townsend's Warbler		Marsh Wren
Chimney Swift	Tree Swallow		Mourning Dove
Chuck-will's-widow	Vaux's Swift		Phainopepla
Clay-colored Sparrow	Veery		Pine Warbler
Cliff Swallow	Warbling Vireo		Red-headed Woodpecker
Common Yellowthroat	Western Flycatcher		Red-shafted Flicker
Dickcissel	Western Kingbird		Red-winged Blackbird
Eastern Kingbird	Western Tanager		Scott's Oriole

Neotropical Migrants		Nearctic Migrants	Short-Distance Migrants
Eastern Wood-Pewee	Western Wood-Pewee		Song Sparrow
Golden-winged Warbler	White-eyed Vireo		Spotted Towhee
Gray Catbird	White-throated Swift		Turkey Vulture
Gray Flycatcher	Willow Flycatcher		Vermillion Flycatcher
Gray-cheeked Thrush	Wilson's Warbler		Western Bluebird
Great Crested Flycatcher	Wood Thrush		Western Meadowlark
Hammond's Flycatcher	Worm-eating Warbler		White-winged Dove
Hermit Warbler	Yellow Warbler		Yellow-shafted Flicker
Hooded Oriole	Yellow-bellied Flycatcher		
Hooded Warbler	Yellow-billed Cuckoo		
Indigo Bunting	Yellow-breasted Chat		
Kentucky Warbler	Yellow-throated Vireo		
Lark Sparrow	Yellow-throated Warbler		
Lazuli Bunting	Unknown Empidonax		
Least Flycatcher	Unknown Warbler		
Lesser Nighthawk			
Permanent Residents	Waterbirds	Raptors	Unknown
Abert's Towhee	American Avocet	Broad-winged Hawk	Unknown Accipiter
Anna's Hummingbird	American Bittern	Mississippi Kite	Unknown Bird
Barn Owl	Black Tern	Osprey	Unknown Blackbird
Barred Owl	Blue-winged Teal	Swainson's Hawk	Unknown Buteo
Black Phoebe	Caspian Tern	Merlin	Unknown Cowbird
Black Vulture	Cinnamon Teal	Northern Harrier	Unknown Dove
Black-tailed Gnatcatcher	Eared Grebe	Sharp-shinned Hawk	Unknown Duck
Blue Jay	Franklin's Gull	Red-shouldered Hawk	Unknown Egret
Boat-tailed Grackle	Greater Yellowlegs	Prairie Falcon	Unknown Flycatcher
Brown-headed Nuthatch	Least Bittern	American Kestrel	Unknown Gnatcatcher
Bushtit	Least Sandpiper	Cooper's Hawk	Unknown Grackle
Cactus Wren	Lesser Yellowlegs	Red-tailed Hawk	Unknown Hawk
Carolina Chickadee	Little Blue Heron		Unknown Heron
Carolina Wren	Long-billed Curlew		Unknown Hummingbird
Clapper Rail	Long-billed Dowitcher		Unknown Ibis
Common Ground-Dove	Snowy Egret		Unknown Myiarchus
Common Raven	Solitary Sandpiper		Unknown Nightjar
Crissal Thrasher	Sora		Unknown Oriole
Downy Woodpecker	Spotted Sandpiper		Unknown Owl
Eastern Screech Owl	Unknown Dowitcher		Unknown Passerine

Neotropical Migrants		Nearctic Migrants	Short-Distance Migrants
Eastern Tufted Titmouse	Virginia Rail		Unknown Raptor
Eurasian Collared Dove	Western Sandpiper		Unknown Sandpiper
Fish Crow	Willet		Unknown Shorebird
Gambel's Quail	Ring-billed Gull		Unknown Sparrow
Gila Woodpecker	Bufflehead		Unknown Swallow
Great Horned Owl	California Gull		Unknown Swift
Greater Roadrunner	Common Goldeneye		Unknown Tanager
Great-tailed Grackle	Common Loon		Unknown Thrasher
Hairy Woodpecker	Common Merganser		Unknown Thrush
House Finch	Double-crested Cormorant		Unknown Vireo
Hutton's Vireo	Forster's Tern		Unknown Woodpecker
Inca Dove	Gadwall		Unknown Wren
Ladder-backed Woodpecker	Northern Pintail		
Northern Bobwhite	Northern Shoveler		
Northern Cardinal	Ruddy Duck		
Northern Mockingbird	Wilson's Snipe		
Pileated Woodpecker	American Wigeon		
Red-bellied Woodpecker	American Coot		
Red-cockaded Woodpecker	Black-crowned Night-Heron		
Ring-necked Pheasant	Black-necked Stilt		
Rock Pigeon	Canada Goose		
Verdin	Cattle Egret		
White-breasted Nuthatch	Common Moorhen		
White-tailed Kite	Great Blue Heron		
Wild Turkey	Great Egret		
	Green Heron		
	Killdeer		
	Mallard		
	Pied-billed Grebe		
	White-faced Ibis		
	Wood Duck		

observers' abilities. Moreover, a close examination of the data collected indicated that observer bias may have been a large and confounding problem during some sampling seasons (e.g., Figures 17 and 18). Pooling the data collected by all observers at the regional scale ensures that this source of error remains relatively constant from one day to the next, thereby making trends easier to detect. Second, it proved extremely difficult to calculate exodus densities for each site separately from the radar data. By the time migrants reached an altitude high enough to be captured in the radar beam they were displaced an unknown distance from their source habitat and the migrant images from the different sites began to blend together. Lastly, the diffuse nature of migration, once birds were in the atmosphere, did not lend itself to calculating site-specific peak migration values.

High correlation ($r > 0.8$ in some cases) between peak migration and exodus densities prevented the team from including both explanatory variables in the same regression models. Additionally, because the same variables were recorded in the same place day after day, there was the possibility that turnover and abundance measurements were not independent over time (i.e., the change in migrant abundance on day_d was not independent of the change in migrant abundance on day_{d-1}). Thus, the team chose to use PROC AUTOREG (SAS Institute, Cary, NC 2009) for all regression analyses. PROC AUTOREG uses maximum likelihood theory to simultaneously estimate the regression coefficients of interest (β values) and the parameters for an autoregressive model (φ values) which explains the error term of a given day (V_t) as a function of the error value from the previous day (V_{t-1}) using the formulas

$$Y_t = \beta_0 + \beta_1 X_t + V_t$$

$$V_t = \varphi V_{t-1} + \varepsilon_t$$

Using these procedures, the team modeled the change in migrant abundance as a function of exodus and peak migration values separately for each region, year and season combination (this was necessary since PROC AUTOREG does not utilize categorical variables such as region or year). The team also modeled positive turnover as a function of peak migration radar values and negative turnover as a function of exodus radar values for each region, year and season combination. The significance level for parameter estimates was 0.05.

Close inspection of the radar data revealed that both exodus and peak migration values tended to behave like continuous variables for low values and categorical variables for high values (see results). Because regression assumes continuous explanatory variables, the team also chose to divide

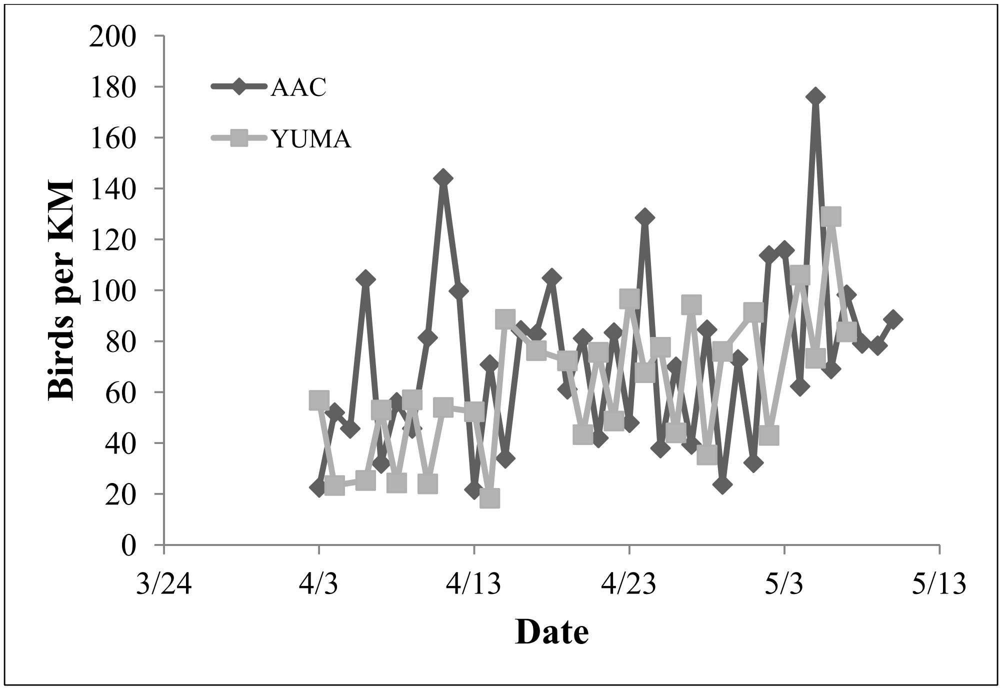

Figure 17. Total number of birds recorded per morning transect at each Yuma site over time in the spring of 2006. The trends at the two sites tend to be mirror opposites of one another and the pattern reflects the fact that, for the most part, two observers alternated the days on which they sampled these sites (though a third observer was used on a few occasions). Thus, the trend indicates that one observer consistently counted more birds than the other regardless of which site they were both sampling.

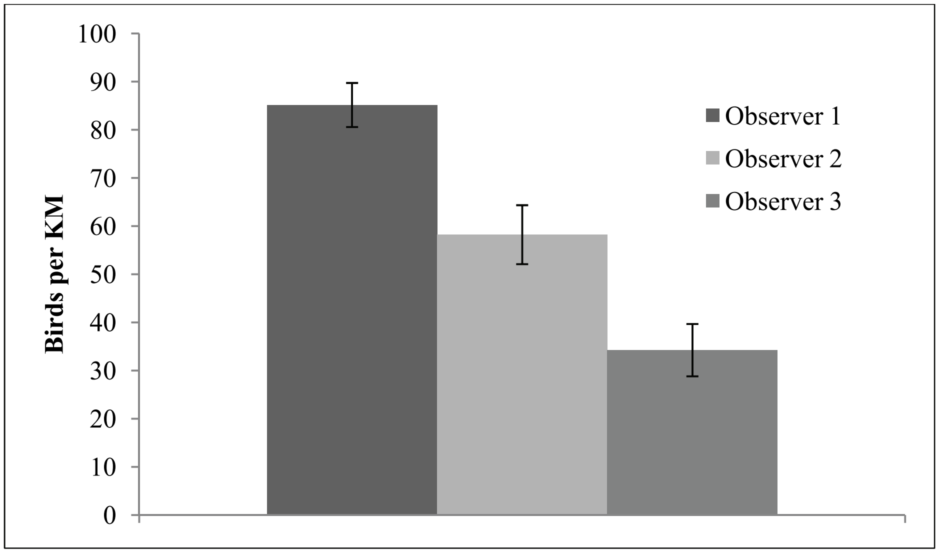

Figure 18. Mean and standard error of the total number of birds per km recorded per morning transect by each observer at Yuma in 2006. Values were calculated by averaging the number of birds per km the observer counted on each morning he or she surveyed. Results indicate that observer 1 consistently counted more birds than observer 2 who consistently counted more birds than observer 3. Thus, since observers were rotated, it is impossible to determine how much of the change in migrant abundance from one day to the next at the site level was attributable to real turnover and how much to observer bias.

exodus and peak migration values into two categories representing high and low migratory events and investigate the impacts of these “treatments” on change in migrant abundance. Due to differences in the nature of migration across the country, the dividing point for these categories varied slightly for different regions. At Fort Polk and Eglin AFB, high migratory events included greater than 100 birds per cubic kilometer (birds per km^3), while low migratory events involved smaller densities. At Yuma high migratory events included greater than 70 birds per km^3. The team used PROC GLM (SAS Institute, Cary, NC) to simultaneously model the change in migrant abundance as a function of these exodus and peak migration events for each year, region and season. A significance level of 0.05 was used for treatment effects as well.

Objective 5: Avian Habitat Use in Southwestern Riparian Systems

It was too difficult for observers to identify the exact location of each individual bird recorded during ground-based surveys near the Yuma Proving Ground. However, observers did divide each 500 m transect survey into four 125 m longitudinal sections and made note of which birds were recorded within each section. In 2007, a single observer then identified the dominant vegetation types at each of these 125 m sections at all three sites. The team then classified each section into one of five habitat categories: native trees (NT), native shrubs (NS), native-dominated with non-natives (ND), non-native / invasive shrub and tree community (NNI), or non-native / invasive dominant with some natives (NND; Table 4). Due to the broad nature of these habitat categories and the fact that annual changes in vegetation cover and dominance are very minimal in this region, the team was able to use this information to compare abundance and richness data collected both in 2006 and 2007. Habitat within two surveyed sections was too heterogeneous to classify.

Data Analyses

Due to the fact that the team was primarily interested in terrestrial migrant habitat use, only species listed as neotropical or nearctic migrants in Table 3 were retained. All swifts and swallows were also eliminated from the data because most were detected as flyovers, and it was not possible to determine whether these birds were actually using the habitat. Pacific-slope Flycatchers (*Empidonax difficilis*) and Cordilleran Flycatchers (*Empidonax occidentalis*) were considered Western Flycatchers because of the difficulty in distinguishing them in the field. Lastly, because the majority of the NT

Table 4. Distribution and vegetation composition of 125 m transect sections from three sites[a] near Yuma, AZ that were surveyed for spring migrants in 2006 and 2007.

Habitat[b]	AAC	YUMA	IMP	Total	Dominant Woody Vegetation
NS	13	0	9	22	Palo Verde and Mesquite with or without Creosote Bush
ND	2	0	2	4	Palo Verde and Mesquite with or without Creosote Bush; some Saltcedar present but <50% dominance
NND	4	3	8	15	Saltcedar >50% in dominance with some Willow, Mesquite or Creosote Bush
NNI	9	8	1	18	Saltcedar-dominated community
NT	0	11	4	15	Cottonwood, Willow

[a] Sites represent three geographically unique locations associated with the Colorado River called All-American Canal, Yuma and Imperial.

[b] Sections were categorized according to dominant vegetation and were classified as either native shrub (NS), native-dominated with non-natives (ND), non-native/invasive dominant with some natives (NND), non-native/invasive shrub and tree community (NNI), or native tree (NT).

sections (11 of 15) were located in Cottonwood restoration sites, the four sections located in mature Cottonwood stands were eliminated, as they were deemed too structurally different from the others. These mature Cottonwood stands were not included in their own habitat category because they were only sampled in 2007.

The team calculated total migrant abundance per kilometer, individual species abundance per kilometer, and total migrant species richness per section for each date a section was sampled. To account for the possibility of counting a single individual multiple times on different days, each metric was averaged across dates within years. Individuals not identified to species were removed from the data prior to calculating species richness.

First, total abundance per kilometer and species richness per section were modeled as a function of habitat while including year as a fixed block effect. The 20 most abundant species (83% of detections; see results) were then selected and investigated as to whether or not habitat influences avian community composition. This was accomplished by including a species and species-by-habitat interaction term in the model. Results from this analysis indicated that habitat affected species differently, so abundance of each of those 20 species was also modeled individually as a function of habitat blocked on year. All modeling was conducted using PROC GLIMMIX (SAS Institute Inc., Cary, NC); abundance variables were best modeled by assuming a negative binomial distribution and all richness data were best modeled assuming a normal distribution. When there was evidence that habitat significantly affected any of the response variables ($\alpha = 0.05$), all pair-wise comparisons of habitat types were investigated using a Tukey-Kramer adjustment of the P values.

4 Results and Discussion

Objective 1: Migrant Use of Military Installations

Radar data indicated that 18 of the 40 installations investigated had significant exodus events occur during fall migration either on or directly adjacent to the installation (Table 5). Two such installations with very clear and repetitive exodus events were Fort Polk, Louisiana, and Eglin AFB, Florida. (Figures 19 and 20). Similarly, 17 installations showed consistently large exodus events during spring migration, including Fort Polk, Louisiana and the Yuma Proving Ground, Arizona (Figures 21 and 22). Spring and fall composite migration maps generated for each of the remaining 40 installations can be found in Appendix B.

These results reinforce the notion that military installations often play a critical role in supporting avian communities. Since installations tend to contain large expanses of natural areas, they often provide habitat oases in heavily developed landscapes. Such resources are particularly important to birds during their migratory journeys due to the precarious nature of the process and the high energy demands incurred.

The team classified each installation into whether or not it contained stopover hotspots, but it should be noted that most installations showed significant spatial variability in migrant use. This is likely due to high variability in resources across a landscape and serves as further indication that migrants distinguish among habitat types. Natural resources managers on specific installations interested in providing and protecting stopover habitat should take a closer look at specific regions within the borders of their properties, using a combination of radar and ground surveys, in order to prioritize conservation areas.

Lastly, while the team only investigated installations ≥200 km^2 in size, it should not be assumed that smaller installations do not provide valuable stopover habitat. This distinction was used as a means of narrowing down potential sites for further sampling, and not based on any biological significance. It is likely that many smaller installations also provide important stopover habitat, and this should not be discounted.

Table 5. DoD military installations greater than 200 km^2 and located within 120 km of NEXRAD stations. The columns labeled “Spring” and “Fall” indicate whether or not that installation served as a stopover hotspot for migrating birds. It was not possible to generate appropriate maps for some installations in some seasons due to complications with weather and beam blockage by proximal mountain ranges.

Installation	State	Region	Area (km^2)	NEXRAD Station	NEXRAD Station Location	Spring	Fall
Blair Lake Air Force Range	AK	W	278	APD	Fairbanks, AK	-	-
Fort Wainwright	AK	W	3182	APD	Fairbanks, AK	-	-
Fort Wainwright Maneuver Area	AK	W	1203	APD	Fairbanks, AK	-	-
Camp Grayling Military Reservation	MI	MW	538	APX	Gaylord, MI	No	Yes
Fort McCoy	WI	MW	239	ARX	La Crosse, WI	No	No
Saylor Creek Air Force Range	ID	W	412	CBX	Boise, ID	Yes	No
Fort Stewart	GA	E	1130	CLX	Charleston, SC	No	No
Fort Huachuca	AZ	W	330	EMX	Tucson, AZ	-	Yes
Fort Rucker Military Reservation	AL	E	225	EOX	Fort Rucker, AL	Yes	Yes
Eglin Air Force Base	FL	E	1886	EVX	Eglin AFB, FL	Yes	Yes
China Lake Naval Weapons Center	CA	W	4035	EYX	Edwards AFB, CA	No	No
Edwards Air Force Base	CA	W	1244	EYX	Edwards AFB, CA	No	No
Fort Irwin	CA	W	2086	EYX	Edwards AFB, CA	No	No
Fort Sill Military Reservation	OK	MW	380	FDR	Frederick, OK	Yes	Yes
Camp Swift N. G. Facility	TX	W	210	GRK	Ft. Hood, TX	No	Yes
Fort Hood	TX	W	952	GRK	Ft. Hood, TX	No	Yes
Holloman Air Force Base	NM	W	213	HDX	Holloman AFB, NM	Yes	Yes
White Sands Missile Range	NM	W	8977	HDX	Holloman AFB, NM	Yes	Yes
Fort Bliss	TX	W	503	HDX/EPZ	Holloman AFB, NM/El Paso, TX	Yes	Yes
Fort Bliss McGregor Range	TX	W	2727	HDX/EPZ	Holloman AFB, NM/El Paso, TX	Yes	Yes
Fort Campbell	KY	E	406	HPX	Fort Campbell, KY	Yes	Yes
Fort Knox	KY	E	444	LVX	Louisville, KY	Yes	Yes
Fort A. P. Hill Military Reservation	VA	E	299	LWX	Sterling, VA	No	No
Quantico Marine Corps Base	VA	E	249	LWX	Sterling, VA	Yes	Yes
Camp Lejeune Marine Corps Base	NC	E	391	MHX	Morehead City, NC	No	Yes
Avon Park AF Bombing Range	FL	E	443	MLB	Melbourne, FL	No	No
Hill Air Force Range	UT	W	1444	MTX	Salt Lake City, UT	Yes	No
Wendover Range (Hill AFB)	UT	W	437	MTX	Salt Lake City, UT	No	No
Fort Benning Military Reservation	GA	E	736	MXX	Maxwell AFB, AL	No	No
Camp Pendleton Marine Corps Base	CA	W	491	NKX	San Diego, CA	No	Yes
Boardman Naval Bombing Range	WA	W	255	PDT	Pendleton, OR	No	No

Installation	State	Region	Area (km²)	NEXRAD Station	NEXRAD Station Location	Spring	Fall
Fort Polk Military Reservation	LA	E	772	POE	Ft. Polk, LA	Yes	Yes
Fort Carson Military Reservation	CO	W	1131	PUX	Pueblo, CO	No	Yes
Fort Bragg Military Reservation	NC	E	571	RAX	Raleigh-Durham, NC	No	No
Sierra Army Depot	CA	W	381	RGX	Reno, NV	No	No
Fort Riley Military Reservation	KS	MW	414	TWX	Topeka, KS	Yes	Yes
Fort Drum	NY	E	447	TYX	Fort Drum, NY	No	No
Vandenberg Air Force Base	CA	W	449	VBX	Vandenberg AFB, CA	Yes	Yes
Barry M. Goldwater AF Range	AZ	W	4242	YUX	Yuma, AZ	Yes	Yes
Yuma Proving Ground	AZ	W	2927	YUX	Yuma, AZ	Yes	Yes

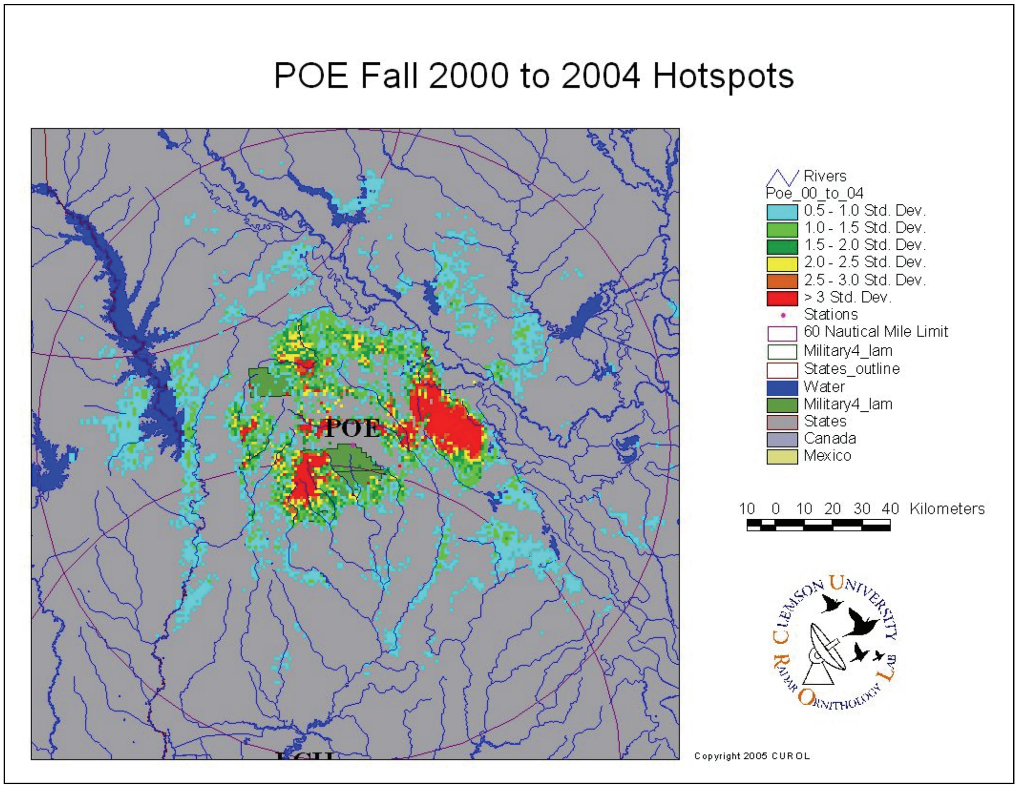

Figure 19. Map showing migration stopover areas based on WSR-88D detection of migrating birds during significant exodus events from Fort Polk, LA, during the fall migrations of 2000-2004. The data are quantified and displayed as standard deviations above mean.

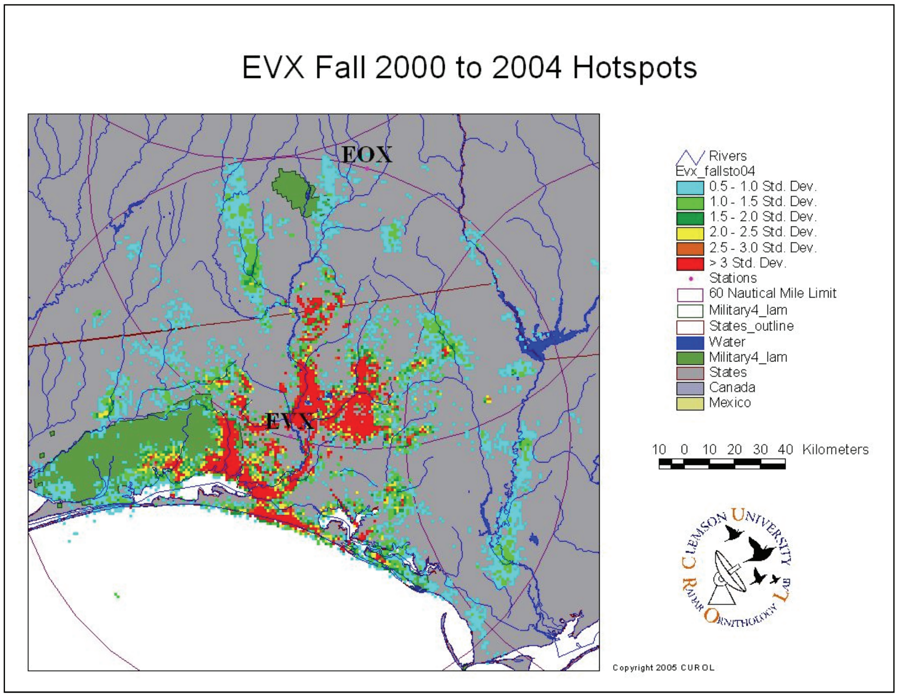

Figure 20. Map showing migration stopover areas based on WSR-88D detection of migrating birds during significant exodus events from Eglin AFB, FL, during the fall migrations of 2000-2004. The data are quantified and displayed as standard deviations above mean.

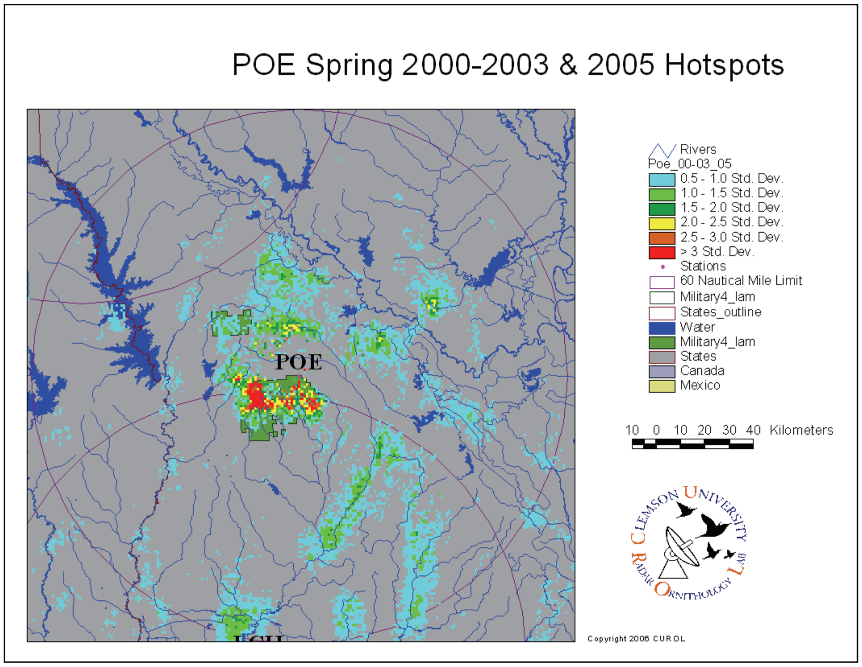

Figure 21. Map showing migration stopover areas based on WSR-88D detection of migrating birds during significant exodus events from Fort Polk, LA, for the spring migrations of 2000-2003, and 2005. The colors represent standard deviations of above the mean density of birds per km^3. Note that many of the stopover areas are associated with riparian habitat.

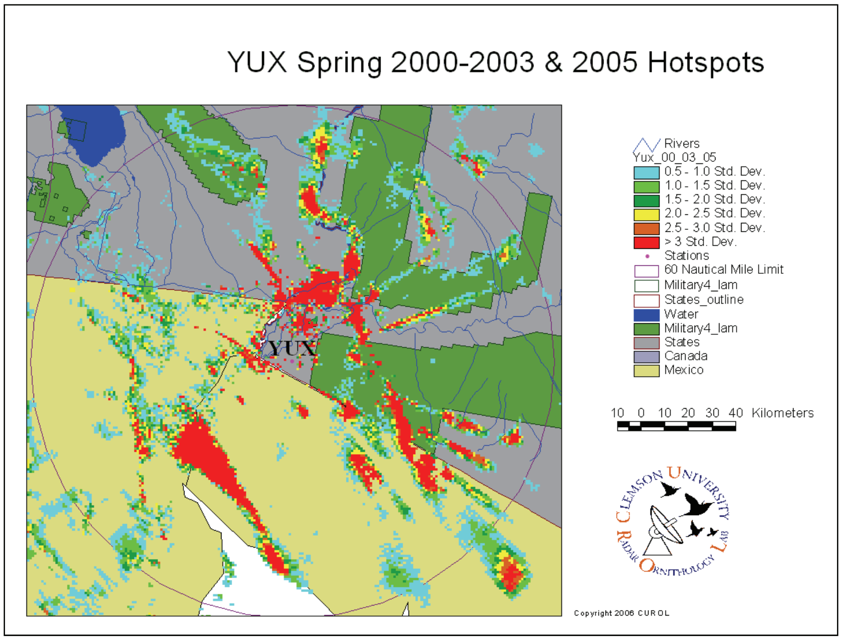

Figure 22. Map showing migration stopover areas based on WSR-88D detection of migrating birds during significant exodus events on and around Yuma Proving Ground, AZ for the spring migrations of 2000-2003 and 2005. The colors represent standard deviations above the mean density of birds per cubic km. The large red areas to the SW and SE of the radar site are not from migrant exodus events and are the results of ground clutter. breakthrough and radar blockage patterns in these areas. The DoD installation to the lower right is the Barry M. Goldwater Air Force Range, and the one above it is the Yuma Proving Ground.

Objective 2: Quantifying Seasonal Migration

Fall Migration

The seasonal temporal pattern of nocturnal bird migration in fall over Eglin Air Force Base in Florida for the years 2000-2005 can be found in Figures 23 and 24. Migration in the month of August was minimal as were the values of the standard error (SE) of the mean. The quantity of migration increased in mid-September as did the values of the standard error of the mean. Peak of fall migration occurred between the end of September and the middle of October when the values of the standard error of the mean reached were greatest. Values of the standard error of the mean are greatest during this period because large movements occurred when conditions were favorable for migration, but migration was absent when conditions were poor (adverse winds, rain). After the middle of October migration density declined, and the values of the standard error of the mean also declined. During the six year period, a maximum migration density of 583 birds per km^3 was recorded at Eglin Air Force Base on two dates: 28 September 2003 and 13 October 2004 (Figure 24).

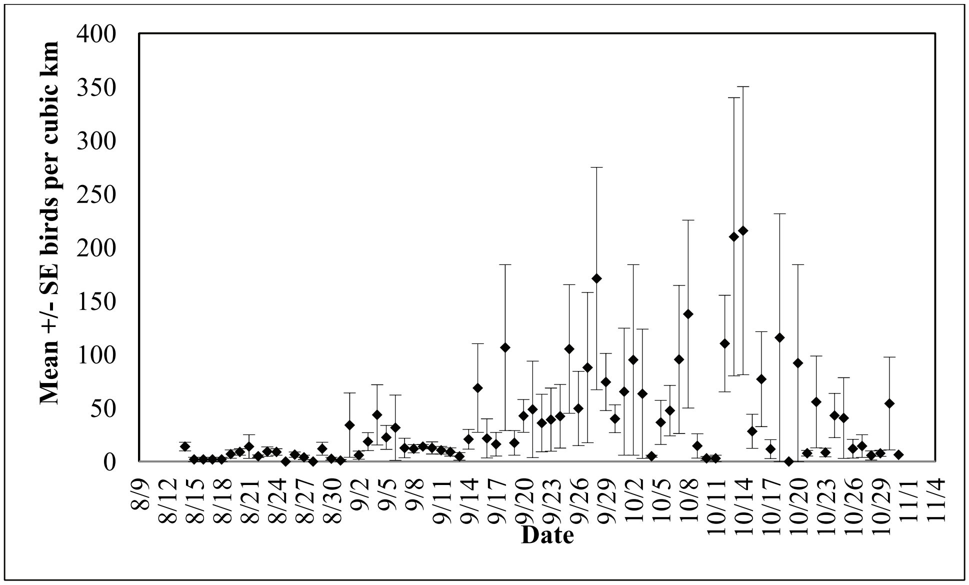

Figure 23. Seasonal temporal pattern of nocturnal bird migration in fall over Eglin Air Force Base, FL for the years 2000-2005. The symbols represent the mean number of birds per km³ and the bars indicate the standard error of the mean.

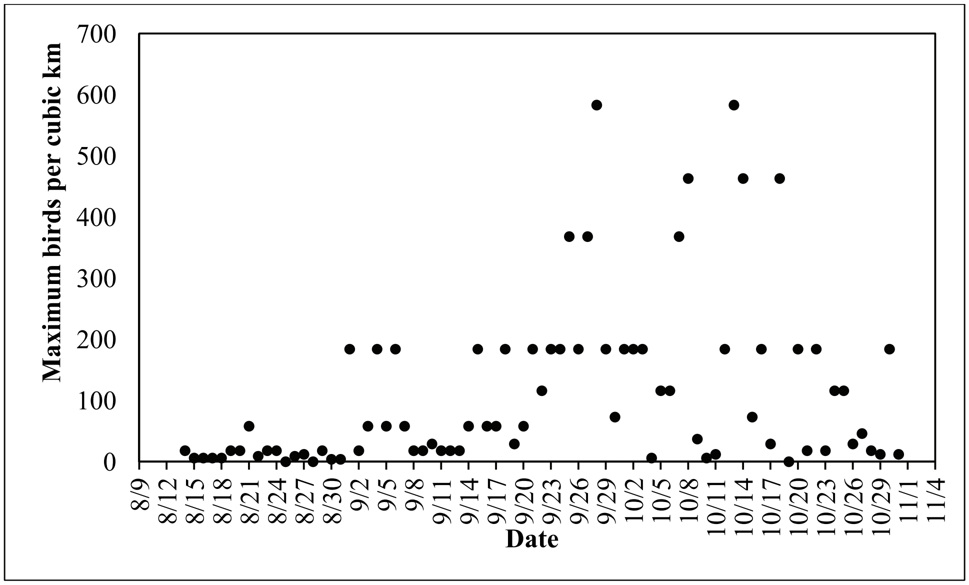

Figure 24. Seasonal temporal pattern of nocturnal bird migration in fall over Eglin Air Force Base, FL for the years 2000-2005. The symbols indicate the maximum value of birds per km³ for each date of fall during the six year period.

The seasonal temporal pattern of fall, nocturnal bird migration over Fort Polk in Louisiana for the years 2000-2005, can be found in Figures 25 and 26. Migration in the month of August was minimal with low standard error of the mean values. In September, migration and standard error of the mean values increased. The peak of migration occurred from mid-September through the middle of October, and the values of the standard error of the mean reached a maximum during this period. From mid-October through the end of October, the amount of migration declined, and the values of the standard error of the mean also declined. During the six-year period, the maximum density of a migratory flight was 184 birds per km3 and this value was reached on 13 dates between 9 September and 24 October (Figure 26).

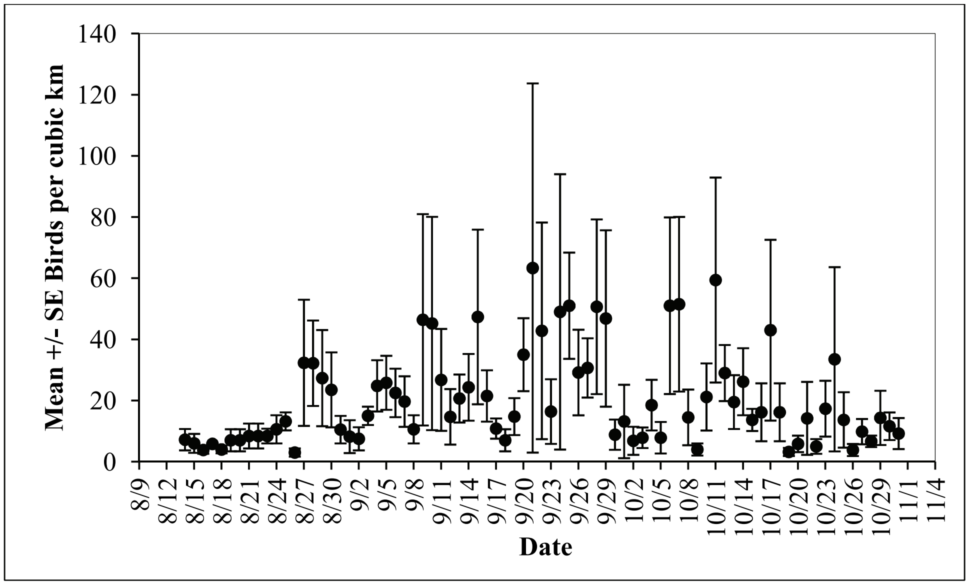

Figure 25. Seasonal temporal pattern of nocturnal bird migration in fall over Fort Polk, LA for the years 2000-2005. Symbols represent the mean number of birds per km^3 and the bars indicate the standard error of the mean.

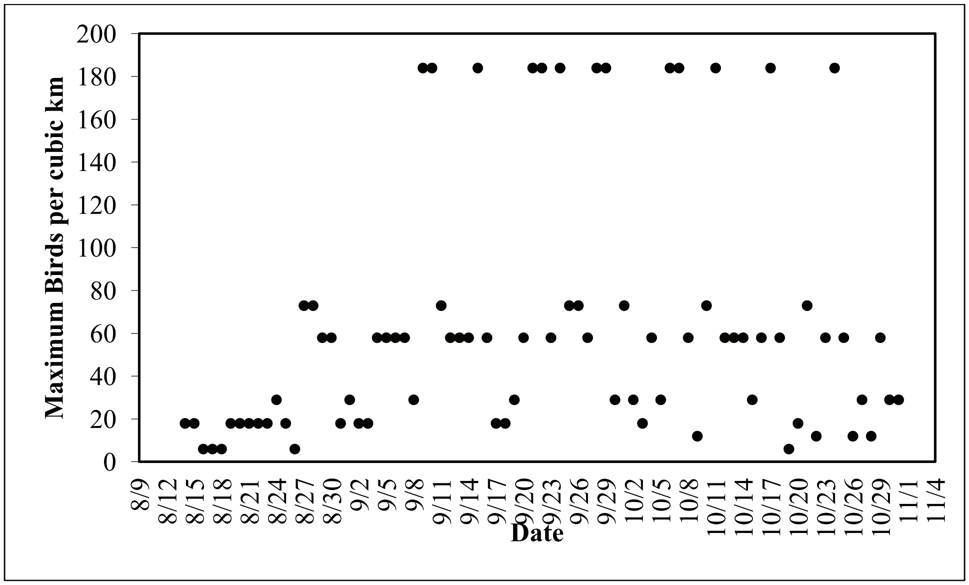

Figure 26. Seasonal temporal pattern of nocturnal bird migration in fall over Fort Polk, LA for the years 2000-2005. Symbols indicate the maximum value of birds per km^3 for each date of fall during the six year period.

Spring Migration

The seasonal temporal pattern of nocturnal bird migration in spring over Fort Polk, Louisiana for the years 2000-2003 and 2005-2006 can be found in Figures 27 and 28. The mean density (number of birds per km3) was low until the end of March when it began to increase. By the middle of April, the mean density of migration was near peak values, and the period of peak density extended from mid-April until approximately 10 May. After this date, the density of migration declined steadily until the end of May. Values of the standard error of the mean followed the behavior of the mean. Near the beginning and end of the spring migration season, the SE values were low, because the differences between no migration and weak migration were small. During the period of peak migration, however, the SE values were high, because the differences between no migration and high density migration were great. The maximum density (birds per km3) for each date of spring during the six year period can be found in Figure 28. Maximum densities of 583 occurred on 17, 28 April and 1, 3, and 6 May.

The seasonal temporal pattern of nocturnal bird migration in spring over Yuma, Arizona for the years 2000-2003 and 2005-2006 can be found in Figures 29 and 30. The mean density (number of birds per km3) was low mid-March, increased steadily until mid-April, and then declined a bit until the beginning of May. The highest mean density of migration was in

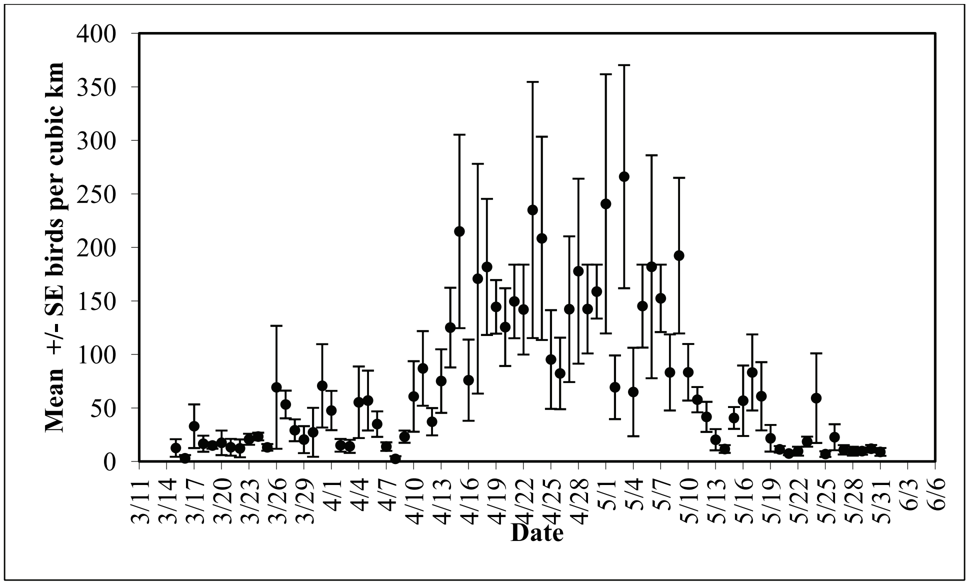

Figure 27. Seasonal temporal pattern of nocturnal bird migration in spring over Fort Polk, LA for the years 2000-2003 and 2005-2006. Symbols represent the mean number of birds per km^3 and the bars indicate the standard error of the mean.

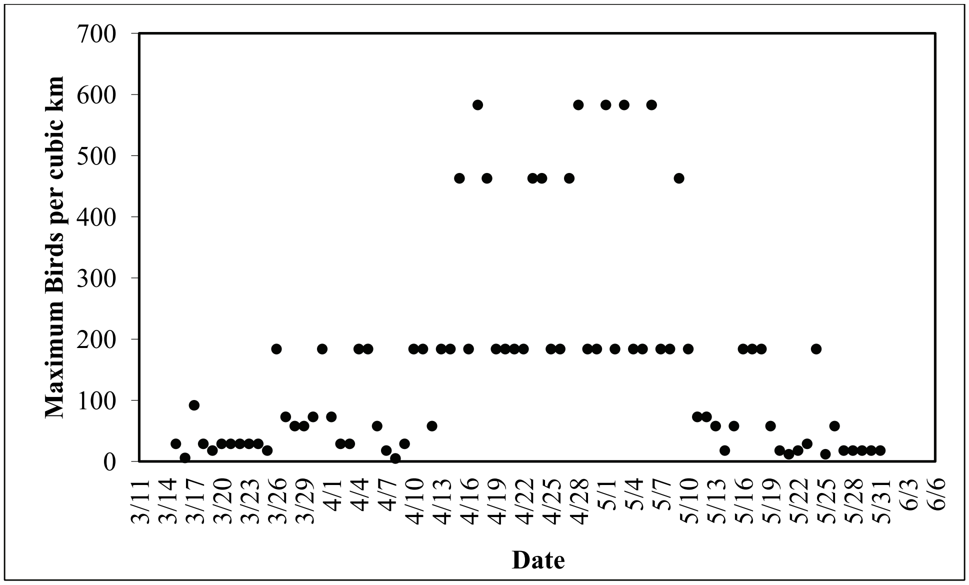

Figure 28. Seasonal temporal pattern of nocturnal bird migration in spring over Fort Polk, LA for the years 2000-2003 and 2005-2006. Symbols indicate the maximum value of birds per km^3 for each date of spring during the six year period.

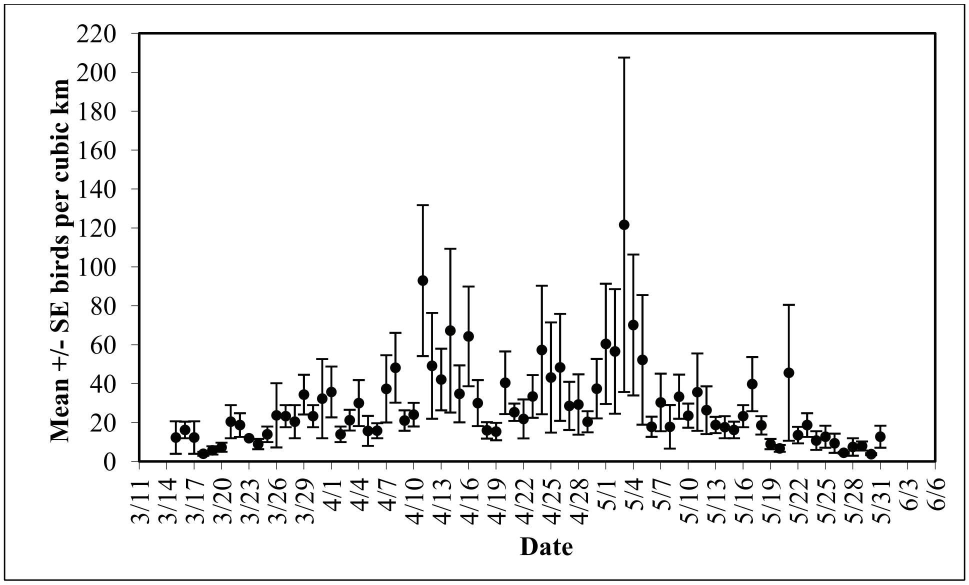

Figure 29. Seasonal temporal pattern of nocturnal bird migration in spring over Yuma, AZ for the years 2000-2003 and 2005-2006. Symbols represent the mean number of birds per km^3 and the bars indicate the standard error of the mean.

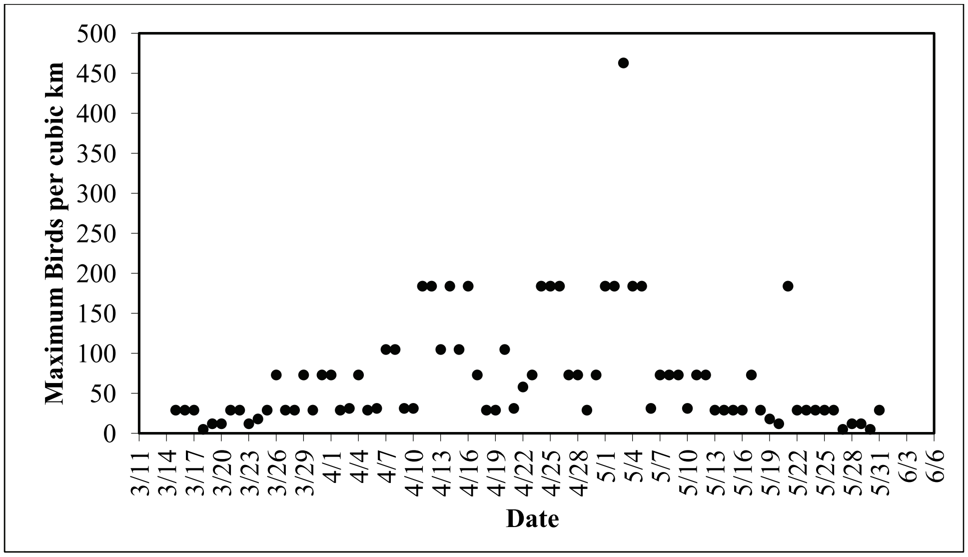

Figure 30. Seasonal temporal pattern of nocturnal bird migration in spring over Yuma, AZ for the years 2000-2003 and 2005-2006. Symbols indicate the maximum value of birds per km^3 for each date of spring during the six year period.

early May and then the mean density declined steadily until the end of May (Figure 29). The maximum density (birds per km^3) for each date of spring during the six year period can be found in Figure 30. The highest density recorded during the six spring seasons was 463 birds per km^3 on 3 May 2005. The next highest density was 184 birds per km^3; this density was recorded on 12 dates ranging from 11 April through 21 May.

Discussion

The amount of migration over military installations for a particular date in spring and fall varies from year-to-year, and variation is greatest for dates during the period of peak seasonal migration. In this study, the periods of peak migration were clearly defined based on six years of data, but the amount of migration one observes on a particular date is strongly dependent on the number of grounded migrants in the area ready to migrate and the weather conditions present at the end of the day when nocturnal migration begins. When weather conditions are ideal during the period of peak movements very high density migrations can occur, but when weather conditions are poor (rain, or adverse winds, or both), no migration is recorded. At the beginning and end of seasonal migration, movements are generally of low density even when weather conditions are ideal for a flight, because the maximum number of birds ready to migrate is small.

Migrations in the fall with the highest mean densities were recorded at Eglin Air Force Base. This is not surprising because winds prevailing from the west over the United States drift birds migrating southward towards the east and southeast, and as a result, fall migration densities in the Southeast are greater than in other areas of the South. Migrations in the spring with the highest mean densities were recorded at Fort Polk. This too is not surprising as the greatest densities of migrants entering the United States in spring arrive from over the Gulf of Mexico on the upper Texas coast and on the southwestern Louisiana coast. These flights originate south of the Gulf and the birds depart at the beginning of the night. Because of the distance across the Gulf, the flights arrive on the northern coast in the afternoon and early evening and continue inland passing over Fort Polk. The mean densities of migration in the spring are twice as great at Fort Polk as those passing over Yuma, and the magnitude of trans-Gulf migration is largely responsible for this difference.

Objective 3: Development of Migration Forecast Models

The neural net model for Eglin Air Force Base was based on the peak density of migration on 183 nights during the fall seasons of 2000 through 2005. The R^2 is 0.8217 and the CV R^2 is 0.4228. Of the 20 tours, two converged at best, 15 converged less than best, and three reached the maximum number of iterations. The plot of actual bird density by predicted bird density can be found in Figure 31. The most influential predictor variables were temperature, humidity, surface cross winds, and 925mb head winds. As temperature and humidity declined, the density of migration increased, and as surface winds shifted to blowing from the west, the density of migration increased. As winds at 3000 ft increased in velocity from the north, the amount of migration increased.

The neural net model for Fort Polk was based on the peak density of migration on 40 nights during the fall of 2005. The R^2 is 0.9906 and no cross validation was used because only one season of data was used. Of the 16 tours, two converged at best, 13 converged worse than best, and one reached the maximum number of iterations. The plot of actual bird density by predicted bird density can be found in Figure 32. The most influential predictor variables were surface head and cross winds, 925mb head winds. As surface winds from the north increased in velocity, the density of migration increased, and as surface cross winds from the west increased (as happens just before a cold front passage), the density of migratory movements increased. The density of migratory movements increased as winds at 3000 ft increased in velocity from the north.

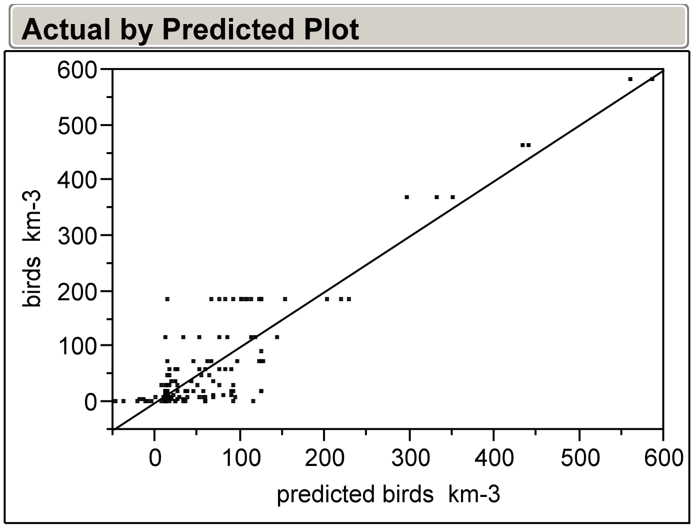

Figure 31. Plot of actual birds per km³ by predicted birds per km³ for fall data from the years 2000-2005 at Eglin Air Force Base in Florida.

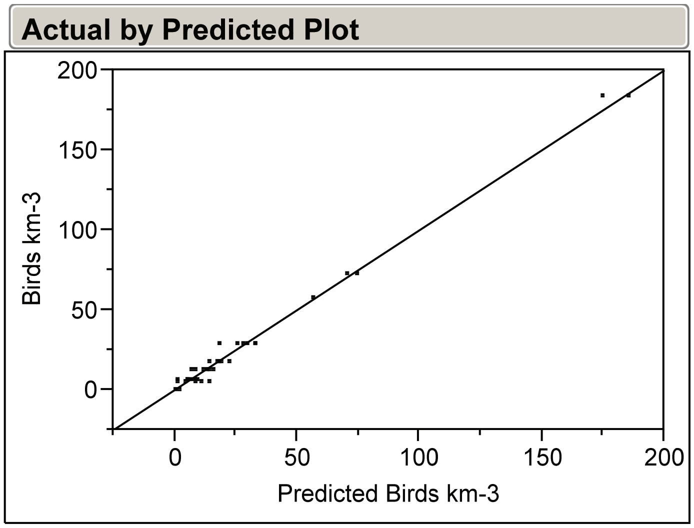

Figure 32. Plot of actual birds per km³ by predicted birds per km³ for fall data from 2005 at Fort Polk Army Base in Louisiana.

The neural net model for Yuma, Arizona was based on the peak density of migration on 186 nights during the spring seasons from 2001 through 2005. The overfit penalty for this analysis was 0.3. The R^2 is 0.4774 for the neural net model, and the CV R^2 is 0.1266 for the 5-fold cross validation. The fit results indicate that eight of the 20 tours converged at best, nine converged worse than best, and three reached the maximum number of iterations. None of the predictor variables showed a great influence on the prediction of migration density. As ordinal date increased the density of bird migration increased, and as surface winds from the south increased the density of migration tended to increase. When 925mb winds increased from the east the density of migratory flights increased. The plot of actual bird density by predicted bird density can be found in Figure 33.

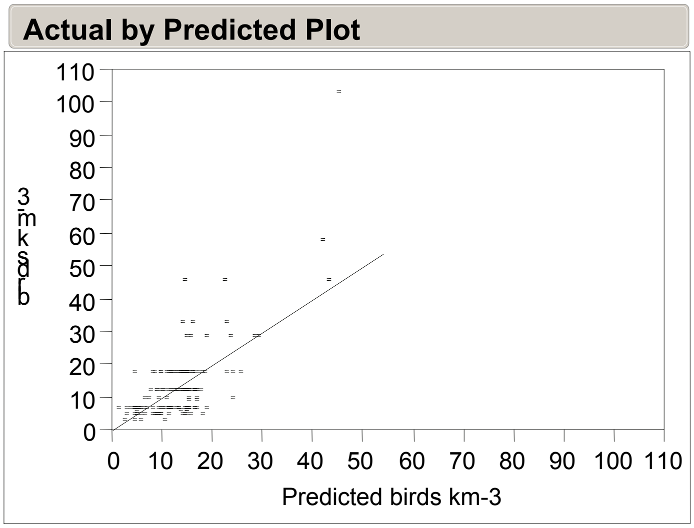

Figure 33. Plot of actual birds per km^3 by predicted birds per km^3 for data from the spring seasons from 2001 through 2005 at Yuma, AZ.

Discussion

All of the forecast models performed poorly when the densities of migration were low. The neural net models for Eglin Air Force Base and Fort Polk do a fairly good job at predicting dense migratory movements, and these are the movements that should be of the greatest concern for aviation safety. Poor performance for low density movements is of lesser concern. The neural net model for Yuma is not a good predictor of migration density, and this is likely the result of the number of low density movements that were used for building the model. Because winds are rarely favorable over Yuma, migratory flights frequently occur when unfavorable winds are present, and the flights are of low density. The density of migration actually increased when temperature decreased in spring.

In both spring and fall, temperature, wind, and rain are the most influential variables (Gauthreaux 1978). In an investigation of correlations between radar measures of bird migration density and 20 weather variables in Lithuania from 1974 to 1977, Zhalakyavichus (1985) found that the most important variables were air temperature and cloud type in spring and cloud type and wind direction in fall. The correlation was better for spring than in fall and for migrations in the continental part of the region. Van

Belle et al. (2007) also found that significant input variables for regression models that predicted migration intensity included: seasonal migration trend, wind profit, 24-hour trend in barometric pressure, and rain, but they cautioned that the mismatch between measurements and predictions was large for existing models, and that existing models are only valid locally and cannot be extrapolated to new locations.

Most of the multivariate analyses of the influence of weather variables on migration have R^2 values ranging from 0.40 to 0.62 in spring and 0.26 to 0.61 in fall (Gauthreaux 1978). Several factors are responsible when weather variables fail to explain much of the night-to-night variance in the density of bird migration:

- There are no birds physiologically ready to migrate when weather conditions are ideal.
- In the fall most birds that are ready to migrate leave the first night after the passage of a cold front. If the weather is still very favorable for migration on subsequent night(s), few birds are present to migrate.
- If unfavorable weather conditions persist too long, migrants will depart in unfavorable weather conditions.
- Weather conditions well away from the study site may influence peak migration density more than local conditions.

Objective 4: Comparison of Migrant Survey Techniques

Between the fall of 2005 and the spring of 2007, the team conducted 1900 fall migrant surveys and 2724 spring migrant surveys along 2,312 km of transects across the three study regions (Table 6). The team made 149,231 bird detections of 274 different species but 25,258 of those detections were birds flying over the site and were not included in the data analyses. Species richness tended to be greater during spring surveys and was greater at Yuma (Table 7) than at either Ft. Polk (Tables 8 and 9) or Eglin AFB (Table 10). Overall, the team had 202 paired sampling dates from which Δ migrant abundance could be calculated (Figures 34-37). However, only peak migration densities could be estimated for 192 of those paired dates and migrant exodus densities for 179 (Table 11).

Peak migration density was not a significant predictor of Δ migrant abundance observed during ground surveys for any region during either season in any year (Table 12). In fact, though we expected to see a positive relationship between peak migration densities and Δ abundance, the data

Table 6. Summary of the sampling effort and number of birds detected at each region by year and season. The N for surveys is the total number of 500m transects completed during each season; distance sampled is reported in km.

Season	Region	Year	Surveys			Distance Sampled			Ground Detections			Flyover		
			AM	*PM*	*Total*	*AM*	*PM*	*Total*	*AM*	*PM*	*Total*	*AM*	*PM*	*Total*
Spring	Yuma	2006	439	3	442	219.5	1.5	221	50404	161	50565	3838	0	3838
		2007	832	0	832	416	0	416	31133	0	31133	5937	0	5937
	Ft. Polk	2006	633	272	905	316.5	136	452.5	13147	2250	15397	577	192	769
		2007	348	197	545	174	98.5	272.5	7083	2116	9199	146	79	225
Fall	Eglin AFB	2005	166	71	237	83	35.5	118.5	2268	673	2941	42	6	48
		2006	314	172	486	157	86	243	8214	2715	10929	99	18	117
		2007	284	205	489	142	102.5	244.5	6989	3313	10302	78	31	109
	Ft. Polk	2005	194	115	309	97	57.5	154.5	2921	718	3639	96	133	229
		2006	232	147	379	116	73.5	189.5	2895	873	3768	64	22	86

Table 7. Number of ground and flyover detections per species recorded during 1271 morning and three evening transect surveys conducted during spring migration at Yuma in 2006-2007. Species highlighted in bold were included in all statistical analyses.

Species	Ground	Flyovers		Species	Ground	Flyovers
Mourning Dove	7968	532		**Green Heron**	**81**	**17**
White-winged Dove	**5859**	**379**		Northern Mockingbird	81	8
Brown-headed Cowbird	4182	574		**Summer Tanager**	**78**	**0**
Red-winged Blackbird	4118	2184		Black Phoebe	75	0
Verdin	3372	0		**Unknown Sparrow**	**68**	**14**
Common Yellowthroat	**3161**	**1**		**Bell's Vireo**	**67**	**0**
Wilson's Warbler	**3048**	**4**		**Spotted Sandpiper**	**62**	**1**
Brewer's Sparrow	**2463**	**204**		Tree Swallow	61	8215
House Finch	2166	232		Rock Pigeon	59	52
Gambel's Quail	2022	13		**Ruby-crowned Kinglet**	**58**	**0**
Abert's Towhee	1798	3		Blue-gray Gnatcatcher	53	0
Ash-throated Flycatcher	**1791**	**8**		Black-crowned Night-Heron	51	6
Unknown Warbler	**1334**	**110**		**Least Bittern**	**50**	**0**
Pacific-slope Flycatcher	**1301**	**0**		**Sora**	**50**	**0**
Warbling Vireo	**1209**	**1**		**Mallard**	**48**	**31**
Unknown Passerine	1182	164		N. Rough-winged Swallow	46	975
Orange-crowned Warbler	**1130**	**1**		**Western Flycatcher**	**45**	**0**
Black-tailed Gnatcatcher	1118	2		Vaux's Swift	43	464
Cliff Swallow	1056	4884		**Hermit Warbler**	**42**	**0**
Gila Woodpecker	1008	8		**Cassin's Vireo**	**41**	**0**
Ladder-backed Woodpecker	939	14		**Olive-sided Flycatcher**	**41**	**2**
American Coot	**935**	**0**		**House Wren**	**39**	**0**
Yellow-headed Blackbird	882	146		**Green-tailed Towhee**	**37**	**0**

Species	Ground	Flyovers		Species	Ground	Flyovers
Song Sparrow	**815**	**0**		**Cinnamon Teal**	**37**	**0**
Great-tailed Grackle	815	494		**Unknown Flycatcher**	**35**	**11**
Nashville Warbler	**634**	**0**		**Great Blue Heron**	**34**	**32**
Yellow-rumped Warbler	**566**	**10**		European Starling	34	11
Unknown Empidonax	**536**	**2**		**Unknown Vireo**	**34**	**0**
Western Kingbird	526	121		**Snowy Egret**	**34**	**42**
Anna's Hummingbird	469	4		**Least Sandpiper**	**29**	**3**
Cactus Wren	444	0		Lesser Goldfinch	28	17
Western Tanager	**409**	**19**		Western Meadowlark	28	0
Black-throated Gray Warbler	**408**	**2**		**Cedar Waxwing**	**27**	**0**
Yellow Warbler	**400**	**1**		**Dark-eyed Junco**	**25**	**0**
Lucy's Warbler	**378**	**0**		American Kestrel	22	6
MacGillivray's Warbler	**351**	**0**		Red-tailed Hawk	22	3
Bullock's Oriole	**304**	**10**		Great Egret	22	97
Unknown Hummingbird	301	31		Cooper's Hawk	21	5
White-faced Ibis	**295**	**570**		Unknown Thrasher	21	0
Blue Grosbeak	**292**	**0**		Inca Dove	19	0
Townsend's Warbler	**277**	**0**		**Ruddy Duck**	**18**	**0**
Phainopepla	**277**	**25**		**Brown-crested Flycatcher**	**17**	**0**
Chipping Sparrow	**225**	**0**		Say's Phoebe	16	0
Western Wood-Pewee	**224**	**1**		**Long-billed Dowitcher**	**16**	**0**
Black-chinned Hummingbird	219	3		**Western Sandpiper**	**16**	**0**
Yellow-breasted Chat	**212**	**0**		**Unknown Ibis**	**15**	**0**
Marsh Wren	**208**	**0**		Osprey	15	16
Black-headed Grosbeak	**201**	**11**		Loggerhead Shrike	15	1
Lesser Nighthawk	177	71		**Bufflehead**	**15**	**1**
White-crowned Sparrow	**177**	**0**		Common Raven	15	5
Crissal Thrasher	169	0		Common Ground-Dove	14	8
Common Moorhen	**159**	**0**		Great Horned Owl	14	0
Greater Roadrunner	142	0		Northern Harrier	12	6
Killdeer	**126**	**26**		Unknown Cowbird	12	0
Barn Swallow	125	113		**Swainson's Thrush**	**12**	**0**
Lazuli Bunting	**125**	**6**		**Unknown Myiarchus**	**12**	**12**
Turkey Vulture	115	114		**Red-shafted Flicker**	**12**	**0**
Black-necked Stilt	**111**	**68**		Cattle Egret	11	4
Pied-billed Grebe	**102**	**0**		**Hooded Oriole**	**11**	**0**

Species	Ground	Flyovers		Species	Ground	Flyovers
Unknown Swallow	86	2022		**Gray Flycatcher**	**10**	**0**
Unknown Shorebird	**86**	**20**		**Unknown Thrush**	**10**	**0**
Unknown Sandpiper	**10**	**11**		Eurasian Collared Dove	2	0
Belted Kingfisher	**10**	**4**		White-tailed Kite	2	1
Double-crested Cormorant	9	95		American Pipit	1	0
Hermit Thrush	**9**	**0**		Broad-winged Hawk	1	0
Common Merganser	**9**	**0**		Swainson's Hawk	1	0
Greater Yellowlegs	**9**	**4**		Unknown Hawk	1	1
White-throated Swift	7	33		American Crow	1	1
Sharp-shinned Hawk	7	6		American Robin	1	0
American Goldfinch	7	2		Horned Lark	1	0
Unknown Oriole	**7**	**4**		Unknown Heron	1	1
Ring-necked Pheasant	7	0		**Alder Flycatcher**	**1**	**0**
Willow Flycatcher	**6**	**0**		**Baltimore Oriole**	**1**	**0**
Bewick's Wren	**6**	**0**		**Plumbeous Vireo**	**1**	**0**
Vermillion Flycatcher	**6**	**0**		**Unknown Tanager**	**1**	**2**
Unknown Gnatcatcher	6	0		**Common Poorwill**	**1**	**0**
Unknown Woodpecker	6	4		**Scott's Oriole**	**1**	**0**
Franklin's Gull	5	1		**Spotted Towhee**	**1**	**0**
Black-throated Sparrow	**5**	**0**		**Lesser Yellowlegs**	**1**	**9**
Unknown Raptor	4	0		**Solitary Sandpiper**	**1**	**0**
Northern Parula	**4**	**0**		**Unknown Dowitcher**	**1**	**0**
Gadwall	**4**	**0**		**Virginia Rail**	**1**	**0**
Long-billed Curlew	**4**	**14**		**Willet**	**1**	**13**
Wilson's Snipe	**4**	**1**		Barn Owl	1	0
Unknown Bird	4	0		Bushtit	1	0
Unknown Owl	4	0		Clapper Rail	1	0
Northern Shoveler	**3**	**0**		Hutton's Vireo	1	0
Prairie Falcon	3	1		Unknown Wren	1	0
Unknown Accipiter	3	0		Brewer's Blackbird	0	3
Unknown Buteo	3	0		Bank Swallow	0	11
American Wigeon	3	0		Unknown Swift	0	24
Black Tern	3	1		Unknown Blackbird	0	25
Sage Thrasher	**3**	**0**		California Gull	0	22
Black-and-white Warbler	**3**	**0**		Caspian Tern	0	2
Clay-colored Sparrow	**2**	**0**		Common Loon	0	5

Species	Ground	Flyovers		Species	Ground	Flyovers
Calliope Hummingbird	2	0		Forster's Tern	0	1
Rufous Hummingbird	2	0		Ring-billed Gull	0	2
Bronzed Cowbird	2	0		Unknown Egret	0	15
Costa's Hummingbird	2	0		**Lark Sparrow**	**0**	**2**
Western Bluebird	2	0		**American Avocet**	**0**	**72**
Lincoln's Sparrow	**2**	**0**		**American Bittern**	**0**	**1**
Hammond's Flycatcher	**2**	**0**		**Common Goldeneye**	**0**	**1**
Black-chinned Sparrow	**2**	**0**		**Northern Pintail**	**0**	**1**
Blue-winged Teal	**2**	**0**		**Unknown Duck**	**0**	**6**
Eared Grebe	**2**	**0**				

Table 8. Number of ground and flyover detections per species recorded during 981 morning and 469 evening transect surveys conducted during spring migration at Ft. Polk in 2006-2007. Species highlighted in bold were included in all statistical analyses.

Species	Ground	Flyovers		Species	Ground	Flyovers
Eastern Tufted Titmouse	2723	0		Broad-winged Hawk	26	51
Red-eyed Vireo	**2402**	**0**		American Goldfinch	26	40
Northern Cardinal	2289	0		**Magnolia Warbler**	**26**	**0**
Hooded Warbler	**1493**	**0**		**Common Yellowthroat**	**24**	**0**
Carolina Wren	1378	0		**Yellow-bellied Sapsucker**	**23**	**0**
Yellow-rumped Warbler	**1263**	**6**		**Veery**	**22**	**0**
Carolina Chickadee	1213	0		Red-headed Woodpecker	20	1
Pine Warbler	**1071**	**0**		**Yellow-breasted Chat**	**20**	**0**
Red-bellied Woodpecker	918	3		Eastern Phoebe	18	0
Ruby-crowned Kinglet	**781**	**0**		**Yellow-bellied Flycatcher**	**18**	**0**
Blue-gray Gnatcatcher	741	0		**American Redstart**	**17**	**0**
Blue Jay	710	17		Eastern Bluebird	16	4
American Crow	617	220		**Brown Thrasher**	**16**	**0**
White-throated Sparrow	**590**	**0**		**Northern Waterthrush**	**15**	**0**
Pileated Woodpecker	446	9		**Rose-breasted Grosbeak**	**15**	**0**
Unknown Warbler	**432**	**6**		**Tennessee Warbler**	**15**	**0**
Summer Tanager	**344**	**0**		**Unknown Empidonax**	**15**	**0**
Acadian Flycatcher	**343**	**0**		**Nashville Warbler**	**14**	**0**
Great Crested Flycatcher	**331**	**0**		**Scarlet Tanager**	**14**	**0**
Yellow-throated Vireo	**287**	**0**		Brown-headed Nuthatch	13	0
Downy Woodpecker	255	0		Brown-headed Cowbird	12	19
Louisiana Waterthrush	**243**	**1**		**Warbling Vireo**	**11**	**0**

Species	Ground	Flyovers		Species	Ground	Flyovers
Wood Thrush	**189**	**0**		**Swainson's Warbler**	**10**	**0**
Barn Swallow	181	122		**Ovenbird**	**9**	**0**
Blue-headed Vireo	**177**	**0**		Turkey Vulture	8	52
White-eyed Vireo	**177**	**0**		**Yellow Warbler**	**8**	**0**
Barred Owl	145	0		**Canada Warbler**	**7**	**0**
Indigo Bunting	**144**	**9**		**Eastern Towhee**	**7**	**0**
Hermit Thrush	**143**	**0**		Unknown Swallow	6	15
Black-throated Green Warbler	**121**	**0**		Unknown Hawk	6	1
Ruby-throated Hummingbird	117	1		**Gray-cheeked Thrush**	**6**	**0**
Red-shouldered Hawk	114	64		**Prothonotary Warbler**	**6**	**0**
Northern Parula	**114**	**0**		**Blackpoll Warbler**	**5**	**0**
Hairy Woodpecker	103	0		**Philadelphia Vireo**	**5**	**0**
Cedar Waxwing	**98**	**89**		**Bachman's Sparrow**	**5**	**0**
Yellow-billed Cuckoo	**96**	**0**		Chimney Swift	4	102
Unknown Passerine	88	0		Tree Swallow	4	3
Mourning Dove	86	3		Little Blue Heron	4	0
Unknown Woodpecker	76	0		**Blue-winged Warbler**	**4**	**0**
Wood Duck	**73**	**1**		**Wilson's Warbler**	**4**	**0**
Swainson's Thrush	**69**	**0**		Northern Bobwhite	4	0
Kentucky Warbler	**68**	**0**		**Belted Kingfisher**	**4**	**0**
Unknown Bird	67	17		Eastern Kingbird	3	0
Black-and-white Warbler	**53**	**0**		Common Grackle	3	0
Worm-eating Warbler	**51**	**0**		**Black-billed Cuckoo**	**3**	**0**
Yellow-shafted Flicker	**46**	**0**		**Cerulean Warbler**	**3**	**0**
Orange-crowned Warbler	**44**	**0**		**Golden-winged Warbler**	**3**	**0**
Baltimore Oriole	**44**	**0**		**Orchard Oriole**	**3**	**0**
Yellow-throated Warbler	**44**	**0**		**Unknown Sparrow**	**3**	**0**
Brown Creeper	**42**	**0**		**Unknown Duck**	**3**	**0**
Wild Turkey	42	0		Black Vulture	3	14
Eastern Wood-Pewee	**41**	**0**		Cooper's Hawk	2	0
Great Blue Heron	**39**	**29**		Red-tailed Hawk	2	1
Blackburnian Warbler	**38**	**0**		Unknown Raptor	2	1
Unknown Thrush	**38**	**0**		American Robin	2	0
Golden-crowned Kinglet	**37**	**0**		**Swamp Sparrow**	**2**	**0**
Unknown Vireo	**37**	**0**		**Alder Flycatcher**	**2**	**0**
Chestnut-sided Warbler	**31**	**0**		**Blue Grosbeak**	**2**	**0**

Species	Ground	Flyovers		Species	Ground	Flyovers
Chipping Sparrow	**28**	**0**		**Chuck-will's-widow**	**2**	**0**
Winter Wren	**27**	**0**		Red-cockaded Woodpecker	2	2
Gray Catbird	**27**	**0**		Unknown Owl	2	0
Green Heron	**1**	**0**		**Killdeer**	**0**	**3**
Mississippi Kite	1	17		Bank Swallow	0	1
Sharp-shinned Hawk	1	3		Cliff Swallow	0	3
Unknown Buteo	1	1		Purple Martin	0	38
Unknown Heron	1	0		Unknown Accipiter	0	1
Palm Warbler	**1**	**0**		Red-winged Blackbird	0	5
Bay-breasted Warbler	**1**	**0**		Black-crowned Night-Heron	0	2
Black-throated Blue Warbler	**1**	**0**		Cattle Egret	0	7
Mourning Warbler	**1**	**0**		Double-crested Cormorant	0	6
Painted Bunting	**1**	**0**		**Dickcissel**	**0**	**3**
Common Ground-Dove	1	0		Fish Crow	0	1
Unknown Wren	1	0				

Table 9. Number of ground and flyover detections per species recorded during 426 morning and 262 evening transect surveys conducted during fall migration at Ft. Polk in 2005-2006. Species highlighted in bold were included in all statistical analyses.

Species	Ground	Flyovers		Species	Ground	Flyovers
Blue Jay	1033	33		**Red-eyed Vireo**	**4**	**0**
Eastern Tufted Titmouse	946	0		**Chipping Sparrow**	**3**	**0**
Carolina Chickadee	692	0		American Kestrel	3	0
American Crow	685	110		Unknown Hawk	3	2
Carolina Wren	633	3		American Robin	3	0
Red-bellied Woodpecker	618	2		**Hermit Thrush**	**3**	**0**
Northern Cardinal	433	0		**Blue-headed Vireo**	**3**	**0**
Yellow-shafted Flicker	**349**	**1**		**Gray-cheeked Thrush**	**3**	**0**
Pileated Woodpecker	304	1		Unknown Buteo	2	0
Downy Woodpecker	174	0		Red-headed Woodpecker	2	0
Pine Warbler	**167**	**0**		**House Wren**	**2**	**0**
Wood Thrush	**134**	**0**		**Swainson's Thrush**	**2**	**0**
Wood Duck	**133**	**7**		**Yellow-throated Vireo**	**2**	**0**
Brown Thrasher	**116**	**0**		Ruby-throated Hummingbird	1	0
Unknown Warbler	**109**	**1**		Unknown Swift	1	2
Ruby-crowned Kinglet	**97**	**0**		Broad-winged Hawk	1	0
Red-shouldered Hawk	73	25		Sharp-shinned Hawk	1	0
Unknown Woodpecker	64	0		Brown-headed Cowbird	1	0
Hooded Warbler	**51**	**0**		Eastern Meadowlark	1	0

Species	Ground	Flyovers		Species	Ground	Flyovers
Gray Catbird	**36**	**0**		Unknown Egret	1	0
Barred Owl	36	0		**Orange-crowned Warbler**	**1**	**0**
Yellow-bellied Sapsucker	**34**	**0**		**Blackburnian Warbler**	**1**	**0**
Eastern Phoebe	31	0		**Chuck-will's-widow**	**1**	**0**
Unknown Thrush	**29**	**0**		**Kentucky Warbler**	**1**	**0**
White-eyed Vireo	**29**	**0**		**Least Flycatcher**	**1**	**0**
Hairy Woodpecker	24	0		**Louisiana Waterthrush**	**1**	**0**
Brown-headed Nuthatch	23	0		**Magnolia Warbler**	**1**	**0**
Summer Tanager	**22**	**0**		**Nashville Warbler**	**1**	**0**
Black-throated Green Warbler	**21**	**0**		**Ovenbird**	**1**	**0**
Great Crested Flycatcher	**20**	**0**		**Painted Bunting**	**1**	**0**
Blue-gray Gnatcatcher	19	0		**Prothonotary Warbler**	**1**	**0**
Eastern Wood-Pewee	**19**	**0**		**Rose-breasted Grosbeak**	**1**	**0**
Golden-crowned Kinglet	**17**	**0**		**Yellow-throated Warbler**	**1**	**0**
Veery	**16**	**0**		**Eastern Towhee**	**1**	**0**
Unknown Bird	16	99		**Snowy Egret**	**1**	**0**
Wild Turkey	14	0		Common Ground-Dove	1	0
Eastern Bluebird	13	5		Eastern Screech Owl	1	0
Mourning Dove	13	0		Fish Crow	1	0
American Redstart	**13**	**0**		White-breasted Nuthatch	1	0
Black-and-white Warbler	**13**	**0**		Unknown Owl	1	0
Common Yellowthroat	**9**	**0**		Unknown Wren	1	0
Yellow-billed Cuckoo	**9**	**0**		**Canada Goose**	**0**	**1**
Belted Kingfisher	**9**	**0**		**Killdeer**	**0**	**1**
Northern Mockingbird	8	0		Chimney Swift	0	1
Winter Wren	**7**	**0**		Tree Swallow	0	6
Great Blue Heron	**6**	**0**		Cooper's Hawk	0	1
American Goldfinch	6	1		Merlin	0	1
Unknown Empidonax	**6**	**0**		Red-tailed Hawk	0	2
Northern Bobwhite	6	0		Turkey Vulture	0	8
Indigo Bunting	**5**	**1**		Black Vulture	0	1
Northern Parula	**4**	**0**				

Table 10. Number of ground and flyover detections per species recorded during 764 morning and 448 evening transect surveys conducted during fall migration at Eglin AFB in 2005-2007. Species highlighted in bold were included in all statistical analyses.

Species	Ground	Flyovers		Species	Ground	Flyovers
Gray Catbird	**5884**	**5**		**Scarlet Tanager**	**9**	**0**
Northern Cardinal	2609	3		American Robin	8	0
Blue Jay	2041	25		**Yellow-bellied Flycatcher**	**8**	**0**

Species	Ground	Flyovers		Species	Ground	Flyovers
Carolina Wren	2016	0		Eastern Screech Owl	8	0
Red-bellied Woodpecker	1633	1		Swamp Sparrow	7	0
Wood Thrush	1311	0		Orange-crowned Warbler	6	0
Carolina Chickadee	961	3		Yellow-throated Vireo	5	0
Eastern Tufted Titmouse	834	3		Great Blue Heron	4	0
Pileated Woodpecker	637	6		American Kestrel	4	2
White-eyed Vireo	595	2		Sharp-shinned Hawk	4	0
Yellow-shafted Flicker	509	9		Cedar Waxwing	3	0
Pine Warbler	507	4		Unknown Raptor	3	4
Unknown Passerine	416	66		Brown-headed Cowbird	3	0
Downy Woodpecker	380	1		Turkey Vulture	3	45
Common Yellowthroat	359	0		Blue-headed Vireo	3	0
Blue-gray Gnatcatcher	310	0		Worm-eating Warbler	3	0
Eastern Towhee	284	1		Black Vulture	3	4
American Crow	229	17		Chipping Sparrow	2	0
Unknown Warbler	217	0		Brown Creeper	2	0
Brown Thrasher	199	1		Broad-winged Hawk	2	1
American Redstart	138	0		Red-headed Woodpecker	2	0
Unknown Thrush	135	12		Great Egret	2	1
Red-shouldered Hawk	123	5		Golden-crowned Kinglet	2	0
Eastern Phoebe	118	0		Blackburnian Warbler	2	0
Unknown Bird	97	15		Canada Warbler	2	0
Yellow-bellied Sapsucker	95	0		Great Crested Flycatcher	2	1
Swainson's Thrush	91	0		Kentucky Warbler	2	0
Common Grackle	87	6		Nashville Warbler	2	0
Hooded Warbler	86	1		Yellow-breasted Chat	2	0
Brown-headed Nuthatch	83	0		Bewick's Wren	2	0
Hairy Woodpecker	78	0		Unknown Sparrow	2	0
Barred Owl	75	0		Mallard	2	0
House Wren	72	0		House Finch	2	0
Unknown Woodpecker	57	1		White-breasted Nuthatch	2	0
Eastern Wood-Pewee	52	0		Purple Finch	1	0
Ruby-crowned Kinglet	46	0		Cooper's Hawk	1	0
Eastern Bluebird	44	6		Mississippi Kite	1	1
Summer Tanager	44	0		Red-winged Blackbird	1	0
Magnolia Warbler	43	0		Common Loon	1	0
Red-eyed Vireo	42	0		Unknown Heron	1	0
Wild Turkey	42	0		Sedge Wren	1	0
Blue Grosbeak	40	2		Unknown Nightjar	1	0
Acadian Flycatcher	31	0		Vesper Sparrow	1	0

Species	Ground	Flyovers		Species	Ground	Flyovers
Black-and-white Warbler	28	0		Winter Wren	1	0
Unknown Empidonax	27	0		Baltimore Oriole	1	0
Yellow-billed Cuckoo	26	0		Black-throated Blue Warbler	1	0
Ruby-throated Hummingbird	23	0		Indigo Bunting	1	0
Rose-breasted Grosbeak	23	0		MacGillivray's Warbler	1	0
Veery	23	0		Northern Parula	1	0
Great Horned Owl	23	0		Olive-sided Flycatcher	1	0
Gray-cheeked Thrush	21	0		Prothonotary Warbler	1	0
Unknown Wren	21	0		Unknown Vireo	1	0
Belted Kingfisher	21	1		Yellow Warbler	1	0
Mourning Dove	20	1		American Woodcock	1	0
Northern Mockingbird	19	0		Wood Duck	1	1
Ovenbird	17	0		Fish Crow	1	0
Hermit Thrush	16	0		Red-cockaded Woodpecker	1	0
Black-throated Green Warbler	14	0		Unknown Dove	1	0
Tennessee Warbler	14	0		Osprey	0	1
Unknown Grackle	13	0		Unknown Accipiter	0	1
Chestnut-sided Warbler	12	0		Unknown Buteo	0	1
American Goldfinch	10	4		Unknown Hawk	0	3
Chimney Swift	9	5		Boat-tailed Grackle	0	2

actually exhibited a negative trend for six of the nine sampling seasons modeled (Figure 38) and seven of these models explained less than 20% of the variation in the data. The model for Eglin AFB fall 2006 explained the largest proportion of the variance of any of these models (51%), but examination of the data indicates that the trend line may be heavily influenced by two data points representing abnormally large migratory events (Figure 38b). Nonetheless, the autoregressive error model parameter was the only significant model parameter in any sampling season.

Migrant exodus densities were also not a significant predictor of Δ migrant abundance observed during ground surveys for any region during either season in any year (Table 13). In fact, none of the linear models created for each of the nine sampling seasons explained > 16% of the variation in the data. Moreover, five of the regression lines had positive slopes (Figure 39), which was the opposite of the expected trend. The autoregressive error model parameter was significantly greater than 0 in 5 of the models indicating auto-correlated error terms.

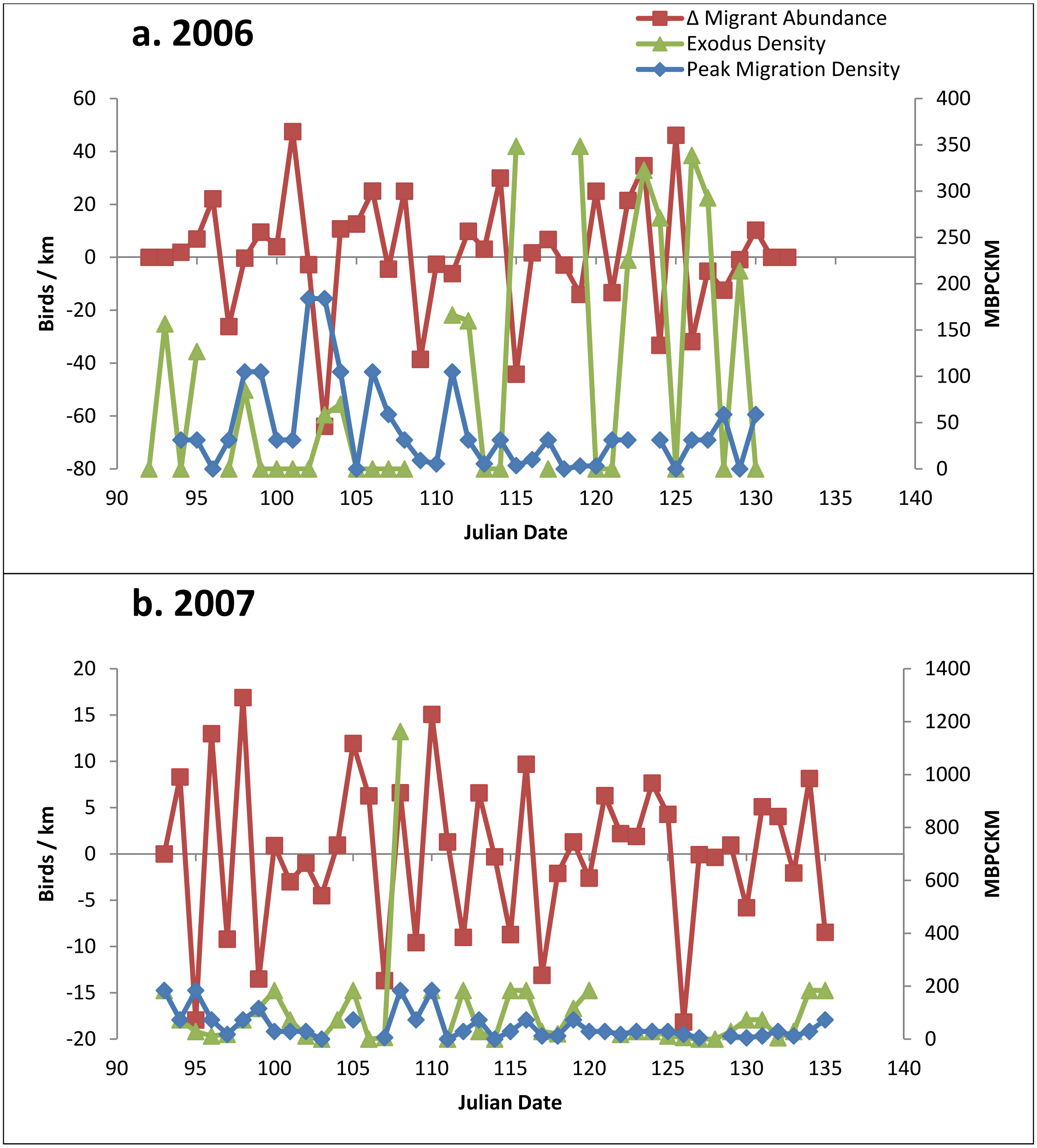

Figure 34. Comparison of the daily change in nocturnal migrant survey abundance with daily exodus and peak migration densities (calculated from radar reflectivity) during spring migration of a) 2006 and b) 2007 near Yuma Proving Ground. The graphs depict 2 y-axes; values on the left axis are in birds/km and represent Δ migrant abundance while the right axis is measured in mean birds birds per km^{3}and represents exodus and peak migration densities. For Δ migrant abundance, values represent the number of migrants recorded on the morning of the plotted date minus the number of migrants recorded on the previous morning. Exodus and peak migration densities represent radar imagery captured in the early hours of the plotted date or the late hours of the previous evening, respectively. Note the differences in scale between figures a and b.

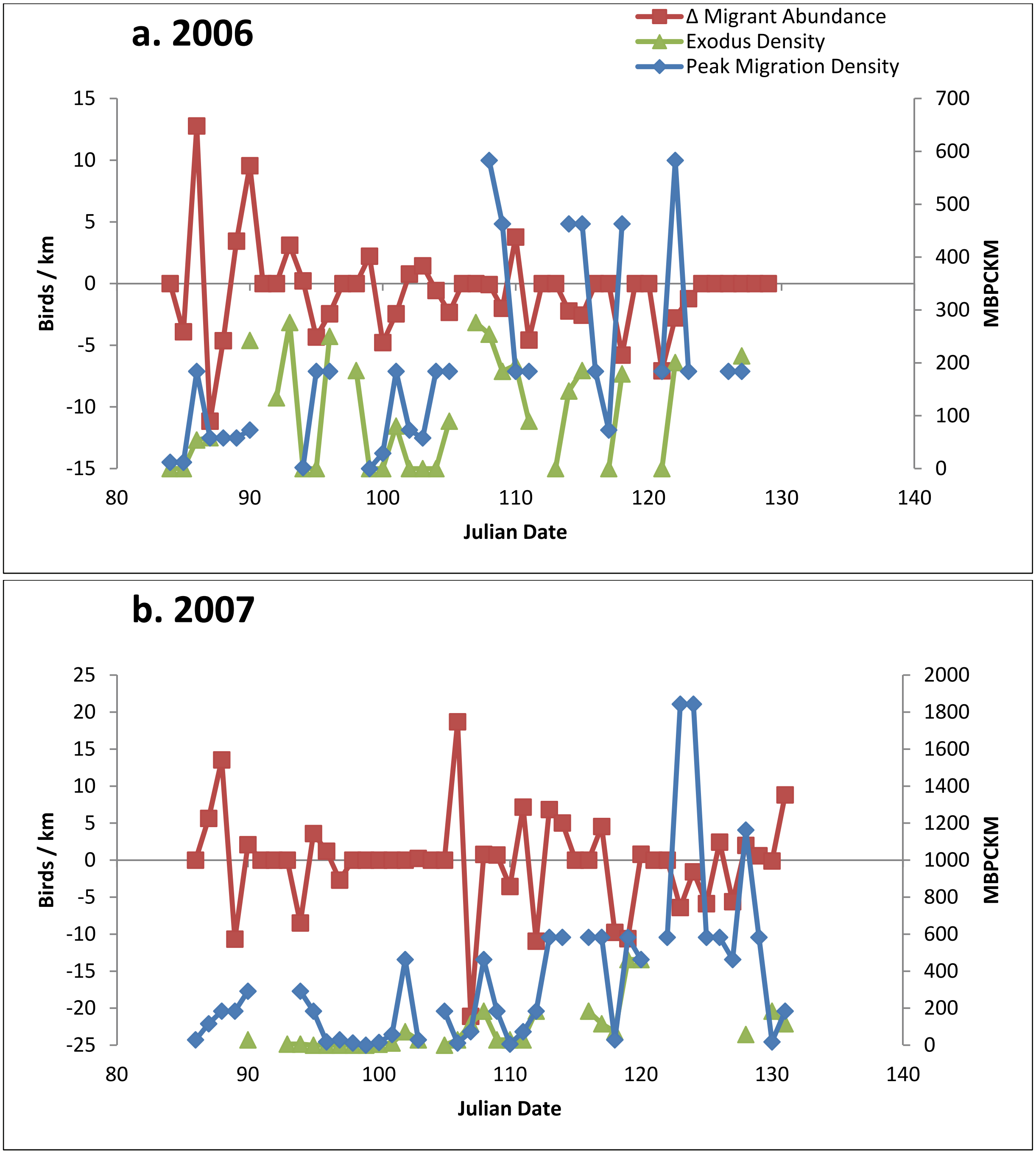

Figure 35. Comparison of the daily change in nocturnal migrant survey abundance with daily exodus and peak migration densities (calculated from radar reflectivity) during spring migration of a) 2006 and b) 2007 at Ft. Polk. The graphs depict 2 y-axes; values on the left axis are in birds/km and represent Δ migrant abundance while the right axis is measured in mean birds per km^{3}and represents exodus and peak migration densities. For Δ migrant abundance, values represent the number of migrants recorded on the morning of the plotted date minus the number of migrants recorded on the previous morning. Exodus and peak migration densities represent radar imagery captured in the early hours of the plotted date or the late hours of the previous evening, respectively. Note the differences in scale between figures a and b.

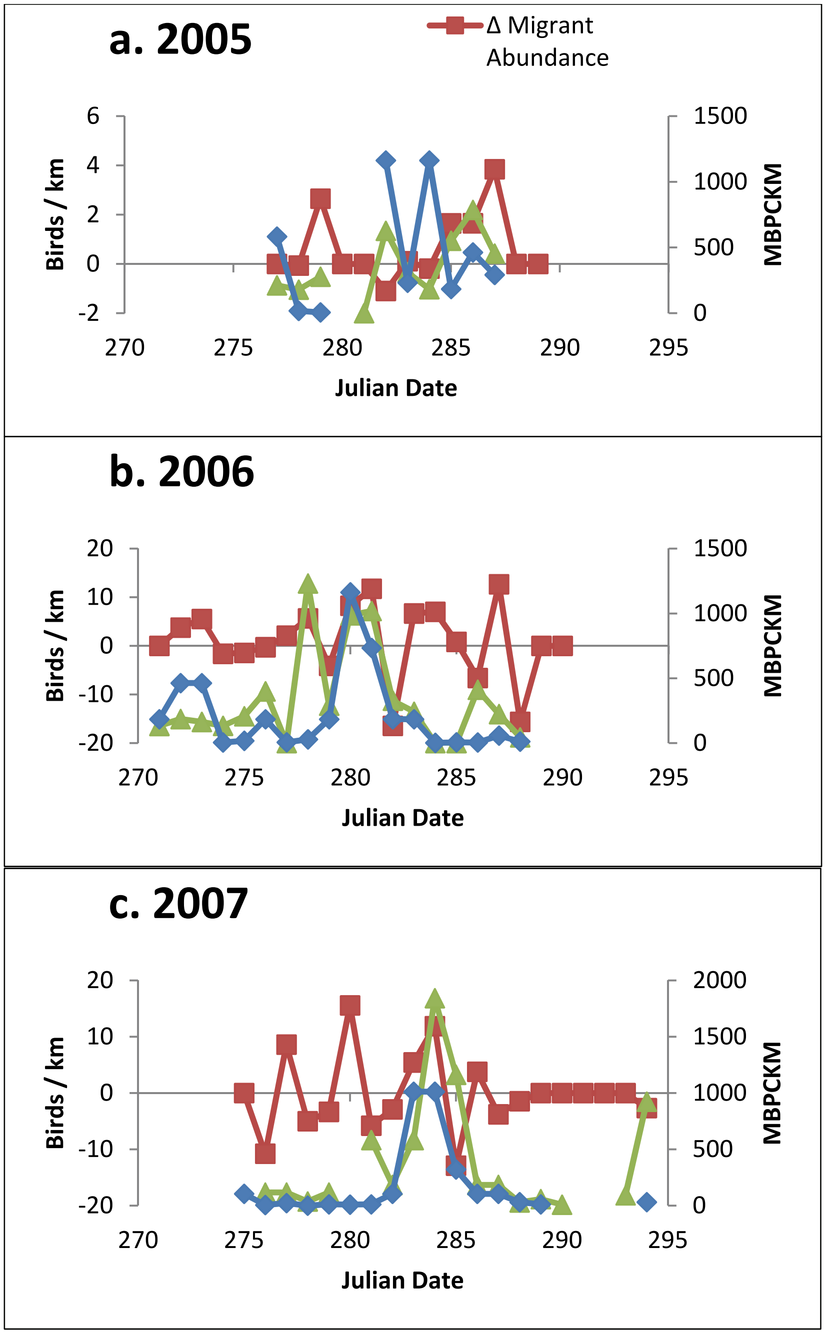

Figure 36. Comparison of the daily change in nocturnal migrant survey abundance with daily exodus and peak migration densities (calculated from radar reflectivity) during fall migration of a) 2005, b) 2006 and c) 2007 at Eglin AFB. The graphs depict 2 y-axes; values on the left axis are in birds/km and represent Δ migrant abundance while the right axis is measured in mean birds per km^{3}and represents exodus and peak migration densities. For Δ migrant abundance, values represent the number of migrants recorded on the morning of the plotted date minus the number of migrants recorded on the previous morning. Exodus and peak migration densities represent radar imagery captured in the early hours of the plotted date or the late hours of the previous evening. Note the differences in scale between figures a, b and c.

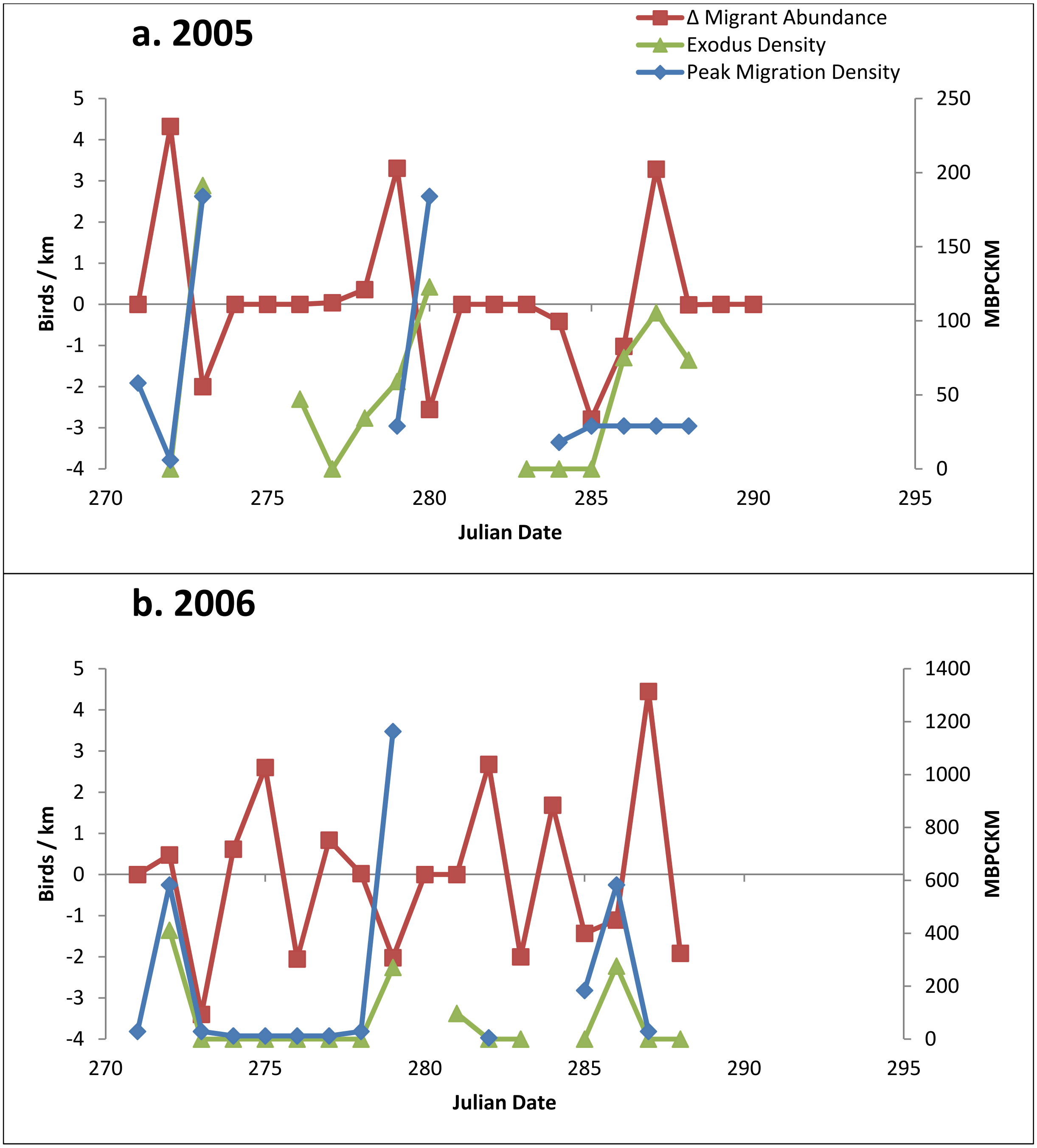

Figure 37. Comparison of the daily change in nocturnal migrant survey abundance with daily exodus and peak migration densities (calculated from radar reflectivity) during fall migration of a) 2005 and b) 2006 at Ft. Polk. The graphs depict 2 y-axes; values on the left axis are in birds/km and represent Δ migrant abundance while the right axis is measured in mean birds per km^{3}and represents exodus and peak migration densities. For Δ migrant abundance, values represent the number of migrants recorded on the morning of the plotted date minus the number of migrants recorded on the previous morning. Exodus and peak migration densities represent radar imagery captured in the early hours of the plotted date or the late hours of the previous evening. Note the differences in scale between figures a and b.

Table 11. Sample sizes for regression models built to explain Δ migrant abundance as a function of peak migration densities and migrant exodus densities captured on radar during spring and fall migration at three military installations.

Season	Region	Year	Peak	Exodus
Spring	Yuma	2006	36	32
		2007	39	40
	Ft. Polk	2006	26	24
		2007	31	20
Fall	Eglin AFB	2005	8	8
		2006	17	17
	Ft. Polk	2007	14	13
		2005	9	11
		2006	12	14

Table 12. Parameter estimates[a] (± standard errors[b]) and fit statistics for linear regression models built to explain the daily change in migrant abundance recorded during bird surveys as a function of peak migration densities captured on radar.

Season	Region	Year	Intercept		Peak Migration		φ_1[c]		R^2
Spring	Yuma	2006	4.50	(4.12)	-0.09	(0.07)	0.33	(0.17)	0.05
		2007	-1.10	(1.32)	0.02	(0.02)	**0.52**	(0.15)	0.01
	Ft. Polk	2006	-0.23	(1.25)	< 0.01	(< 0.01)	0.26	(0.23)	0.29
		2007	0.18	(1.35)	< 0.01	(< 0.01)	**0.43**	(0.17)	0.18
Fall	Eglin	2005	1.87	(0.95)	< 0.01	(< 0.01)	-0.21	(0.73)	0.16
		2006	-0.06	(1.36)	0.01	(< 0.01)	**0.61**	(0.26)	0.51
		2007	-1.12	(1.62)	0.01	(< 0.01)	0.50	(0.25)	0.12
	Ft. Polk	2005	2.15	(1.40)	-0.03	(0.01)	-0.36	(0.44)	0.03
		2006	0.39	(0.62)	< 0.01	(< 0.01)	0.42	(0.40)	0.03

[a] Parameter estimates which were significantly different from 0 are indicated in bold.

[b] Standard error estimates are indicated in parentheses next to the parameter estimate.

[c] Parameter estimate for the autoregressive error model indicating the magnitude of the effect of the error term for day_{t-1} on day_t.

For eight of the nine sampling seasons, peak migration densities were not a significant predictor of positive migrant turnover, and linear models did not explain > 19% of the variance in their respective data sets (Table 14). For Ft. Polk, fall 2006 peak migration density actually showed a significant negative effect on positive species turnover (Figure 40d). This trend is opposite of what was expected as it indicates that larger densities of birds migrating over the region result in more migrant species leaving the region. While this model explains 37% of the variance in the data for that season, the trend line is likely heavily influenced by a large migratory event on one

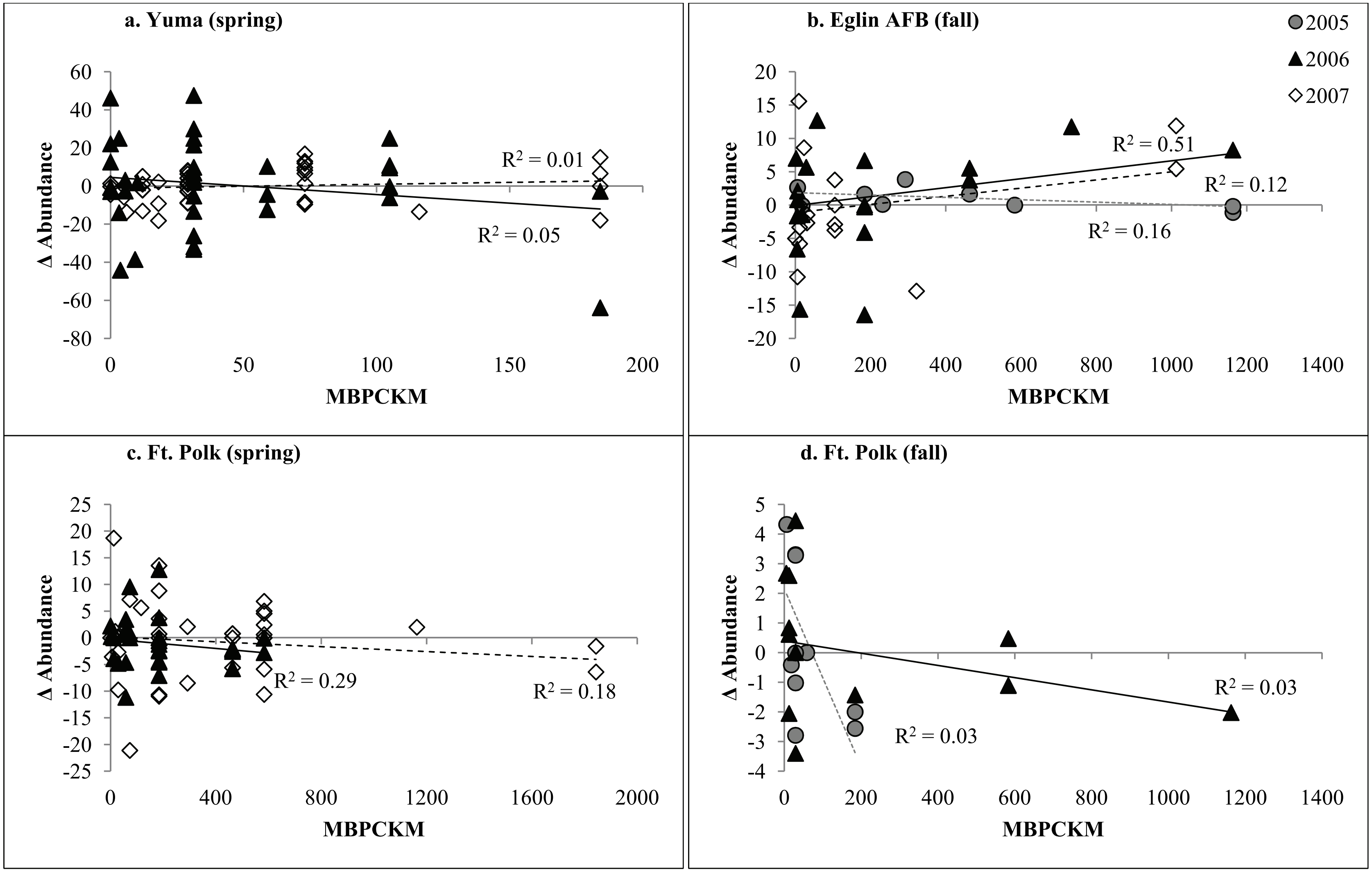

Figure 38. Plots of linear regression models built to explain the daily change in migrant abundance recorded during bird surveys as a function of peak migration densities captured on radar at military installations during spring and fall migration.

Table 13. Parameter estimates[a] (± standard errors[b]) and fit statistics for linear regression models built to explain the daily change in migrant abundance recorded during bird surveys as a function of migrant exodus densities captured on radar.

Season	Region	Year	Intercept		Exodus		φ_1[c]		R^2
Spring	Yuma	2006	7.60	(4.39)	-0.05	(0.03)	0.27	(0.19)	0.09
		2007	-0.22	(0.97)	< 0.01	(0.01)	**0.52**	(0.14)	< 0.01
	Ft. Polk	2006	-1.10	(1.04)	< 0.01	(0.01)	**0.55**	(0.21)	< 0.01
		2007	0.29	(1.53)	-0.02	(0.01)	**0.58**	(0.21)	0.16
Fall	Eglin	2005	0.92	(2.04)	< 0.01	(< 0.01)	-0.23	(0.84)	< 0.01
		2006	-0.21	(1.83)	< 0.01	(< 0.01)	**0.56**	(0.26)	0.08
		2007	-2.35	(1.86)	< 0.01	(< 0.01)	0.50	(0.28)	0.12
	Ft. Polk	2005	-0.06	(0.94)	0.01	(0.01)	0.53	(0.39)	0.03
		2006	0.20	(0.46)	< 0.01	(< 0.01)	**0.57**	(0.25)	0.08

[a] Parameter estimates which were significantly different from 0 are indicated in bold.

[b] Standard error estimates are indicated in parentheses next to the parameter estimate.

[c] Parameter estimate for the autoregressive error model indicating the magnitude of the effect of the error term for day_{t-1} on day_t.

evening that was approximately twice as large as those recorded on all other evenings. For all nine models the intercept was significantly greater than zero, indicating that a certain number of species are present or detected on day_x which were not on day_{x-1} regardless of the migration intensity between days.

As with peak migration density, there was also no significant effect of migrant exodus density during eight of nine sampling seasons on negative migrant turnover, and five of those models explained ≤ 5% of the variance in the respective data (Table 15). Migrant exodus density did have a significant negative effect on Δ migrant abundance at Eglin AFB in the fall of 2007 (Figure 41), but again this was the opposite of what would have been expected, as it indicates that smaller exodus events result in more species leaving the region. This model explains 37% of the variance in the data and the model for Eglin AFB fall 2007 explains 30% of the variance in the data, yet these negative trend lines are counterintuitive. The intercept for all nine models was significantly greater than 0, indicating that a certain number of species are not present or detected on day_x, which were on day_{x-1}, regardless of the migrant exodus intensity between days.

Finally, treating peak migration and exodus densities as categorical variables did not yield different results. There was no significant effect of high vs. low peak migration densities or high vs. low migrant exodus

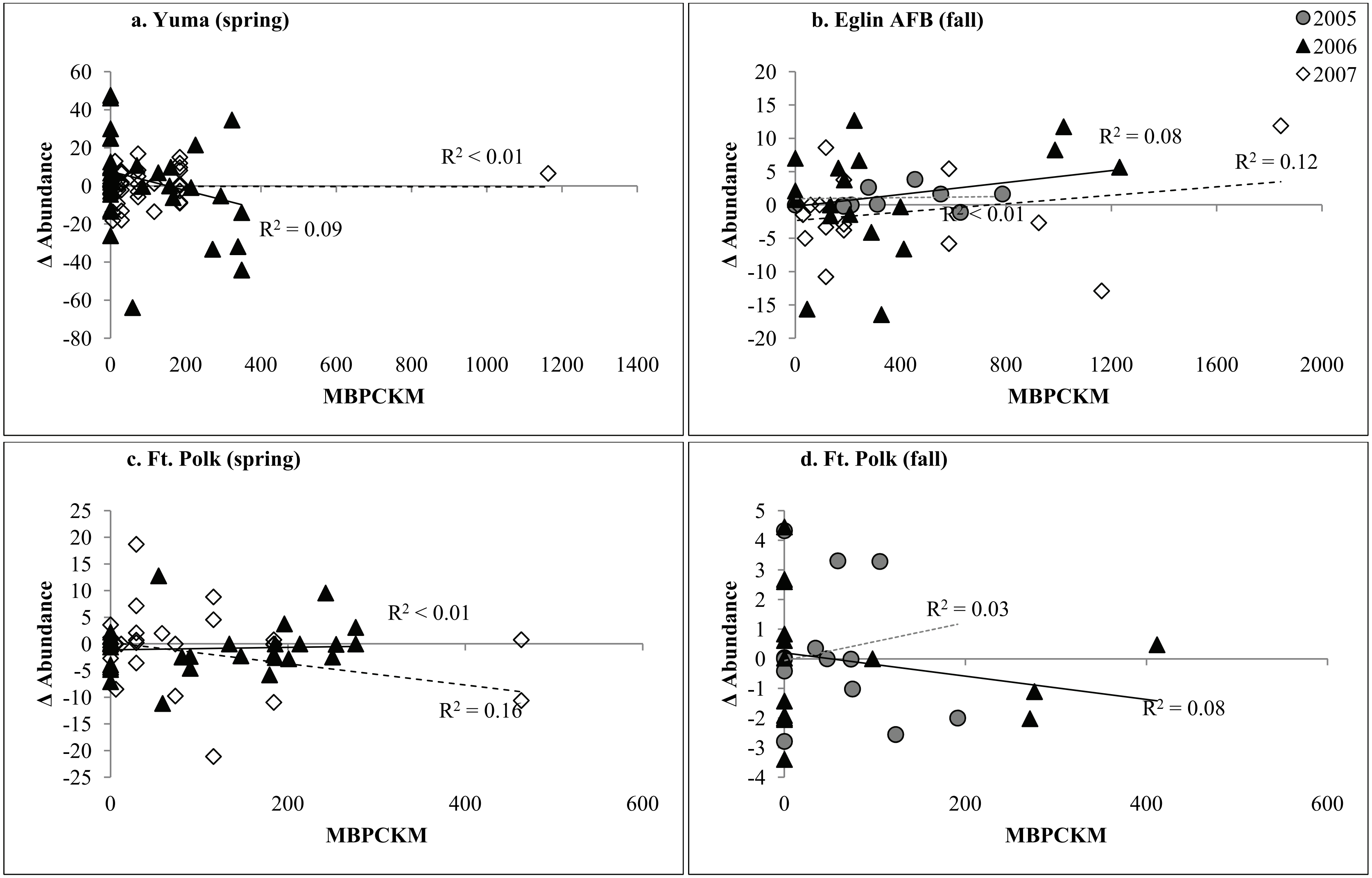

Figure 39. Plots of linear regression models built to explain the daily change in migrant abundance recorded during bird surveys as a function of migrant exodus densities captured on radar at military installations during spring and fall migration.

Table 14. Parameter estimates[a] (± standard errors[b]) and fit statistics for linear regression models built to explain daily positive migrant turnover recorded during bird surveys as a function of peak migration densities captured on radar.

Season	Region	Year	Intercept		Peak Migration		φ_1[c]		R^2
Spring	Yuma	2006	**8.83**	(0.82)	-0.01	(0.01)	**0.35**	(0.17)	0.01
		2007	**7.37**	(0.63)	0.02	(0.01)	0.32	(0.16)	0.10
	Ft. Polk	2006	**4.29**	(0.30)	< 0.01	(< 0.01)	**0.67**	(0.16)	< 0.01
		2007	**6.15**	(0.79)	< 0.01	(< 0.01)	0.02	(0.20)	< 0.01
Fall	Eglin	2005	**3.97**	(1.05)	< 0.01	(< 0.01)	0.77	(0.31)	0.06
		2006	**4.89**	(0.58)	< 0.01	(< 0.01)	0.18	(0.26)	0.19
		2007	**5.37**	(0.57)	< 0.01	(< 0.01)	0.41	(0.29)	0.01
	Ft. Polk	2005	**6.70**	(1.21)	-0.01	(0.02)	0.54	(0.36)	0.08
		2006	**3.78**	(0.31)	**< 0.01**	(< 0.01)	**0.84**	(0.14)	0.37

[a] Parameter estimates which were significantly different from 0 are indicated in bold.

[b] Standard error estimates are indicated in parentheses next to the parameter estimate.

[c] Parameter estimate for the autoregressive error model indicating the magnitude of the effect of the error term for day_{t-1} on day_t.

densities on Δ migrant abundance for any region during either season in any year (Figure 42). In fact, not a single predicted Δ migrant abundance value was significantly different from 0 for any combination of treatments in any sampling season. There was apparently an enormous amount of variation in Δ migrant abundance values which simply could not be explained by peak migration and migrant exodus values alone.

Discussion

The team's results did not show any significant relationships between ground-based avian transect data and two radar measures of bird density over the three study regions in either the eastern or western United States. As far as is known, this is the first study to investigate the relationship between daily changes in migrant communities recorded using field surveys and nightly radar data. Interestingly, Buler and Diehl (2009) had very different results when they analyzed the correspondence between radar and ground-estimated bird densities at 24 survey sites in Mississippi and Louisiana. Their study involved averaging ground and radar data over seasons and using a large number of sites as replicates, whereas the present study used days as replicates within a small number of sites. Unfortunately, the present team was unable to take the same analytical approach as Buler and Diehl for a direct comparison because, in the context of the present team's experimental design, there were only three study sites. However, these results seem to indicate that daily variation associated with migrant movements or detection probabilities may be too high to allow for an accurate daily estimate of input or exodus due to migration.

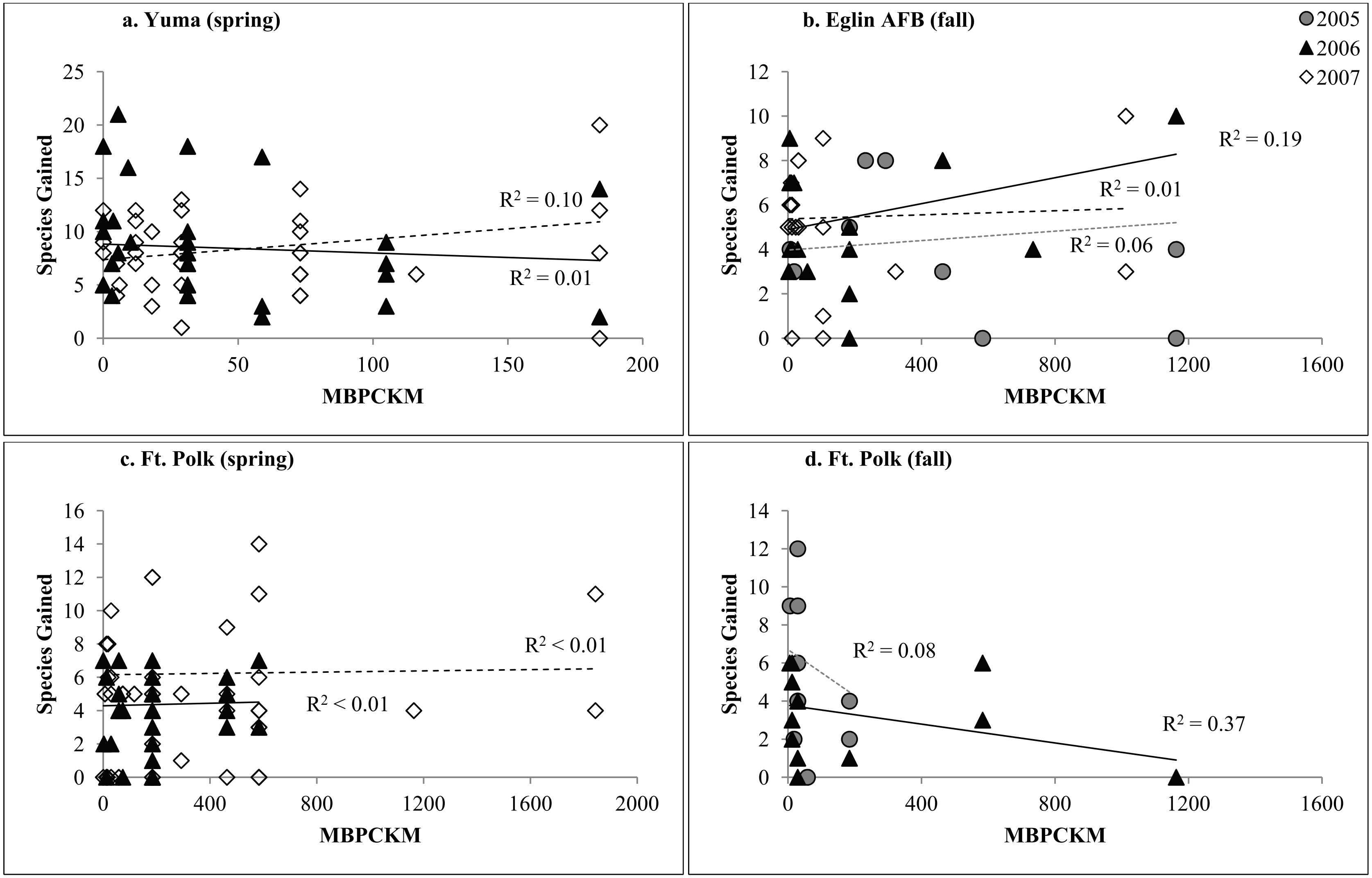

Figure 40. Plots of linear regression models built to explain daily positive migrant turnover recorded during bird surveys as a function of peak migration densities captured on radar at military installations during spring and fall migration.

Table 15. Parameter estimates[a] (± standard errors[b]) and fit statistics for linear regression models built to explain daily negative migrant turnover recorded during bird surveys as a function of migrant exodus densities captured on radar.

Season	Region	Year	Intercept		Exodus		φ_1[c]		R^2
Spring	Yuma	2006	**9.31**	(0.56)	< 0.01	(< 0.01)	**0.66**	(0.14)	0.04
		2007	**7.95**	(0.33)	< 0.01	(< 0.01)	**0.41**	(0.16)	0.03
	Ft. Polk	2006	**7.27**	(1.24)	< 0.01	(0.01)	**-0.60**	(0.18)	0.02
		2007	**6.89**	(0.80)	< 0.01	(< 0.01)	0.28	(0.24)	0.05
Fall	Eglin	2005	**6.76**	(1.38)	< 0.01	(< 0.01)	**0.86**	(0.19)	0.30
		2006	**5.42**	(0.59)	< 0.01	(< 0.01)	-0.08	(0.28)	0.01
		2007	**6.34**	(0.35)	**< 0.01**	(< 0.01)	**0.67**	(0.22)	0.37
	Ft. Polk	2005	**4.58**	(1.83)	0.02	(0.02)	-0.18	(0.47)	0.11
		2006	**3.42**	(0.36)	< 0.01	(< 0.01)	**0.72**	(0.20)	0.09

[a] Parameter estimates which were significantly different from 0 are indicated in bold.

[b] Standard error estimates are indicated in parentheses next to the parameter estimate.

[c] Parameter estimate for the autoregressive error model indicating the magnitude of the effect of the error term for day_{t-1} on day_t.

The hypothesis that change in daily migrant abundance can be explained by nightly migrant exodus or input assumes that virtually all change in migrant abundance stems from birds either arriving or leaving as part of their migratory journey. It does not take into account that birds may remain resident in stopover habitat for varying amounts of time, or move short distances within a small geographical area in search of resources. Residence time by transient migrants in stopover habitat varies and is a function of many factors, including weather (e.g., prevailing winds, weather fronts), habitat quality, species, and physiological condition of individual birds (reviewed in Moore et al. 2005). Also, birds utilizing a region as stopover habitat do not have territories established as they would on their breeding grounds and thus may not be found in the same place on consecutive days, despite being present. Migrants often move in flocks, especially during the fall, and changes in abundance recorded during transect surveys could be heavily impacted by whether or not one of these flocks were present near the transect on a given day independently of when those birds actually arrive or depart. Similarly, the hypothesis does not take into account that individuals, despite being primarily nocturnal migrants, may actually arrive or depart during the day, avoiding capture on nightly radar images (Lowery 1955). Moreover, daily changes in the detectability of species due to weather-related factors could also confound the results. Large fluctuations in daily abundance of permanent residents during some of our study seasons lend credence to the theory that not all changes in the number of migrant birds encountered could be attributed to individuals leaving or arriving as part of their migratory journey.

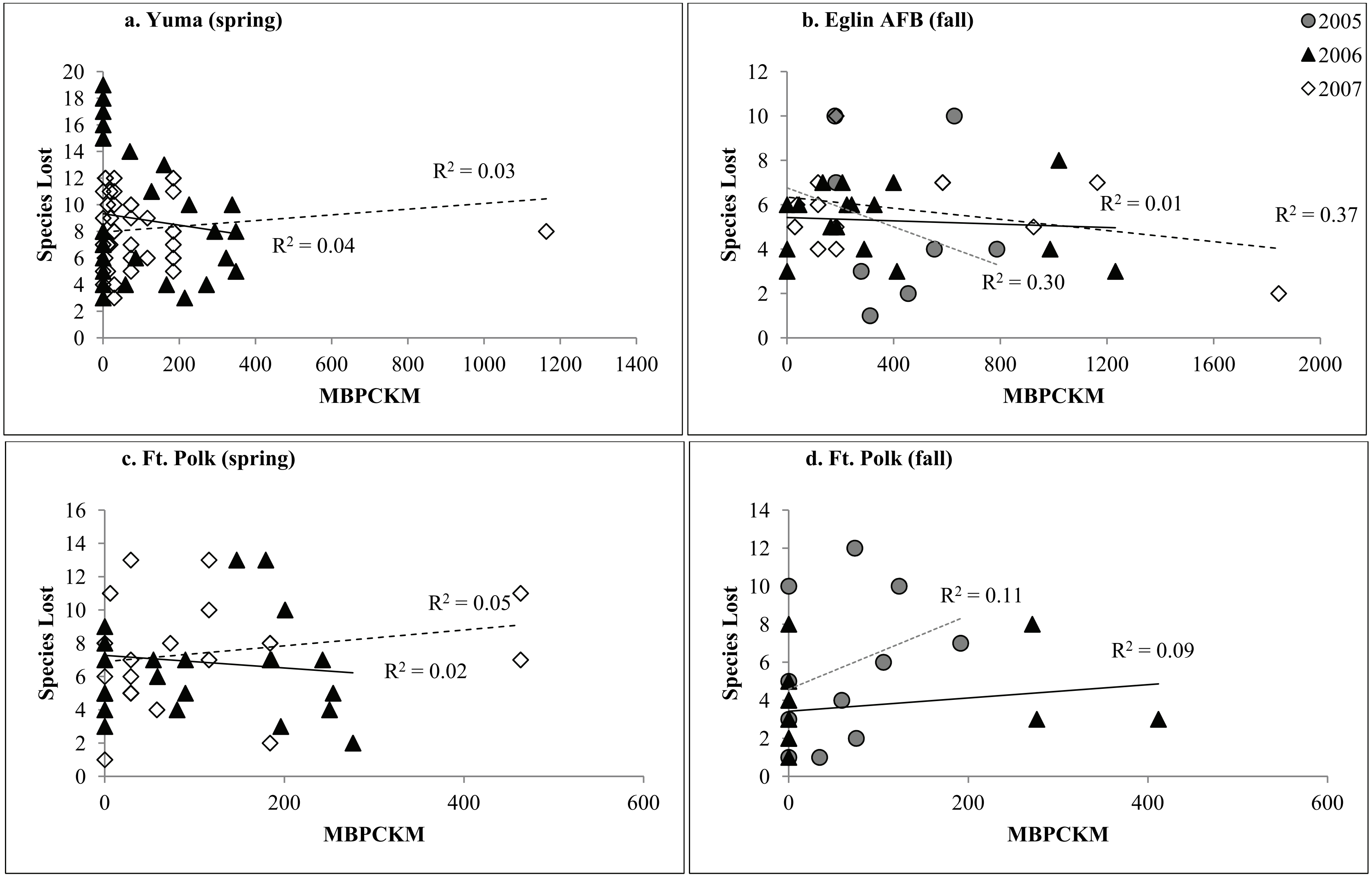

Figure 41. Plots of linear regression models built to explain daily negative migrant turnover recorded during bird surveys as a function of migrant exodus densities captured on radar at military installations during spring and fall migration.

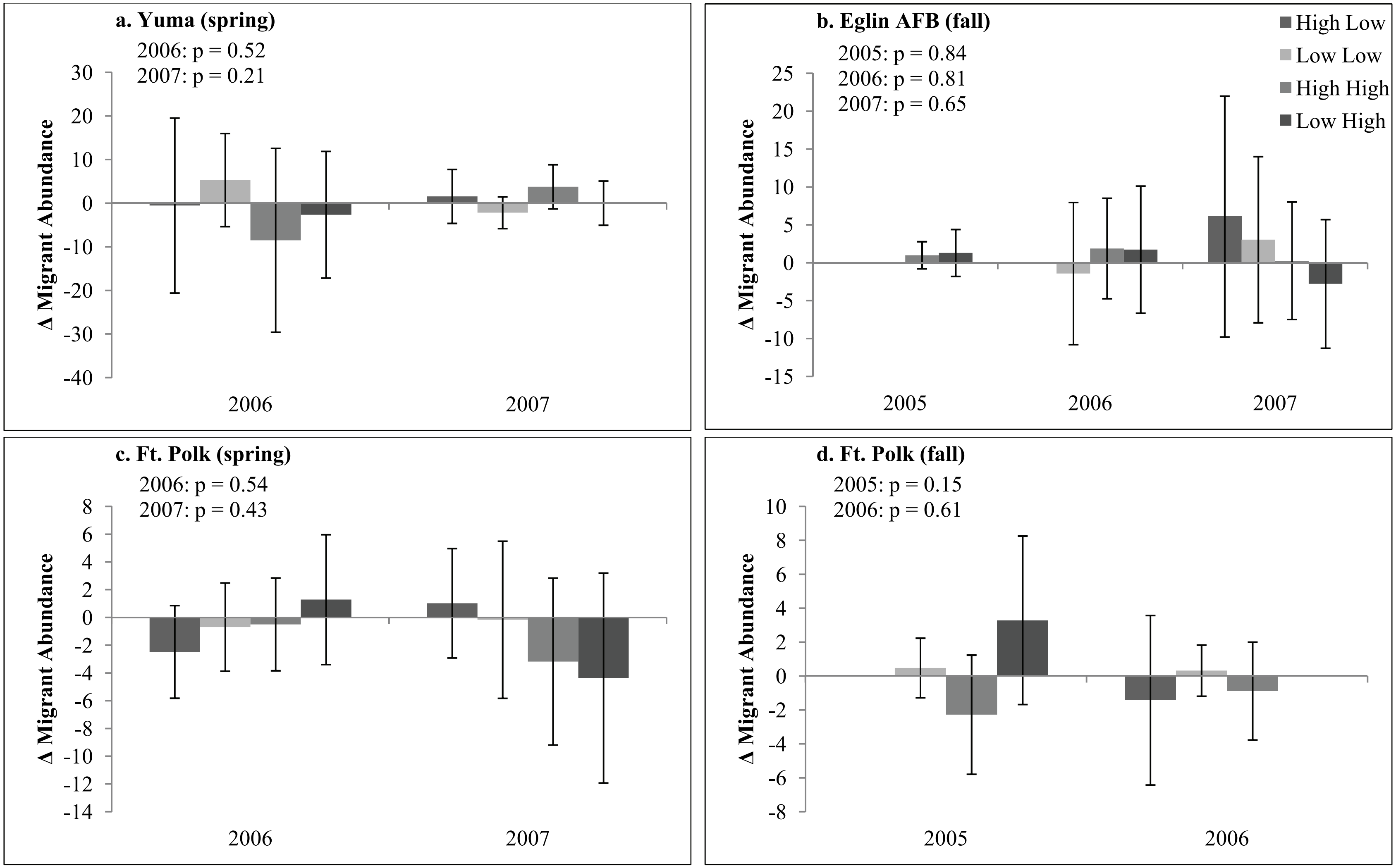

Figure 42. Predicted change in migrant abundance values (and 95% confidence intervals) for days with different combinations of peak migration and exodus treatments. The first label for a bar indicates the peak migration treatment and the second indicates the exodus treatment. Places where a bar is missing from the graph indicate that the treatment combination did not exist in the particular sampling season.

Another factor to consider is that the change in migrant abundance, which is attributable to birds actually arriving or departing the region, is in fact some combination of the two values. It was not possible to include both measures in the same regression models here due to high correlation between the values, and it was not possible to subtract one from another, due to the fact that the measures were not quite on par with one another. While it can be reasonably assumed that all individuals recorded via radar during an exodus event are leaving from the study region, an unknown proportion of birds detected by radar during peak nightly migration are settling down into the habitat. This is currently a difficult parameter to measure with any monitoring technique. Moreover, that proportion may change throughout the course of the night, depending on when the radar reflectivity values were calculated. Peckford and Taylor (2008), for instance, found that the correlation between their ground censuses and radar data varied throughout the course of a night and peaked just before sunrise on nights with unfavorable headwinds, and just after sunset on nights with favorable tailwinds. The fact that all radar reflectivity data for “input” were collected closer to sunset each night (and during the peak of exodus as shown by radar) may suggest that the team was not collecting “input” value at the right time of night. Radar data collected at a smaller spatial scale and over a larger temporal scale may be required to accurately estimate how many individuals are actually arriving on any given night.

The ability to assign birds — captured on radar during an exodus event to specific stopover habitat — as aloft is a challenge that is being addressed by various researchers (e.g., Buler and Diehl 2009). The displacement, or distance, between actual stopover habitat and the location where birds enter the radar beam, is an issue and is related to several factors, including the distance of the birds from the radar, how quickly birds are climbing into the night sky, and atmospheric conditions that may affect bending of the radar beam (Diehl and Larkin 2004). The WSR-88D provides relatively coarse 1° x 1-km (pulse volume) resolution cells. At that level of resolution, it can be difficult to be extremely specific about the origin of departing migrants. Bonter et al. (2009) successfully assigned birds detected aloft by WSR-88D radar to habitat on the ground. They concluded that radar is a powerful tool for identifying stopover habitats of migratory birds, especially when those habitats are discrete and easily identified via land cover maps. Their work linked areas of high migrant activity as evidenced by radar-indicated exodus events to various land-cover types in near-shore terrestrial habitats in the Great Lakes basin. Stopover concentrations of departing migrants were readily identified via radar as “exodus images.” Important habitats included forest fragments that were dispersed in a sea of agriculture and development. The team is confident that within the effective range of the radar beam from point of origin (within approximately 120 km; Gauthreaux and Belser 1998), it was possible to successfully identify stopover habitats at approximately the same scale as the radar. A couple of examples illustrate this point. First, work by Gauthreaux and Belser (1998, 2005) in southern Louisiana and coastal South Carolina strongly suggested that the geometry of reflectivity images from departing migrants were strongly associated with the landscape geometry of forested wetlands and riparian areas along major drainages. This was the main reason riparian habitats the team selected focused ground sampling. Second, at the Yuma, Arizona sites along the Colorado River, the only suitable stopover habitats were discrete riparian areas adjacent to the river (most other vegetated areas were either Sonoran desert or agriculture). Radar data showed that the geometry of the radar-indicated exodus is of similar shape to the available habitat on the ground.

Since radar properly identified broad-scale hotspots at the three sites, another explanation for the lack of correspondence may be that migrants were keying in on specific microhabitats that are not identifiable at the resolution used with the WSR-88D imagery. In other words, exodus imagery may allow the proper labeling of a particular riparian system as a hotspot, but birds may be localized in their habitat use within these systems. Thus, it may be possible that the ground surveyors missed large groups of transient migrants using these microhabitats. This could be especially true in the eastern sites where riparian areas are embedded in a much larger matrix of upland forest. In heavily forested landscapes with few identifiable discrete habitat patches (i.e., discriminated via aerial imagery), such as what is typically found at the study sites on Eglin AFB and Fort Polk, the identification of stopover habitats via radar imagery can be more difficult. The team detected very few transient migrants each day at the eastern sites during both spring and fall and were unable to ascertain whether migrants that were stopping over were using very specific microhabitats in radar-indicated hotspots, or whether they were dispersed over larger areas within these extensive drainages and across adjacent ecotone and upland habitats. If the former is true, and the team didn’t sample in the exact microhabitats where migrants were concentrated, correlations would be expected to be low. In the latter case, large numbers of transient migrants dispersed widely throughout the extensive forested habitat would be difficult to detect in sufficient numbers to show strong relationships with radar data. However, transect sampling covered $\geq$2.5 km of stopover habitat as delimited by the 1 km radar resolution images, suggesting that a significant amount of habitat within radar-indicated hotspots were covered and should have traversed at least some small microhabitats where large flocks would have been detected. This is especially true at Yuma sites, where migrants were concentrated in very discrete riparian stopover habitats and where the majority of hotspot habitat (as indicated by radar) was sampled. This lends further evidence that abundance estimates derived solely from transect surveys of birds in stopover habitat simply are not a good metric for comparison with radar-generated density estimates of birds aloft during exodus.

Additionally, observer bias issues could have contributed significantly to the lack of correspondence between data types. The team attempted to control variation in observer abilities by using skilled birders and having individuals rotate among sites on a daily basis whenever possible. A thorough analysis of ground data, however, showed that observer abilities to detect migrants did vary significantly. To reduce this problem, the team pooled data across sites and developed a single metric of abundance for each region; yet there was likely still some variation introduced by the rotating observers. In retrospect, it may have been prudent to keep each observer at a single site within seasons.

Several recent studies have attempted to relate radar data to avian information collected on the ground. Each of these studies met varying degrees of success and all used different approaches to seeking a relationship between the two. Three of these studies have shown that mist-netting is perhaps the ground-sampling method which yields results most reflective of migratory events captured on radar (Zehnder et al. 2001, Simons et al. 2004, Peckford and Taylor 2008). Simons et al. (2004) found that the number of migrants captured per net-hour in southern Louisiana was significantly correlated with WSR-88D-indicated numbers of migrants aloft. Peckford and Taylor (2008) used three indices of birds on the ground, including mist-netting, and found significant correlations with migrants detected along the Maine coast with a small mobile marine radar. Unlike mist-netting, transect censuses cannot tell researchers whether the migrants they are detecting have been resident in stopover habitat for several days or are the result of migration input. Similarly, on days with low numbers of detections, it cannot be discriminated whether birds departed on migration or whether the birds may have dispersed through the landscape beyond the transects and did not migrate. Daily numbers of transient migrants varied greatly at each of the study regions. Future research should focus on gaining a better understanding of this variation, as it has significant implications for interpreting the results obtained.

Lastly, finer-scale radar data, which is not currently possible with the WSR-88-D, would have been useful for generating metrics for individual sites. The resolution of the WSR-88D is too coarse to detect individual birds as they depart from migration stopover areas. High resolution mobile radar units like eBIRDRAD, can be moved and placed in strategic locations where individual birds can be tracked as they depart from migration stopover areas. Such an effort would allow quantification of echo size, flight direction, flight speed, and quantity of migrant birds leaving from different habitat types. For example, the bird survey data collected along riparian transects on the All-American Canal just North of Yuma, Arizona suggested that migrant bird densities varied significantly among native versus non-native reaches of the transect, with migrants being highly concentrated in native shrub/tree habitats. Although the WSR-88D Doppler weather radar was used to locate important migration stopover areas near Yuma, the resolution of the WSR-88D is too coarse (1° x 1 km for base reflectivity data and 1° x 0.25 km for base radial velocity data) to detect individual birds as they depart from migration stopover areas. The resolution cells contained many different targets and the data reported for the resolution cells are average values. Because eBIRDRAD is mobile it can be moved to several stopover areas to gather high-resolution data on habitat preferences of migrants. By strategically locating eBIRDRAD between habitat types, the team could attempt to quantify the number of migrant birds leaving from different habitat types.

Near the end of the study, the team initiated some very promising collaborative work with Dr. Andrew Farnsworth (Cornell Laboratory of Ornithology) at the Yuma sites, using automated acoustic recording devices. Six of these devices were placed along the YUMA and AAC sites (three at each site) and set up to record nocturnal flight calls from dusk to dawn during each night of the 2007 sampling season. The team's intention is to use these tools as a third measure of bird abundance and species richness. The combination of ground-based survey and acoustics data, along with radar data, will add an additional and interesting analysis of bird migration from this discrete stopover habitat.

Objective 5: Avian Habitat Use in Southwestern Riparian Systems

Data from 70 different sections was analyzed, and over the two years, the team recorded 20,665 migrant detections on the ground from 49 unique species (Table 16). In 2006, 1,496 bird surveys were conducted (26-33 surveys per section) and in 2007, 2,896 bird surveys were conducted (37 and 42 per section). Yearly estimates of mean daily total migrant abundance for individual sections ranged from 5.9 birds/km to 178.4 birds/km and yearly estimates of mean daily migrant species richness ranged from 0.5 species/section to 5.7 species/section.

There was a significant overall habitat effect on both total migrant abundance (F = 15.89, $P < 0.01$) and migrant species richness ($F = 15.64$, $P < 0.01$), and the results from the analyses of these metrics were remarkably similar (Figure 43). The team encountered the greatest abundance and richness values in NS habitats, followed respectively by ND, NND, NT, and NNI habitat sections. In both cases, NNI habitats had significantly lower values than all but ND habitats, and NT habitats had significantly lower values than NS sections.

There was strong evidence that individual species differed in their response to habitat type ($F = 5.31$, $P < 0.01$). Of the 20 species investigated individually, the abundance of 12 differed significantly between habitats while six did not (Table 16). Models for two species were not able to be constructed in PROC GLIMMIX. Nineteen of these species were found in all habitat types, while Yellow-headed Blackbirds were found in all but ND habitats. Peak densities were found of nearly 75% of species analyzed in NS communities, while no species peaked in NNI communities. In fact, abundances were lowest in NNI habitats for 40% of bird species.

Discussion

The team found that spring migrant abundance, species richness, and community composition are all affected by riparian vegetation composition. Results indicate that riparian habitats completely dominated by invasive saltcedar support fewer migrants and migrant species in the spring than other riparian habitat types in the study area. The presence of native vegetation, even in small concentrations, appears to greatly improve habitat value for birds at this time of year. Many species tended to prefer habitats comprised entirely or partially of native shrubs (which here include some shrubs more typical of upland systems), rather than riparian trees.

Table 16. Mean abundance per kilometer for all migrant species recorded at 125 m transect sections of various habitat types during spring migration near Yuma Proving Ground in 2006 and 2007. The 20 most abundant species are indicated with an asterisk, and were tested for statistical differences among habitat types. Habitat types that were not statistically different from one another with regard to abundance of a species share a letter. It was not possible to construct appropriate habitat models for Orange-crowned Warbler or Bullock's Oriole.

Species	Scientific Name	NT		NS		ND		NND		NNI		Total Counted
*Wilson's Warbler	*Wilsonia pusilla*	4.22 ± (0.65)	AC	8.73 ± (1.14)	B	4.32 ± (0.96)	ABC	5.36 ± (1.07)	AB	2.68 ± (0.40)	C	2817
*Common Yellowthroat	*Geothlypis trichas*	9.16 ± (1.43)	A	2.13 ± (0.55)	B	1.97 ± (1.51)	AB	5.61 ± (1.75)	A	5.1 ± (1.52)	AB	2396
*Brewer's Sparrow	*Spizella breweri*	0.03 ± (0.03)	AB	10.29 ± (4.25)	B	10.63 ± (10.44)	AB	0.94 ± (0.32)	A	0.59 ± (0.35)	A	2069
*Ash-throated Flycatcher	*Myiarchus cinerascens*	0.77 ± (0.14)	A	4.73 ± (0.47)	B	4.22 ± (1.35)	BC	3.16 ± (0.78)	BC	2.39 ± (0.33)	C	1617
Unknown Warbler	—	2.6 ± (0.49)		2.61 ± (0.34)		1.86 ± (0.44)		3.31 ± (0.81)		1.67 ± (0.20)		1255
*Western Flycatcher	—	1.02 ± (0.16)	A	3.85 ± (0.33)	B	3.81 ± (0.62)	BC	1.96 ± (0.36)	AC	1.08 ± (0.18)	A	1230
*Warbling Vireo	*Vireo gilvus*	1.28 ± (0.30)	A	3.21 ± (0.44)	B	2.44 ± (0.79)	AB	2.66 ± (0.57)	B	1.05 ± (0.16)	A	1128
*Orange-crowned Warbler	*Vermivora celata*	2.29 ± (0.40)	-	2.84 ± (0.30)	-	1.49 ± (0.45)	-	1.84 ± (0.42)	-	1.45 ± (0.24)	-	1066
*Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	6.48 ± (2.31)	A	0.3 ± (0.12)	B	0 ± (0)	AB	0.62 ± (0.36)	B	0.49 ± (0.22)	B	781
*Nashville Warbler	*Vermivora ruficapilla*	0.5 ± (0.10)	AC	1.9 ± (0.27)	B	1.59 ± (0.59)	ABC	1.14 ± (0.26)	AB	0.43 ± (0.11)	C	600
Unknown Empidonax	—	0.27 ± (0.06)		1.47 ± (0.20)		1.17 ± (0.27)		1.15 ± (0.32)		0.41 ± (0.08)		460
*Yellow-rumped Warbler	*Dendroica coronata*	0.46 ± (0.14)	A	1.07 ± (0.15)	A	0.31 ± (0.15)	A	0.74 ± (0.17)	A	0.74 ± (0.16)	A	406
*Western Kingbird	*Tyrannus verticalis*	0.72 ± (0.18)	A	1.23 ± (0.35)	A	0.6 ± (0.37)	A	0.53 ± (0.14)	A	0.49 ± (0.13)	A	390
*Western Tanager	*Piranga ludoviciana*	0.34 ± (0.10)	A	1.2 ± (0.24)	B	0.53 ± (0.23)	AB	0.86 ± (0.23)	AB	0.36 ± (0.06)	A	385
*Black-throated Gray Warbler	*Dendroica nigrescens*	0.53 ± (0.11)	AB	1.08 ± (0.21)	A	1.19 ± (0.48)	AB	0.75 ± (0.18)	AB	0.19 ± (0.04)	B	380
*Lucy's Warbler	*Vermivora luciae*	0.01 ± (0.01)	A	0.81 ± (0.21)	A	0.92 ± (0.49)	A	1.36 ± (0.51)	A	0.33 ± (0.13)	A	365
*MacGillivray's Warbler	*Oporornis tolmiei*	0.41 ± (0.08)	A	0.86 ± (0.12)	A	1.05 ± (0.42)	A	0.67 ± (0.17)	A	0.18 ± (0.07)	A	328
*Yellow Warbler	*Dendroica petechia*	0.5 ± (0.12)	A	0.85 ± (0.13)	A	0.37 ± (0.15)	A	0.44 ± (0.10)	A	0.38 ± (0.09)	A	320
*Blue Grosbeak	*Passerina caerulea*	0.94 ± (0.16)	A	0.15 ± (0.05)	B	0.51 ± (0.15)	AB	0.63 ± (0.20)	A	0.64 ± (0.16)	AB	265

Species	Scientific Name	NT		NS		ND		NND		NNI		Total Counted
*Townsend's Warbler	*Dendroica townsendi*	0.49 ± (0.12)	AB	0.71 ± (0.12)	A	0.38 ± (0.10)	AB	0.59 ± (0.14)	AB	0.16 ± (0.04)	B	260
*Bullock's Oriole	*Icterus bullockii*	0.38 ± (0.12)	-	0.93 ± (0.17)	-	0.1 ± (0.07)	-	0.28 ± (0.06)	-	0.24 ± (0.08)	-	239
Unknown Hummingbird	—	0.31 ± (0.12)		0.58 ± (0.12)		0.38 ± (0.20)		0.44 ± (0.09)		0.51 ± (0.14)		237
*Black-chinned Hummingbird	*Archilochus alexandri*	0.14 ± (0.05)	A	0.66 ± (0.17)	A	0.1 ± (0.04)	A	0.42 ± (0.14)	A	0.2 ± (0.07)	A	204
Black-headed Grosbeak	*Pheucticus melanocephalus*	0.27 ± (0.09)		0.39 ± (0.07)		0.45 ± (0.13)		0.38 ± (0.07)		0.26 ± (0.07)		179
Western Wood-Pewee	*Contopus sordidulus*	0.09 ± (0.03)		0.52 ± (0.06)		0.35 ± (0.06)		0.46 ± (0.10)		0.1 ± (0.03)		175
White-crowned Sparrow	*Zonotrichia leucophrys*	0.08 ± (0.06)		0.51 ± (0.12)		0.66 ± (0.32)		0.12 ± (0.04)		0.22 ± (0.07)		160
Yellow-breasted Chat	*Icteria virens*	0.36 ± (0.10)		0.19 ± (0.09)		0.41 ± (0.26)		0.76 ± (0.22)		0.04 ± (0.02)		160
Chipping Sparrow	*Spizella passerina*	0 ± (0)		0.37 ± (0.22)		0.24 ± (0.16)		0.31 ± (0.20)		0.41 ± (0.25)		152
Lazuli Bunting	*Passerina amoena*	0.18 ± (0.07)		0.3 ± (0.07)		0.35 ± (0.25)		0.18 ± (0.07)		0.09 ± (0.03)		111
Bell's Vireo	*Vireo bellii*	0 ± (0)		0.2 ± (0.13)		0 ± (0)		0.26 ± (0.18)		0 ± (0)		67
Blue-gray Gnatcatcher	*Polioptila caerulea*	0.05 ± (0.02)		0.18 ± (0.05)		0.03 ± (0.03)		0.05 ± (0.03)		0.08 ± (0.03)		50
Ruby-crowned Kinglet	*Regulus calendula*	0.1 ± (0.03)		0.1 ± (0.03)		0.22 ± (0.11)		0.05 ± (0.03)		0.07 ± (0.02)		45
Olive-sided Flycatcher	*Contopus cooperi*	0.03 ± (0.02)		0.07 ± (0.02)		0.1 ± (0.07)		0.11 ± (0.04)		0.06 ± (0.02)		41
Hermit Warbler	*Dendroica occidentalis*	0.07 ± (0.03)		0.05 ± (0.02)		0.03 ± (0.03)		0.13 ± (0.05)		0.1 ± (0.04)		40
Cassin's Vireo	*Vireo cassinii*	0.03 ± (0.02)		0.11 ± (0.03)		0.06 ± (0.06)		0.11 ± (0.04)		0.01 ± (0.01)		38
Green-tailed Towhee	*Pipilo chlorurus*	0.03 ± (0.02)		0.12 ± (0.03)		0.06 ± (0.06)		0.07 ± (0.03)		0.02 ± (0.01)		35
Unknown Flycatcher	—	0.04 ± (0.02)		0.07 ± (0.02)		0.13 ± (0.09)		0.03 ± (0.02)		0.04 ± (0.01)		33
House Wren	*Troglodytes aedon*	0.02 ± (0.02)		0.12 ± (0.04)		0.1 ± (0.07)		0.04 ± (0.03)		0.02 ± (0.01)		32
Unknown Vireo	—	0.04 ± (0.02)		0.1 ± (0.03)		0 ± (0)		0.05 ± (0.02)		0.03 ± (0.01)		32
Summer Tanager	*Piranga rubra*	0 ± (0)		0.03 ± (0.01)		0 ± (0)		0.18 ± (0.10)		0.01 ± (0.01)		26
Say's Phoebe	*Sayornis saya*	0.01 ± (0.01)		0.06 ± (0.03)		0 ± (0)		0.02 ± (0.02)		0.01 ± (0.01)		13
Unknown Myiarchus	—	0 ± (0)		0.02 ± (0.01)		0 ± (0)		0.06 ± (0.02)		0.01 ± (0.01)		12

Species	Scientific Name	NT		NS		ND		NND		NNI		Total Counted
Swainson's Thrush	*Catharus ustulatus*	0.02 ± (0.02)		0.03 ± (0.01)		0 ± (0)		0.02 ± (0.01)		0.01 ± (0.01)		10
Unknown Thrush	—	0.02 ± (0.02)		0.02 ± (0.01)		0.03 ± (0.03)		0.02 ± (0.01)		0.01 ± (0.01)		10
Hermit Thrush	*Catharus guttatus*	0.02 ± (0.02)		0.02 ± (0.02)		0 ± (0)		0.01 ± (0.01)		0.01 ± (0.01)		8
Hooded Oriole	*Icterus cucullatus*	0 ± (0)		0.05 ± (0.03)		0 ± (0)		0 ± (0)		0 ± (0)		8
Unknown Oriole	—	0 ± (0)		0.03 ± (0.02)		0 ± (0)		0 ± (0)		0 ± (0)		6
Northern Parula	*Parula americana*	0 ± (0)		0.02 ± (0.02)		0 ± (0)		0 ± (0)		0 ± (0)		4
Willow Flycatcher	*Empidonax traillii*	0 ± (0)		0.02 ± (0.01)		0 ± (0)		0 ± (0)		0.01 ± (0.01)		4
Sage Thrasher	*Oreoscoptes montanus*	0.03 ± (0.02)		0 ± (0)		0 ± (0)		0 ± (0)		0.01 ± (0.01)		3
Calliope Hummingbird	*Stellula calliope*	0.01 ± (0.01)		0.01 ± (0.01)		0 ± (0)		0 ± (0)		0 ± (0)		2
Clay-colored Sparrow	*Spizella pallida*	0 ± (0)		0.01 ± (0.01)		0 ± (0)		0.01 ± (0.01)		0 ± (0)		2
Gray Flycatcher	*Empidonax wrightii*	0 ± (0)		0.01 ± (0.01)		0.04 ± (0.04)		0 ± (0)		0 ± (0)		2
Hammond's Flycatcher	*Empidonax hammondii*	0 ± (0)		0.01 ± (0.01)		0 ± (0)		0.01 ± (0.01)		0 ± (0)		2
Lincoln's Sparrow	*Melospiza lincolnii*	0 ± (0)		0 ± (0)		0.03 ± (0.03)		0.01 ± (0.01)		0 ± (0)		2
Plumbeous Vireo	*Vireo plumbeus*	0 ± (0)		0 ± (0)		0 ± (0)		0.01 ± (0.01)		0 ± (0)		1
Rufous Hummingbird	*Selasphorus rufus*	0 ± (0)		0.01 ± (0.01)		0 ± (0)		0 ± (0)		0 ± (0)		1
Unknown Tanager	—	0 ± (0)		0 ± (0)		0.03 ± (0.03)		0 ± (0)		0 ± (0)		1

NNI habitat sections supported significantly fewer migrants and species than almost all other habitat types. Previous investigations into migrant use of Saltcedar have produced mixed results. In the middle Rio Grande Valley of New Mexico, Kelly et al. (2000) recorded greater spring and fall migrant capture rates in riparian areas dominated by willows than other plants. Walker (2008), however, found that migrant abundance and energy consumption were actually highest in Saltcedar habitats during the fall. Avian use of Saltcedar may be influenced by climatic variables (Hunter et al. 1988), but in the team's study region, high concentrations of the invasive plant appear to reduce habitat value for migrants. While the investigation did not examine the cause for the more depauperate bird community in Saltcedar-dominated habitats, it may be that such areas offer reduced structural complexity, cover, or food resources.

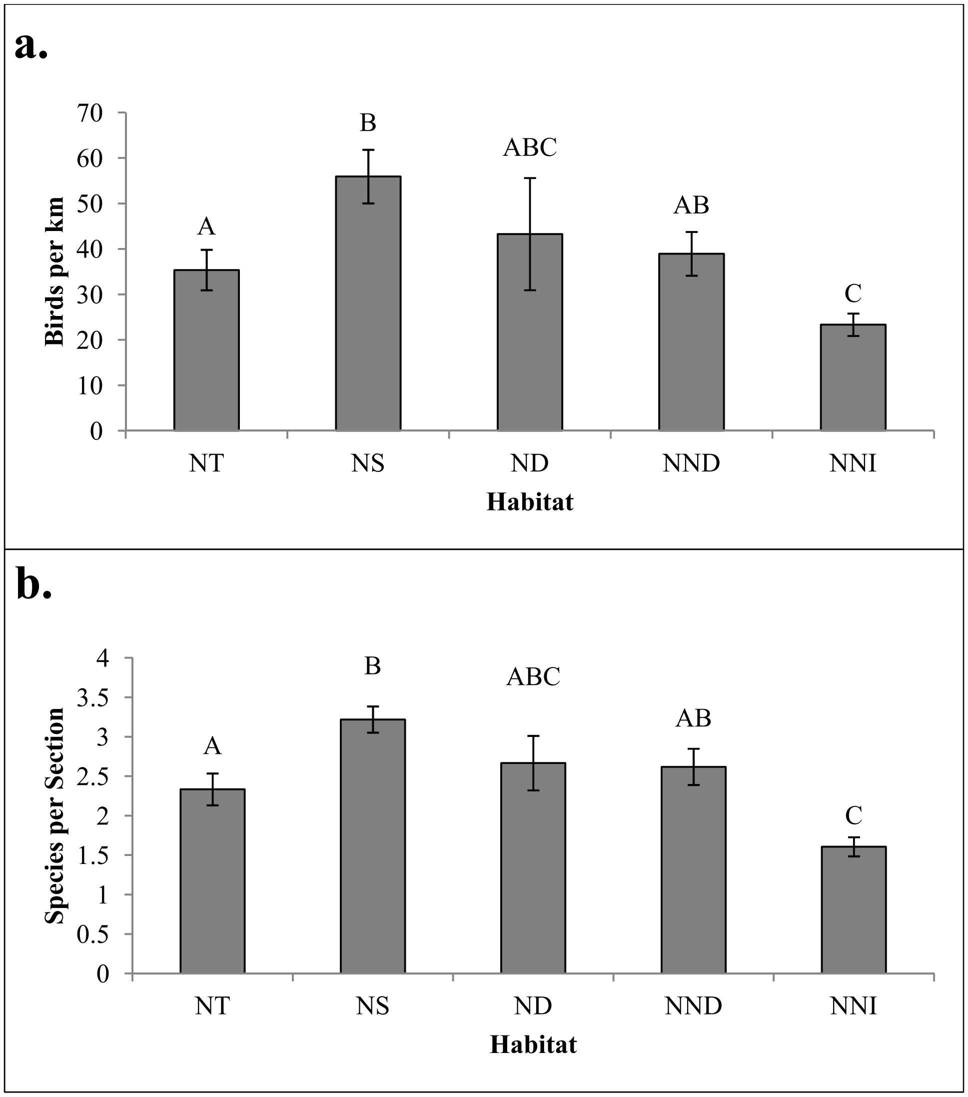

Figure 43. Mean (±*SE*) total migrant abundance per kilometer (a) and migrant species richness per transect section (b) recorded at 125 m transect sections of different habitat types near Yuma Proving Ground during spring migration in 2006 and 2007. Sections were classified as native tree (NT), native shrub (NS), native-dominated with non-natives (ND), non-native/invasive dominant with some natives (NND), or non-native/invasive shrub and tree community (NNI). Bars that do not have a letter in common indicate the response variable was significantly different between those habitat types.

Van Riper et al. (2008) surveyed bird communities throughout the year just north of the present study area and found that abundance of many bird species was highest at intermediate concentrations of Saltcedar. These researchers suggested that there may be a threshold for Saltcedar composition, above and below which the avian habitat value is reduced. The results of the present study somewhat contradict this hypothesis; while NND sections, which included low levels of native vegetation, did attract more migrants than NNI sections, it was also found that habitats completely dominated by native shrubs supported the greatest abundance and richness of migrant birds. Van Riper et al. (2008) did not investigate avian use of habitats dominated by shrub vegetation, but focused on plants that have historically been more typical of riparian communities. However, it is important to consider avian use of these habitats as well, given that it may not be realistic to expect regeneration of Cottonwood and Willows in systems that have been impacted by intense hydrologic alterations (Livingston and Schemnitz 1996; Sogge et al. 2008).

While both NS and ND sections supported greater migrant richness, total migrant abundance, and abundance of several individual species than did NT sections, it is important to remember that all of the did NT sections included in the present analysis were located at Cottonwood restoration sites and were comprised of very young trees. When the team considered avian communities from the four mature Cottonwood sections surveyed in 2007, it was found they also supported lower numbers of migrants (46.33 ± 10.61 birds per kilometer) than NS sections. However, they had substantially greater species richness (3.69 ± 0.80 species per section) than any other habitat type; however, only a small number of mature Cottonwood sections were sampled in one of the sample years. Indeed, Szaro and Jakle (1985) found bird densities and species richness values in areas dominated by riparian trees were greater than or similar to those found in adjacent shrub communities. Thus, further research is necessary to compare migrant habitat use between mature native riparian trees and those dominated by other native shrubs.

The United States Department of Agriculture recently decided to shut down its Saltcedar biological control program over concerns that it was destroying critical Willow Flycatcher nesting habitat. In light of this, it is important to note that nearly half of the migrant species the team detected, including Willow Flycatchers, were found in greatest abundance in shrub habitats. By contrast, nearly 35% of species were found in lowest abundance in NNI habitats. Consequently, allowing the uninhibited expansion of Saltcedar may have detrimental effects on many western migrant species by causing reductions in the availability of preferred stopover habitat. However, results of the present study also suggest that complete restoration of hydrologic processes to support native riparian tree communities may not be necessary to provide decent-quality habitat for en route migrants. Full consideration should be given to the annual life-cycle requirements of riparian species prior to making decisions about Saltcedar contol.

5 Conclusions and Implications for Future Research and Implementation

The national WSR-88D radar system proved to be an effective coarse tool for investigating migrant use of U.S. military installations. The team successfully downloaded and processed archived data to identify installations with high density estimates of migrant use in the spring and the fall, to identify specific locations on installations with varying densities of migrants departing stopover habitat, to summarize temporal peaks in migration, and to develop relatively accurate migration forecast models. Such information can be used by natural resources personnel to identify priority habitats or areas within installations (or, in some cases, contiguous areas outside base boundaries) for conservation and management, and to help reduce the likelihood of BASH incidents by minimizing the overlap between training missions and large migratory events. While the migration forecast models that were developed had high explanatory power, they should be validated with radar and weather data collected in the future to fully understand their predictive capabilities. The authors of this study also recommend testing these models at other military installations in proximity to those investigated in this study. Such information will help determine the usefulness of these models and whether similar models should be developed for other regions or installations.

WSR-88D radar data do have some limitations, however, that cannot be overcome with current technology. First, this system cannot be used to monitor migration on military installations that are located too far away from a NEXRAD radar. Second, WSR-88D radar data can, at best, only quantify migrant densities in 250 m^3 volumes, meaning that it cannot be used to identify smaller-scale migration hotspots or fine-scale movements on and around airfields. Third, WSR-88D radar data cannot provide detailed species composition information. Lastly, the team's results indicated that changes in migrant density calculated from radar surveys and ground-based surveys expressed very different results, which may be related to differences in the scale of observations. The team suggests that future research comparing ground surveys in discrete patches of stopover habitat be compared with radar data collected with high-resolution, mobile eBIRDRAD units to help further understand the relationship between traditional and progressive survey methods.

While it was only possible to closely examine stopover habitat on three installations, this broad-scale survey suggested that many other installations support stopover habitats having high densities of migrants in both spring and fall migration seasons (Appendix B). It is the team's recommendation that these installations use available resources to implement or continue migration monitoring using a combination of radar and ground-based surveys to inventory species and identify priority stopover habitats for conservation and management. These results also suggested that migrant use of such habitats is highly variable both spatially and temporally, so such information should be taken into account when planning inventory and monitoring programs. In particular, special care should be taken to monitor a variety of plant communities because the composition of vegetation seems to have a significant impact on avian use.

Finally, the team's collaborative work with Dr. Andrew Farnsworth and acoustics (Cornell Laboratory of Ornithology) at the Yuma sites may provide additional information on sound-based indices of migrants on the ground versus the transect survey data. The team is currently analyzing those data as a comparison between acoustic data and results of the ground-based surveys. The combination of ground-based survey and acoustics data, along with radar data, will add an additional and interesting analysis of bird migration from this discrete stopover habitat.

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Appendix A: Movement Ecology and Migrant-Habitat Relations: Red-Eyed Vireos During Spring Stopover

Introduction

Movement ecology, or the study of why and how an organism moves from one spatial location to another, is a component of nearly all aspects of animal behavior. An animal's decision to move is likely influenced by a complex combination of internal state and external stimuli (Nathan et al. 2008). An understanding of movement in relation to changing internal state or in a heterogeneous environment is important for understanding ecological processes ranging from life history strategy (Farmer and Weins 1999) to meta-population analyses (With and King 2001). Temporal and spatial decisions about movement are likely to have costs and benefits (Nathan et al. 2008) and costs may be intensified by current environmental changes such as habitat loss or fragmentation (Belisle et al. 2001, Turcotte and Desrochers 2003). Given its importance, there have been relatively few hypothesis driven studies of individual movement decisions within a landscape context (Lima and Zollner 1996, Graham 2001, but see Belisle et al. 2001, Turcotte and Desrochers 2003).

Songbird migrants spend the majority of the migratory period refueling en route (Alerstam 2003) and stopover periods are uniquely well suited to studying movement decisions and their consequences. First, migrants are unlikely to be biased by previous information or experience at stopover sites because extrinsic factors such as weather influence the migratory route (Gauthreaux 1971, Moore and Kerlinger 1991, Nemeth and Moore 2007). Second, decisions are likely to be based on immediate costs and benefits because stopover is temporally restricted by the benefits of arriving early to the breeding sites (Moore et al. 2003, Smith and Moore 2005) and migrants landing after long nocturnal flights are likely to be energetically constrained and needing to refuel to continue their energetically demanding journey (i.e., Bairlein 1985, Moore and Kerlinger 1987, and Wang and Moore 1997). Pressures to arrive early to breeding locations should act to minimize time spent migrating and these pressures are expected to increase as the season progresses (Weber et al. 1998). However, migration is a time of exceptional energetic demands (Blem 1980) and migrants with fewer fuel reserves may require more time for refueling at stopover sites (Kuenzi et al. 1991, Wang and Moore 1993). Therefore, movement decisions during stopover reflect strategies for minimizing assessment time and maximizing refueling rate while avoiding predators and the consequences of decisions are likely to be expressed in a short time period.

Migratory birds may exhibit two types of movement during stopover: 1) within habitat patch for direct resource acquisition and avoidance of stress and 2) between habitat patch for selection of quality. When migratory birds stopover to refuel, habitat quality may vary in terms of prey abundance (i.e., Delingat and Dierschke 2000, Parrish 2000, Farrington 2003, Smith et al. 2004), predation pressure (Lindström et al. 1990, Cimprich and Moore 1999), and competitor abundance (Hutto 1985a). While there is likely some innate preference for specific habitat types (see Berthold 1990), temporal variability in resources between habitat types has led to shifts in use by migrants (i.e., Bairlein 1983, Hutto 1885b, Moore et al. 1990), indicative of selection for habitat quality. To optimize refueling, migrants in unfamiliar landscapes are expected to select the highest quality habitat, containing the most abundant food resources, while expending the least searching effort (e.g., Lindström et al. 1990, Moore 1994, Cimprich et al. 2005). Migrants do preferentially select habitat during stopover because they are not randomly distributed across habitats types (Petit 2000). However, due to the difficulties in following passerines along the migratory route, when that selection occurs is not well understood. Songbird night vision probably is not good enough to make any more than a rough distinction of terrain at night (Martin 1990) and distributions of migrants captured in multiple habitat types differ from the morning to the afternoon (Bairlein 1983, Winker et al. 1995), suggesting that most selection likely occurs the day after landing during an initial exploratory phase (Aborn and Moore 1997). There have been few studies of individual movements in relation to habitat of birds newly arrived at stopover sites but Sedge warblers (*Acrocephalus schoenobaenus*) that landed the previous night moved out of poor habitat during the first hours after dawn (Spina and Bezzi 1990) and Ovenbirds translocated into low and high quality habitat moved out of the low quality habitat but not out of the high quality habitat (Buler 2006).

Migrants have to balance the need to move to access food resources while having little time to assess the predation risk from avian predators attracted to movement (Cimprich et al. 2005). Therefore, a migrant is expected to offset the risk of predation by foraging within as restricted an area as contains the necessary food resources (Cimprich et al. 2005). In habitat characterized by greater density of food resources, migrants do not need to move as far to secure those resources (Delingat and Dierschke 2000). A migrant landing in a high quality habitat can maximize refueling rate and reduce predation risk by exhibiting area-restricted movements and is unlikely to move out of that habitat type. Energetic condition upon arrival at a stopover site is also expected to influence migratory refueling strategy because energetically constrained individuals are under more pressure to replenish fuel stores (Wang and Moore 2005). Constrained migrants increase their predation risk in favor of refueling (Cimprich and Moore 2006) by foraging both more rapidly and over a greater area to access prey resources (Loria and Moore 1990, Moore and Aborn 2000, Wang and Moore 2005, Buler 2006). An energetically constrained migrant may remain within a lower quality habitat, moving over a larger area to acquire fewer resources until it gains some threshold level of fat reserves, after which it may make the decision to search for a better habitat type. Wang and Moore (2005) found that foraging strategies during stopover varied with energy reserves for four species of thrushes. The greater energetic cost of searching for resources and greater risk of predation within a lower quality habitat may mean the constrained migrant is less likely to survive to continue migration. Habitat associations then result in costs and benefits to the individual that affect future movement decisions and, ultimately, survival to the next stage of migration.

Further, after landing at a stopover site, migrants likely use multiple ecological cues to make movement and habitat selection decisions, yet these cues remain poorly understood (Moore and Aborn 2000). Direct sampling of food resources is the most accurate measure of habitat quality, but time and energetic constraints may require migrants to rely on structural or vegetative cues (Moore and Aborn 2000, Buler et al. 2007, McGrath et al 2009). In addition to personally acquired information, social information may be especially useful during migratory stopover when there is environmental uncertainty and little time for assessment of unfamiliar surroundings (Chernetsov 2006, Nemeth and Moore 2007). Acoustic cues or soundscape orientation may be an important component of the available social information (Slabbekoorn and Bouton 2008).

The team conducted an experiment to test the following central assumptions about migrant movement ecology and habitat relations during stopover:

- *Hypothesis A.* Migrants stopping over in a heterogeneous landscape move to select high quality habitat.

  Prediction. Migrants move 1) across habitat boundaries to change habitat types and 2) the frequency of movement out of low quality habitat types is higher than out of high quality habitat types.

- *Hypothesis B.* Movement within a habitat type is related to the quality of that habitat type.

  Prediction. A migrant in higher quality habitat, with greater densities of food resources, will exhibit more area-restricted movement than in a lower quality habitat.

- *Hypothesis C.* Movement during stopover is related to the energetic condition of the bird.

  Prediction. During stopover energetically constrained individuals will move faster and further than will individuals with more fuel reserves.

- *Hypothesis D.* The duration of stay at a stopover site is related to the time of the season and to the energetic condition of the bird.

  Prediction. Migrants stopping over 1) in better energetic condition or 2) later in the season will spend less time at stopover sites than those arriving earlier or in worse condition.

- *Hypothesis E.* Migratory songbirds use conspecific song as a cue to assess the quality of a habitat at stopover sites.

  Prediction. Migrants will remain longer in poor quality habitat with added conspecific song and will behave more similarly to migrants in a higher quality habitat type.

Methods

Focal Species

The red-eyed vireo (*Vireo olivaceus*) was chosen as focal species for this study for several reasons: First, it is one of the most common migrants captured at the netting location (see below) and the most common migrant detected during spring surveys at the release site (see below and this report). Although red-eyed vireos use a variety of substrates for foraging, they concentrate activity in the canopy and subcanopy (Cimprich et al. 2000), so an analysis of their stopover movement ecology and habitat relations is applicable to other canopy gleaners. Furthermore, while red-eyed vireos are primarily foliage-gleaners of Lepidoptera larvae during breeding (Cimprich et al. 2000), they have been found to vary their foraging behaviors according to energetic condition during spring stopover (Loria and Moore 1990). This result suggests that red-eyed vireos change their stopover strategy with energetic condition. The result also provides evidence for making hypotheses about how they will move in relation to habitat quality. The term “migrant” refers to red-eyed vireos throughout the remainder of this chapter.

Capture site

The team captured migrants in chenier habitat in coastal southwestern Louisiana near Johnson’s Bayou (29° 45’ N 93° 30’ W, Figure A1). Cheniers are narrow strips of coastal woodlands dominated by hackberry (*Celtis laevigata*) along the northern coast of the Gulf of Mexico. They are the first available habitat to rest and replenish fat stores following the trans-Gulf flight (Moore 1999). Extensive mist-netting for spring migrants has been conducted at the site since 1993, with the exception of one year (1997). Capture rates vary annually and with netting effort but up to 223 red-eyed vireos have been captured in one season. Because the netting effort covers the chenier and most migrants arrive over the Gulf after 1000 h (see Gauthreaux 1971, 1972), it is relatively certain that a bird captured in the afternoon is a migrant that arrived that day.

Release site

The Vernon Unit of the Calcasieu Ranger District in Kisatchie National Forest (30° 57’ N 93° 08’ W) is in the western portion of Louisiana and is adjacent to Fort Polk, the United States Army’s Joint Training and Readiness Center (Figure 1). This site was initially chosen because it was found to have a high density of spring migrants using radar ornithology (this report). In addition, forest cover types in the Kisatchie National Forest are characteristic of those found throughout the Gulf Coast region (Keddy 2009). They include longleaf pine, pine-hardwood, hardwood, pine regeneration, and harvested or open areas (Evans 1994). There is active management for upland longleaf pine (*Pinus palustris*) stands, and pine-hardwood stands are largely composed of a longleaf pine canopy with a hardwood understory. Hardwood dominated forests are primarily along creeks and slightly lower in elevation than the longleaf pine savannas (Figure A1 inset).

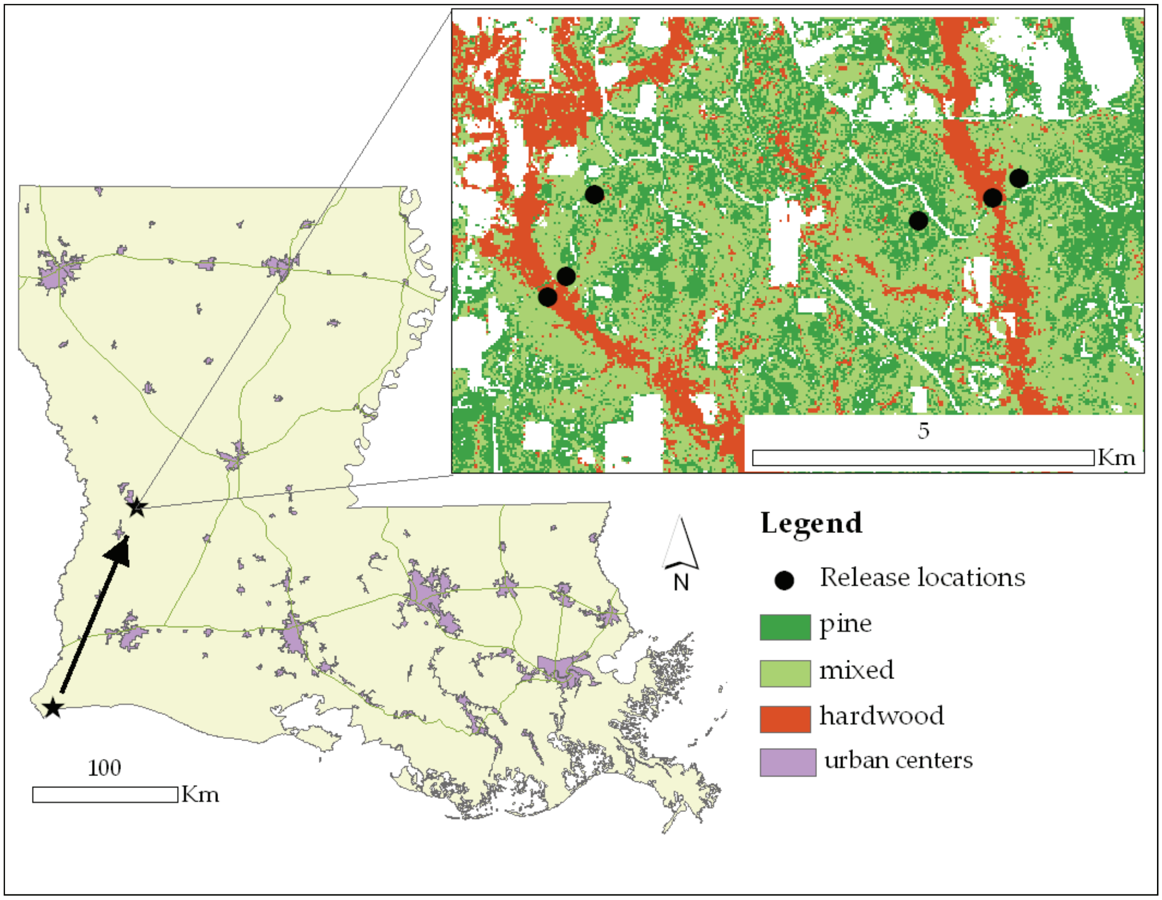

Figure A1. Map of the state of Louisiana with translocation direction (arrow) from capture at Johnson's Bayou to Kisatchie National Forest. Inset map of the study area within Kisatchie National Forest with release locations at Bundick (three ● on left) and Drakes Creek (three ● on right).

Experimental releases

To simulate arrival at a stopover site, the team translocated red-eye vireos with varying amounts of fuel reserves to an unfamiliar heterogeneous landscape and released them before dawn into habitat types varying in quality. Migrants captured in mist nets at Johnson's Bayou were transported the afternoon or evening of the day of capture approximately 17^o and 143 km north to Kisatchie National Forest (Figure A1). Birds were held in individual cages for up to 12 hours and provided with food (meal worms and monkey biscuits) and water ad libitum. The migrants were fitted with radio-transmitters weighing less than 3% of their body mass (models LB-2 and

LB-2N, Holohil Systems). Feathers were removed from the synsacrum and the transmitter was glued to the exposed area using nontoxic glue. Each migrant's mass, fat score (Helms and Drury 1960), wing length, and tarsus length was recorded and a Fish and Wildlife Service band and a unique combination of colored leg bands were placed on the birds.

Migrants were released in the two landscapes at six predetermined locations in three habitat types representative of the region: upland pine savanna (pine), deciduous forests along creeks (hardwood), and an intermediate between the two (mixed) (Figure A1 inset). The hardwood release sites were placed adjacent to Drakes Creek and Bundick Creek along transects where concurrent migrant surveys for radar ground-truthing were being conducted. One pine and one mixed release site were associated with each creek (Drakes and Bundick). The pine and mixed sites were placed in the closest accessible locations that were surrounded by predominately pine or mixed habitat, respectively (Figure A1). The mass and fat score at the time of release was recorded; then the birds were released simultaneously before first light. In the case of rain, birds were released as soon as possible later in the morning. To determine energetic condition, size-specific fat-free masses for red-eyed vireos were calculated. The team ran a regression of wing chord length on mass for all fat score zero (Helms and Drury 1960) red-eyed vireos captured from 1998 to 2006 at Johnson's Bayou (n= 1775). The energetic condition of each individual was determined by subtracting the fat-free mass specific to their wing chord length from their release mass (Owen and Moore 2006). Migrants in positive energetic condition had fuel reserves while migrants in negative energetic condition were below lean body mass and therefore significantly energetically constrained.

During the spring of 2009, the team released migrants at only two of the predetermined locations in upland pine savanna (pine) and deciduous forests (hardwood) associated with Bundick Creek. The team conducted only paired daily releases of one migrant in pine and one in hardwood; each simultaneously released at 6:30 am. From 24 April through 6 May 2009, the team conducted six paired releases of migrants in pine and hardwood with playback (see "Audio recording and playback" below) added to pine.

Movement observations

Individuals were continuously radio-tracked from dawn to dusk for the first three days after release with locations taken every 15 minutes. To minimize the impact of the observer, the birds were located to within 30 m and then the locations were circled to verify the accuracy before approaching and attempting to make a visual observation. Whenever possible, the team recorded the substrate, height, the success or failure of foraging maneuvers, prey items and other behaviors such as preening or resting (Remsen and Robinson 1990). In 2008, when the team visually observed a bird more detailed recordings were made of all behaviors according to definitions (i.e., foraging, vocalizing, perched, preening, or flying) with the number of seconds that each behavior was continuously observed.

In 2007, migrants were tracked continuously for the first five hours and the last hour of each day of stopover. In 2008, migrants were tracked continuously throughout the entire day for the first three days. In 2008, migrants were located once or twice daily after the first three days to determine the duration of stay in the landscape. Searching for a bird tracked the previous day began at first light at the last known location. Once an individual was no longer detected, a set of locations surrounding the entire study site were visited daily to check signals and verify that migrants no longer detected had continued migration. In addition, once per season personnel from Fort Polk verified from a helicopter that signals not detected on the ground were no longer in the landscape.

Audio recording and playback

On 20 April 2009, the team used a Sennheiser© ME-65 omindirectional microphone, a Telinga© Pro parabola, and an Olympus© WS-110 WMA digital voice recorder to record singing red-eyed vireos near the hardwood release site. The team was reasonably certain that different individuals were recorded based on locations and counter-singing. The recordings were minimally edited to reduce background noise and then chose the one minute with the least background noise and most song clarity for each of three individuals. Three iPods (Apple©) with folding speakers (©Radio-Shack) were placed in the same distances and directions surrounding the pine release site as the detected red-eyed vireos surrounding the hardwood release site (we refer to this artificially added song as “playback”). The playback setup was situated as high in the vegetation as logistically possible to replicate the canopy singing height of red-eyed vireos singing in the hardwood. Each playback setup looped a one minute recording of a single individual and played continuously as long as the migrant tracked remained within 300 m of the release site.

Designation of habitat quality

While categorization of habitat quality in a changing environment can be difficult, the combination of sampling for prey, predators, and competitors should provide a strong line of evidence for habitat quality within the spatiotemporal frame of the study. To measure prey abundance, the team used arthropod sampling and to measure avian predators and density of songbirds (potential competitors), banding and transect surveys were used.

Migrant distribution. During the spring of 2006, the team sampled the relative use of adjacent pine, mixed and hardwood habitats by migratory species using mist-nets to capture and band birds. Twenty standard 12 by 2.5 m, 30 mm mesh mist-nets were used and placed in each habitat type near the ground, mid-canopy, and upper-canopy. Nets were kept open throughout the day except in the case of rain, flooding or high winds.

Daily surveys were conducted along transects associated with each of the release sites in each habitat type in 2008. Transects were 500 m long passing through each release site and flagged every 25 m. The same surveyor conducted the surveys the entire season. Each day from 10 min prior to sunrise until 10 am, he walked at a constant pace (1 km/ hr) along all three of the transects associated with one of the two creeks (pine, mixed, and hardwood). The daily order of the habitat types surveyed was systematically rotated and the creek sampled (Bundick or Drakes) was alternated each day. Surveys were not conducted in rain or high winds. The surveyor recorded the first detection location, species, detection method, and age or sex (whenever possible) for every bird observed within 50 m of the survey transect.

Arthropod abundance. To quantify food resources, the team used canopy branch clipping (Cooper and Whitmore 1990), a method that has been shown to be effective in measuring arthropod prey density on and near vegetation used by foliage-gleaning birds (Johnson 2000). Each year, twenty-four samples were collected at the same location points — every 100 m along transects associated with the release sites — in each habitat type during a week in the early, middle and late spring. The team considered the samples collected systematically in the habitat types to be random in terms of bird use and samples were also collected to compare to food resources in locations where migrants were moving. Some arthropod samples were also taken in locations where migrants were located in 2007 and in 2008. For the majority of birds tracked, the team returned within ten days to take an arthropod sample at the first location point of every second hour along a migrants' movement track for the entire first day of movement. A hoop net was used on an extending survey pole to encompass and then clip a branch 4 to 6 m above the ground (Johnson 2000). The team alternated the times of day that each habitat type was sampled, but did not sample in the very early morning because insects were not as active when it was cooler. Branches approximately 0.25 m long were chosen from the pine (*Pinus spp.*), oak (*Quercus spp.*), or sweetgum (*Liquidambar styraciflua*) canopy tree (≥ 7 m tall), with a branch 4 to 6 m above the ground closest to the sampling point. If there were no trees that fit these criteria within 40 m of the point, then the team sampled the highest branches of the closest of the specified species that was taller than 3 m. When there was more than one designated species present within the sampling area, the team alternated between them at successive sampling locations. Clipped branches were weighed and collected arthropods were identified to order and measured to length.

Statistical Analyses

Designation of habitat quality. Testing was conducted to check for differences in the number of arthropods and the number of Lepidoptera larvae per sample among habitat types and time of season (categorized as early, middle and late in the spring). Testing was also conducted to check for differences in arthropods and Lepidoptera larvae between years and creeks. To determine if migrants were selecting areas with higher food resources in each habitat type, the team tested for differences in the number of arthropods and Lepidoptera larvae per sample between locations selected by migrants and locations along transects. The transect survey data was used to test for differences in the number of red-eyed vireos and avian predators in each habitat type or between drainages. For pair-wise comparisons the non-parametric Mann-Whitney U-test was used because the normality assumptions for parametric tests were rarely met. One-tailed tests were used when *a priori* predictions were directional. Pair-wise comparisons were conducted in SPSS 15.0 (2006).

Movement patterns. Because it was expected that multiple factors to influence migrant behavior, a multi-model inference and an information – theoretic approach were used to analyze the relative explanatory power of seven factors on movement patterns throughout the day — in two hour increments — for each individual during the first three days of stopover. Two parameters were used to quantify movement patterns: Linear displacement (the linear distance between the first and last location of the time period; m) and rate (the cumulative distance between all locations divided by the time in a time period; m hr-1). Due to the fact that the team quantified movement throughout the day for the same individuals, linear mixed-effects models were fitted with restricted maximum likelihood parameter estimation (REML function in library nlme for R, Pinheiro et al. 2010) with the individual bird as the random component. This allowed the team to control for correlations between observations from the same individual. REML estimation was used because it is less sensitive to small sample sizes relative to the number of fixed-effects than traditional maximum likelihood estimation (Zuur et al. 2009). First, models were compared with the same full set of fixed-effects and different random components: 1) no random term, 2) random intercept only and 3) random intercept and slope (Zuur et al. 2009). Akaike's Information Criterion and Bayesian Information Criterion were used to compare models and found the models, including a random intercept — but not a random slope — to be the most parsimonious (Zuur et al. 2009).

To measure the effects of factors on movement throughout the day, 43 biologically plausible models were created and compared. The models were composed of six fixed effects: hour of day (in two hour increments: 6:30 to 8:30, 8:31 to 10:30, 10:31 to 12:30, 12:31 to 14:30, 14:31 to 16:30 and 16:31 to 18:30 CST; hour 2, 4, 6, 8, 10, and 12, respectively); arrival energetic condition (condition); habitat type of the release site (release habitat); creek of the release site (creek); day of season (season); and day of stopover (day) as well as one interaction term, arrival energetic condition by release habitat type. There were no differences between years in exploratory analyses, so the team did not include year in candidate models. A subset of the same set of models without hour (28 candidate models) was used to assess the differential influence of five fixed effects (condition, release habitat, creek, season, and day) and one interaction term (condition by release habitat) on movement during each time period throughout the day. Data transformation (log [x +1]) was used to achieve homogeneity of variance for movement rate and linear displacement.

Akaike's Information Criterion for small sample sizes (AICc) was used to rank, compare, and evaluate all candidate model sets (Burnham and Anderson 2002). All models were presented with a ΔAICc ≤ 2 as plausible competing models (considered the subset of best supported models, Burnham and Anderson 2002). The team also presented the null (intercept only) model for assessment of the relative explanatory power of the plausible models. For variables in more than one top model ($\Delta AICc \leq 2$), parameter estimates were averaged across models containing each explanatory variable and standard errors were calculated from conditional variances due to model selection uncertainty (Burnham and Anderson 2002). The relative influence of each variable (j) was also estimated by calculating w+ (j), the sum of wi (Akaike weights) across all models in the dataset in which variable j occurred (Burnham and Anderson 2002). Model building was conducted using library nlme (Pinheiro et al. 2010) for R (R version 2.1.11, R Core team 2010) and comparison of competing models was conducted using library bbmle for R (Bolker 2010). Relative importance of variables and model-averaged parameter estimates were calculated in Excel according to Burnham and Anderson 2002.

Stopover duration. To analyze the relative influence of condition, release habitat, creek, and season on the duration of stay at the study site, the team built and compared 15 biologically plausible generalized linear models. Akaike's Information Criterion for small sample sizes (AICc) was used to rank, compare, and evaluate all candidate model sets (Burnham and Anderson 2002) as described above.

Conspecific song. To determine if migrants used conspecific song as a cue to habitat quality, the team quantified the amount of time migrants spent within their release habitat for all birds tracked from Bundick pine (with and without playback added) and hardwood during 2007 to 2009. The team constructed and compared the same set of four generalized linear models including all combinations of two main effects: energetic condition (condition) and group (pine, pine with added playback, and hardwood) and one interaction (condition* group) on the amount of time spent in the release habitat during the first five hours after release. The team tested the expectation that added song would be a top supported variable for comparisons of birds released at the same site in pine (with and without song) but not for birds released in pine with song as compared to birds released in hardwood. Therefore, models containing the variable group (pine versus hardwood) would be more supported for comparisons of birds released in pine and hardwood without the addition of playback in the pine (during 2007 and 2008) than for comparisons of birds released in the same two habitat types but with the addition of playback in pine (during 2009). Akaike's Information Criterion for small sample sizes (AICc) was used to rank, compare, and evaluate all candidate model sets (Burnham and Anderson 2002) as described above.

Results

Designation of habitat quality

Migrant distribution. Nets were run for 35 days from 27 March to 5 May 2006 (closed five days due to weather) and 116 individuals of 28 migratory species were caught (Table A1). The majority of the migratory species captured breed in the landscape so most of the individuals captured could have been either breeding or migratory. Some individuals were recaptured on successive days (Table A1). Migrants were found using more than one habitat type, with the majority of the captures in the mixed habitat (86%), few in the hardwood (5%), and a moderate number in the pine (13%). Capture numbers varied during the season but were highest the last week of April and first week of May (Figure A2).

Table A1. Summary of banding effort and captures of migratory species in pine, mixed and hardwood habitat in Kisatchie National Forest from 27 March through 5 May 2006.

	Pine	Mixed	Hardwood	Total
Number of nets	6	6	8	20
Net hours	1254.8	1286.7	1418.3	3959.7
Number captured	13	98	5	116
Number recaptures	4	35	0	39
Number caught per net hour	0.010	0.076	0.004	0.030
Number caught per net hour including recaptures	0.014	0.103		0.040

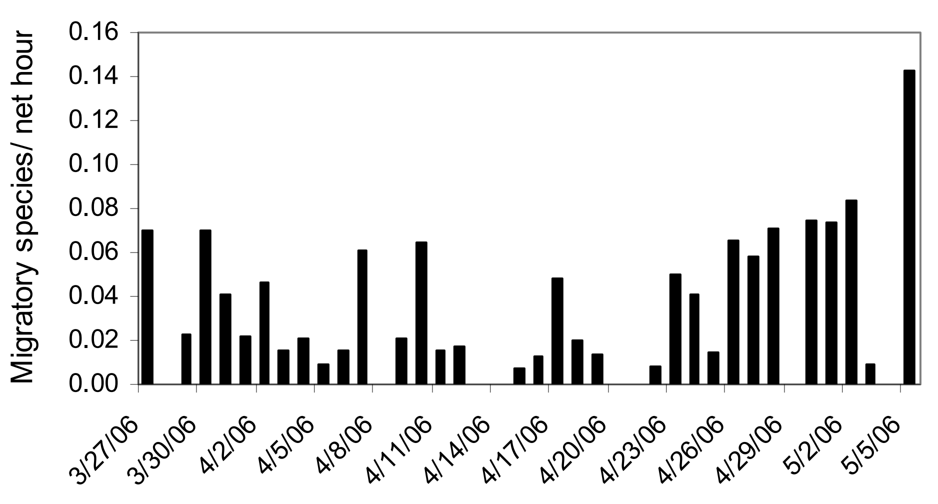

Figure A2. Number of mist-net captures of migrant species (corrected for daily netting effort) by date at Fort Polk, LA from 21 March to 5 May 2006 (excluding five days).

The team recorded 2337 birds on 99 transect surveys during 33 sampling days from 7 April to 18 May 2008. There were no red-eyed vireos detected in pine; singing red-eyed vireos were detected three times in mixed habitat (at Bundick transect on 15 April, 22 April and 16 May). Two to seven red-eyed vireos were detected daily ($\overline{x}$ = 4.36 ± 1.03) on hardwood transects, with more at Bundick than at Drakes Creek (Bundick $\overline{x}$ = 4.94 ± 0.84, n= 17, Drakes $\overline{x}$ = 3.75 ± 0.86, n= 16, $p < 0.001$). Throughout the season only, 3 broad-winged hawks, 17 red-shouldered hawks, 1 sharp-shinned hawk, and 4 hawks of unknown species were detected. The sharp-shinned was detected in the pine habitat, the broad-winged hawks were detected as fly-overs in all three habitat types, and the red-shouldered were detected primarily in pine habitat (n=12) but also in mixed (n=2) and pine (n=3). There were more hawks detected near Bundick (n=17) than Drakes Creek (n=8) but they were detected in all three habitats at both sets of transects.

Arthropod abundance. During the early, middle and late spring transect sampling periods, the team collected a total of 180 arthropod samples in 2007 and 216 in 2008. At locations selected by migrants, 36 samples were collected in 2007 and 368 in 2008. There was no difference between the creeks in number of arthropods (n=198 Drakes, n=198 Bundick, p=0.11) or the number of Lepidoptera larvae (n=198,198, p=0.15). There was also no annual difference in number of arthropods (n=180, 216, p=0.59) or the number of Lepidoptera larvae (n=180, 216, p=0.18). The team combined years and creeks for comparisons of food resources during times of spring and habitat types.

There were no seasonal differences in the number of arthropods (n=108 early, n= 144 middle, n= 144 late, p=0.47) but there were significantly more Lepidoptera larva early versus late in the spring (early n=108, $\overline{x}$=1.42 ± 7.46; late n=144, $\overline{x}$=0.17 ± 0.61, p=0.02), with no difference between those timeframes and the middle of the spring. Significant differences were found in the number of arthropods for all comparisons of pine, mixed and hardwood ($p < 0.000$, Figure A3) and differences between pine and hardwood and pine and mixed habitat in the number of Lepidoptera larvae (both comparisons $p < 0.000$, Figure A3), but no difference between hardwood and mixed (p=0.136, Figure A3). In pine and mixed habitats there were more arthropods in areas selected by migrants (pine p=0.01 and mixed p=0.02) but the converse was true for hardwood habitat (p=0.05, Figure A4). The number of Lepidoptera larvae was greater in areas where migrants selected in pine (p=0.03) but were lower in mixed (p=0.004) and not different in hardwood (p=0.10, Figure A5).

Experimental releases and movement observations

Fifty red-eyed vireos were successfully translocated and tracked during April and May of 2007 (n=17) and 2008 (n=33). In 2007, the team recorded 1,093 individual locations in over 47 days of tracking and in 2008, 3,305 individual locations were recorded on over 66 days of tracking. A total of 24 migrants were released and tracked at the Drakes Creek release sites and 26 migrants at the Bundick Creek release sites for a total of 17 released in hardwood, 16 in mixed and 17 in pine. Migrants moved 21 to 2347 m linear distances from release locations during the first day of stopover ($\overline{x}$ = 618 ± 75 m). The furthest movements occurred during the first two hours of the first day and distances gradually declined throughout the day and with successive days (Figure A6). However, hours four and six (8:31 to 12:30) and ten and twelve (14:31 to 18:30) were similar in displacement distances (Figure A6). Movement rate was also fastest during the first two hours of the first day of stopover (Figure A7). There was not a clear pattern to rate on the second day of stopover but on the first and third day rate gradually declined throughout the day until the last hour when there was an increase (Figure A7).

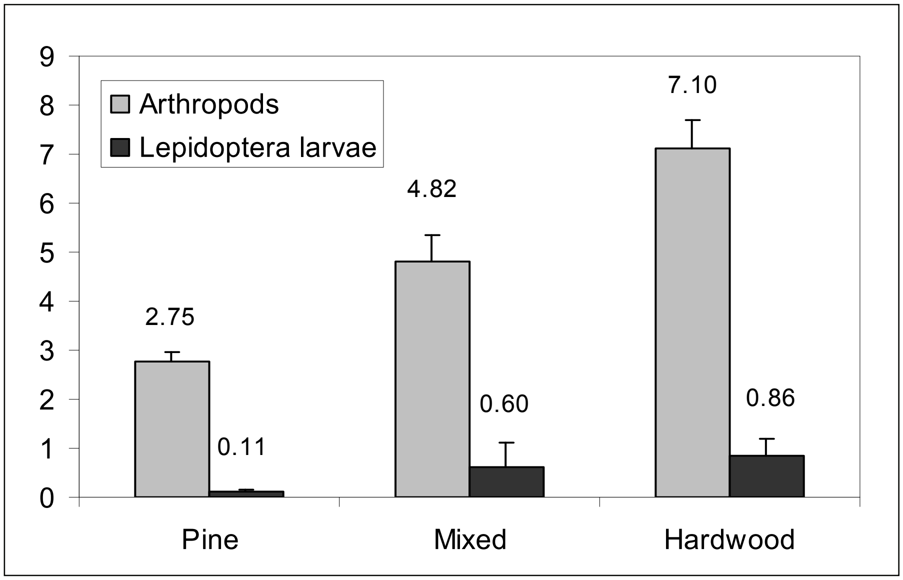

Figure A3. Number of Arthropods and Lepidoptera larvae detected along transects during spring of 2007 and 2008. The mean values are shown and the error bars represent standard deviation. The number of arthropods differed for all comparisons of pine, mixed and hardwood (p <0.001). The number of Lepidoptera larvae were different for pine and hardwood and pine and mixed habitat in (both comparisons p <0.001) but not for hardwood and mixed (p=0.136).

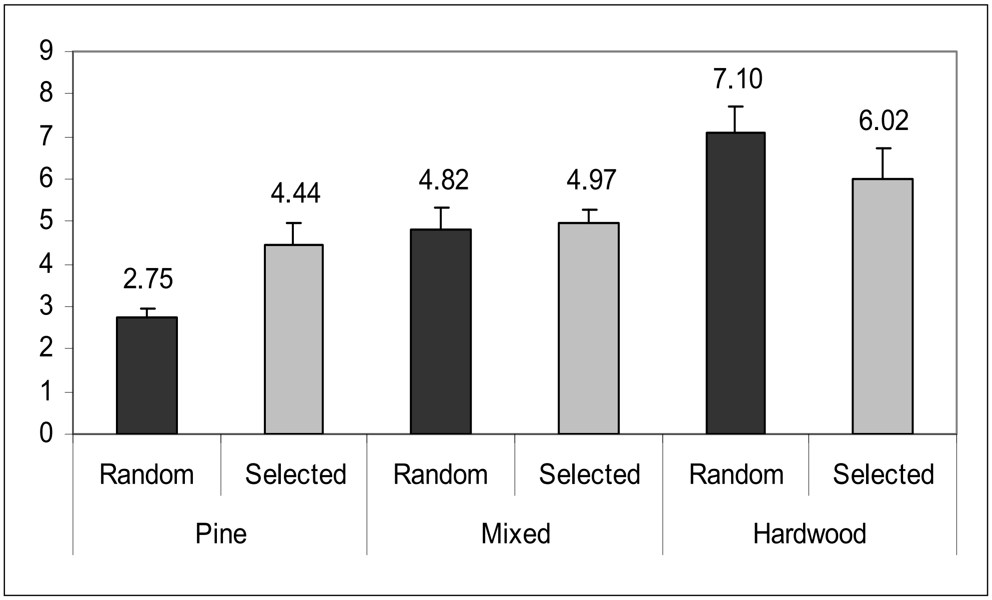

Figure A4. Mean number (bars represent standard error) of arthropods detected along transects (Random) and areas where migrants were located (Selected) in pine, mixed and hardwood habitat (pine p=0.01 and mixed p=0.02 and hardwood p=0.05).

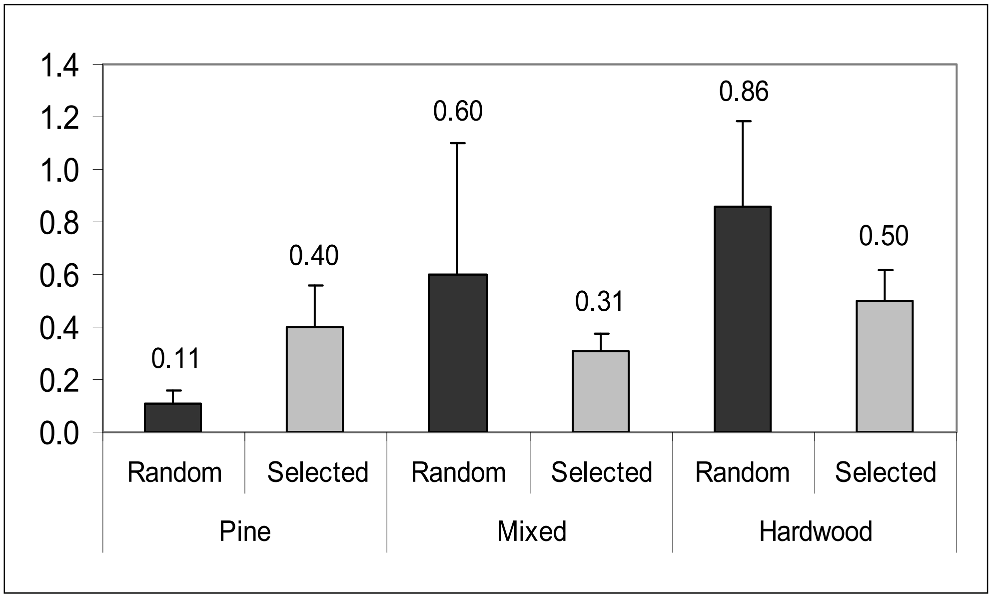

Figure A5. Mean number (bars represent standard error) of Lepidoptera larvae detected along transects (Random) versus areas where migrants were located (Selected) in each habitat type (pine p=0.03, mixed p=0.004 and hardwood p=0.10).

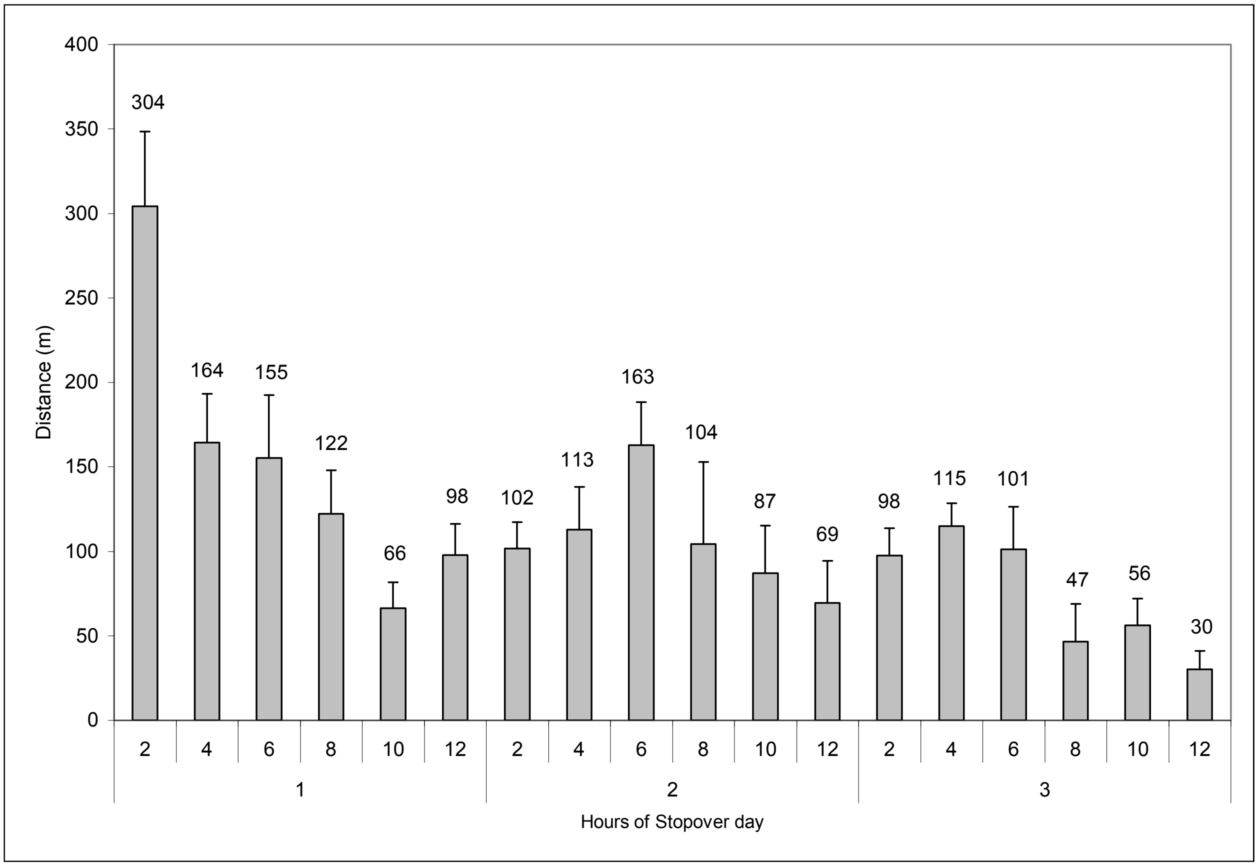

Figure A6. Mean linear displacement (m) by hour of the day and stopover day for the first three days of stopover. Mean values labeled and bars represent standard error.

The team visually observed 38 radio-tagged individuals on 306 occasions. On five occasions interactions were observed between the migrant that was being tracked and a verified unbanded conspecific individual. Two of these migrants were observed having aggressive interactions with another red-eyed vireo and one had a total of three different interactions in different times and locations, all in hardwood habitat. In all cases the migrant tracked subsequently moved away from the area of the interaction. A third tagged migrant was observed perched within three inches of an unbanded red-eyed vireo which was fluttering its wings while making twittering calls and later chased the migrant.

The team did not observe any vocalizations from migrants. Foraging was the most commonly observed behavior (49% of observations). Other commonly observed behaviors were preening (9%), flying (11%), and perching (25%). Migrants were observed foraging in all three habitat types and all except three of the 39 prey items identified were Lepidoptera larvae. Migrants were observed foraging once in *Sassafras albidum*, *Pinus palustris* and *Ostrya*

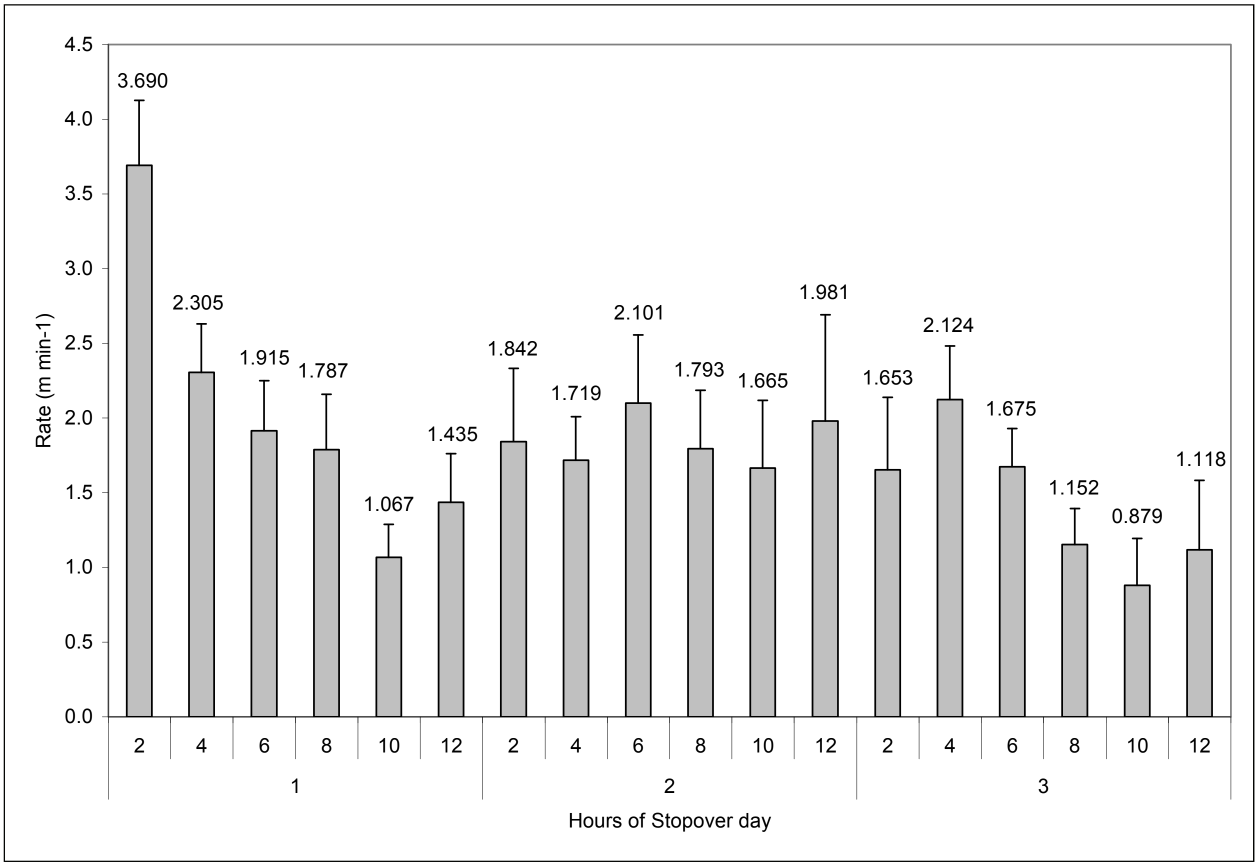

Figure A7. Mean movement rate (m min^{-1}) by hour of the day and stopover day for the first three days of stopover. Mean values labeled and bars represent standard error.

virginiana infrequently in *Cornus florida* (2% of observations), *Acer rubrum* (4%), *Ilex spp.* (5%), *Fagus grandifolia* (6%), and *Magnolia spp.* (10%) and frequently in *Quercus spp.* (51%) and *Liquidambar styraciflua* (20%). There was at least one observation of a successful prey attack in all of the tree species observed frequently or infrequently except *Ilex spp.* The team observed migrants from 1 to 35 m above the ground with a mean of 14.3 ± 8.6 m (n = 192). The number of successful attacks increased from pine to mixed to hardwood habitat (Figure A8).

Hypothesis A

Twenty nine of the 47 birds that we were able to follow continuously throughout the first day changed habitat types after release. The time from release until changing habitat types ranged from 33 min to seven hours, with a mean of 2.65 ± 0.269 hours. The majority of the birds released in the pine and mixed left those habitat types (pine 88% left out of n=16 released; mixed 71%, n=14 released) while the majority of the birds released in hardwood remained in hardwood (29% left, n=17 released, Table A2). Most migrants that left pine or mixed habitat types moved into higher quality habitat types (pine to mixed, pine to hardwood or mixed to hardwood, 75%, n=24, Table A2). Many of the migrants that initially selected one habitat type later moved again to select another habitat type.

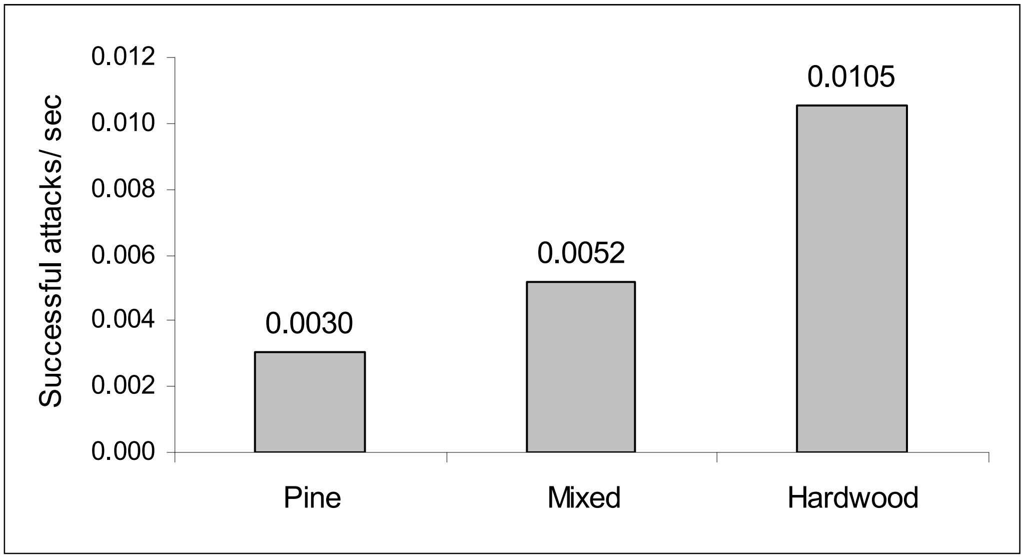

Figure A8. The number of successful attacks per time spent foraging in pine, mixed and hardwood habitat.

Table A2. Number of migrants released in pine, mixed or hardwood that left those habitat types during the first day of stopover and moved pine, mixed, hardwood habitat or another habitat type.

	Selected Habitat				
Release habitat	Pine	Mixed	Hardwood	Other	Total
Pine	---	8	4	2	14
Mixed	1	---	6	3	10
Hardwood	0	3	---	2	5
Total	1	11	10	7	29

Hypotheses B and C

When all hours and stopover days were combined, movement rate and linear displacement were influenced by migrant arrival condition and landscape (creek) but not by the habitat type of the release patch or the day of the season (Table A3). Rate and displacement also decreased with the hour of the day and the day of stopover (Table A4). Habitat type of the release site was only influential in the linear displacement during the first two hours after release. During the first two hours of the first day, migrants released in pine moved further and faster (pine $\overline{x}$ = 462 ± 80 m) than those

Table A3. Comparison of the relative influence of generalized linear models in predicting the movement rate and linear displacement of red-eyed vireos. The number of parameters (K), differences in AICc values (ΔAICc) and Akaike weights (w_i) are shown for all top models (ΔAICc ≤ 4) as well as the null model. Models with ΔAICc ≤ 2 considered equally plausible. Results shown for all hours combined and for each two hour period of the day. Two outliers were removed from hour 2 (6:30 to 8:30).

Time Period[a]	Model description	AICc	K	w_i	Individuals	Observation
All Hours	Linear Displacement				50	382
	Hour of day, Arrival condition, Creek, Day of stopover	0.0	7	0.924		
	Null	33.9	3	< 0.001		
	Movement Rate					
	Hour of day, Arrival condition, Creek, Day of stopover	0.0	7	0.990		
	Null	43.3	3	< 0.001		
6:30 - 8:30[b]	Linear Displacement				48	74
	Habitat, Arrival condition	0.0	5	0.475		
	Arrival condition, Creek	2.3	5	0.151		
	Habitat, Arrival condition, Creek, Condition*Habitat	2.8	7	0.117		
	Arrival condition, Creek, Day of stopover	2.9	6	0.109		
	Null	8.2	3	0.008		
	Movement Rate					
	Habitat	0.0	4	0.266		
	Null	0.0	3	0.261		
	Arrival condition, Creek	1.4	5	0.132		
	Creek	1.9	4	0.105		
	Habitat, Arrival condition	2.5	5	0.078		
	Arrival condition	3.4	4	0.048		
	Day of stopover	3.6	4	0.043		
8:31 - 10:30	Linear Displacement				49	94
	Arrival condition, Creek	0.0	5	0.460		
	Arrival condition	0.4	4	0.368		
	Null	10.4	3	0.003		
	Movement Rate					
	Arrival condition, Creek	0.0	5	0.952		
	Null	13.0	3	0.001		
10:31 - 12:30	Linear Displacement				39	71
	Arrival condition, Creek	0.0	5	0.656		
	Arrival condition, Creek, Day of season	3.9	6	0.092		
	Null	7.1	3	0.019		
	Movement Rate					
	Arrival condition, Creek	0.0	5	0.680		
	Arrival condition, Creek, Day of season	3.7	6	0.105		
	Null	6.3	3	0.029		
12:31 - 14:30	Linear Displacement				33	59
	Day of season	0.0	4	0.226		
	Null	1.9	3	0.158		
	Arrival condition, Day of season	2.7	5	0.101		
	Arrival condition	3.9	4	0.057		
	Movement Rate					
	Arrival condition, Creek	0.0	5	0.406		
	Day of Season	1.0	4	0.236		
	Arrival condition, Day of season	2.7	5	0.107		
	Null	2.8	3	0.093		
14:31 - 16:30	Linear Displacement				32	56
	Null	0.0	3	0.573		
	Arrival condition	3.0	4	0.131		
	Creek	3.5	4	0.099		
	Movement Rate					
	Null	0.0	3	0.819		
16:31 - 18:30	Linear Displacement				14	26
	Null	0.0	3	0.713		
	Movement Rate					
	Null	0.0	3	0.288		
	Arrival condition	0.7	4	0.206		
	Arrival condition, Day of stopover	0.7	5	0.204		
	Day of stopover	1.3	4	0.148		

Table A4. Relative importance and model-weighted averaged parameter estimates (when parameter was included in more than one supported model) of parameters included in top explanatory models (ΔAICc ≤ 2) for movement rate and linear displacement of red-eyed vireos. The conditional 95% confidence interval is calculated for parameters included in more than one top model.

Time Period	Model description	Parameter estimate [a]	Standard error	Degrees of freedom
All Hours	Linear Displacement			
	Hour of Day	-0.1205	0.0226	330
	Arrival Condition	-0.3189	0.0784	47
	Creek [b]	1.5359	0.3089	47
	Day of Stopover	-0.2437	0.0989	330
	Movement Rate			
	Arrival Condition	-0.1351	0.0272	47
	Hour of Day	-0.0495	0.0074	330
	Creek	0.5845	0.1003	47
	Day of Stopover	-0.0861	0.0320	330
6:30 to 8:30	Linear Displacement			
	Arrival Condition	-0.2306	0.0662	45
	Habitat [c]	-0.4249	0.1604	45
	Movement Rate	Null a top model		
8:31 to 10:30	Linear Displacement [d]			
	Arrival Condition	-0.3595	0.0994	46
	Creek	1.1419	0.4058	46
	Movement Rate			
	Arrival Condition	-0.1606	0.0322	46
	Creek	0.5894	0.1205	46
10:31 to 12:30	Linear Displacement			
	Arrival Condition	-0.3576	0.1145	36
	Creek	2.4922	0.4755	36
	Movement Rate			
	Arrival Condition	-0.1312	0.0340	36
	Creek	0.6436	0.1274	36
12:31 to 14:30	Linear Displacement	Null a top model		
	Movement Rate			
	Arrival Condition	-0.1503	0.0391	30
	Creek	0.6562	0.1499	30
	Day of season	0.0297	0.0070	25
14:31 to 16:30	Linear Displacement	Null a top model		
	Movement Rate	Null a top model		
16:31 to 18:30	Linear Displacement	Null a top model		
	Movement Rate	Null a top model		

[a] Values back-transformed from Log10 + 1

[b] Values for creek are Drake = 1 and Bundick = 2

[c] Values for habitat are pine = 1, mixed = 2 and hardwood = 3

[d] Arrival condition parameter estimate and error averaged from top two models

released in mixed ($\overline{X}$ = 238 ± 75 m) or hardwood habitat ($\overline{X}$ =185 ± 52 m). The team released birds with energetic conditions ranging from well below lean body mass (-2.28) to far above (6.3) and the measure of energetic condition was well correlated with visual estimation of fat scores for the migrants released ($R^2 = 0.562$, $p < 0.001$, Figure A9). Condition was a highly influential variable throughout the day for movement rate and linear displacement (Table A3). Throughout the day, as energetic condition increased, movement rate and linear displacement decreased (Table A4). The null (intercept only) model was the top model for most periods in the afternoon, indicating that none of the variables included in candidate models influenced linear displacement after 12:30 or movement rate after 14:30, migrants also moved less during the afternoon hours (Table A3). The only other period when variables did not explain movement pattern was for rate during the first two hours of the day.

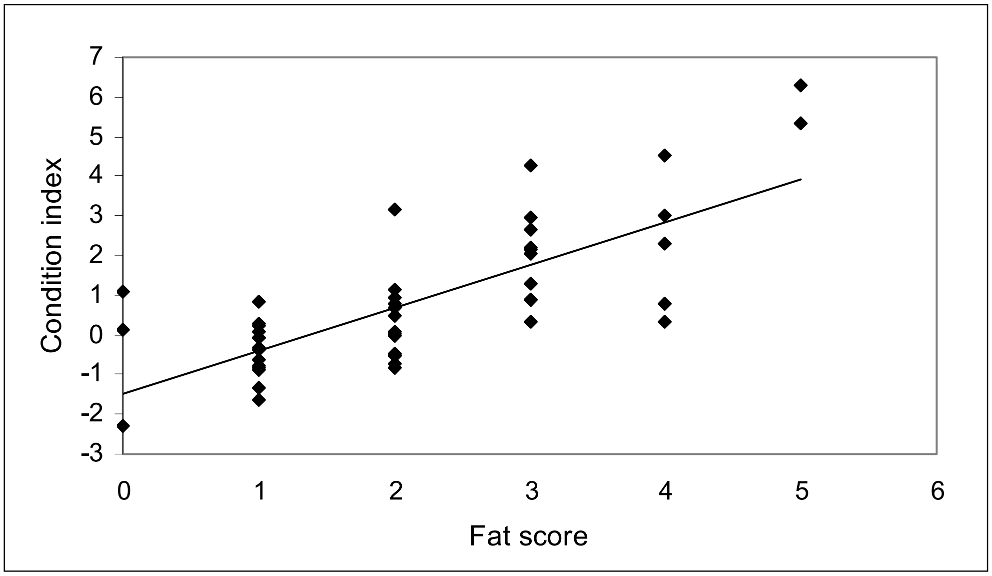

Figure A9. The correlation between fat score (Helms and Drury 1960) and the condition index ($R^2 = 0.56$, $P < 0.001$). A condition index of zero corresponds to zero fat stores or lean body mass.

The release landscape (creek) also consistently explained variability in movement after the first two hours of the day (Table A3). Migrants moved both faster and further at Bundick Creek than they did at Drakes Creek (Bundick rate $\overline{X}$ = 2.444 ± 0.153 m min^{-1} and displacement $\overline{X}$ = 157.046 ± 13.660 m for two hour periods; Drakes rate $\overline{X}$ = 1.494 ± 0.132 m min^{-1}, displacement $\overline{X}$ = 115.880 ± 12.535 m). When all hours were combined, the day of stopover was an important explanatory model, with movement decreasing as migrants stayed successive days (Tables A3 and A4). Time of the season was not highly influential, except from 12:31 to 14:30 when the movement rate increased slightly as the season progressed (Table A4).

Hypothesis D

The team was able to determine the stopover duration of 43 migrants (15 in 2007, 28 in 2008). One migrant stopped over for thirteen days and this bird was excluded from stopover duration analyses because the duration may have been extended due to an unseasonably cold week. For the remaining cases, weather or the end of the season prevented the team from determining whether migrants remained in the landscape. Migrants stopped over from one to eight days (2.857 ± 0.3 days). One third of migrants left the night of the release day (33 percent), 21 percent stayed an additional day and an equal 12 percent stayed for three, four and five days. Finally, four birds stayed longer; one stayed six days, two stayed seven days, and one stayed eight days.

There were two supported models for stopover duration, which explained 61.1 percent of the variation in the data (percent from sum of Akaike weights, w_i), compared to the null model, which accounted for 0.034 percent of the total variation. Both top models included energetic condition and one included day of season. The model-averaged parameter estimate and SE for energetic condition (-0.403 ± 0.156) reflects decreasing duration of stay at the stopover site with increasing arrival energetic condition (Figure A10). In addition, as the spring progressed, migrants spent less time at the stopover site (-0.048 ± 0.027) but most of this relationship was due to the four birds that stayed longer than five days, all of which occurred during the first three weeks of April. When these four individuals are excluded, day of season was no longer a supported variable.

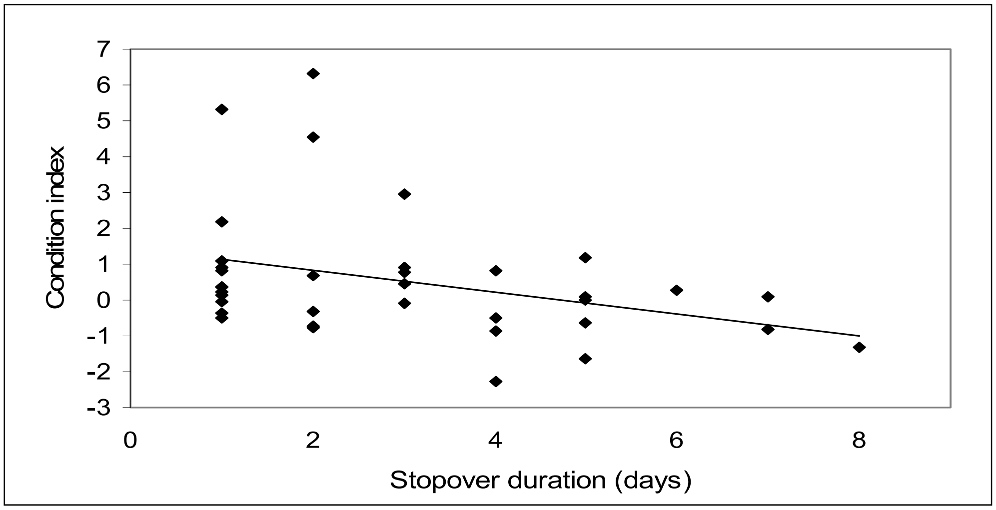

Figure A10. Duration of stay for red-eyed vireos radio tracked in Kistachie National Forest and the relationship between the condition of the bird (negative values are below lean body mass and positive are above) and the duration of stay in days.

Hypothesis E

The team did not find support for differences in behavior of migrants released in pine with and without the addition of conspecific song (Table A5). Energetic condition alone was the only supported model for both the amount of time spent in the release habitat type (Table A5). Without added playback in pine, the habitat type was the only influential variable on the time spent in release habitat. Habitat type, together with condition, continued to influence the time spent in the release habitat with added song in pine (Table A5). Without added playback in pine, migrants released in hardwood spent 2.913 more hours in hardwood than migrants released in pine spent in that habitat type. With added playback, migrants released in hardwood spent 3.381 more hours in their release habitat type than did birds released in pine (Table A5).

Table A5. Relative influence of generalized linear models in predicting the time during the first five hours spent in the release habitat type for migrants released 1) at the same location in pine with and without playback of conspecific song, 2) in hardwood and pine in years without added playback (2007 & 2008) and 3) in hardwood and pine in years with added playback of conspecific song (2009). Number of parameters (K), differences in AICc values (ΔAICc), and Akaike weights (w_i) are shown. All top models (ΔAICc ≤ 2) and the null model are shown. Parameter estimates and standard errors for variables influencing the time in release habitat during the first five hours after release.

Time in release habitat	K	ΔAICc	w_i	Variable	Parameter estimate	se	n
Pine with and without added song (2007 to 2009)							12
Condition	3	0.00	0.789	Condition	0.244	0.058	
Null	2	8.60	0.011				
Hardwood and pine without added song (2007 & 2008)							17
Habitat	3	0.00	0.756	Habitat	2.913	0.685	
Null	2	10.50	0.004				
Hardwood and pine with added song (2009)							10
Habitat and Condition	4	0.00	0.878	Habitat	3.381	0.522	
				Condition	0.427	0.104	
Null	2	9.40	0.008				

Since sample sizes were small, the team conducted a *post hoc* analysis to determine whether increasing the sample size (assuming the current sample is representative of the population) would increase the team's ability to detect the predicted differences. The team also wanted to determine whether the predicted results would be achieved with the addition of a sample size that could be obtained in one logistically possible additional field season. The current sample was randomly sampled to increase each group by factors of three. The sample was built and compared to the resulting models for comparisons of migrants released in pine with and without playback. Six individuals per release type were added, with added playback influencing the amount of time spent in the pine habitat and remaining important with the addition of 12 individuals per release type (Table A6).

Table A6. Comparison of generalized linear models comparing relative influence in predicting the time during the first five hours spent in pine for migrants released with and without playback added (Group). All top models (ΔAICc ≤ 2) and the null model are shown. Each set of models presented represents an addition of 3, 6 and 12 randomly selected pairs of individuals to each group. Number of parameters (K), differences in AICc values (ΔAICc), and Akaike weights (w_i) are shown. All top models (ΔAICc ≤ 2) and the null model are shown.

Model description	K	ΔAICc	w_i
Time in release habitat			
Pine with and without song with n increased by three			
Cond	3	0.00	0.554
Null	2	16.10	<0.001
Pine with and without song with n increased by six			
Cond	3	0.00	0.39
Cond, Group	4	0.50	0.31
Null	2	19.20	<0.001
Pine with and without song with n increased by twelve			
Cond, Group	4	0.00	0.37
Cond, Group, Group*cond	5	0.50	0.29
Cond, Group, Day, Group*Cond	6	1.90	0.14
Null	2	29.80	<0.001

Discussion

The first necessary component in understanding migrant-habitat relations is characterizing habitat quality in terms of availability of food resources and threats or sources of stress. The team found support in terms of food resources for the expectation of variability in habitat quality with hardwood the highest quality, pine lowest and mixed intermediate. There were more arthropods in hardwood than mixed or pine and more in mixed than pine and there were more Lepidoptera larvae in hardwood than pine and in mixed than pine but no difference between mixed and pine. Variability in food resources was also reflected in foraging observations, with migrants having the most successful attacks in hardwood followed by mixed and the least success in pine. However, except for three occasions in mixed habitat, all red-eyed vireos detected on daily surveys were in hardwood habitat and behavioral observations of interactions with breeding red-eyed vireos suggest that conspecific competition may be a source of stress for migrants in hardwood. It's possible that migrant distribution wasn't detectable migrants because the migrants rarely vocalized. Radio-tagged migrants were never observed vocalizing during extensive visual observations. In addition, densities of detected red-eyed vireos along transects remained fairly consistent throughout the survey period indicating a majority of them were breeding birds. Using mist-nets the team detected the greatest density of migratory species in mixed habitat. This could be reflective of greater usage of mixed habitat by migratory — versus breeding — individuals which are less likely to be detected on surveys. However, the difference in canopy height between the hardwood (> 20 m) and mixed (5 to 10 m) habitat in the area sampled makes it difficult to compare capture rates. Even if migrants eventually moved out of the mixed habitat they may have been more likely to be captured in nets while there than while in hardwood. The team's combined measures indicate that hardwood and mixed habitat also contained greater densities of migratory species as potential competitors for the greater abundance of food resources. However, behavioral results suggest that food resources may be the most influential measure of quality for migrants during stopover in this landscape.

Habitat selection may occur at multiple scales from the region to the landscape to the habitat patch (Moore et al. 2005, Chernetsov 2006, Buler et al. 2007 and Packett and Dunning 2009). While some level of selection likely occurs at the regional or landscape scale (Chernetsov 2006, Buler et al. 2007, but see Packett and Dunning 2009), limitations of vision in nocturnal migrants (Martin 1990) mean that selection likely also occurs the morning after landing in a novel landscape. The true frequency of active habitat selection has been difficult to document during stopover because trapping and tracking most often occur after an unknown period of time has already been spent at a stopover site (but see Buler 2006 and Cochran and Wikelski 2005). Present study results indicate that the majority of migrants that found themselves in low quality habitat moved further and faster to select better quality habitat than migrants in higher quality habitat. Selection of locations within habitat types was most strongly related to distribution and abundance of food resources in the poorest quality habitat type but not related to food resources in the highest quality habitat type. The highest quality habitat type was characterized by both greater food resources and foraging success rates.

The present study found support for multiple ecological factors affecting red-eyed vireo movement from one spatial location to another. Movement patterns were also reflective of behavioral variability in relation to habitat quality. Migrants released in the poorest quality moved the furthest and fastest, suggesting searching, and then most changed habitat types, whereas migrants released in high quality habitat initially did not move as far or as fast and moved in a more restricted area. Therefore, migrants that land in high quality habitat may not expose themselves to threats or lose time searching and begin foraging earlier in the morning. Multiple extrinsic factors contributed to the decision to change spatial locations. Rate and displacement distances of movement were also influenced by the release landscape. The release sites were chosen for homogeneity of surrounding habitat in as large an area as possible but sites were embedded within a heterogeneous landscape. Differences between release sites in the same habitat type indicate that landscape context, or the pattern and distribution of habitat types, is also important in determining migratory movement. For example, many of the migrants released in pine moved into small patches of mixed habitat composed of young pine and hardwood along seasonal creeks and surrounded by pine savanna. The distances and directions to these patches differed between the two pines release sites. Also, Bundick Creek, where birds moved both further and faster, has a larger and wider hardwood drainage than Drakes Creek. These results suggest that landscape context may be an important factor influencing migrant behavior.

Migrants made movement decisions based on their internal state in terms of the amount of fat stored and the temporal proximity to the breeding season. Energetic condition and time of season also influenced the duration of time spent in the landscape. Energetic condition did not determine whether migrants moved because even birds with large fat reserves moved out of low quality habitat types to forage in higher quality habitat types, but condition was influential in determining how migrants moved. Fat migrants in high quality habitat moved faster and further than lean migrants in the same habitat type while fat migrants in poorer quality habitat types moved slower and stayed closer than lean migrants also in poorer quality habitat types. This suggests that migrants with stored energy took advantage of foraging opportunities in high quality habitat but were less likely to expose themselves to stress or predation risk by moving to foraging in lower quality habitat. There was minimal support for time of season, which may be due to the fact that it was not possible to accurately measure individual temporal and spatial distance to breeding areas. Inclusion of individual breeding locations as well as age and sex could strengthen the influence of this variable on movement.

Nocturnal migrants arriving in an unfamiliar landscape likely use a combination of cues to assess their surroundings while balancing the need to refuel and avoid predators (Chernetsov 2006, Moore and Aborn 2000). Behavior during stopover may also be influenced by internal factors such as energetic condition and an individuals' time program (Wang and Moore 2005, Moore et al. 2003). Therefore, the team did not expect conspecific song to be the only factor involved or cue used to make movement decisions. Little is known about the role of breeding conspecific individuals in areas where migratory birds stopover during migration. Resident, or breeding, individuals may have had more time to assess a landscape or habitat patch and therefore have more information about the quality. Conversely, a high density of breeding birds may also represent more competition for food resources (Moore and Wang 1991). So it is also possible that conspecific song could have repellant qualities as an indication of density. The team did observe aggressive interactions between migrants and resident singing vireos on several occasions (see above, this report). This suggests that conspecific song may be an attractant at the landscape level (i.e., where the high quality habitat types are) but it may also be a deterrent at the patch level (i.e., where the defended territories are). The majority of the migrants released at the site in the pine habitat (with or without song added) eventually moved into small mixed hardwood patches characterized by seasonal creeks that were similar in plant composition to hardwood but were much smaller in area. There were no breeding red-eyed vireos detected in these patches. This suggests that these habitat types may provide resources valuable for the short-term of stopover but not sufficient for a breeding red-eyed vireo.

These results are suggestive of the value of conspecific song but also indicate that a larger sample size is needed to make any definitive conclusions about the value of conspecific song during stopover. Condition was also found to be important, a factor that could not be logistically controlled for in a field setting. This finding illustrates the value of testing the relative influence of representative models in a field experimental setting. To date, there is little information about cues used to make decisions during stopover. The team would like to continue this experiment with another season of sampling and conduct another experiment in the fall because hatch year birds would be expected to rely more heavily on conspecific song since they are less experienced with the variability of vegetative cues (Stamps 1988).

Migrating songbirds are challenging subjects with brief stopover periods along unpredictable routes and there is currently no technological capability to follow individuals for the duration of migration. However, migration may be when most mortality occurs (Sillett and Holmes 2002) and most of the migratory period is spent refueling at stopover sites (Alerstam 2003). Therefore, understanding the causes of mortality during this period is essential for the conservation of the many migratory species currently in decline (Kirby et al. 2008). In the present study, an experimental hypothesis-driven approach was used to better understand migrant-habitat relations and movement ecology at a stopover site characteristic of the region. The results show migrants made movement decisions in relation to both intrinsic and extrinsic factors and that hardwood habitat — as well as mixed-woody habitat — may be important for migratory refueling at Fort Polk and in Kisatchie National Forest.

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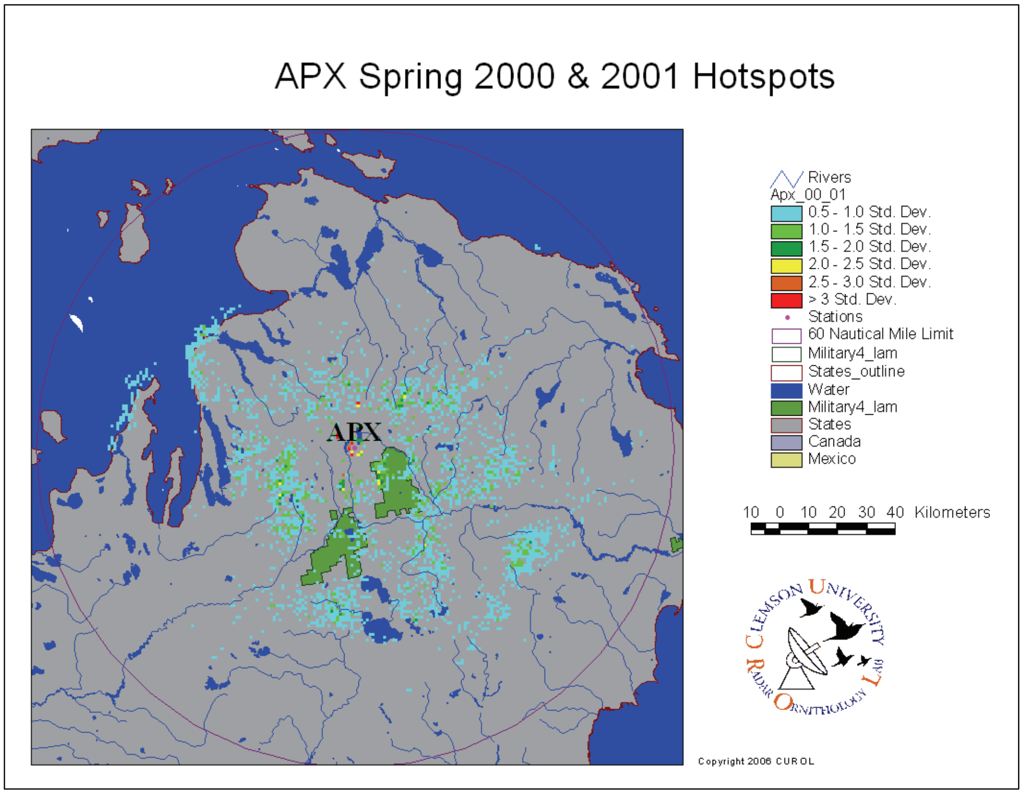
Appendix B: Composite Migration Maps Over U.S. Military Installations



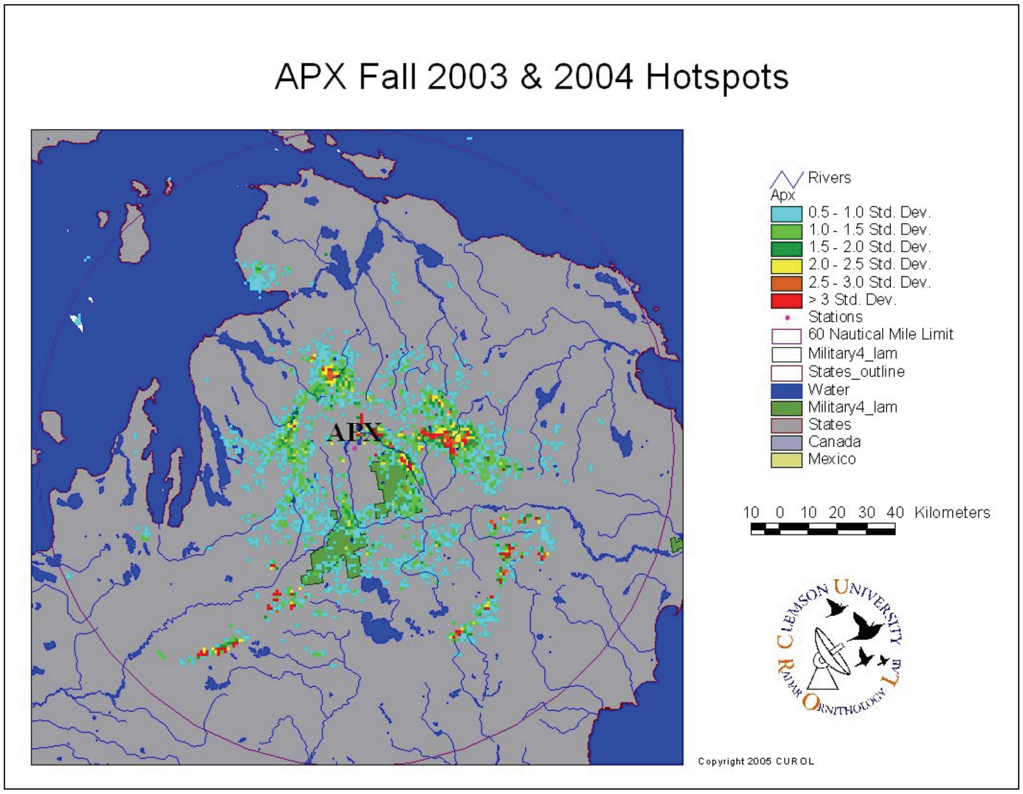


Figure B1. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station APX in northern MI. The survey area encompasses Camp Grayling Military Reservation.

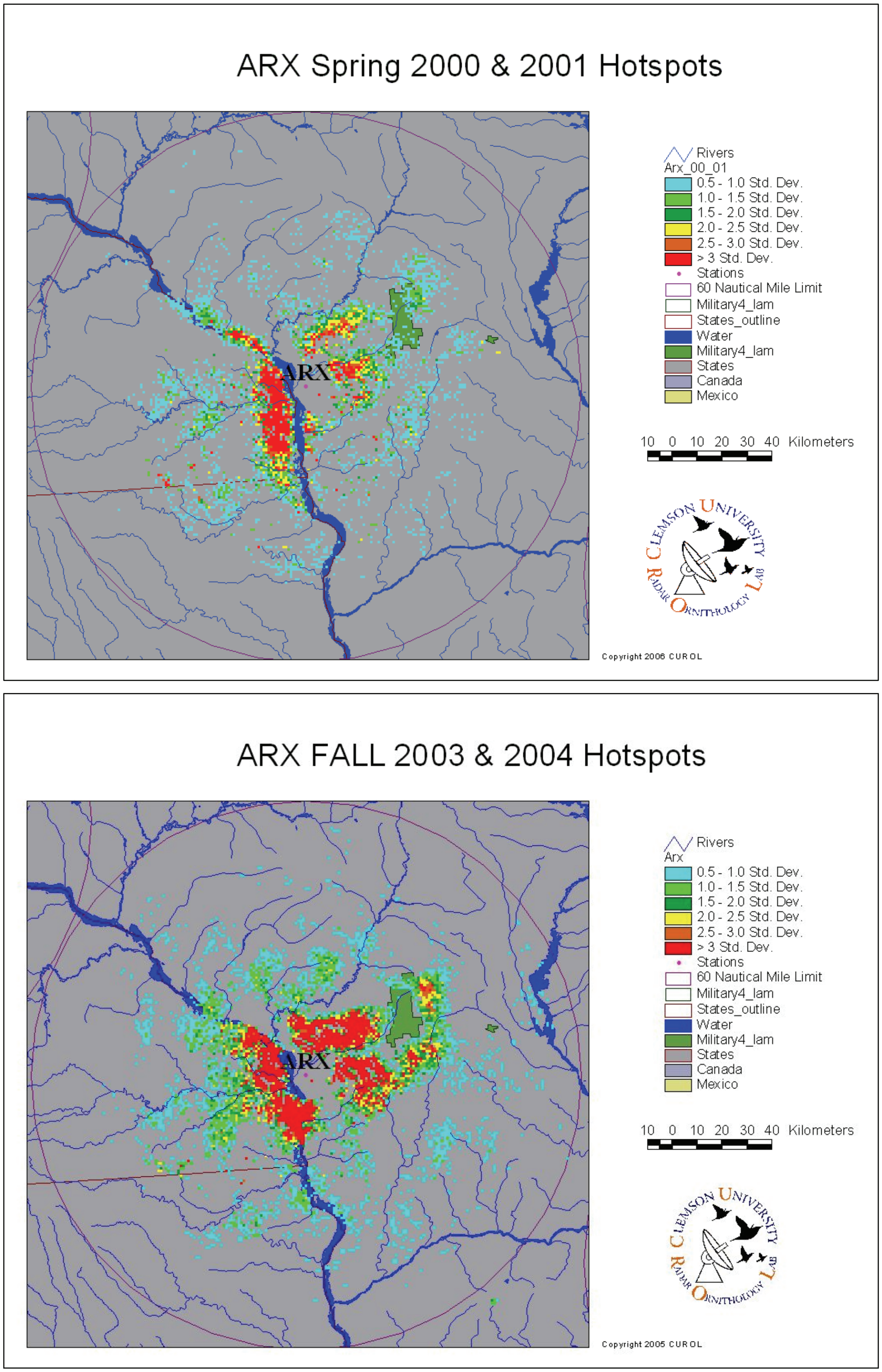
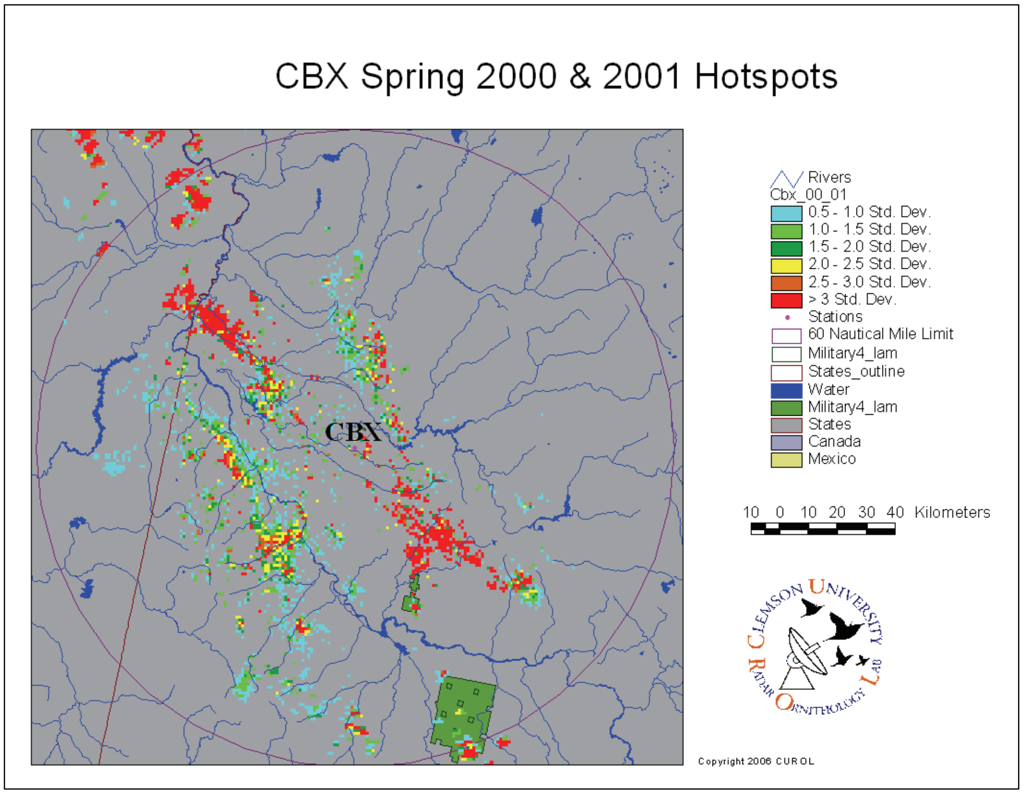
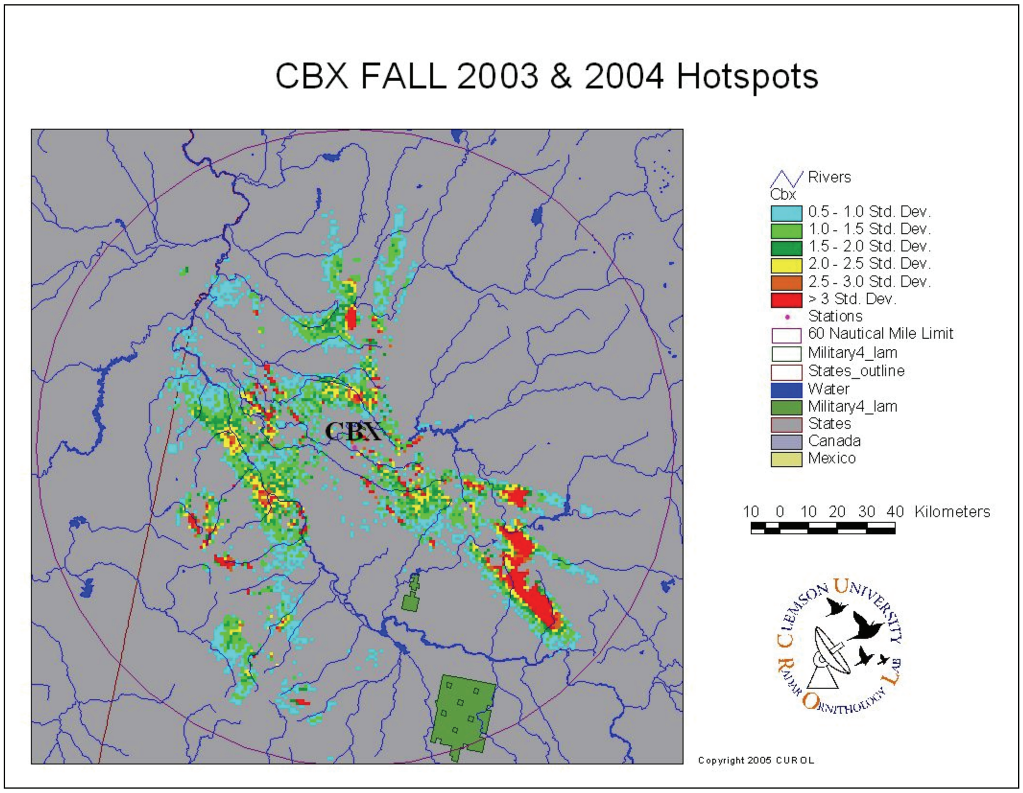


Figure B2. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station ARX in La Crosse, WI. The survey area encompasses Fort McCoy.



CBX Spring 2000 & 2001 Hotspots

Copyright 2006 CUROL



CBX FALL 2003 & 2004 Hotspots

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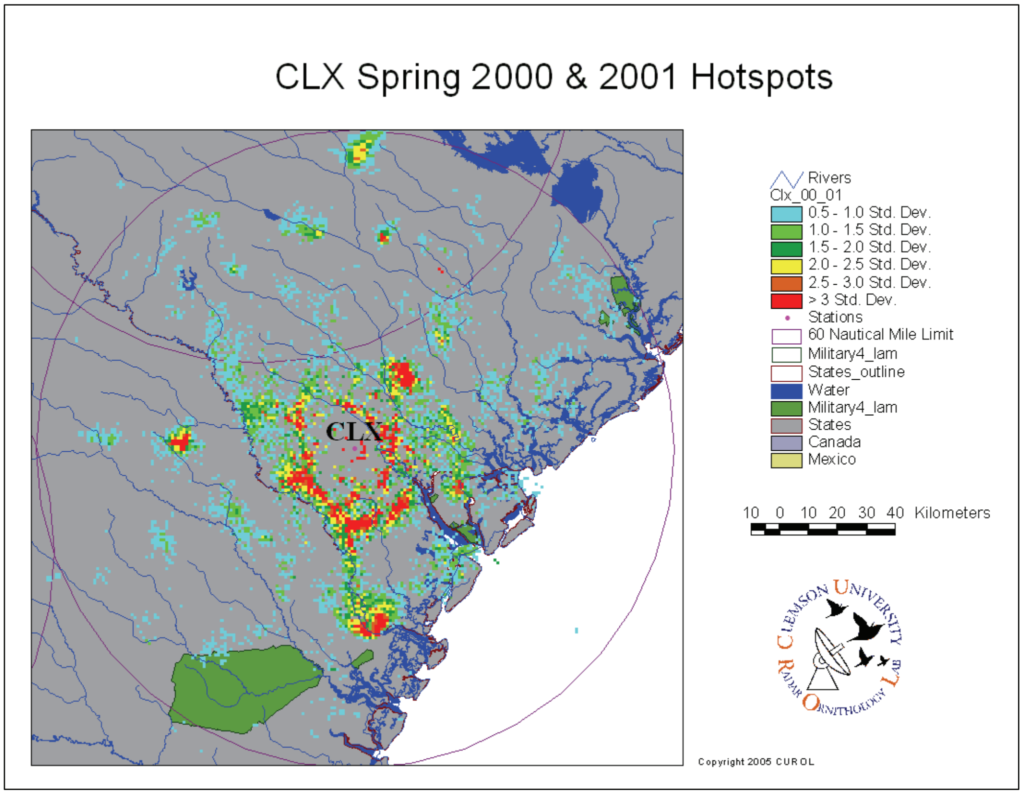
Figure B3. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station CBX in Boise, ID. The survey area encompasses Saylor Creek Air Force Range.



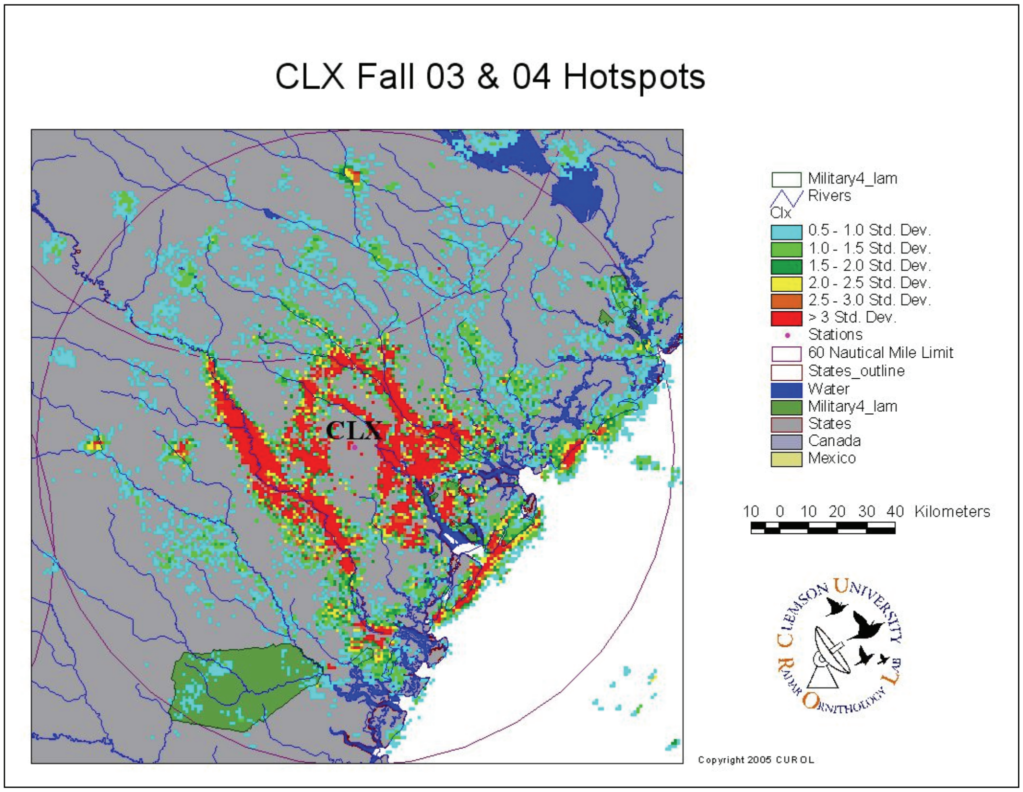


Figure B4. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station CLX in Charleston, SC. The survey area encompasses Fort Stewart.

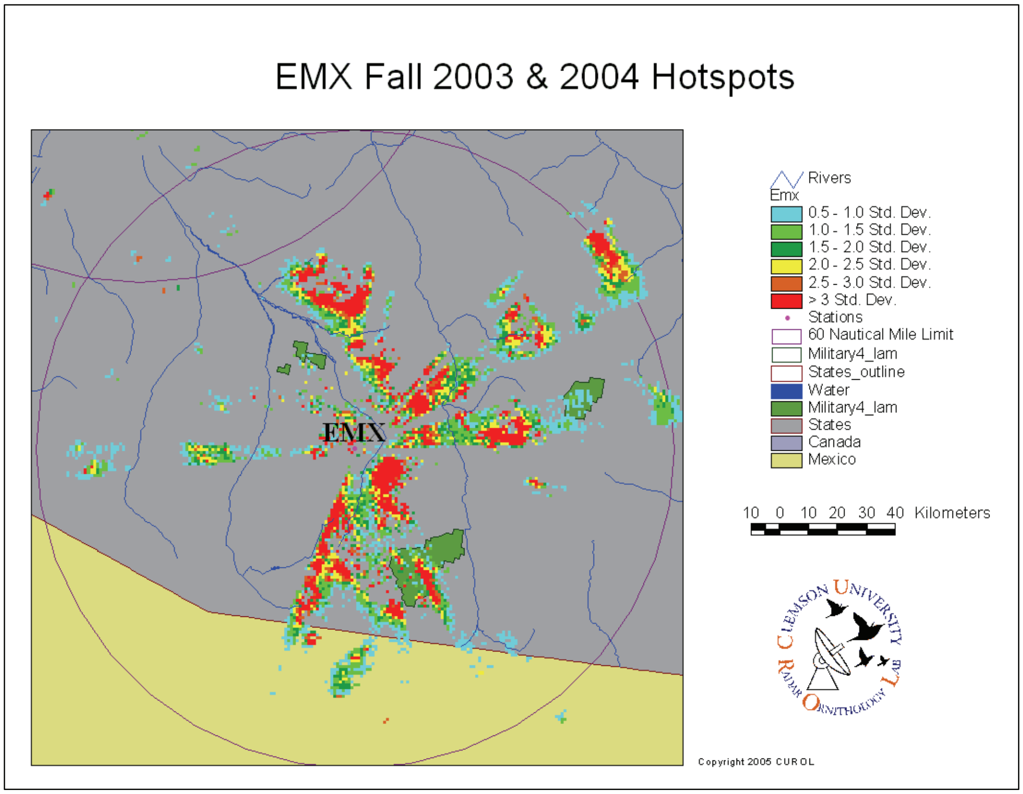
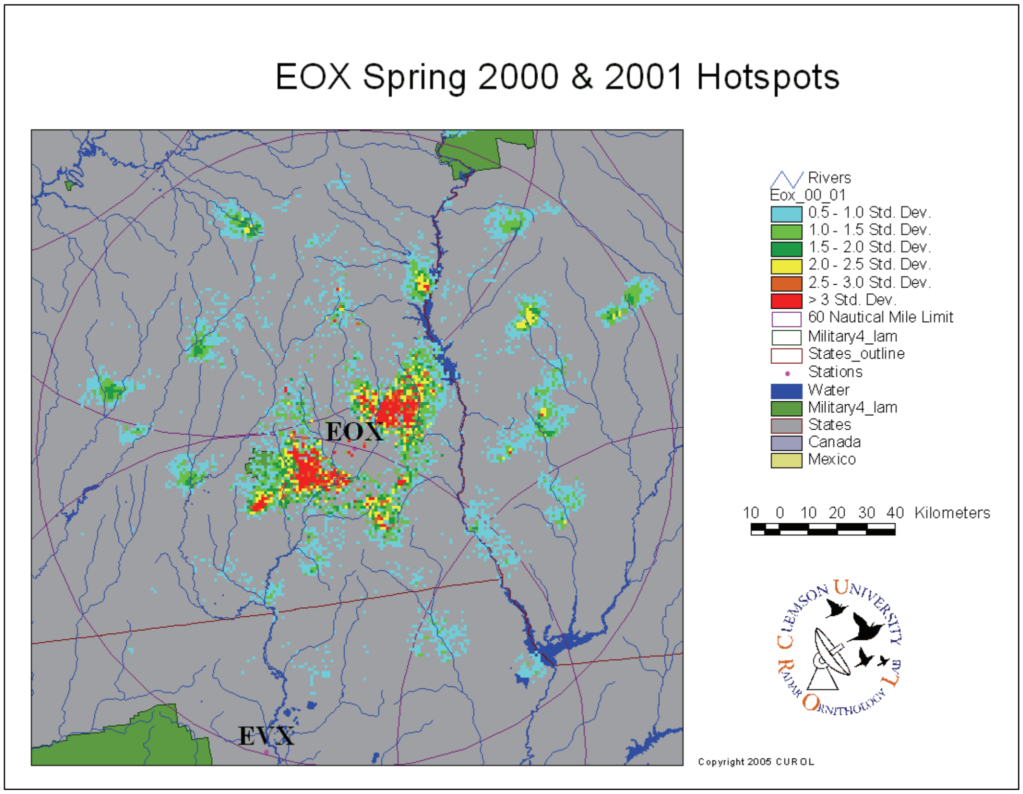


Figure B5. Composite map indicating fall migratory hotspots as recorded by NEXRAD station EMX in Tucson, AZ. The survey area encompasses Fort Huachuca.



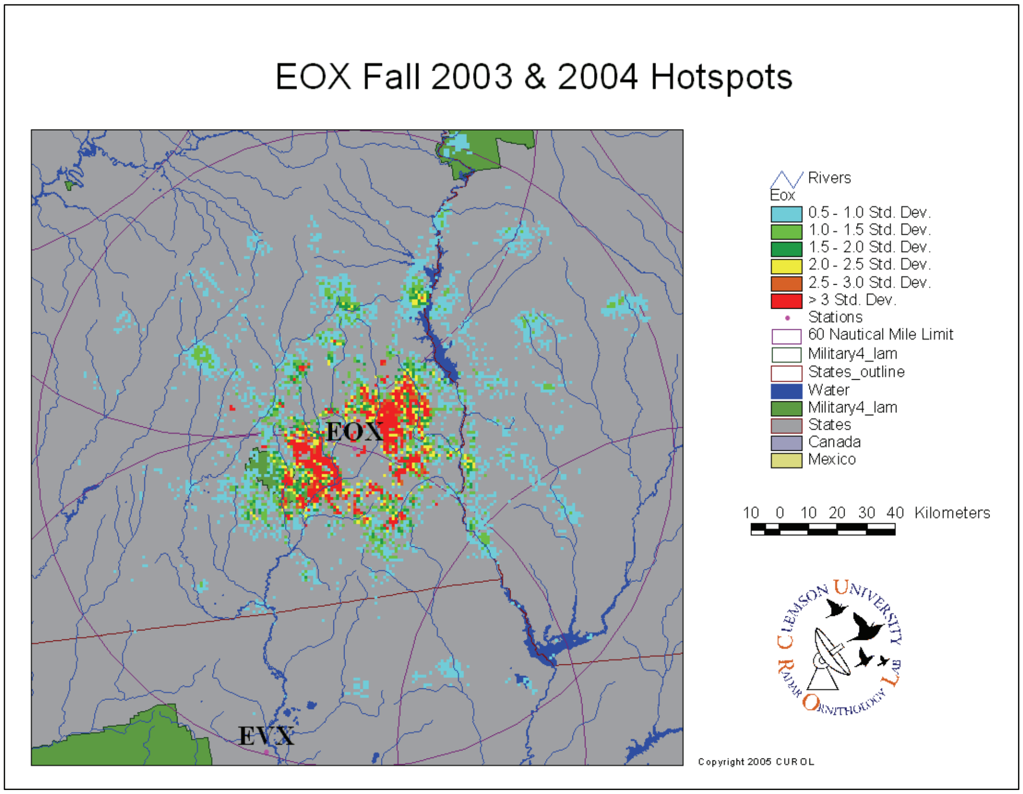
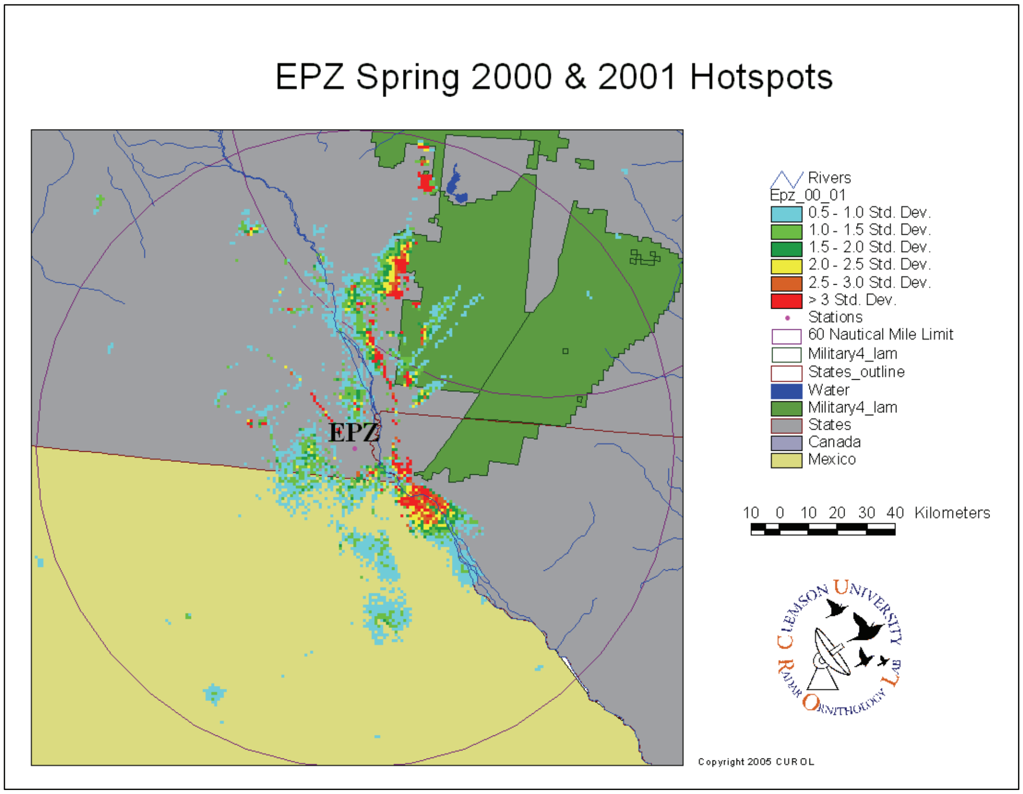


Figure B6. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station EOX in southeastern AL. The survey area encompasses Fort Rucker Military Reservation.


EPZ Spring 2000 & 2001 Hotspots

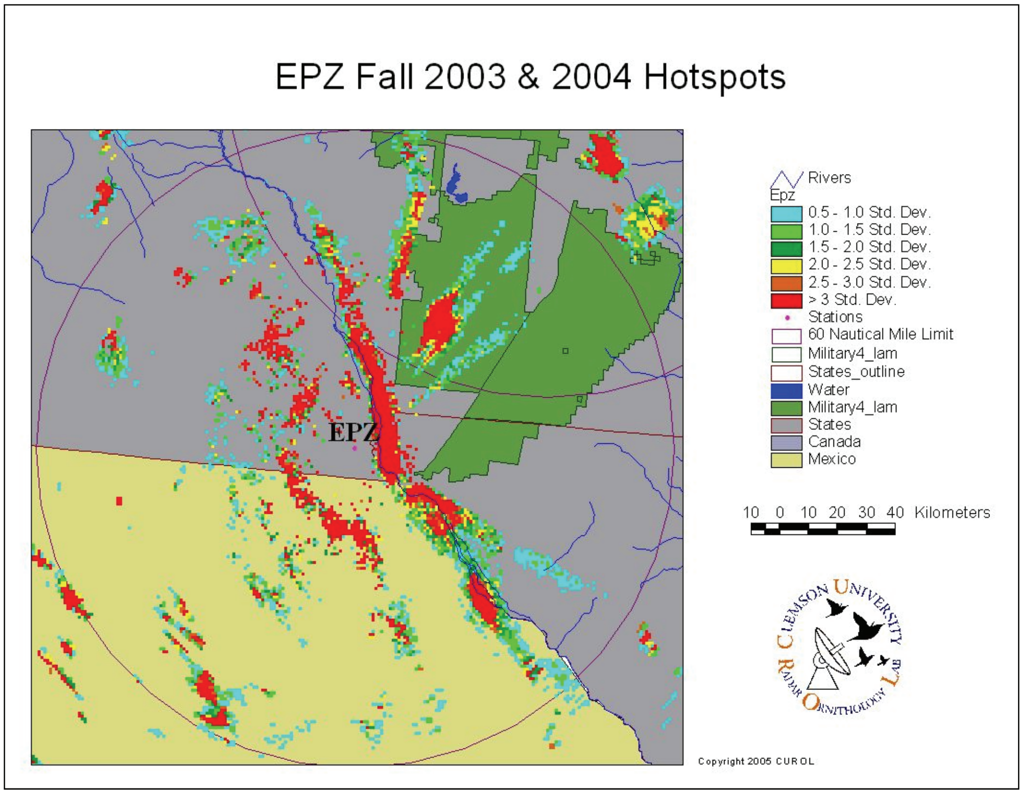

EPZ Fall 2003 & 2004 Hotspots

Figure B7. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station EPZ in El Paso, TX. The survey area encompasses Fort Bliss and the Fort Bliss McGregor Range.

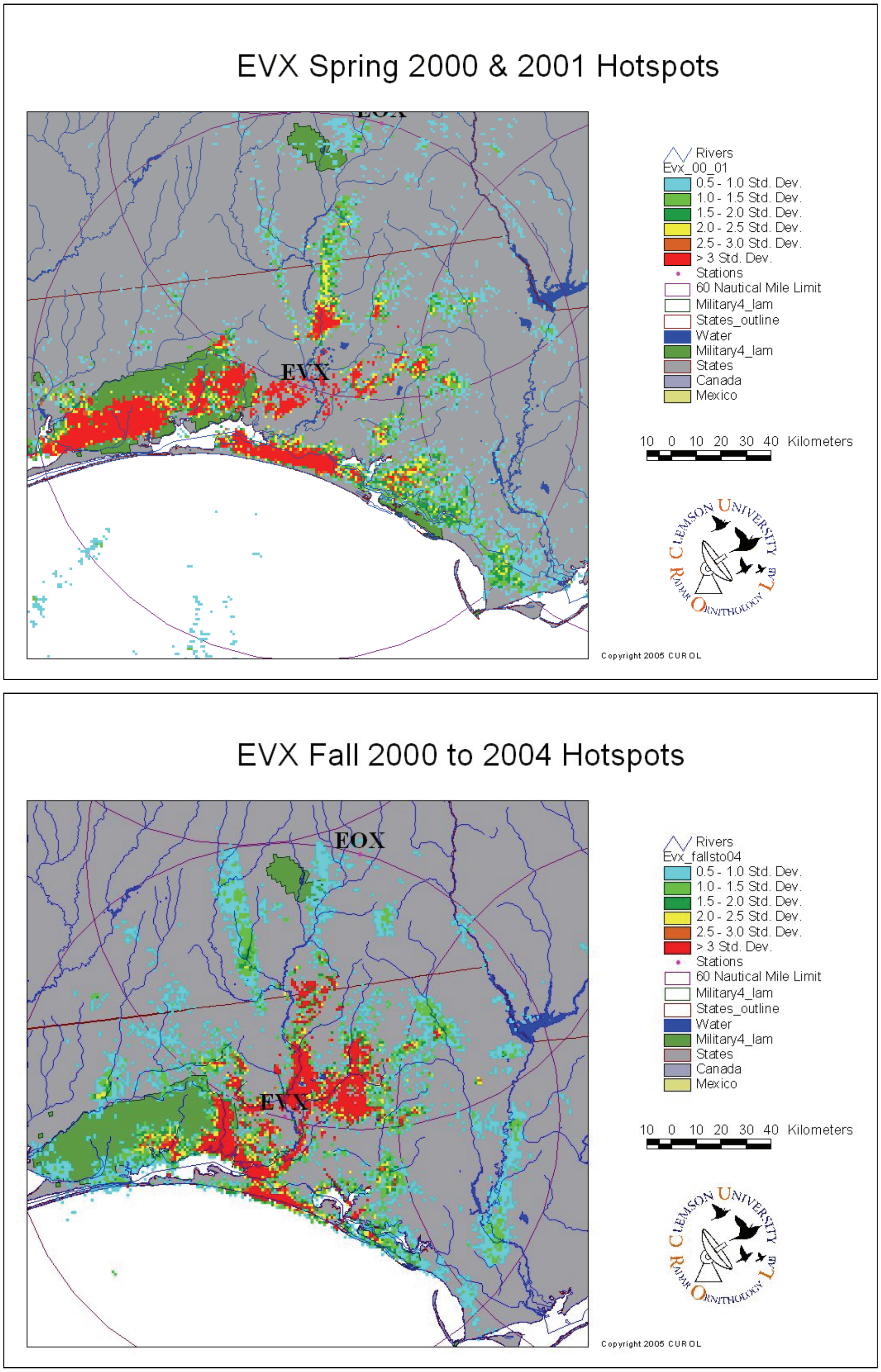


Figure B8. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station EVX in northwestern FL. The survey area encompasses Eglin Air Force Base.

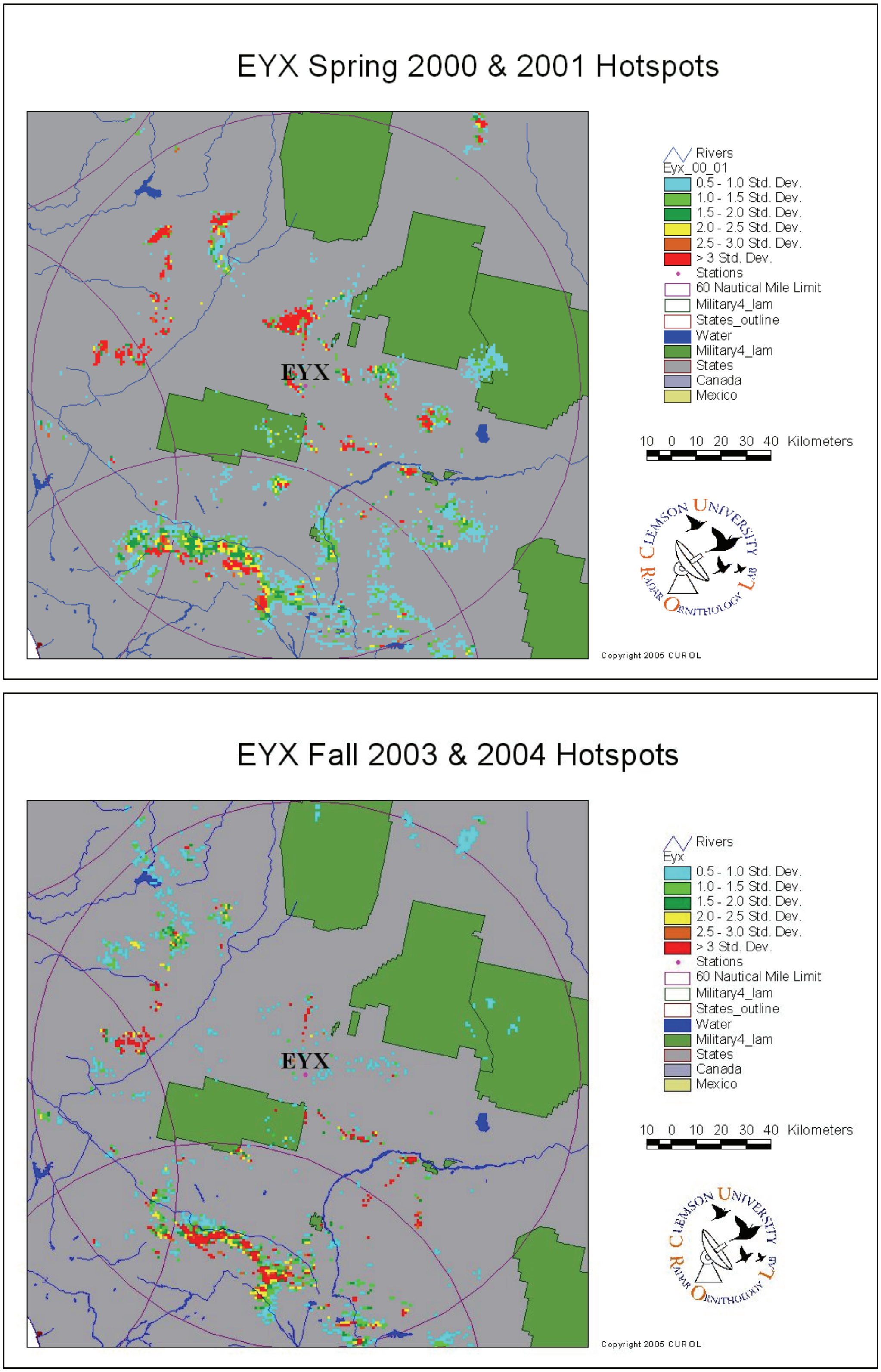


Figure B9. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station EYX in southern CA. The survey area encompasses China Lake Naval Weapons Center, Edwards Air Force Base, and Fort Irwin.

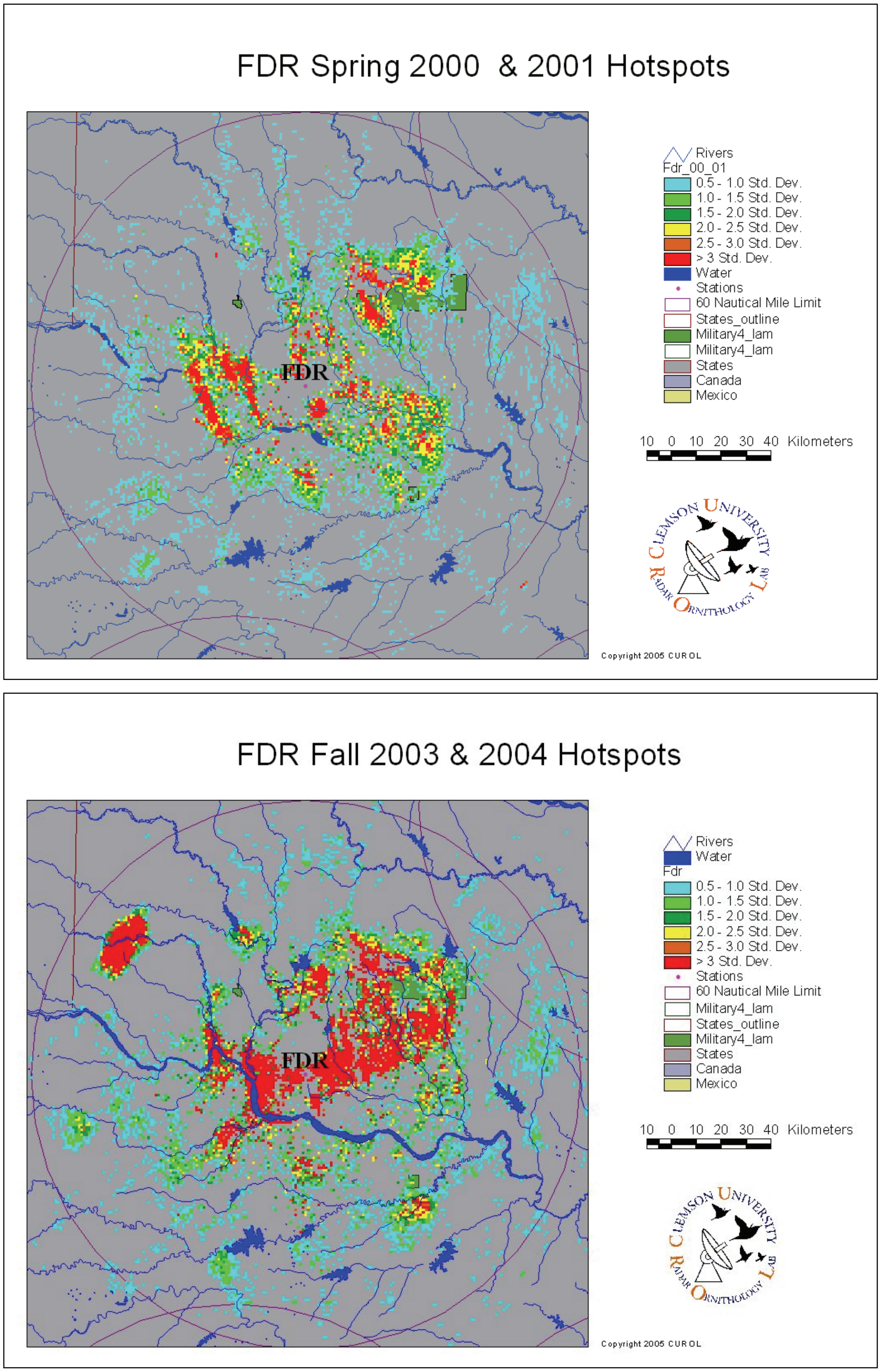


Figure B10. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station FDR in Frederick, OK. The survey area encompasses Fort Sill Military Reservation.

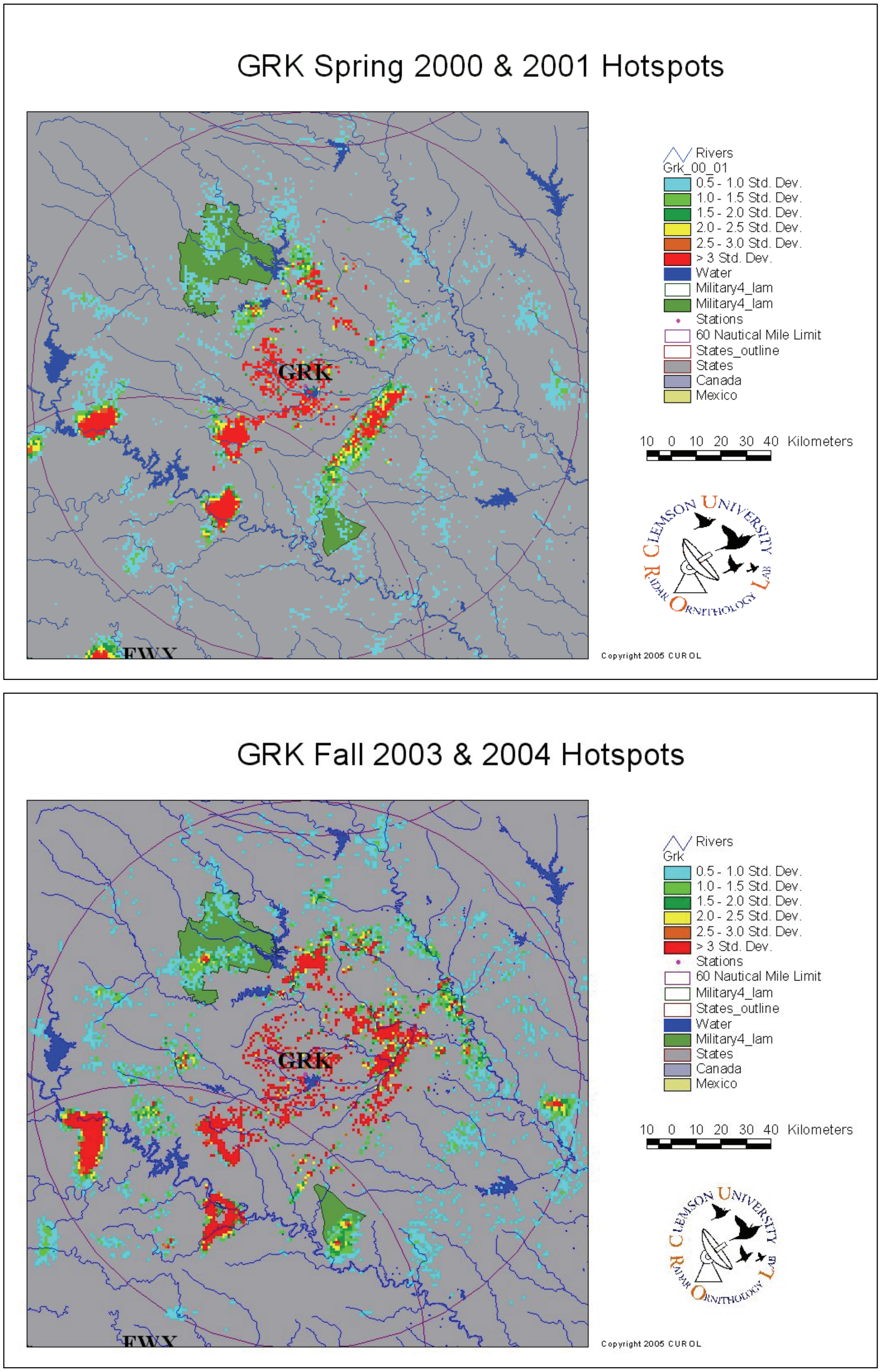
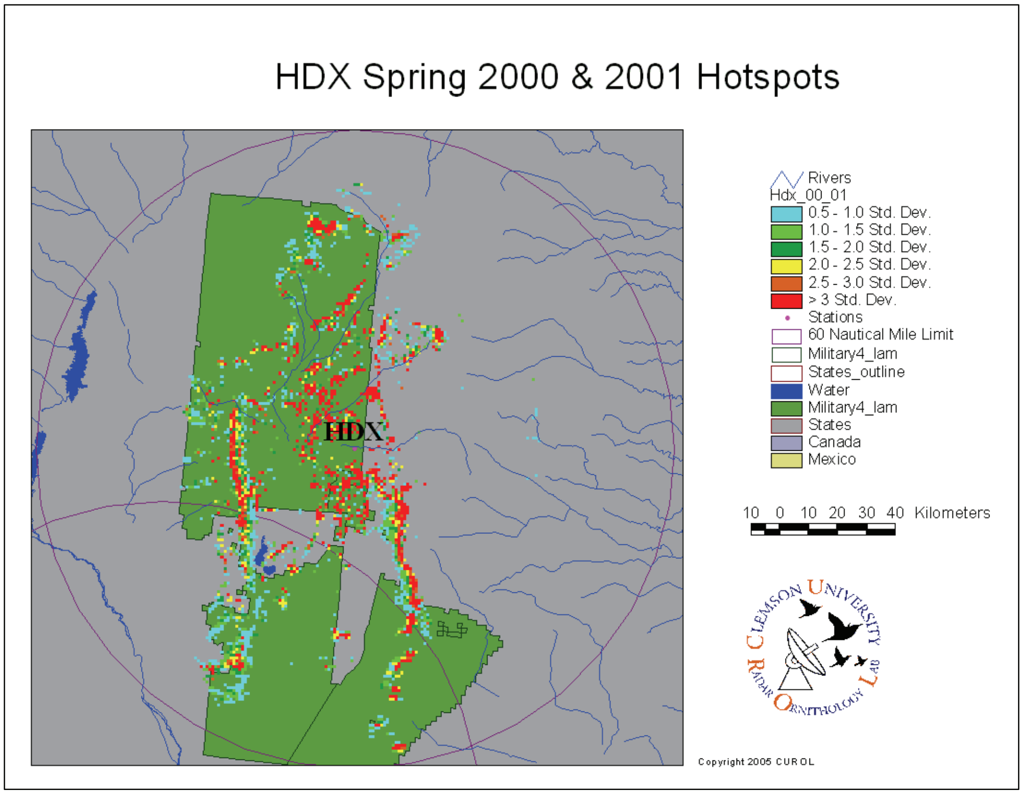


Figure B11. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station GRK in central TX. The survey area encompasses Fort Hood and Camp Swift N. G. Facility.



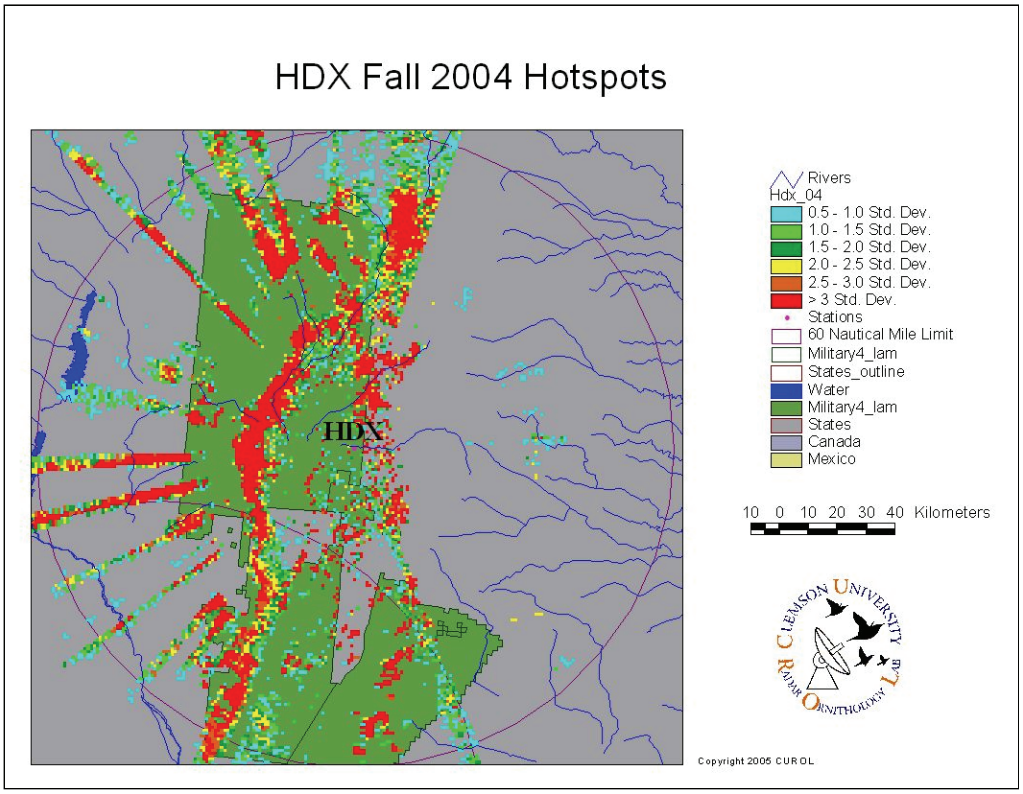


Figure B12. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station HDX in southern NM. The survey area encompasses Holloman Air Force Base, White Sands Missile Range, Fort Bliss, and the Fort Bliss McGregor Range.

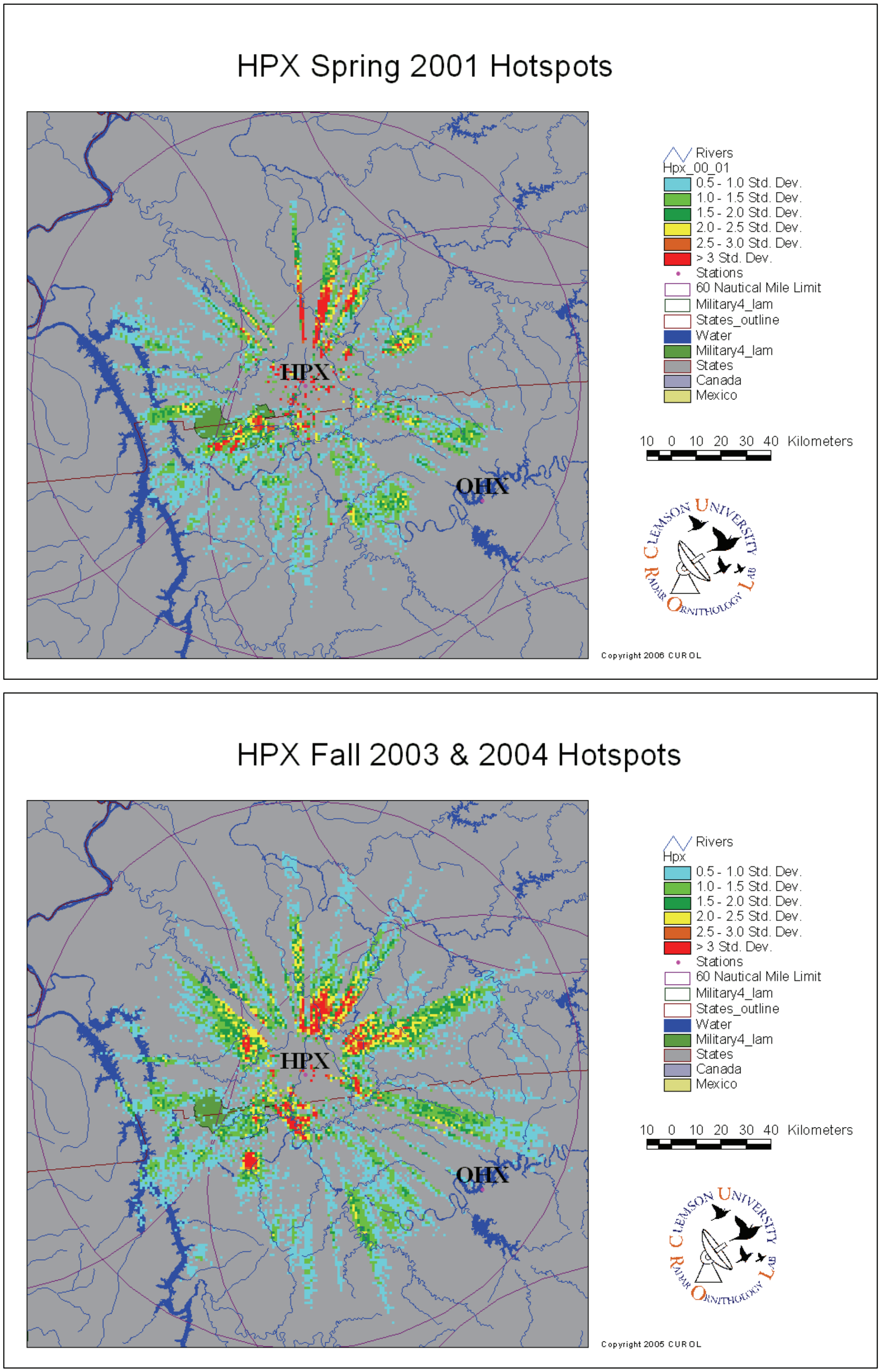
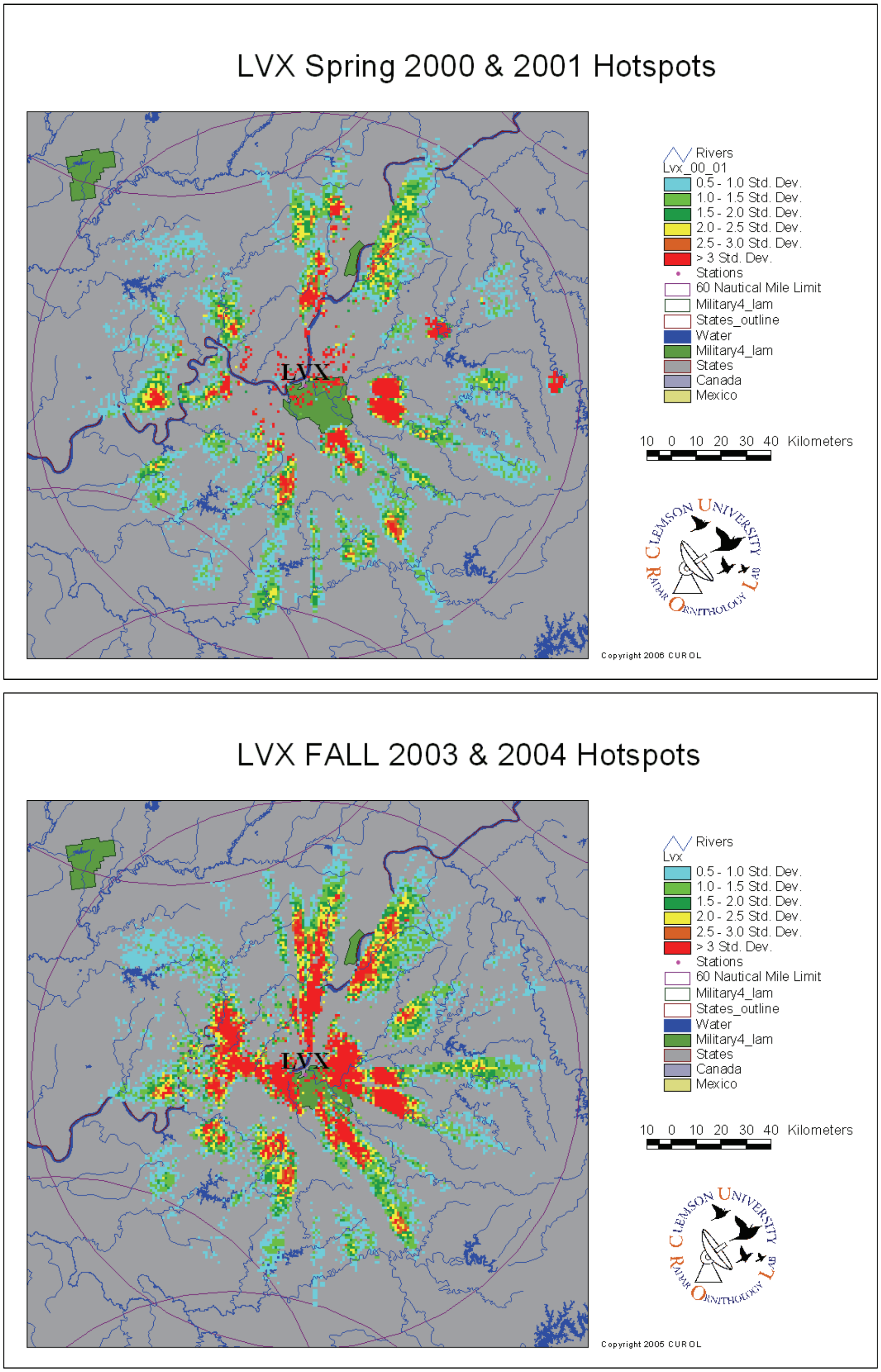


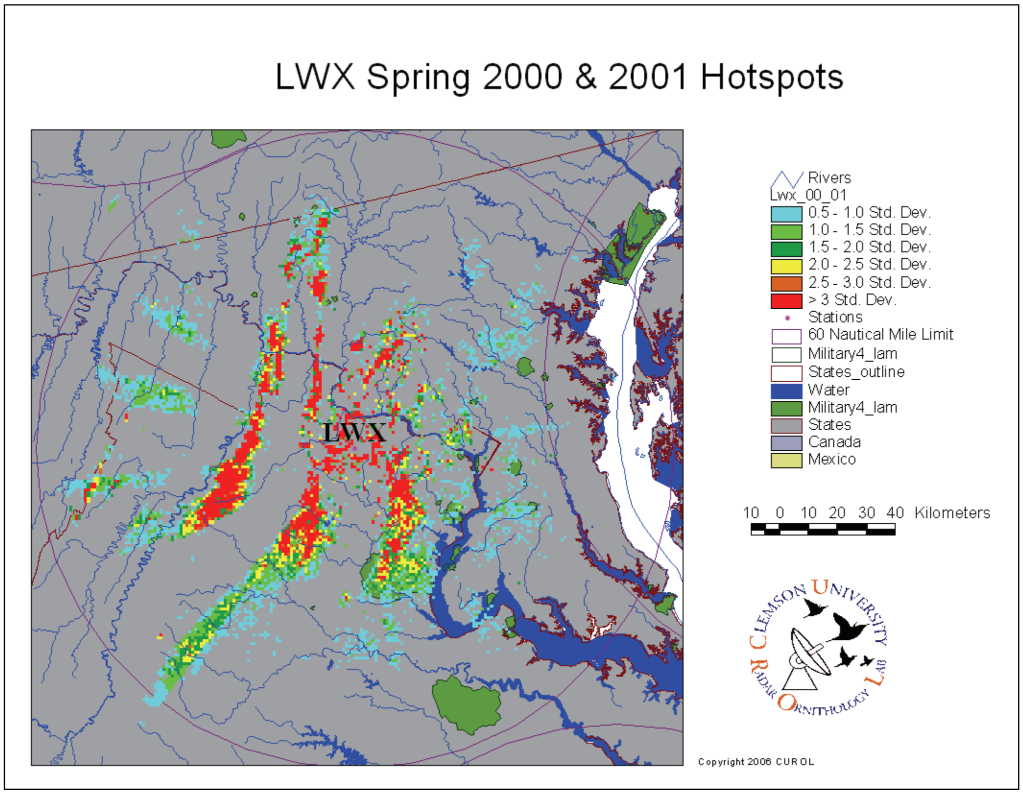
Figure B13. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station HPX in southwestern KY. The survey area encompasses Fort Campbell.



LVX Spring 2000 & 2001 Hotspots

LVX FALL 2003 & 2004 Hotspots

Figure B14. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station LVX in central KY. The survey area encompasses Fort Knox.



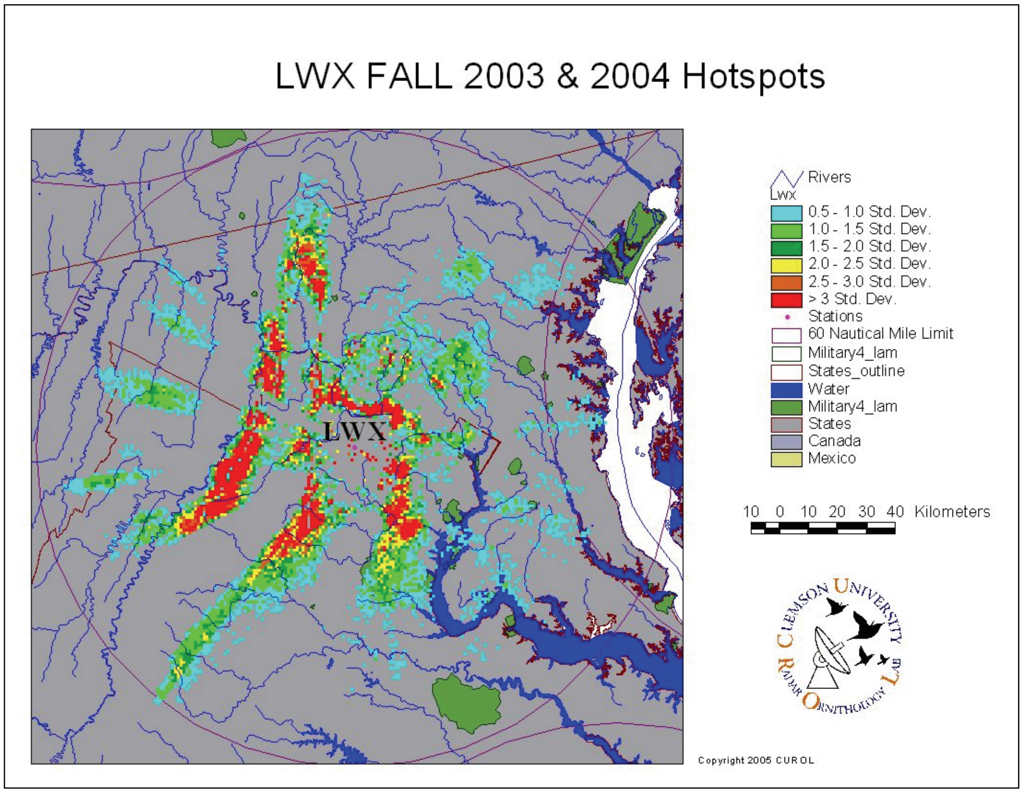


Figure B15. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station LWX in Sterling, VA. The survey area encompasses Fort A.P. Hill Military Reservation and Quantico Marine Corps Base.

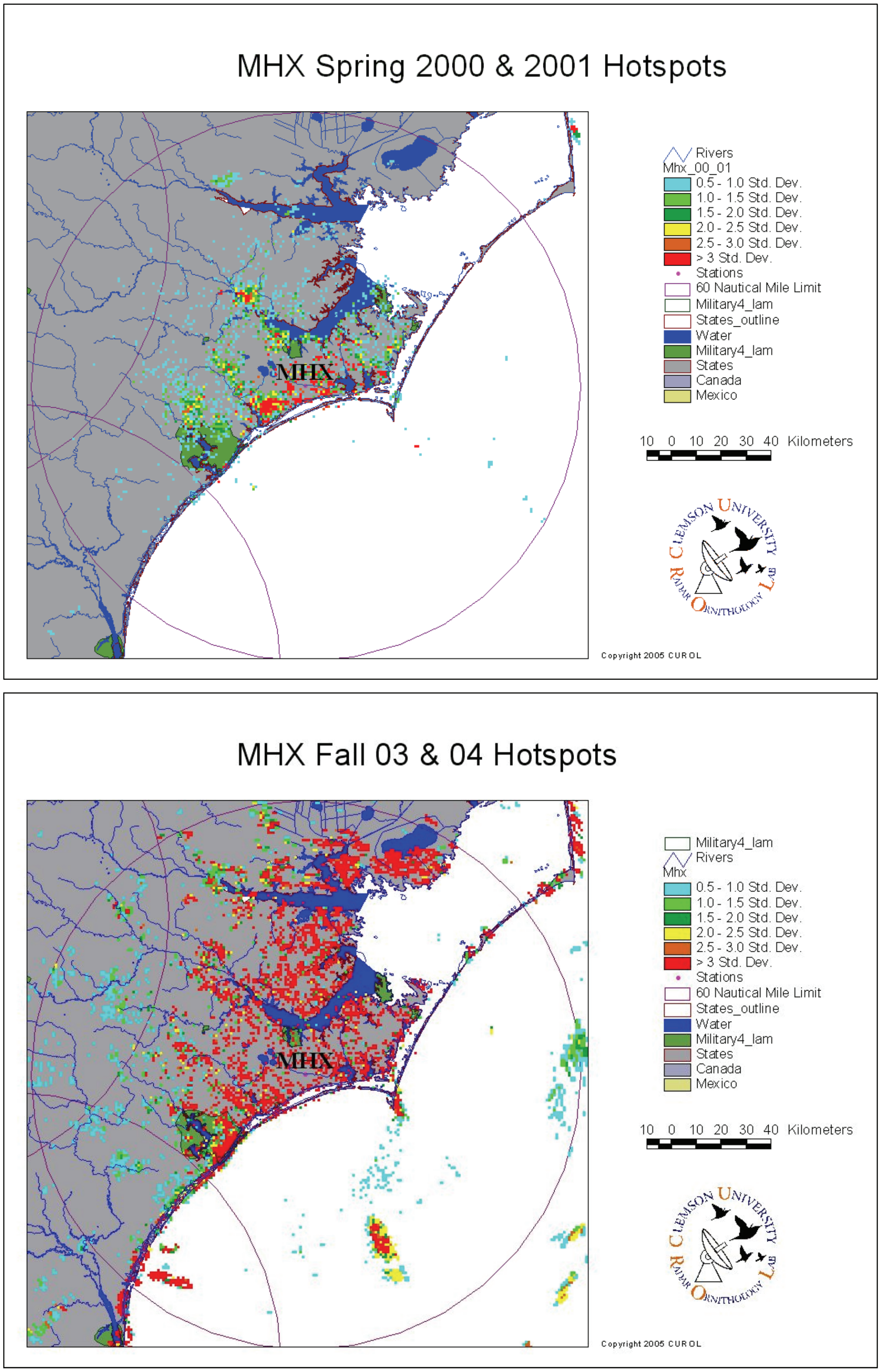


Figure B16. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station MHX in Morehead City, NC. The survey area encompasses Camp Lejeune Marine Corps Base.

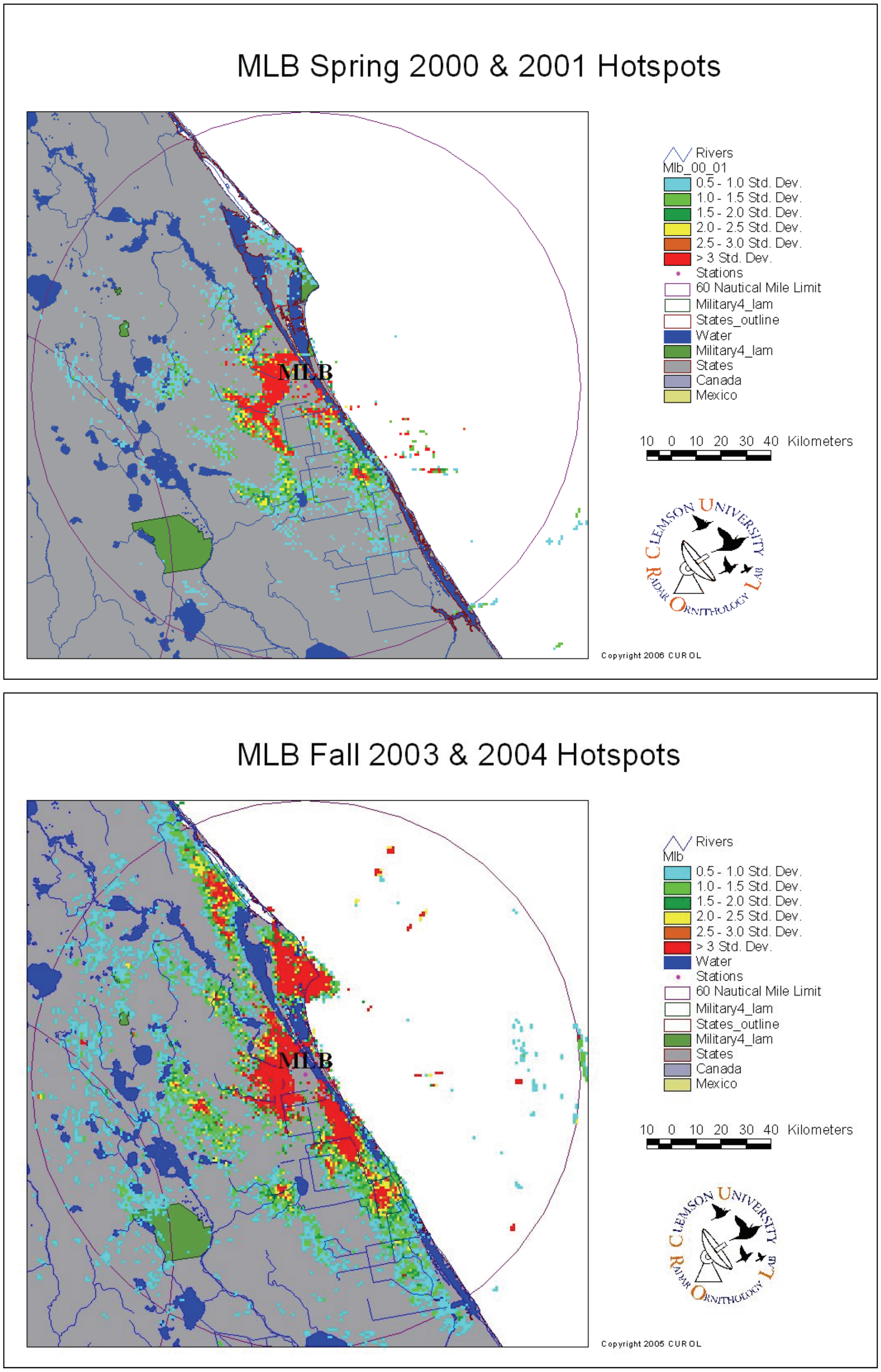


Figure B17. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station MLB in Melbourne, FL. The survey area encompasses Avon Park Air Force Bombing Range.

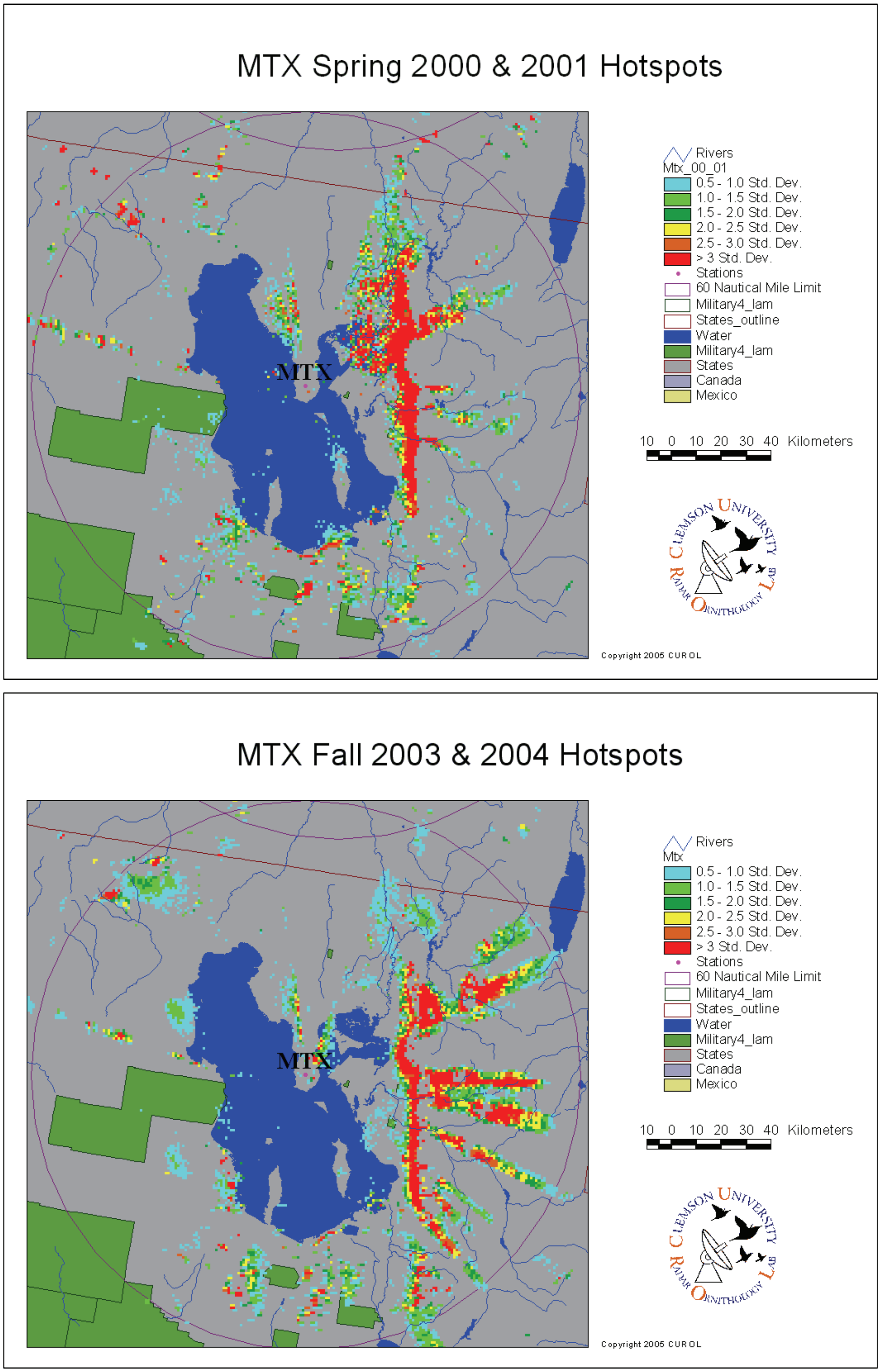


Figure B18. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station MTX in Salt Lake City, UT. The survey area encompasses Hill Air Force Range and the Hill AFB Wendover Range.

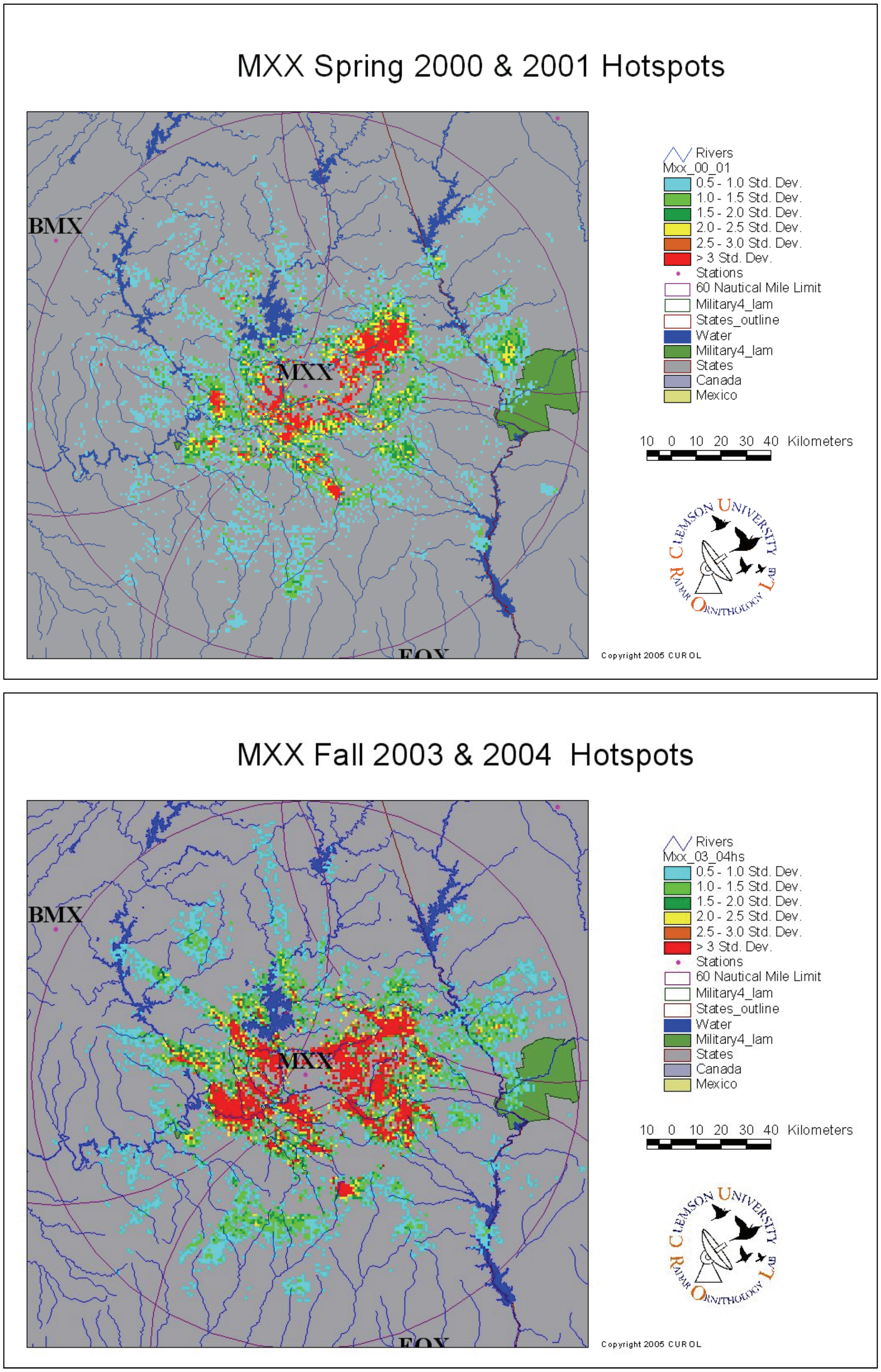
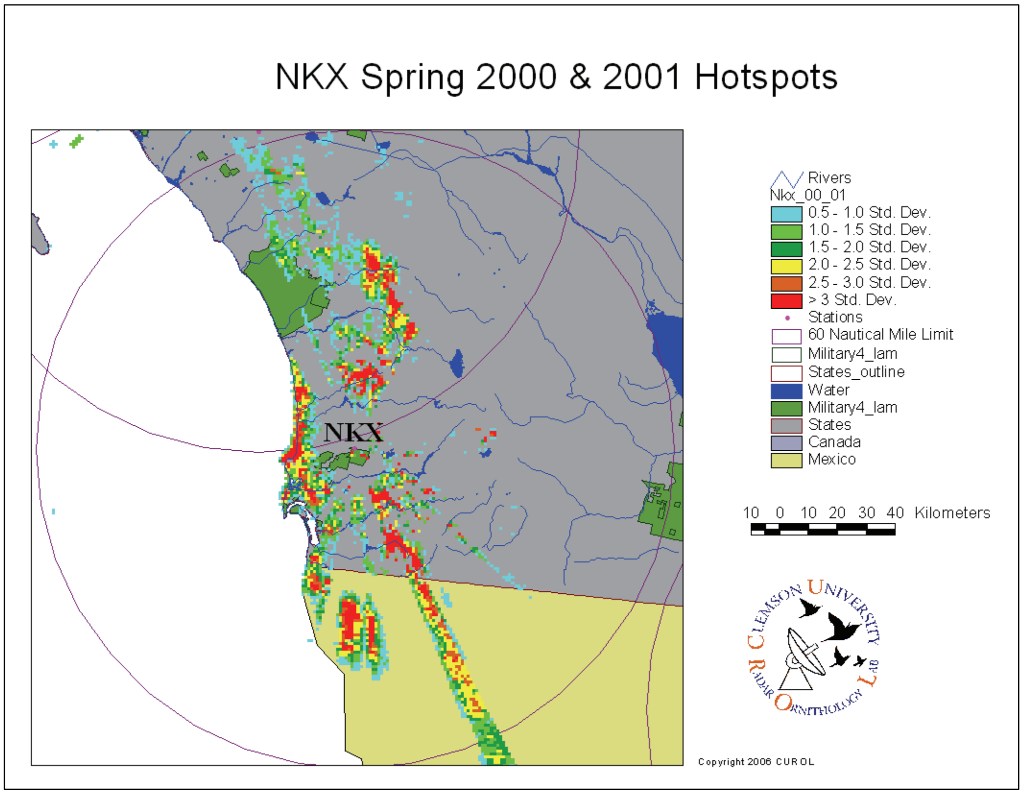


Figure B19. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station MXX in eastern AL. The survey area encompasses Fort Benning.


NKX Spring 2000 & 2001 Hotspots

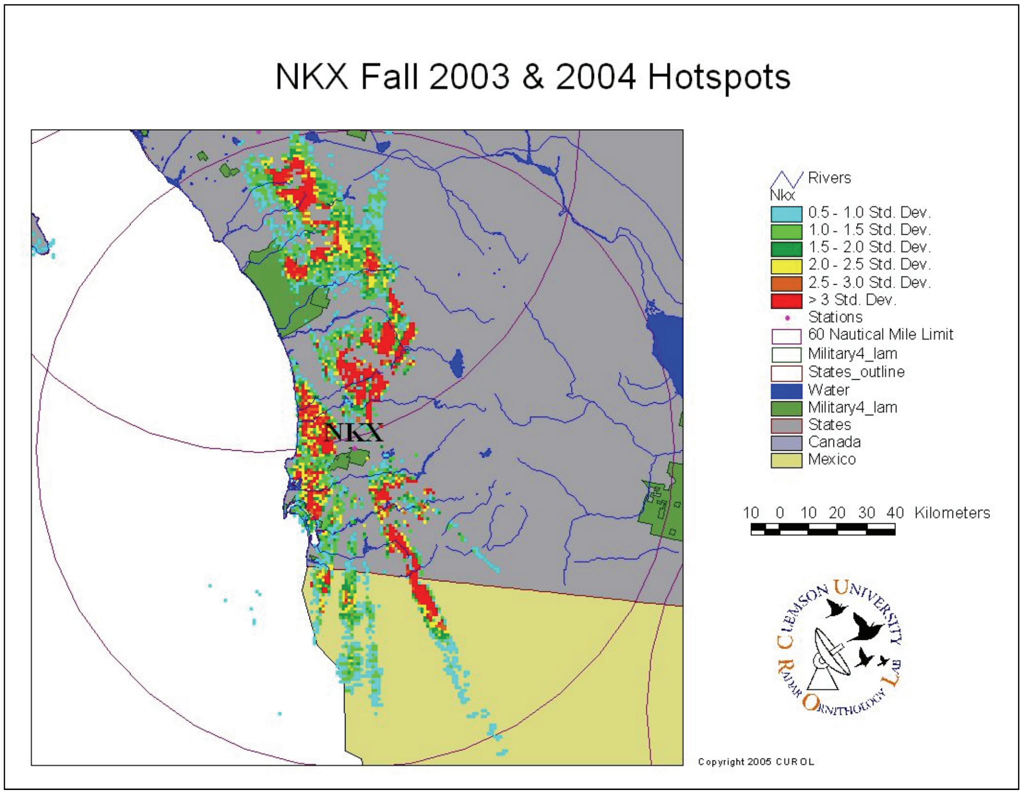

NKX Fall 2003 & 2004 Hotspots

Figure B20. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station NKX in San Diego, CA. The survey area encompasses Camp Pendleton Marine Corps Base.

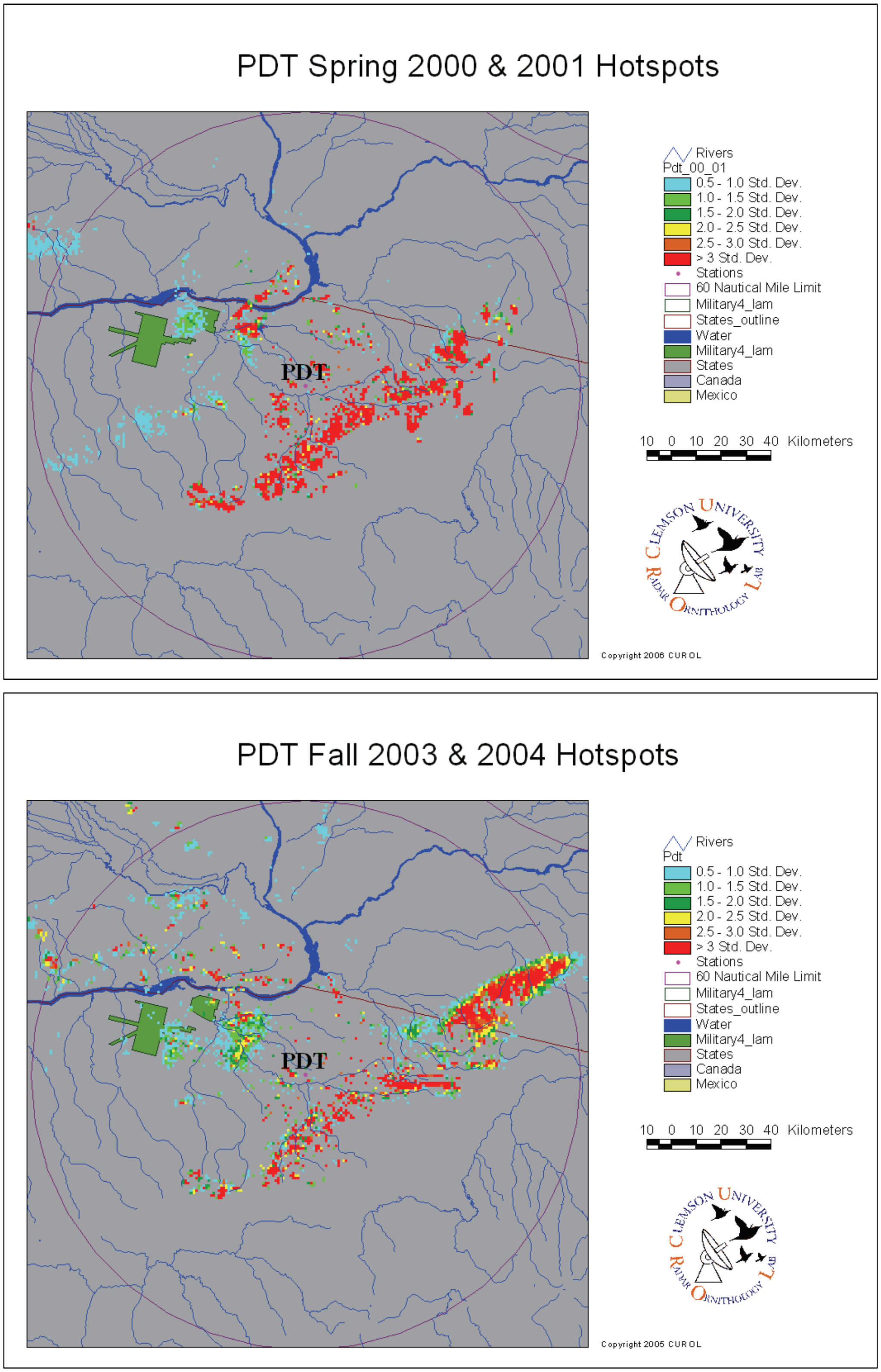
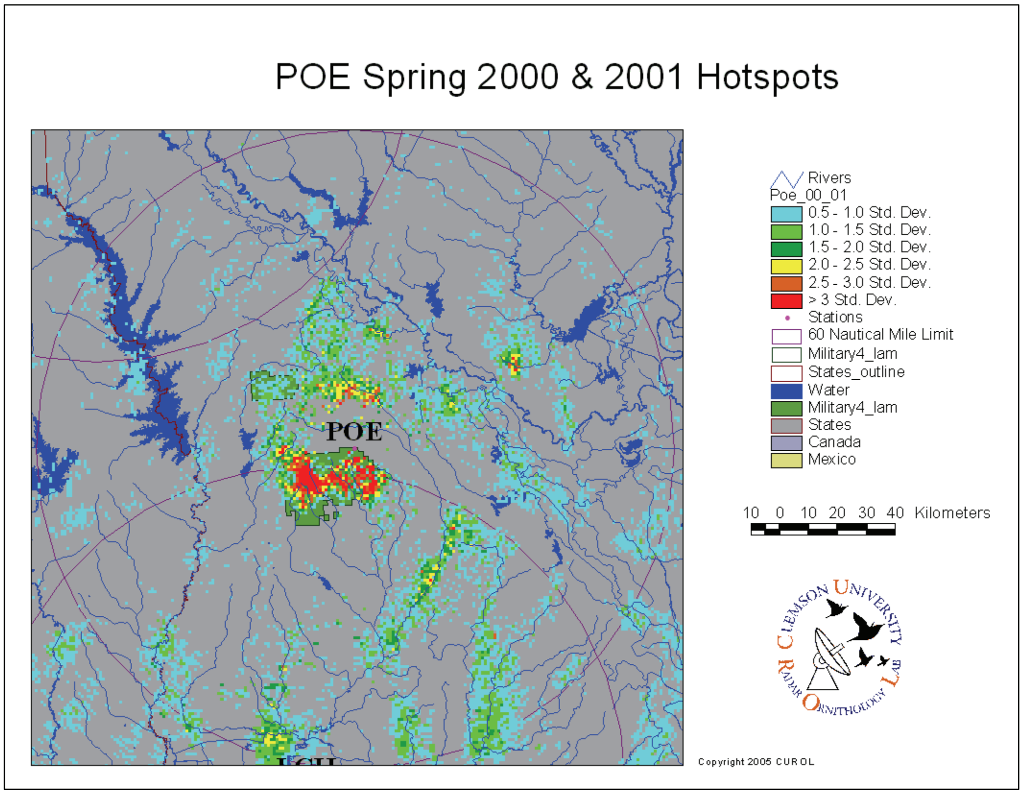


Figure B21. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station PDT in Pendleton, OR. The survey area encompasses the Boardman Naval Bombing Range.


POE Spring 2000 & 2001 Hotspots

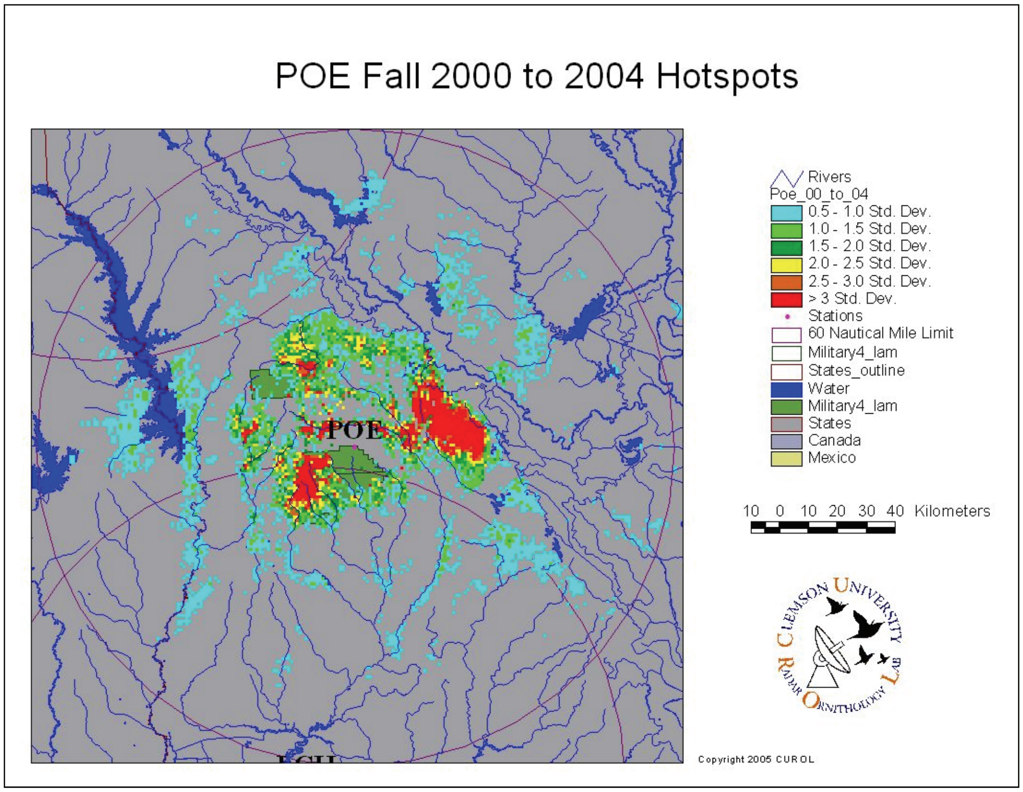
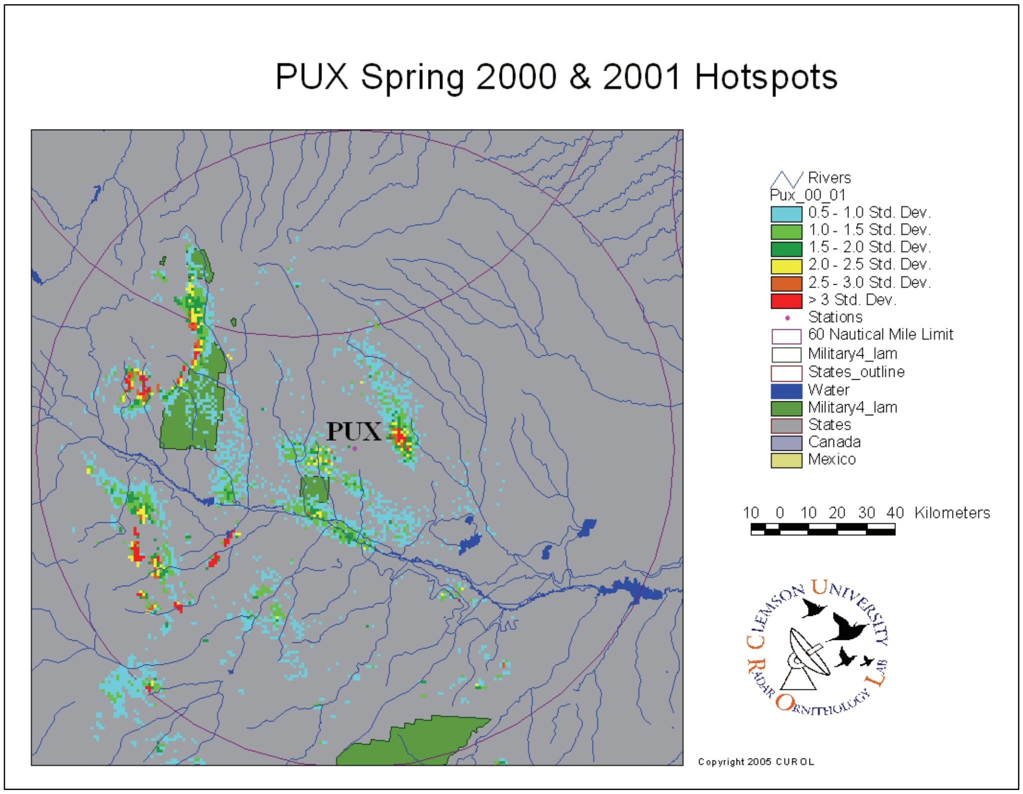

POE Fall 2000 to 2004 Hotspots

Figure B22. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station POE in central, LA. The survey area encompasses Fort Polk.



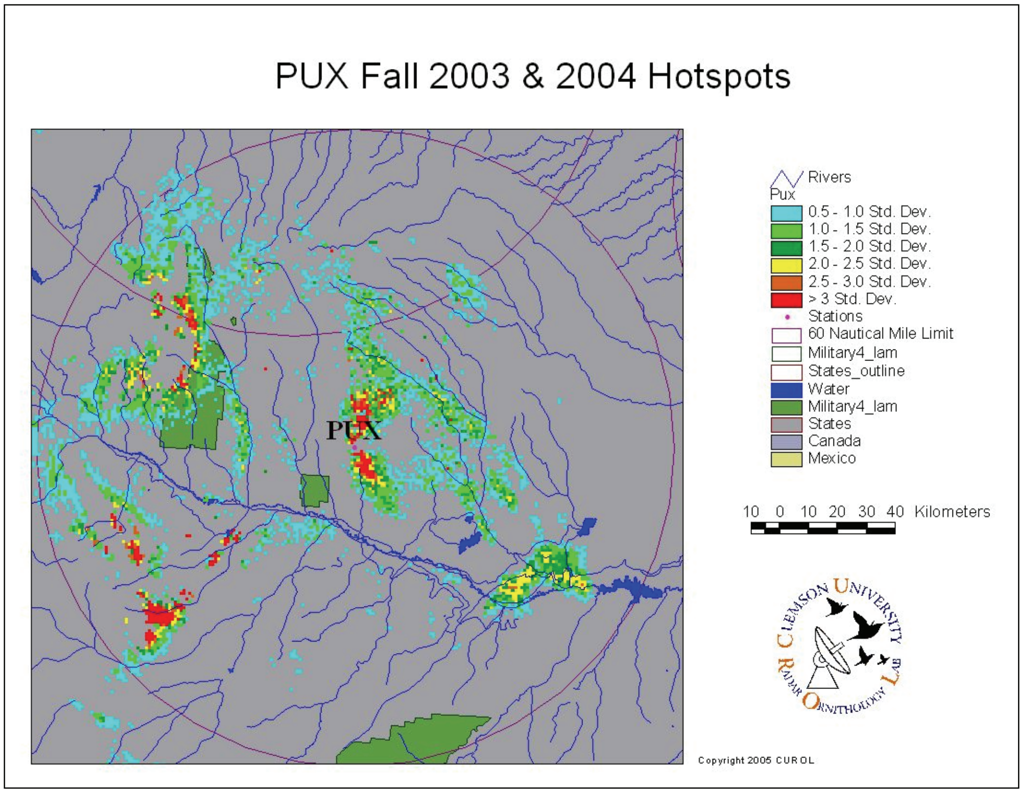
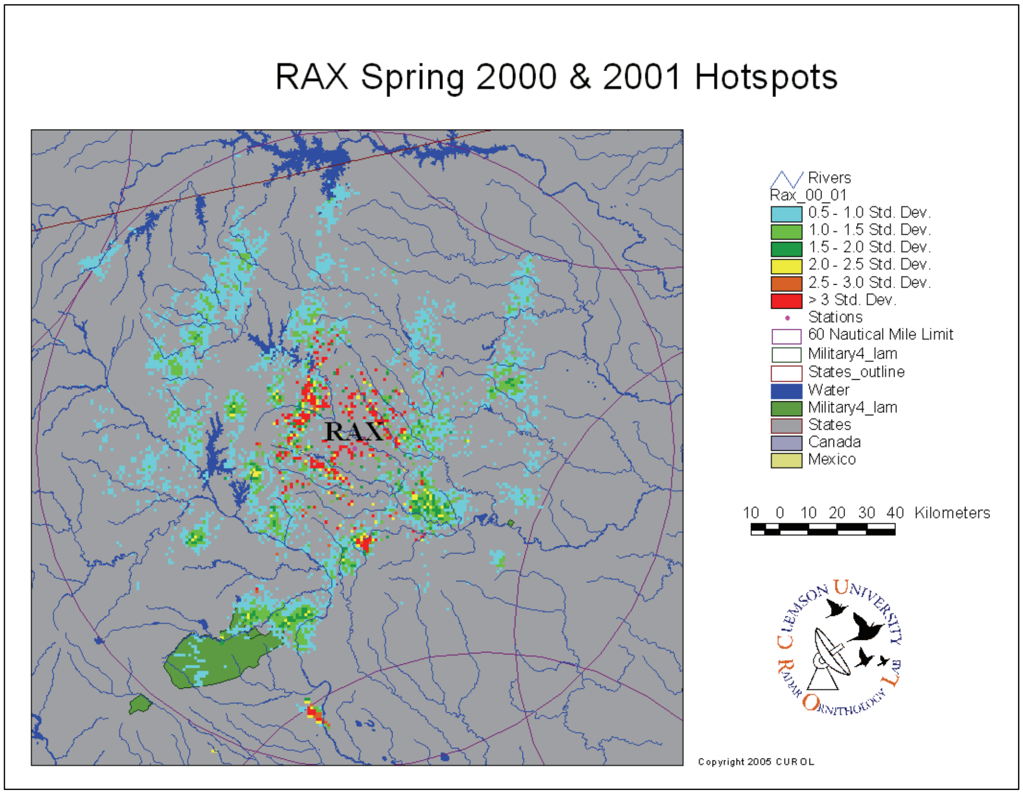


Figure B23. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station PUX in Pueblo, CO. The survey area encompasses Fort Carson Military Reservation.



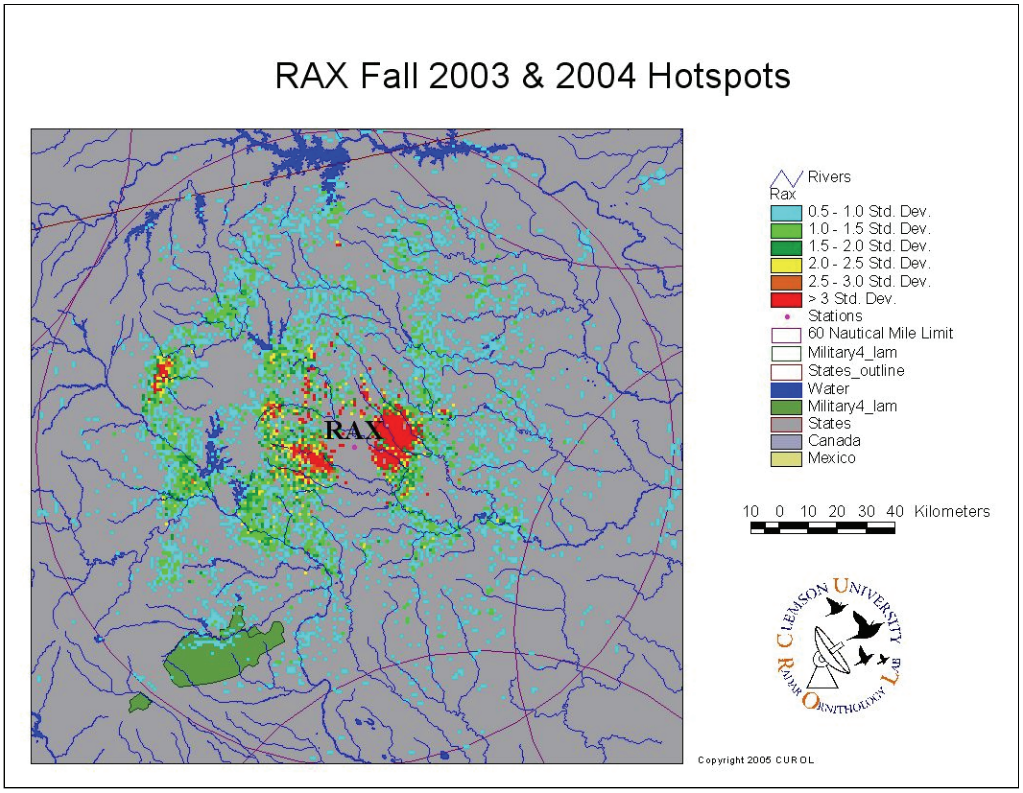
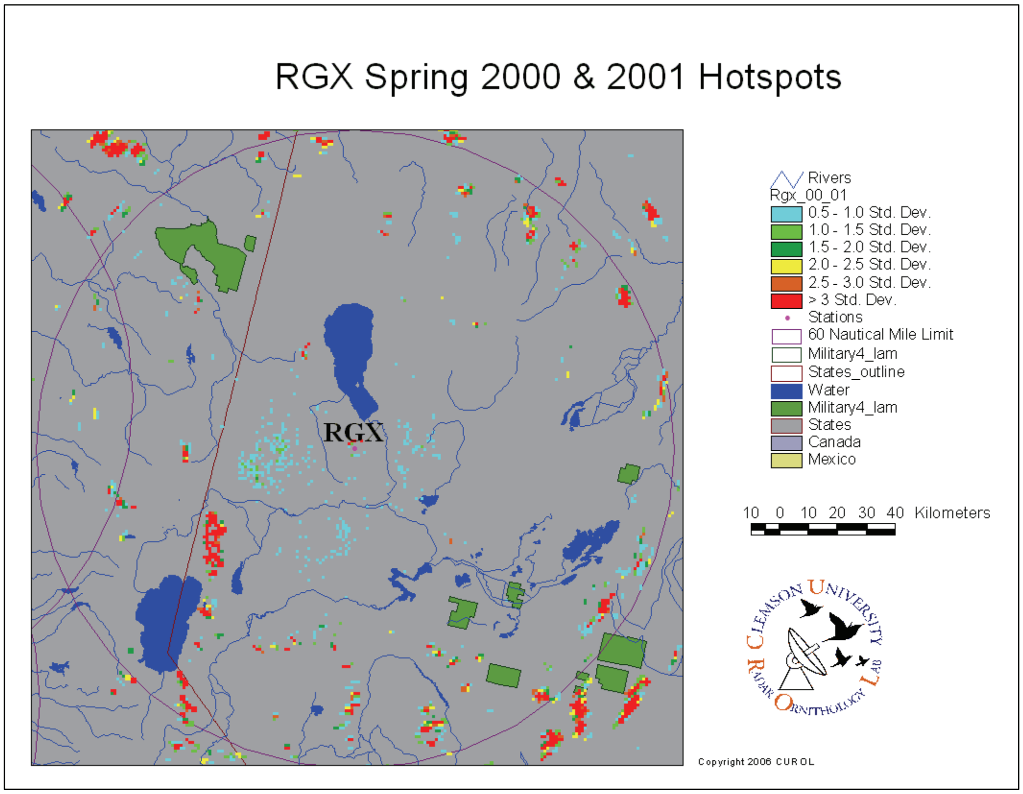


Figure B24. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station RAX in Raleigh-Durham, NC. The survey area encompasses Fort Bragg.



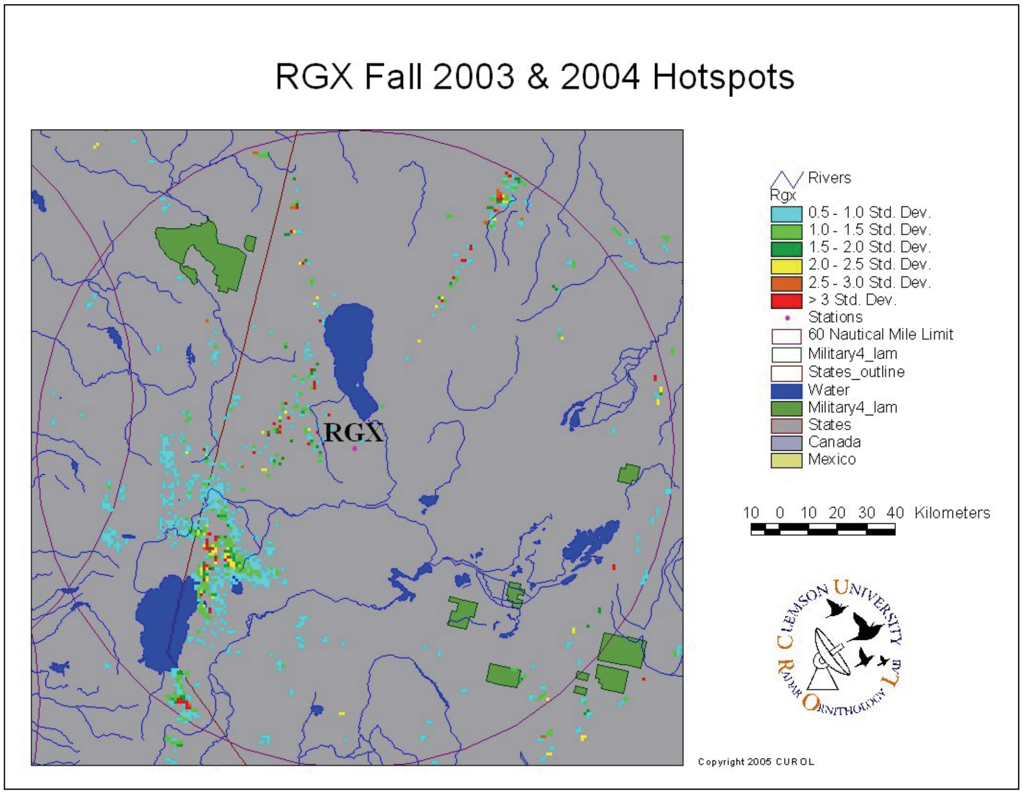
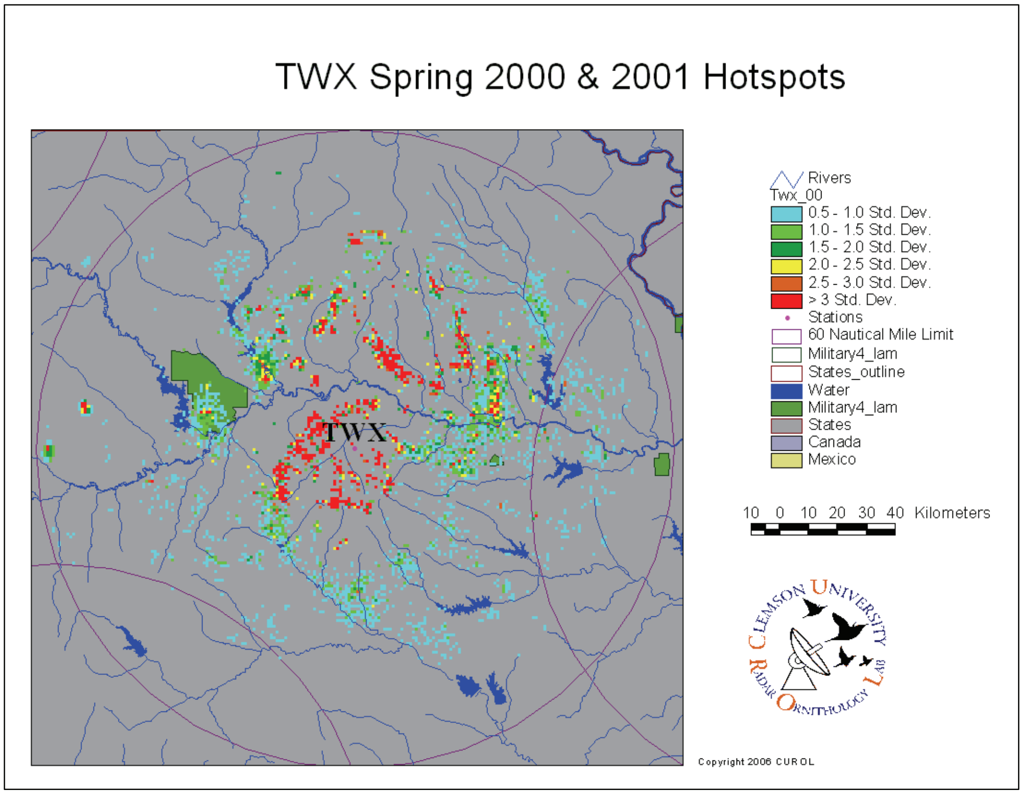


Figure B25. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station RGX in Reno, NV. The survey area encompasses the Sierra Army Depot.



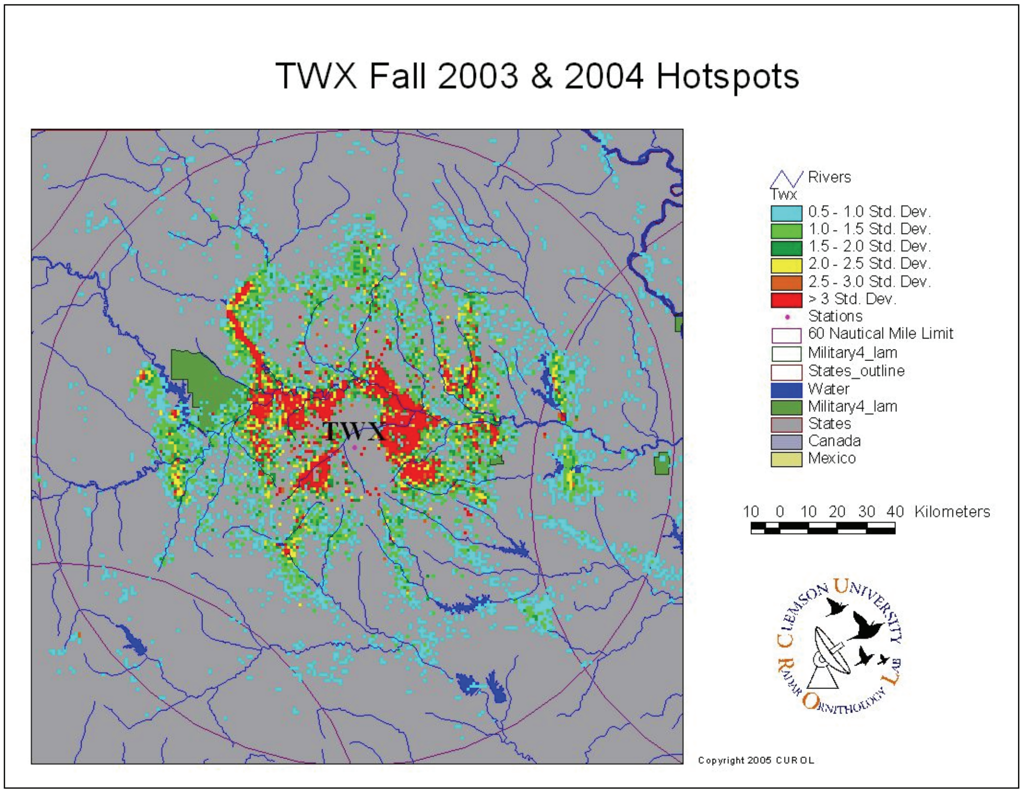
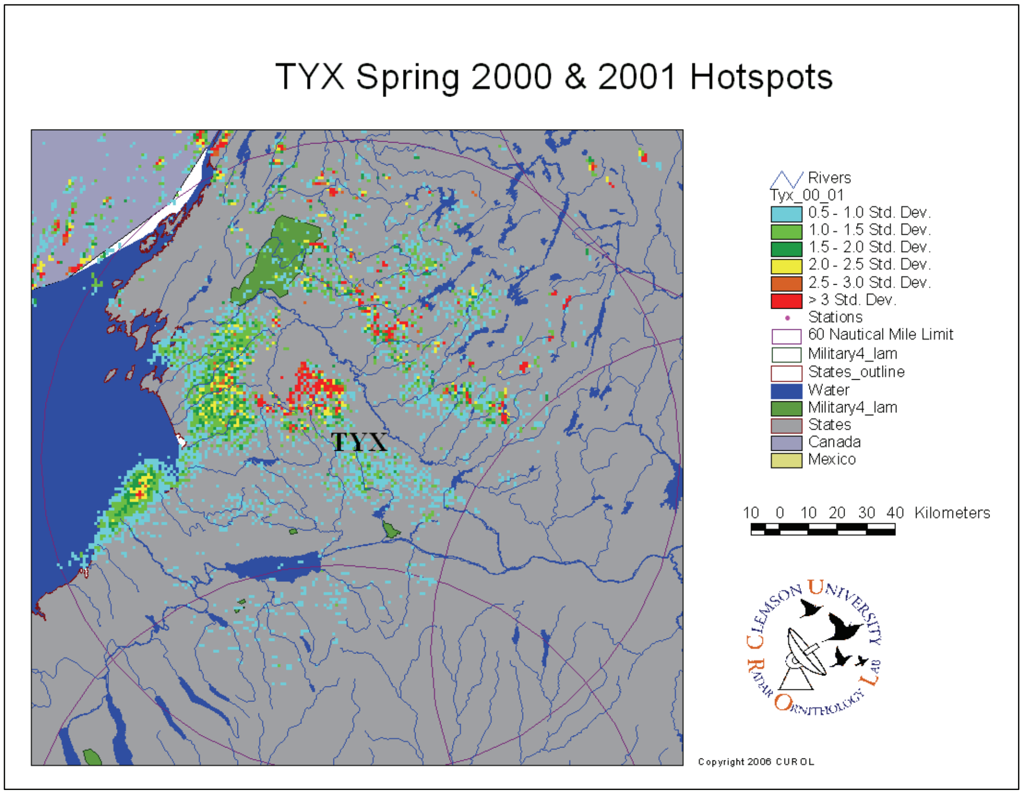


Figure B26. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station TWX in Topeka, KS. The survey area encompasses Fort Riley Military Reservation.


TYX Spring 2000 & 2001 Hotspots

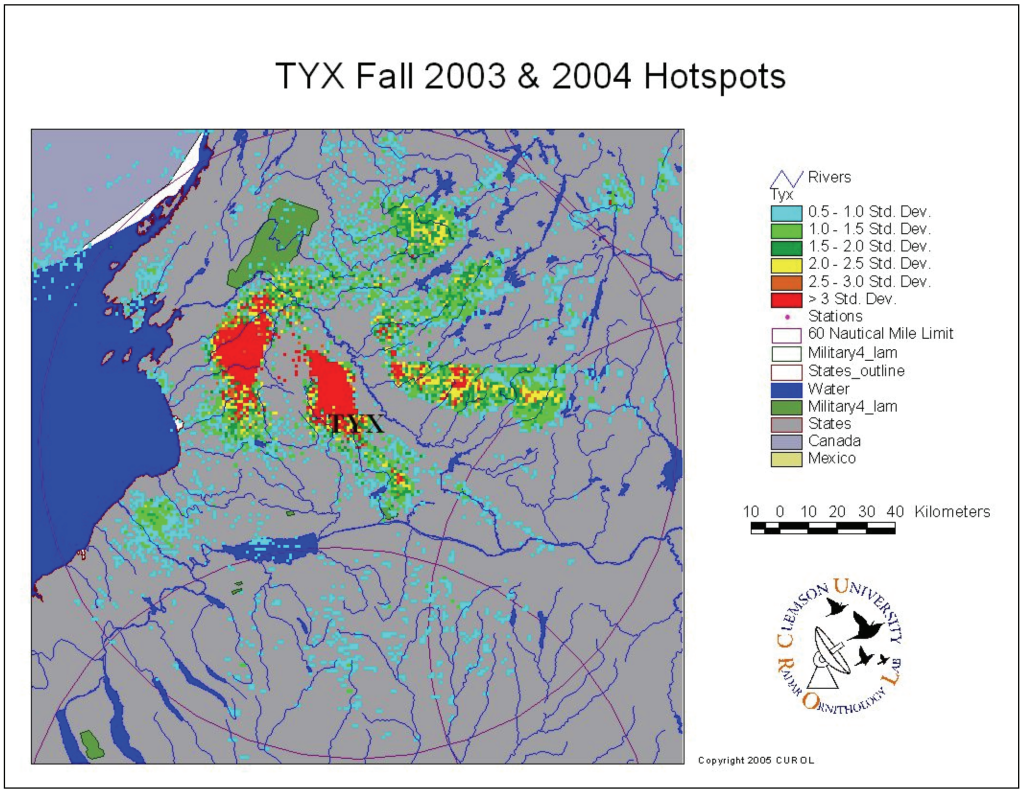
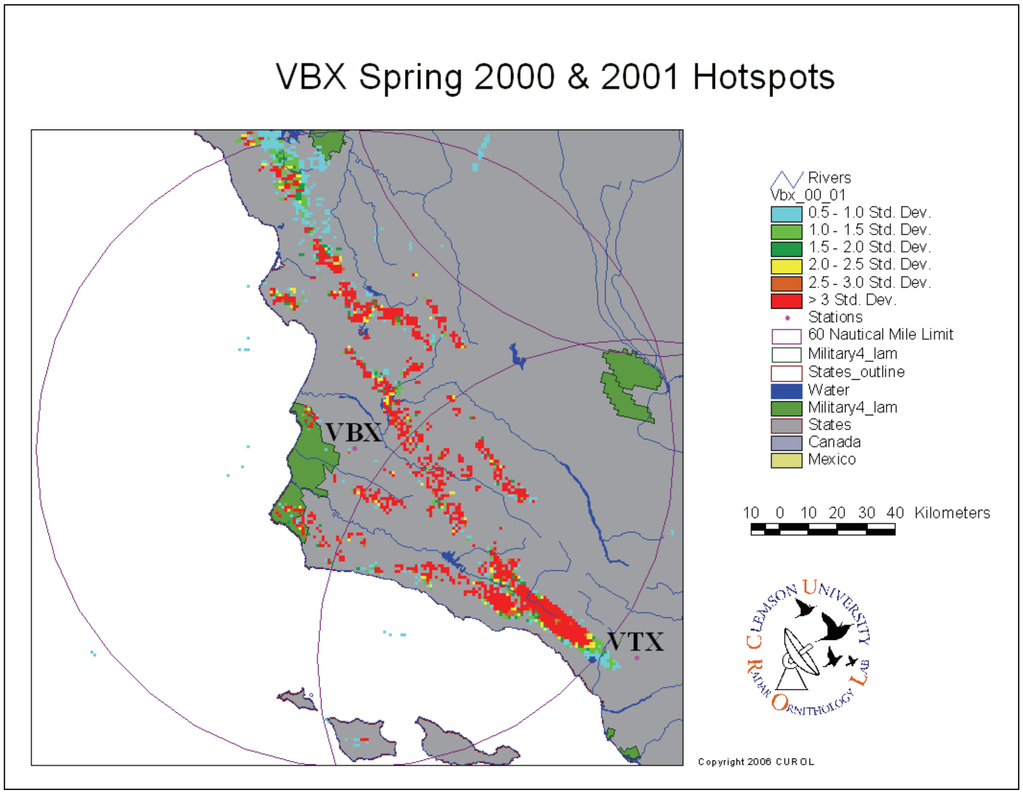

TYX Fall 2003 & 2004 Hotspots

Figure B27. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station TYX in northern NY. The survey area encompasses Fort Drum.



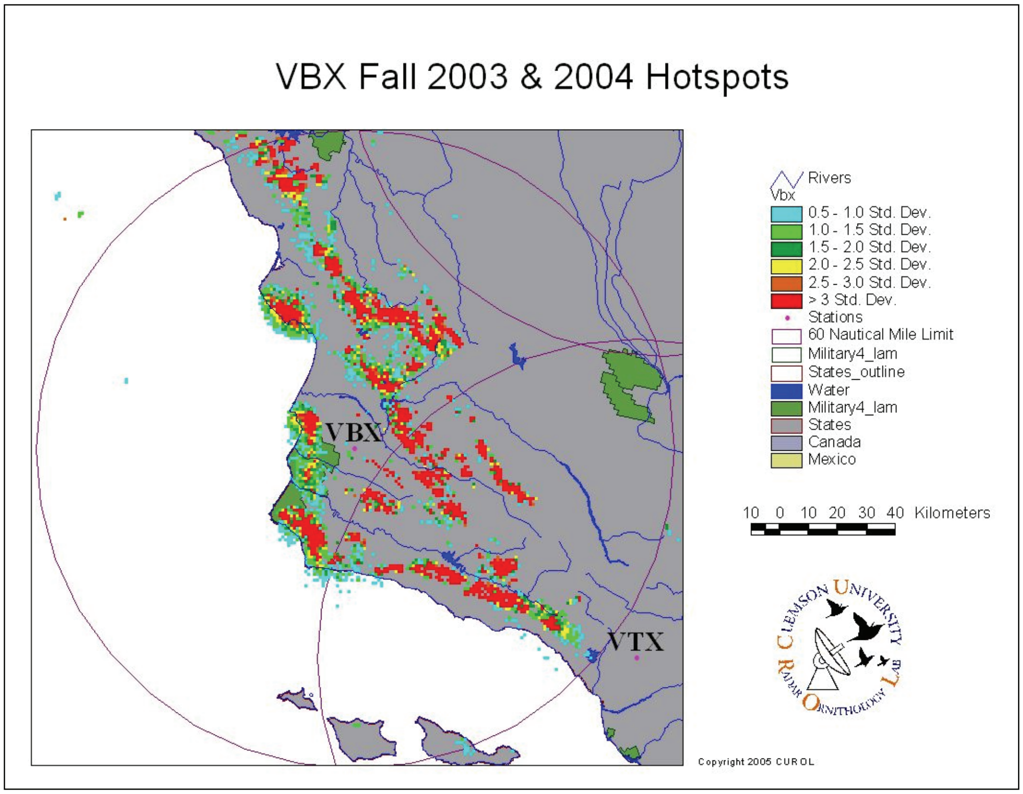
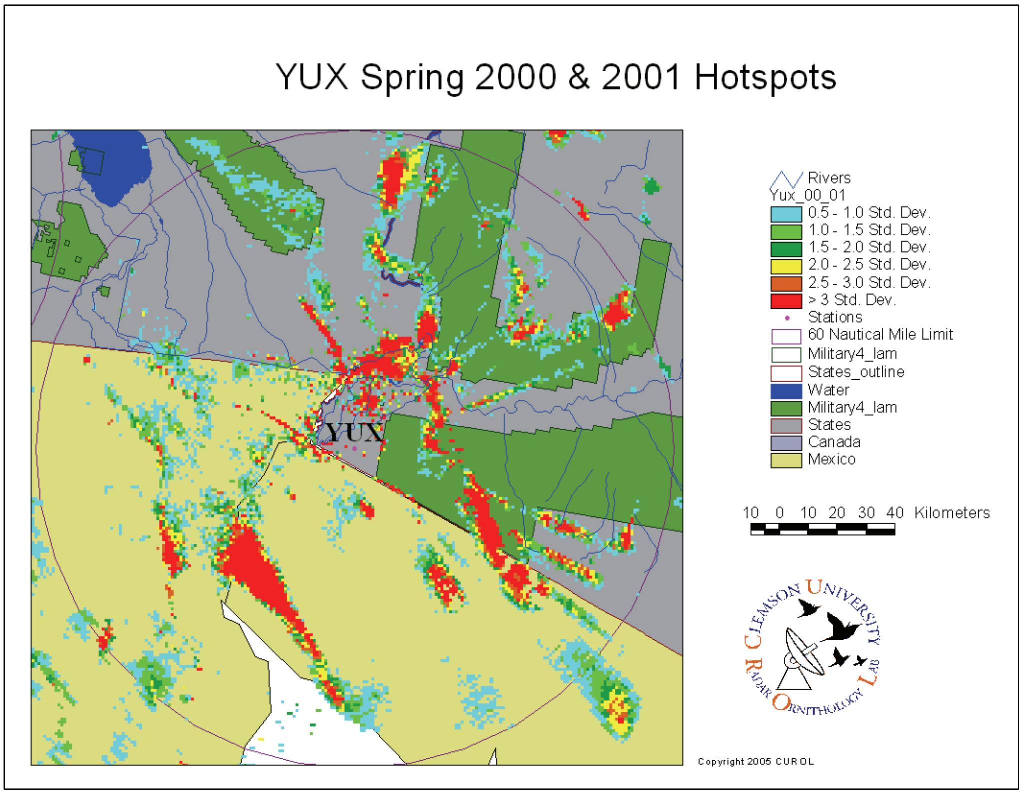


Figure B28. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station VBX in western CA. The survey area encompasses Vandenberg Air Force Base.


YUX Spring 2000 & 2001 Hotspots

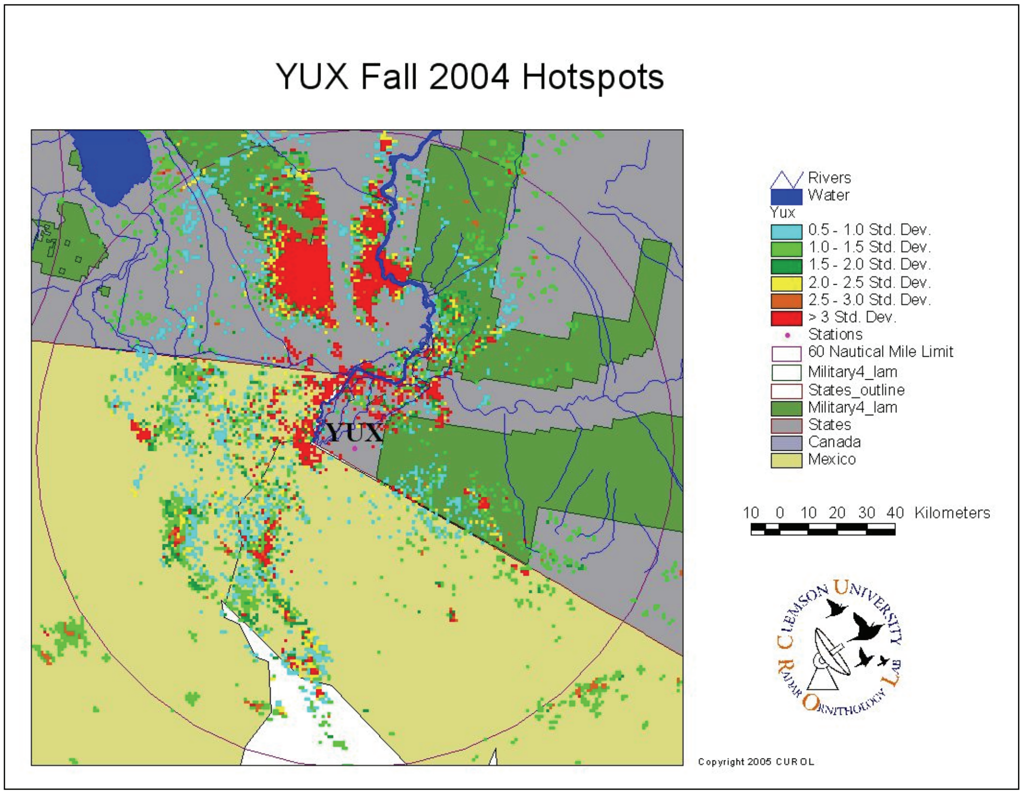

YUX Fall 2004 Hotspots

Figure B29. Composite maps indicating spring and fall migratory hotspots as recorded by NEXRAD station YUX in south-western AZ. The survey area encompasses Barry M. Goldwater Air Force Range and the Yuma Proving Ground.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

Military lands and waters may be particularly valuable for migrating birds requiring stopover habitat to rest and refuel en route to very distant seasonal ranges. Recent developments in radar technology have provided powerful tools for investigating on a broad scale migrant use of military installations; thus providing an opportunity to improve both conservation and flight safety measures. In this study, spring and fall migrant use of 40 military installations across the United States were qualitatively investigated. These times of year were selected since they are the periods when BASH is of most concern. Migratory patterns on three installations (Eglin Air Force Base, FL; Ft. Polk, LA; and Yuma Proving Ground, AZ) were then closely examined and migration forecast models for those locations were developed with the goal of providing a tool for reducing the probability of collisions between birds and military aircraft. A comparison was also made between radar estimates of migrant densities aloft during exodus events and more traditional ground-based surveys to evaluate the effectiveness of estimating migrant abundance in stopover habitat with radar data. At Fort Polk, movement ecology and migrant-habitat relations of the Red-eyed Vireo were investigated during migratory stopover. Lastly, migrant use of diverse riparian habitats was compared along water courses near the Yuma Proving Ground. Results indicated that approximately half of the installations examined with radar data contained migrant stopover "hotspots," reaffirming the fact that military installations are important to migrating birds. Interestingly, migrant abundances, and species turnover as estimated by ground-based surveys, were found to be poorly reflected migrant densities estimated with radar data. Migrant abundance, species richness, and community composition were all also found to be influenced by riparian vegetation composition. This information collectively suggested that radar data can be used to identify migratory hotspots on military installations and improve flight safety on installations with an aviation mission. However, radar data may not be sufficient to distinguish fine-scale differences in habitat use by migrants within an installation's boundaries.

15. SUBJECT TERMS

BASH
Migrating birds
Stopover hotspots
Radar estimates of ground densities
Radar ornithology
Bird migration forecast models

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