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COOPERATIVE UPLAND WILDLIFE RESEARCH AND SURVEYS

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COOPERATIVE UPLAND WILDLIFE RESEARCH AND SURVEYS

FINAL REPORT

Federal Aid Project W-106-R-17-20

Submitted by:

**Cooperative Wildlife Research Laboratory
Southern Illinois University Carbondale**

Presented to:

**Division of Wildlife Resources
Illinois Department of Natural Resources**

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COOPERATIVE WILDLIFE RESEARCH LABORATORY, SIUC
FINAL FEDERAL AID PERFORMANCE REPORT
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Title: Cooperative Upland Wildlife Research and Surveys

Project: W-106-R-17-20

Principal Investigators: Clay Nielsen, Donald Sparling, Eric Schauber, Charlotte Roy, and
Eric Hellgren

Graduate Assistants/Staff: Leah Berkman, Joanne Crawford, Doug Osborne, Tiffany Osborne,
Lyann Rubert, Paul Scharine, and Dan Stoelb (Graduate Research Assistants)

EXECUTIVE SUMMARY

This document represents our final report for W-106-R, Segments 17-20. Our work

spanned 4 separate studies (Study R-1: Bobwhite Response to CRP Grassland Management,

Study R-2: Population Dynamics and Status of the Swamp Rabbit in Illinois, Study R-3: Genetics

of Upland Wildlife, and Study R-4: Effects of Urbanization on Recruitment and Harvest of

Mourning Doves). We are pleased to report that we met all project objectives, largely as part of

3 theses and 1 dissertation conducted by graduate students and project staff. We provide

considerable information to forward management of upland wildlife in Illinois and throughout

the agriculturally-dominated Midwest. Primary accomplishments for each study and job are

summarized below.

Job R-1.1: Bobwhite Response to CRP Grassland Management

This Job's objectives are to: (1) compare bobwhite and other avian responses to different

field management regimes; and (2) compare vegetation structure and invertebrate abundance

among different field management methods. We provide the final report for this Job in form of a

dissertation by Osborne (2010; Appendix A). We evaluated the effects of 3 mid-contract

management regimes, including fall strip disking, fall herbicide spraying (hereafter, spray), and

fall herbicide spraying in combination with spring legume interseeding (hereafter, spray-seed) on nearly 650 ha of tall fescue CRP (Conservation Reserve Program) in south-central Illinois. Spray and spray-seed treatments were more effective than disking at reducing tall fescue cover, increasing plant species diversity, and enhancing the structural characteristics of the plant community that are essential for nesting and brood-rearing bobwhite. Spray-seed and disked treatments increased the percentage of bare ground by burying the dead and dying vegetative biomass beneath the soil surface. Plant species composition in sprayed and spray-seeded fields changed from a dense, monoculture of tall fescue to a diverse assemblage of perennial grasses, annual forbs, and legumes that provided habitat for nesting and brood-rearing bobwhite. Adult bobwhite and broods responded positively to spray and spray-seed treatments in this study. Adult relative densities (i.e., number of adult bobwhite observed/ha) were higher in sprayed and spray-seeded fields than in disked and controls. The probability of higher relative densities was greater in fields with higher plant species diversity, and percentages of bare ground and legumes. This research has added to the understanding of restoring bobwhite habitat to tall fescue CRP, and could assist USDA-Natural Resource Conservation Service personnel and other land managers in restoring and maintaining marginally diverse grassland ecosystems in CRP fields for nesting and brood-rearing bobwhite.

Job R-2.1: Public-Private Partnerships to Improve Swamp Rabbit Habitat

We completed this Job during Segment 18 (Rubert 2007; Appendix B). Habitat modeling indicated that 1% of the study area was classified as highly suitable habitat, and 85% of the areas with highest abundances of swamp rabbits were highly suitable. Owners of properties identified by this analysis as highly suitable were sent mail surveys to determine their willingness to

participate in or learn more about swamp rabbit conservation; most (69%) of landowners surveyed responded positively. Management opportunities for improving swamp rabbit habitat on private lands appear plentiful in southern Illinois.

Job R-2.2: Swamp Rabbit Response to Habitat Change

This Job's objective is to survey new sites for swamp rabbits and forecast the potential impacts of land management activities and farm programs on swamp rabbit habitat. We completed a large portion of this Job during Segment 18, and also conducted surveys of eastern cottontails as an addition to this Job (Scharine 2008; Appendix C). Based on occupancy and relative abundance data derived from pellet surveys and trapping, swamp rabbits used early-successional habitats created via farm programs. We identified several habitat variables that appear crucial for swamp rabbit occupancy in these newly-created habitats and also quantified habitat variables associated with relative abundance of swamp rabbits in bottomland hardwood forests. Early-successional habitat created via farm programs has the potential to increase swamp rabbit and eastern cottontail habitat in southern Illinois. We conducted additional surveys for swamp rabbits at 52 sites in 7 counties during Segments 19 and 20. We detected swamp rabbits at 8 new sites in southern Illinois.

Job R-3.1: Analysis of Bobwhite and Swamp Rabbit Genetics

This Job's objectives are to: (1) obtain genetic samples of bobwhites and swamp rabbits from fragmented habitat patches and mainland populations, and (2) determine extent of genetic differentiation among patches using microsatellite markers. We collected and analyzed 1,620 bobwhite tissue samples from 3 hunting seasons (2006-09) for analysis. Given the level of high gene flow indicated by analysis of F_{ST} ($F_{ST} < 0.05$) and private alleles, the lack of separation

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along principal components, and the results of Bayesian analysis, bobwhite appear to form 1 nearly panmictic population within southern and central Illinois. The lack of an isolation-by-distance pattern was also indicated by the lack of a relationship between ln geographic distance and genetic distance ($r = 0.075$, $P = 0.39$). We found no evidence to suggest that one sex may disperse longer distances or more frequently than another. This cohesion of Illinois bobwhite demographic has multiple consequences. First, the total available habitat may be more important than its arrangement or location within the state. For this reason, we suggest managers should focus on conserving and maintaining any productive habitat rather than prioritizing areas near occupied habitat or creating corridors for dispersal. Second, because subpopulations are so highly connected due to frequent dispersal, dynamics at the subpopulation scale are tied to those of the greater metapopulation. This result implies that bobwhite declines in one portion of the state may impact areas elsewhere. Swamp rabbit tissue samples were obtained during 2007-10 from trapped animals ($n = 82$), hunter harvests ($n = 13$), and latrines ($n = 9$). Analysis with STRUCTURE indicated that K = 4 was the most likely number of populations of swamp rabbits in southern Illinois, indicating genetic separation in the region. Assignment to genetic cluster appeared to be related to geographic location and subpopulation designation. Our results indicate that sites in the lower Cache River are relatively isolated from those in the far upper Cache River. To prevent further isolation, which may be more likely in northern populations, managers should focus on improving and maintaining connectivity along the Cache River. Sites in the Bay Creek watershed appear to receive migrants from the Cache River as evidenced by the similarity of their genetic make-up. We suggest that upland forested corridors may be important for maintaining the relatively sparse populations of swamp rabbits that occur in watersheds adjoining the Cache

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River in Illinois.

Job R-3.2: Combining Genetic Analyses and Habitat Information for Bobwhite and Swamp Rabbits

This Job's objectives are to: (1) examine the relationships among genetic diversity within a patch, time since isolation, and fragment size; and (2) integrate previous habitat maps and genetic analyses for a new understanding of population dynamics. For bobwhites, during Job R-3.1, we concluded that fragmentation of habitat in Illinois was insufficient to produce lasting genetic differentiation among habitat patches. Consequently, we limited our investigation of bobwhite genetics in this Job to the question of diversity and did not pursue an analysis of landscape influences on genetic differentiation. Allelic richness ranged from 7.47 in the Wayne County subpopulation to 8.38 in the Marion and Washington County subpopulations. Confidence intervals of the jackknife estimates of mean allelic richness all overlapped indicating a lack of significant difference between any 2 subpopulations. These results indicate no difference in diversity of subpopulations, which support the assertion that bobwhite in southern and central Illinois are 1 panmictic population. For swamp rabbits, allelic richness ranged from 2.39 in the Hickory subpopulation to 2.91 in Containment Basin. According to the overlap of jackknife 95% confidence intervals, differences in allelic richness among subpopulations were not significantly different. The partial Mantel test indicated that swamp rabbit genetic distance could be attributed to distance over watercourses while controlling for the effect of Euclidean distance ($r = 0.18$, $P = 0.0001$). Management actions intended to promote swamp rabbit colonization should be in areas connected to occupied patches by watercourses. Increased forested habitat in riparian corridors may improve connectivity and decrease extinction risk for

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isolated populations.

Job R-4.1: Effects of Urbanization on Mourning Dove Nesting Success, Nesting Behavior, Movements, and Home Range

The objective of this job was to determine if nesting success dates and cover, movements during nesting season and early fall, and home-range size of mourning doves varied with degree of urbanization (Stoelb 2009; Appendix D). We implanted 59 mourning doves in urban areas and 14 in rural/exurban areas with radiotransmitters during the 2007–09 breeding seasons. Of these birds, we recorded 2 deaths and found 7 transmitters during tracking. We estimated home-range size during the breeding season for all telemetered birds ($n = 26$ [urban] and 3[rural]) for 2007–09 for which we had ≥10 radiolocations. Range size averaged 14.13 ± 4.44 (SE) ha for females ($n = 13$) and 15.81 ± 8.90 ha for males ($n = 13$), compared to 4.36–30.06 ha for 3 males in rural areas. Movements between consecutive locations averaged 144.2 ± 12.4 m for females ($n = 365$ movements) and 159.5 ± 8.5 m for males ($n = 355$ movements) in urban areas. We located 129 nests of mourning doves in urban areas during the 2008 and 2009 nesting seasons. Nest trees were taller and larger in diameter than random, paired trees. Doves did not select nest trees by species. Estimated nest success ($n = 49$) of mourning doves was 66.6% during 2008 in 2 exurban sites, with nesting densities between 0.12 and 0.19 nests/ha. Nest-survival modeling provided weak evidence that nest success was negatively related to canopy closure and nest height. Mourning dove nests were lower in trees and in trees with sparser canopies in areas with greater human population. In all study sites, lawn and buildings were in the top 3 most preferred landcover types for nesting, whereas grasslands, farmland, and water were consistently preferred the least (i.e., selected against) by nesting mourning doves.

Job R-4.2: Impacts of Urbanization on Mourning Dove Abundance and Harvestable Surplus

The objective of this Job is to use band return data to estimate the proportion of annual harvest coming from urban, suburban, exurban, and rural sites. Based on call counts, relative abundance of mourning doves was positively related to human population, but the total number of calls heard decreased from 2007 to 2008. Among sites, the number of calls heard was positively related to the percentage of area occupied by buildings around call-count points. Nearly 20 times as many doves were heard in sites containing the largest percentage of buildings compared to sites that contain the smallest. We received reports of 44 band recoveries of 626 banded doves. The percentage of mourning doves banded in urban areas that were recovered (7.4%) did not vary ($\chi^2 = 0.32$, 1 df, $P > 0.05$) from the proportion recovered in rural areas (6.0%) during the 2007-09 seasons. However, a higher proportion of banded urban doves were recovered in Illinois compared to a similar study in Ohio.

Job R-4.3: Distribution of Eurasian Collared-Doves in Illinois

The objective of this job is to develop baseline data on the occurrence of Eurasian collared-doves in southern Illinois and on interactions between Eurasian collared-doves and mourning doves. We developed a visual survey to estimate relative densities of mourning doves and Eurasian collared-doves during 2007–09. We found that the ratio of mourning doves to Eurasian collared doves exceeded 10:1 in 3 urban study sites (human population of 4,600–16,000), and a fourth urban site contained no Eurasian collared doves. Surveys of 6 additional small towns (population: 224–1,669) and 2 rural areas resulted in observations of Eurasian collared-doves in only 1 small town. We captured 626 mourning doves and 2 Eurasian collared-

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doves during the 2007-09 field seasons. We located 27 nests of Eurasian collared-doves during

the 2008 and 2009 nesting seasons.   Nest-site characteristics of collared-doves and mourning

doves did not vary consistently across years. We recommend our survey technique as a repeatable

method to assess relative abundance of mourning doves and Eurasian collared-doves in urban

areas. Wildlife managers do not have immediate concerns about negative effects of Eurasian

collared-doves on mourning dove populations in southern Illinois, although numbers of collared-

doves should be monitored.

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STUDY R-1. UPLAND WILDLIFE/HABITAT RELATIONSHIPS
JOB R-1.1: BOBWHITE RESPONSE TO CRP GRASSLAND MANAGEMENT

Objectives: (1) compare bobwhite and other avian responses to different field management regimes; and (2) compare vegetation structure and invertebrate abundance among different field management methods.

We attach a completed doctoral dissertation in lieu of annual and final report of the methods, results, and findings for this Job, which was active during Segments 18-20 (Osborne 2010; Appendix A). Following is the abstract from Osborne (2010):

Northern bobwhite (hereafter, bobwhite; *Colinus virginianus*) have experienced long-term declines in population abundance throughout most of their breeding range. In 2004, the United States Department of Agriculture (USDA) authorized mid-contract management (MCM) to restore early successional plant communities in aging Conservation Reserve Program (CRP) fields. I evaluated the effects of 3 MCM regimes, including fall strip disking, fall herbicide spraying (hereafter, spray), and fall herbicide spraying in combination with spring legume interseeding (hereafter, spray-seed) on nearly 650 ha of tall fescue (*Schedonorus phoenix* [Scop]. Holub) CRP in south-central Illinois, USA, during 2005-2008. The objectives of this study were to: 1) evaluate the compositional and structural responses of the vegetation community to MCM, 2) determine the structural vegetation and landscape composition variables that influenced adult bobwhite relative densities and brood presence in CRP, and 3) assess foraging rates and arthropod prey selection of bobwhite chicks relative to MCM. Spray and spray-seed treatments were more effective than disking at reducing tall fescue cover, increasing plant species diversity, and enhancing the structural characteristics of

the plant community that are essential for nesting and brood-rearing bobwhite. Spray-seed and disked treatments increased the percentage of bare ground by burying the dead and dying vegetative biomass beneath the soil surface. However, spraying alone left large amounts of litter accumulation on the soil surface that resulted in a delay in the timing of some annual forbs to recolonize. Plant species composition in sprayed and spray-seeded fields changed from a dense, monoculture of tall fescue to a diverse assemblage of perennial grasses, annual forbs, and legumes that provided habitat for nesting and brood-rearing bobwhite. Adult bobwhite and broods responded positively to spray and spray-seed treatments in this study. Adult relative densities (i.e., number of adult bobwhite observed/ ha) were higher in sprayed and spray-seeded fields than in disked and controls. The probability of higher relative densities was greater in fields with higher plant species diversity, and percentages of bare ground and legumes. Conversely, relative densities were negatively associated with higher percentages of grass cover. At the landscape scale, relative densities were positively correlated higher percentages of cropland and pastureland within a 250 m buffer of CRP fields. Sprayed and spray-seeded fields were 39.6% more likely to have broods present than control fields, whereas disked fields were only 10.0% more likely to have broods than controls. Brood presence was positively correlated with higher percentages of bare ground and negatively correlated with higher percentages of grass cover. Human-imprinted bobwhite chicks consumed a higher abundance and biomass of arthropods in sprayed and spray-seeded fields than in disked and controls, although the abundance of arthropods available was generally highest in

control and disked fields. This suggests, therefore, that bobwhite chicks foraging

rates are not limited by arthropod availability, but rather, by the structure of the

vegetative community and the ability of the chicks to access the food resources.

Chicks consumed a higher proportion of hymenopterans, isopods, and

lepidopterans than expected from nonrandom feeding indicating that they were

actively selecting for particular prey. This research has added to the understanding

of restoring bobwhite habitat to tall fescue CRP, and could assist USDA-Natural

Resource Conservation Service personnel and other land managers in restoring

and maintaining marginally diverse grassland ecosystems in CRP fields for

nesting and brood-rearing bobwhite.

**STUDY R-2. POPULATION DYNAMICS AND STATUS OF
THE SWAMP RABBIT IN ILLINOIS**

**JOB R-2.1: PUBLIC-PRIVATE PARTNERSHIPS TO IMPROVE SWAMP RABBIT
HABITAT**

<u>Objectives</u>: (1) determine the extent and distribution of, and opportunity for bottomland timber management on private lands; and (2) determine potential areas where public-private partnerships could improve habitat and connectivity for extant population assemblages.

A Master's thesis is attached in lieu of an annual report of the methods, results, and

findings for this Job, which was active during Segments 17 and 18 (Rubert 2007; Appendix B).

Following is the abstract of Rubert (2007):

The distribution and abundance of swamp rabbits in southern Illinois have

decreased due to loss and fragmentation of bottomland hardwood forests.

Remaining suitable habitat is fragmented and most populations are isolated

because of limited dispersal across open areas. I created a model of habitat

suitability for swamp rabbits in southern Illinois using geospatial data, expert-

opinion surveys, and a geographic information system (GIS). The expert survey

was distributed to biologists knowledgeable about swamp rabbits to quantify their

opinions about dispersal and habitat suitability by ranking certain habitat features

and variables. I then used a GIS to analyze the data and create a map of habitat

suitability. I determined potential dispersal corridors using a least-cost path

analysis. The resultant corridors were prioritized based on

management goals of population expansion, population conservation, and

identifying parcels of land to target for inclusion in government conservation

incentive programs. About 1% of the study area was classified as highly suitable

habitat, and 85% of the areas with highest swamp rabbit abundances were highly

suitable. Owners of properties identified by this analysis as highly suitable were

sent mail surveys to determine their willingness to participate in or learn more about swamp rabbit conservation. The majority (69%) of landowners surveyed responded positively.

JOB R-2.2: SWAMP RABBIT RESPONSE TO HABITAT CHANGE

<u>Objective:</u> (1) survey new sites for swamp rabbits and forecast the potential impacts of land management activities and farm programs on swamp rabbit habitat.

A Master's thesis is attached in lieu of an annual report of the methods, results, and findings for this much of this Job (Scharine 2008; Appendix C). Furthermore, we also provide information about eastern cottontails' (*Sylvilagus floridanus*) response to farm programs. Following is the abstract of Scharine (2008); this portion of Job R-2.2 was active during Segments 17 and 18:

I studied habitat factors associated with relative abundance, detection, and occupancy of 2 species of lagomorphs (swamp rabbit [*Sylvilagus aquaticus*]; and eastern cottontail [*Sylvilagus floridanus*]) in southern Illinois during 2006-07. I found that the contiguity index of the landscape, the range in contiguity index of upland habitats, and tree stump density were strongly related to relative abundance of swamp rabbits in floodplain forests. Canopy closure and site area had the largest influence on detection probability for both eastern cottontails and swamp rabbits in recently afforested wetlands. Detection probability decreased with increasing canopy closure for eastern cottontails but increased with increasing canopy closure for swamp rabbits. I found that the mean fractal dimension index of the landscape and the mean related circumscribing circle distribution of the landscape had a weak to moderate influence on occupancy of eastern cottontails in recently afforested wetlands. The distance to a semi-permanently flooded or intermittently exposed wetland strongly influenced the probability of occupancy of swamp rabbits in recently afforested wetlands. This study provides useful

information to wildlife managers wishing to improve existing floodplain forests or restore lost forested wetlands for lagomorphs in southern Illinois.

We conducted further swamp rabbit surveys during Segments 19 and 20; those data are summarized below.

INTRODUCTION

Swamp rabbits use bottomland hardwood forests and associated early-successional habitats and may serve as useful indicators of ecosystem health (Launer and Murphy 1994, Fleishman et al. 2000). Swamp rabbits are large, dark cottontails occurring primarily in forested wetlands and wetland-associated habitats in the southeastern United States (Chapman and Feldhamer 1981, Allen 1985). They inhabit wetland habitats from the coastal marshes of Texas, Louisiana, Mississippi, and Alabama, to the bottomland hardwood forests of southern Indiana and southern Illinois (Terrel 1972).

Fragmentation of bottomland hardwood forests has resulted in a patchy distribution for swamp rabbits throughout the northern portion of their range (Terrel 1972, Chapman and Feldhamer 1981, Kjolhaug and Woolf 1988, Barbour et al. 2001). In southern Illinois, swamp rabbits are found clustered in patches of suitable habitat along the Cache, Mississippi, and Ohio rivers, as well as a few sites along smaller rivers (Kjolhaug et al. 1987, Barbour et al. 2001, Woolf and Barbour 2002). The patchy nature of these remaining habitats increases the risk of local extirpations due to habitat loss and stochastic events (Barbour et al. 2001, Woolf and Barbour 2002). Thus, wildlife biologists require information about swamp rabbit presence and relative abundance to ensure the persistence this species. We conducted further swamp rabbit pellet surveys at historical and new sites as part of this Job.

METHODS

Pellet Surveys

During November-Match 2009 and 2010, we surveyed for presence of swamp rabbits by searching for pellets on (1) logs at bottomland hardwood forest sites (Scharine et al. 2009) and (2) artificial latrine logs at early-successional sites lacking downed logs (Schauber et al. 2008). Fecal pellet surveys are the primary survey method used for lagomorphs (McCollum and Holler 1994, Zollner et al. 1996, Woolf and Barbour 2002). For bottomland hardwood forest sites containing downed logs, multiple transects were searched with observers spaced 20 m apart or closer depending on the thickness of the habitat. This continued until the entire area of the site was searched, and we documented presence or absence of swamp rabbits at each site. Search efforts were focused on raised objects such as stumps, logs, and hillocks, as swamp rabbits often defecate on raised objects (Chapman and Feldhamer 1981, Allen 1985). Searches were not conducted if snow cover was present or if a site flooded within the previous 14 days. Swamp rabbit pellets were distinguished from eastern cottontail pellets based on the location of the deposition, size, and appearance of the pellets. In Indiana, swamp rabbit pellets had an average diameter of 12.3 mm, while cottontail pellets had an average diameter of 7.6 mm (Whitaker and Abrell 1986). Similar pellet survey methods have been used in several studies (Kjolhaug et al. 1987, Barbour et al. 2001, Roy Nielsen et al. 2008).

RESULTS AND DISCUSSION

Data were not collected on the number of latrines per site. However, multiple latrines were found at every site where swamp rabbits were noted as present (Table 1). The exception was Bumgard Island, which was determined to be an occupied site based on the presence of just 1 pellet in 2010. Surveyors have noted high latrine log densities at Bumgard Island in the past

(Porath 1997, Cole 2004). At the time of the 2010 survey, the low-lying areas where historic survey transects were located (Woolf and Barbour 2002) were flooded and surveys occurred in adjacent areas. Although recent surveys, including the present one, indicate that swamp rabbit density on Bumgard Island has decreased (Cole 2004), future surveys along established transects (Woolf and Barbour 2002) may be needed to confirm.

Sites for which we found no previous search records included Bates, Broadway, East Unity, Forsythe Mine, McAllister, Old Town Lake, Robnett Creek, and Ullin. The East Unity and Ullin sites were located on the main channel of the Cache river. Considering their placement relative to the historically occupied sites in Illinois (Kjolhaug 1986, Porath 1997, Woolf and Barbour 2002) these 2 sites represent additional portions of the core area that has been consistently populated.

Based on word-of-mouth we surveyed the Forsythe Mine in the Big Muddy watershed. At the time of the survey this property belonged to a private hunt club. The relatively severe topography produced by the mine tailings created a landscape of upland island hills within permanently flooded sloughs and ponds. No sign was found, and given that this site did not contain semi-permanent, temporarily flooded bottomlands, or dense understory vegetation that generally occur in occupied habitat (Allen 1985), it is not recommended that this site be surveyed in the future.

The Bates site was privately owned and within the Bay Creek watershed. Although the site appeared suitable (i.e., containing dense early succession vegetation, and adjacent to Bay Creek), no sign was found in the winter of 2009. For the 2010 survey, 5 artificial latrine logs (Schauber et al. 2008) were placed on the property. On revisit, 2 of the 5 artificial latrine logs contained rabbit pellets. A portion of this property was enrolled in a Natural Resources

Conservation Service program.

Downed logs from an ice storm significantly hampered searches at Stafford Bluff and Robnett Creek. The ability to detect pellets at these sites was much lower than others. Since conditions may improve at these sites after logs decay and these 2 sites are among the few representing the sparsely occupied Bay Creek watershed, it is recommended that they be included in future monitoring efforts.

STUDY R-3. GENETICS OF UPLAND WILDLIFE

JOB R-3.1: ANALYSIS OF BOBWHITE AND SWAMP RABBIT GENETICS

<u>Objectives</u>: (1) obtain genetic samples of bobwhites and swamp rabbits from fragmented habitat patches and mainland populations and (2) determine extent of genetic differentiation among patches using microsatellite markers.

The primary goal of Study R-3 is to investigate the landscape genetics of northern bobwhites (*Colinus virginianus*) and swamp rabbits in Illinois. Suitable habitat for northern bobwhite and swamp rabbits is decreasing and fragmented in Illinois. Habitat models exist for both bobwhite (Roseberry and Sudkamp 1998, Thogmartin 2002) and swamp rabbits in Illinois (Barbour et al. 2001). Combining a landscape genetic analysis and current habitat knowledge can provide information about how these 2 species disperse among patches of suitable habitat. With a greater understanding of bobwhite and swamp rabbit movements at a landscape scale, managers can more effectively prioritize areas for conservation. For this final report, we provide methods, results, and discussion for both species separately.

Bobwhite

INTRODUCTION

Bobwhite typify an r-selected species; meaning they are short-lived, have enormous reproductive capacity, low survival, and early age at first reproduction. Bobwhite suffer 50-80% annual mortality in Illinois and are able to make yearly gains of 400% (Roseberry and Klimstra 1984). In Illinois, bobwhite use upland habitat in multiple successional stages (Roseberry and Klimstra 1984) and depend heavily on disturbance to renew such habitat (Ellis et al. 1969). Consequently, a particular patch that is currently suitable may not be suitable after 10 years, while new suitable habitat becomes available after a disturbance. Small-bodied, short-lived species with high reproductive rates and habitat specificity generally conform to a

metapopulation structure (Murphy et al. 1990) and dispersal and colonization ability dictates the

persistence of a metapopulation.

Wide dispersal is also a characteristic of r-selected species. Paradoxically, Leopold

(1933) regarded bobwhite as the most sedentary game species. Home ranges are generally ≤2.5

km^2 (Lehmann 1946, Murphy and Baskett 1952) and most bobwhite rarely move distances of >2

km (Kabat and Thompson 1963, Roseberry and Klimstra 1984, Fies et al. 2002, Townsend et al.

2003). However, in Oklahoma, Duck (1943) noted 11 bobwhite moved 16 km and 1 individual

moved 42 km. Lehmann (1946) reported possible large-scale movements of Texas bobwhite

evidenced by large fluctuations in population size that were unexplained by environmental

influence. Although variability in movement patterns may be region-specific, these studies

suggest bobwhite are capable of long-distance dispersal movements despite their largely

sedentary nature.

The early observations of sedentary bobwhite may not accurately reflect the population

dynamics of the species at a larger scale. Studies addressing bobwhite dispersal by banding and

recapturing birds (Lehmann 1946, Murphy and Baskett 1952, Kabat and Thompson 1963)

focused on the actions of established individuals in single areas of 388-4,047 ha. Although they

consistently found that most birds moved only short distances, 42-79% of birds were never

recovered after initial banding. Studies using radiotelemetry and intensive efforts to relocate all

birds on a study site censored birds that could not be relocated but rarely provided estimates of

the proportion that may have dispersed off of the study site (Fies et al. 2002, Townsend et al.

2003). One study indicated as many as 8% of radiotracked bobwhite disappeared (Terhune et al.

2006). Although dispersal is considered risky behavior and a small proportion of dispersers may

survive to reproduce, Townsend et al. (2003) found dispersing bobwhite (those that moved

>2,000 m) had a greater survival rate than non-dispersers (those that moved <1,000 m). If

missing birds from these studies survived to reproduce in another area they may play a significant

role in the population dynamics of bobwhite. Genetic structure may illuminate whether a large

number of dispersers generally survive to reproduce or whether sedentary bobwhite are

reproductively isolated.

Early-successional upland habitat, which is critical for bobwhite, has been lost to

agricultural and rural development over the past half century (Brennan 1991, Warner 1994) and

bobwhite declines in Midwestern states have coincided (Peterson et al. 2002). Small-scale

agriculture that had provided suitable habitat for bobwhite has given way to larger farms with

lower habitat diversity (Vance 1976, Brennan 1991). Exotic grasses have invaded old fields

making them unsuitable for bobwhite (Roseberry and Klimstra 1984, Warner 1994). Current

habitat alterations and continued decline require a resolution to the question of whether bobwhite

can or cannot disperse amongst fragmented habitat patches as this will impact management

decisions such as prioritizing areas for conservation and arrangement of conserved fields in

space.

We applied genetic methods to determine whether bobwhite in central Illinois are

composed of distinct population segments, which are isolated by distance due to limited dispersal

among fragmented habitat patches. If bobwhite cannot effectively disperse to all available

habitats, genetic drift may render groups of bobwhite genetically distinct through change in allele

frequencies.

METHODS

Sample Collection. Bobwhite hunters and natural resource professionals were contacted

for assistance in obtaining bobwhite wings from November 2006-January 2009 (Appendix E).

Unrefrigerated wings were sent to the Cooperative Wildlife Research Laboratory at Southern

Illinois University Carbondale. Wings were refrigerated upon arrival, processed, and cataloged

or frozen at 20° C within approximately 3 weeks of arrival. To process wings for longer-term

storage, a piece of connective tissue and muscle (approx. 5 mm) was excised from near the elbow

or wrist joint and stored in a 1.5-mL centrifuge tube at -70° C (Seutin et al. 1991, Oyler-

McCance et al. 2005). Wings without location information at least as specific as the political

section were not processed.

Genotyping. The efficacy of 24 microsatellite primers published previously for bobwhite

(Schable et al. 2004, Faircloth et al. 2009) was determined in samples representing 2 counties,

Marion ($n = 5$) and Saline ($n = 6$). We extracted bobwhite DNA with the Wizard Genomic DNA

Purification Kit (Promega) according to the Mouse Tail Protocol. Polymerase chain reactions

(PCR) consisted of 10 µL total volume of ThermoScientific® PCR Master Mix (0.625 units Taq

polymerase, 75 mM Tris-HCl, 20 mM $(NH_4)_2SO_4$, 2.0 mM $MgCl_2$, 0.01% Tween 20®, 200 µM

each dNTP), 0.4 µM unlabeled primer, 0.04 µM labeled primer, 0.36 µM dye labeled universal

primer (either CAG or M13) and approximately 20 ng genomic DNA. Thermocycling conditions

noted in Schable et al. (2004) were followed and included a touchdown-style PCR: 21 cycles of

96° for 20 sec, 60° for 30 sec less 0.5° each annealing cycle finishing at 50°, and an extension of

60 sec at 72°; then 10 or 15 cycles of 96° for 30 sec, 50° for 30 sec, and 72° for 60 sec. Products

were run with Rox-400 size standard (The Gel Company, San Francisco, California, USA) on an

ABI 3130xl sequencer (Applied Biosystems Inc., Foster City, California, USA).

We genotyped a subset of samples from Marion ($n = 64$) and Saline ($n = 23$) counties at

20 loci that initially produced consistent results. However, instead of using 3 primers in the PCR

reaction; labeled, unlabeled, and dye-labeled universal primer; only 2 primers were used: 0.4 µM

labeled primer and 0.4-µM dye-labeled primer. Products were run with Rox-400 size standard

on an ABI 3130xl sequencer. Multiplex PCR combinations included Q13 with P2D10, P1F3

with PCF5, Q22 with Q30, and Q23 with Q24.

Results were analyzed for scoring errors, specifically the presence of non-amplifying

(null) alleles, using the program MICROCHECKER (Van Oosterhout et al. 2004). After loci that

contained null alleles, lacked sufficient polymorphism, or could not be scored consistently were

dropped from further analysis, bobwhite samples from Marion ($n = 122$), Saline ($n = 137$), Scott

($n = 23$), Perry ($n = 22$), Washington ($n = 78$) and Wayne ($n = 52$) counties (Figure 1) were

genotyped at 11 polymorphic loci: Quail 11, Quail 13, Quail 14, Quail 22, Quail 23, Quail 24,

Quail 30, Quail 32, CV-P1F3, CV-PCF5, CV-PCG2 (Schable et al. 2004, Faircloth et al. 2009).

For some samples heterozygous at locus Q14, we noted drastically higher fluorescent

peaks in 1 allele compared to another. This inconsistency in allele height was thought to be the

results of preferential amplification of 1 allele possibly due to the touchdown style of thermal

cycling. Consequently, thermal cycling conditions were adjusted to 32 cycles of 94° for 30 sec,

52° for 30 sec and 72° for 30 sec. for a subset of samples ($n = 14$) at the Q14 locus and rescored.

We tested for Hardy-Weinberg equilibrium and linkage disequilibrium within

subpopulations using the methods of Guo and Thompson (1992) and Raymond and Rousset

(1995) with the program GENEPOP v. 4 (Rousset 2008). Bonferroni adjustments were made for

multiple comparisons (Rice 1989). The probability of identity, the probability that 2 siblings

share the same genotype, was calculated for each subpopulation with the program GenAlEx v.

6.2 (Peakall and Smouse 2006). If 2 samples had matching genotypes, we removed 1 from the

analysis.

Related Individuals. Hunters were likely harvesting multiple birds from the same covey

and we considered the possibility that some birds in our sample were broodmates. We examined the overall pattern of relatedness in subpopulations to determine whether birds within our samples were more related to one another than expected from random. We calculated the relatedness coefficient (Queller and Goodnight 1989) for all pairs of bobwhite. We generated simulated genotypes based on the allele frequencies in each subpopulation and calculated the relatedness for each simulated pair. Relatedness computations used a pair bias correction and subpopulation allele frequencies as background. We compared the relatedness coefficients and their frequency distributions for both the bobwhite genotypes and the simulated genotypes.

To find related individuals we tested the hypothesis that bobwhite harvested in the same section were full siblings. The likelihood of a relatedness coefficient under the hypothesis of a full sibling relationship was assessed against the likelihood of the same relatedness coefficient under the hypothesis of no relationship. Background allele frequencies were determined using all members of the subpopulation except for those in the section that was under scrutiny. The significance level of the resulting likelihood ratio was determined via simulated genotypes (Goodnight and Queller 1999). All pairs of individuals for which the hypothesis of a full sibling relationship was accepted ($P < 0.001$) were considered related. We randomly removed 1 individual from a pair of related individuals or all but one member of a group of >2 related individuals. The software program KINGROUP v. 2 (Konovalov et al. 2004) performed all calculations of relatedness coefficients, simulated pair genotypes, likelihood ratios, and their probabilities under a null hypothesis. We calculated F_{ST} and determined the most likely number of populations using STRUCTURE v. 2.3 (Pritchard et al. 2000) with related individuals removed and with all samples included for comparison. We conducted the remainder of analyses with related individuals removed. The final sample sizes for each population were Marion $n =$

103; Saline $n = 101$; Washington $n = 72$; Wayne $n = 49$; Scott $n = 23$; and Perry $n = 22$.

Genetic differentiation. We assessed genetic differentiation among bobwhite subpopulations using 2 approaches: determining gene flow between groups of samples designated by their county of harvest, hereafter termed a subpopulation, and Bayesian approaches which determine the most likely number of genetic groups. We calculated gene flow between the sampling sites with global and pairwise F statistics (Weir and Cockerham 1984) and computed bootstrapped 95% confidence intervals with the program FSTAT v. 2 (Goudet 2002). Significance of pairwise F_{ST} values among subpopulations was assessed with 999 permutations using GENALEX v. 6.2 (Peakall and Smouse 2006). We computed an additional measure of gene flow, the number of migrants per generation using the frequency of private alleles (Slatkin 1985), with the program GENEPOP v4 (Rousset 2008) and examined population differentiation using the contingency table method that assesses differences in allele frequency among subpopulations (Rousset 2008).

We used the program STRUCTURE v. 2.3 (Pritchard et al. 2000) to determine the most likely number of populations. We determined model parameters with 300,000 Markov chain Monte Carlo (MCMC) steps and 300,000 burn-in steps assuming a correlated allele frequency model with admixture (Falush et al. 2003). We performed 5 repetitions for every number of populations (K), the maximum being 8, the number of a priori defined subpopulations plus 2 more to search for potential substructure within populations. Ln-likelihood values were averaged to determine the most likely K.

We calculated principal components derived from an allele's presence or absence in an individual. Allele variables were coded as 0 if not present in an individual, 0.5 if 1 copy was present and 1 if 2 copies were present. An inter-class principal components analysis (PCA) was

conducted to maximize the variance between subpopulations and visualize relationships (Jombart 2008). Genetic data were coded for multivatiate analysis using the software program R (R Development Core Team, 2008) and the package *adegenet* (Jombart 2008). Multivariate analysis was accomplished with the package *ade4* and the *dudi.pca* and *between* commands (Dray and Dufour 2007). Allele frequencies were centered but not scaled.

Bobwhite sampling locations provided prior information for a spatial model of genetic structure using the program BAPS (Corander et al. 2008). We calculated centroids of political sections using ArcGIS v. 9.2 software (ESRI 2004) to provide Universal Transverse Mercator (UTM) coordinates for the spatial model. We ran 5 iterations for maximum K=1 through K=8.

We performed a Mantel test (Mantel 1967) to determine whether geographic distance may be correlated with genetic distance of subpopulations. Geographic distance was the Euclidean distance between spatial averages of sample centroids. The natural logarithm of geographic distance was regressed against pairwise F_{ST} values and significance was determined with 999 permutations of the matrices using GENALEX v. 6.2 (Peakall and Smouse 2006).

Sex-biased dispersal. Fies et al. (2002) found that adult bobwhite were less likely to disperse than females or juveniles. Such a difference in dispersal behavior may result in different estimates of genetic structure for each sex (Rassmann et al. 1997). We searched for a signature of sex-biased dispersal using differences in F_{ST} values, the mean assignment index, and the variance of the assignment index. F_{ST} values were expected to be lower among members of the dispersing sex due to more homogeneous allele frequencies. The corrected assignment index (AIc) is based on the probability that a particular genotype would be found in a particular subpopulation (Favre et al. 1997). Because dispersers have genotypes unlike the average residents of a subpopulation, the probability of finding their genotype in a subpopulation would

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be lower. The dispersing sex would, therefore, have a lower mean AIc than the non-dispersing

sex.   Additionally, subpopulations were expected to include both dispersers and residents.

Because members of the dispersing sex would have more disparate genotypes than members of

the non-dispersing sex, the dispersing sex was expected to have a larger AIc variance. The

progsram FSTAT v. 2 (Goudet 2002) was used to perform a 2-tailed test of the hypothesis that

F_{ST}, mean AIc, and variance of AIc of male and female bobwhite were different. Probability

distributions for the test statistics were simulated with 9,999 randomizations of the data.

RESULTS

Sample Collection. A large proportion of all samples originated from collectors in

Marion, Saline, Washington, and Wayne counties (Table 2). Additionally, samples from Perry

and Scott counties originated from concentrated areas (Figure 1). Samples from Pike County ($n =$

3) were included with the Scott subpopulation due to their proximity. These submissions

afforded us the opportunity to analyze an adequate number of individuals in easily defined

groups, hereafter designated as subpopulations. Additionally, adequate samples were obtained

during 2007-08, which negated the need to account for potential temporal variability.

Nevertheless, we collected and stored 1,620 tissue samples from 3 hunting seasons for analysis.

Genotyping. Bobwhite microsatellite loci Quail 47, Quail 25, and Quail 17 (Schable et

al. 2004) failed to produce an amplified fragment consistently after the change in PCR protocol

from 3 primers to 2 primers and were dropped from the analysis. Locus Quail 44 (Schable et al.

2004) appeared to have an insertion or deletion of 1 base pair that made consistent scoring

untenable, and it was also excluded from further analysis. Results of the test for null alleles (Van

Oosterhout et al. 2004) indicated a significant excess of homozygous genotypes in >1

subpopulation, possibly due to null alleles, for 4 loci: CV-P2D10, Quail 10, Quail 21, and Quail

31 (Schable et al. 2004, Faircloth et al. 2009). We, therefore, discontinued genotyping at these loci. We halted genotyping at locus CV-P2D7 (Faircloth et al. 2009), which contained only 2 alleles, in favor of genotyping more polymorphic loci. The remaining 11 loci produced an average polymorphism of 14.5 alleles per locus (Appendix E).

Genetic analysis. Departures from Hardy-Weinberg equilibrium within subpopulations and linkage disequilibrium in any locus pair within subpopulations were not significant following Bonferroni correction ($P < 0.05$). The probability of sibling bobwhite having identical genotypes at the 11 loci assayed was <1 in 10,758 for any subpopulation. Eleven pairs of samples had matching genotypes. Most pairs were collected by the same contributor on the same day and were attributed to submissions of 2 wings from the same bird.

A variable number of samples in each population were more closely related to one another than expected from random (Figure 2). Global F_{ST} and F_{IS} prior to the removal of related samples were 0.011 (CI: 0.008-0.014) and 0.021 (CI: 0.011-0.031), respectively. After removal, F_{ST} and F_{IS} changed to 0.009 (CI: 0.006-0.012) and 0.027 (CI: 0.015-0.038). Pairwise values of F_{ST} remained similar after related samples were removed (Table 3). Results of analysis of population structure prior to removal and after removal did not differ with most likely K in each case being 1 (Figure 3). Analysis of population structure using BAPS indicated 1 population was most likely with a posterior probability of 1.0 (Figure 4). Results from the PCA showed little resolution of populations based on principal components 1 and 2, which together explained 57% of the variance. Saline, Washington, and Scott subpopulations were indistinguishable (Figure 5). However, Wayne, Marion, and Perry subpopulations showed some separation with respect to each other and the other subpopulations.

All pairs of subpopulations had very low levels of differentiation ($F_{ST} < 0.05$) but even

small differences in genetic composition achieved statistical significance ($P < 0.05$). According to the contingency-table method (Rousset 2008), all subpopulations had statistically significant differences in allele frequencies following Bonferroni correction ($P < 0.05$). However, patterns in genetic differentiation did not conform to geography, which might be expected if bobwhite were genetically isolated by distance. The most distant subpopulation, Scott, did not have the greatest genetic differentiation from all other subpopulations. The lack of an isolation-by-distance pattern was also indicated by the lack of a relationship between ln geographic distance and genetic distance ($r = 0.18$, $P = 0.30$) according to the Mantel test.

The subpopulations in our study exchanged 12 bobwhite per generation amongst each other according to the private alleles method and 29 per generation estimated with F_{ST}. Between subpopulations, all estimates of the number of migrants per generation exceeded 1 indicating migration was sufficiently high to prevent detrimental effects of drift (Mills and Allendorf 1996).

Sex-biased dispersal. F_{ST} was lower for males (0.008) than for females (0.010). Mean AIc was also lower for males (-0.00013) than females (0.00014). The variance of AIc, however, was higher for females (14.08) than for males (13.15), but differences between F_{ST} ($P = 0.624$), mean assignment index ($P = 0.999$), and variance of assignment index ($P = 0.643$) were not significant.

DISCUSSION

The distributions of relatedness values for the actual bobwhite pairs and the simulated pairs appeared to have similar modalities (Figure 2) indicating that on the whole, bobwhite had relatedness values similar to what would be expected from a random association of alleles. However, the distribution of relatedness values for actual pairs contained a number of outliers in all subpopulations (Figure 2). Because of the a priori expectation that the sampling of covey

mates may represent related individuals, we believe the removal of related individuals was warranted and the results of analysis without related individuals best represents the true genetic structure. Nevertheless, estimates of gene flow and the number of distinct genetic groups were robust to the inclusion of related individuals as evidenced by the lack of differing results between analysis with and without related individuals.

Given the level of high gene flow indicated by analysis of F_{ST} ($F_{ST} < 0.05$) and private alleles (Nm > 10), the lack of separation along principal components, and the results of Bayesian analysis, bobwhite appear to form 1 nearly panmictic population within southern and central Illinois. We found no evidence to suggest that 1 sex may disperse longer distances or more frequently than another, but given the high amount of gene flow among subpopulations, such a difference may have simply gone undetected.

Genetic differentiation on the whole and between many of the subpopulations was low but statistically significant. We expected to observe genetic differences if subpopulations were isolated by landscape and distance. Indeed, such differences were very small but did exist. However, the pattern of differentiation between bobwhite subpopulations did not conform to one that would be expected from isolation by distance or due to habitat fragmentation. In those cases, we expected the most distant subpopulations, Saline and Scott, to be well differentiated from each other. This pattern was not readily apparent in the pairwise F_{ST} values in which values between closer neighbors (e.g., between Washington and Wayne) were greater than between the most distant ones. Saline and Scott also showed little separation from the more centrally located subpopulation in the PCA. Instead, Marion and Wayne subpopulations, which were located well within the core of highly suitable bobwhite habitat and the core of the study area, appeared slightly different than the rest. Additionally, genetic differentiation due to isolation by distance

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was not strongly indicated by the Mantel test.

Highly polymorphic loci, such as the ones used in our study, have very high power to detect small genetic differences, which may not have a clear biological interpretation (Hedrick 1999). In other words, the small genetic difference that was detected from our analysis but did not conform to the expected patterns may have been due to factors other than reduced gene flow. Non-random sampling due to the close proximity of related individuals may produce a statistically significant yet biologically erroneous result (Waples 1998). Although we removed related individuals within sections, a number of related individuals across multiple sections may have remained in the sample. Pen-raised birds may have also been present in the samples. In this case genotypes from pen raised sources and the F1 hybrids with wild birds may have obscured the spatial pattern. Gene flow from outside sources might also produce a pattern that defies easy interpretation. For instance, dispersers from the east may have settled in Wayne and Marion counties rendering them slightly different than the rest of the study area (Figure 5).

The general pattern of our results coincides with results from similar studies using allozymes as genetic markers. Zink et al. (1987) found that a similar species, the California quail (*Callipepla califormia*), exhibited high levels of gene flow from northern California to the Baja Peninsula ($F_{ST} = 0.032$). Ellsworth et al. (1989) sampled Illinois bobwhite on a smaller spatial scale and found little genetic structure among sampling sites ($F_{ST} = 0.016$). In these 2 studies and in ours, rates of gene flow suggested dispersal of quail is wider and more frequent than their sedentary reputation implies. The distance at which dispersal was certainly limited was not found.

MANAGEMENT IMPLICATIONS

Bobwhite in central Illinois, according to genetic analysis, are 1 population and, therefore

should be managed as such. This cohesion of Illinois bobwhite demography has multiple

consequences. First, the total available habitat may be more important than its arrangement or

location within the state. Greater area of habitat on the whole will likely produce a larger number

of dispersers giving any available habitat a higher probability of being colonized. For this

reason, our results suggest managers should focus on conserving and maintaining any productive

habitat rather than prioritizing areas near occupied habitat or creating corridors for dispersal. This

conclusion is well supported for most of Illinois but may be less robust for the northeastern

portion of the state where suitable habitat is extremely sparse (Roseberry and Sudkamp 1998).

Second, because subpopulations are so highly connected due to frequent dispersal,

dynamics at the subpopulation scale are tied to those of the greater metapopulation. This result

implies that bobwhite declines in one portion of the state may impact areas elsewhere. Bobwhite

declines in neighboring states may influence Illinois populations. Concerted conservation efforts

with neighboring states, particularly those overlapping a common physiographic region (Peterson

et al. 2002), may be necessary to stem declines.

This study was unable to distinguish whether genetic mixture was accomplished through

the action of long-distance dispersers or short-distance movements by a large number of

dispersers. Given that observations of bobwhite include short movements by some and long-

distance movements by few (Lehmann 1946, Townsend et al. 2003), it seems likely that both

dispersal styles play a role in shaping bobwhite genetic structure. Nevertheless, stepping-stone

dispersal likely remains important and, from our analysis, current levels of habitat fragmentation

in southern and central Illinois do not appear to limit dispersal.

Swamp Rabbits

INTRODUCTION

Swamp rabbits are denizens of bottomland hardwood forests in the southeastern United States (Chapman and Feldhamer 1981, McCollum and Holler 1994, Zollner et al. 2000a,b) and occupy habitat with elements related to successional stage (Zollner et al. 2000a,b); proximity to water and upland (Terrel 1972); and area (Korte 1975, Schiebe and Henson 2003). Like other rabbits (Litvaitis 2001), early-successional cover is a necessary habitat component for swamp rabbits (Zollner et al. 2000a,b). Korte (1975) determined that swamp rabbits need >1 km^2 of suitable habitat to support a viable population. Bottomland forests are prone to flooding and in times of flooding, swamp rabbits occupy adjacent upland refugia (Conaway et al. 1960, Terrel 1972, Kjolhaug 1986, Zollner et al. 2000a,b). Areas containing all preferred elements including large enough patches of preferred habitat become temporarily or permanently unavailable due to stochastic events (Barbour et al. 2001) and anthropogenic habitat alteration (Terrel 1972, Korte and Fredrickson 1977, Sheibe and Henson 2003). Additionally, continued maturation of bottomland hardwood forest will decrease the availability of early successional areas and may further reduce available habitat for swamp rabbits (Scharine et al. 2009).

In the northernmost portion of their range, swamp rabbits exist in a patchy distribution due to fragmentation of their preferred habitat (Terrel 1972, Kjolhaug and Woolf 1988, Barbour et al. 2001). A species with similar cover preferences (Allen 1985), the marsh rabbit (*Sylvilagus palustris*), was reluctant to travel through open areas between patches (Forys and Humphrey 1996). Swamp rabbits inhabiting a network of preferred habitat fragmented by agricultural fields and other open land may be effectively isolated with limited movement between patches due to a reluctance to cross open land. To determine whether swamp rabbits are reproductively isolated along the Cache River and adjacent watersheds in Illinois, we applied a population genetic analysis to swamp rabbits to elucidate genetic structure.

Sample collection. Swamp rabbit samples were collected using a variety of methods during 2006-10 (Appendix F). Swamp rabbit trapping was conducted during January-March 2007 in conjunction with another study (Scharine 2008) and during December 2009-March 2010. Ear punches were taken from trapped swamp rabbits (SIUC Institutional Animal Care and Use Committee Protocol #06-035). A small section of tissue (1 mm) was excised from the outer edge of the ear (Halanych and Robinson 1997). This piece of tissue was stored in an individual 2 mL screw-cap or 15 mL centrifuge tube and frozen at -20° C within approximately 2 hr of collection. Ears were received from hunter harvests during Spring 2007 and Spring 2010. Fecal pellet samples (see Job R-2.2) were also collected during pellet-log surveys.

Genotyping. We screened 23 microsatellite primer pairs published for the European rabbit (*Oryctolagus cuniculus*) and the pygmy rabbit (*Brachylagus idahoensis*) (Rico et al. 1994, Mougel et al. 1997, Surridge et al. 1997, Estes-Zumph et al. 2008) and 23 markers developed in conjunction with this study (Berkman et al. 2009) for ≥10 ear-punch samples. Reactions consisted of 10-µL total volume of ThermoScientific® PCR Master Mix (0.625 units Taq polymerase, 75 mM Tris-HCl, 20 mM $(NH_4)_2SO_4$, 2.0 mM $MgCl_2$, 0.01% Tween 20®, 200 µM each dNTP), 0.3-µM unlabeled primer, 0.09-µM labeled primer, 0.21-µM dye labeled universal primer (either CAG or M13) and approximately 20-ng genomic DNA. Cycling conditions consisted of 36 cycles of 94° for 30 sec, either 54°, 56°, or 58° for 30 sec (optimum annealing temperature range was first determined using a gradient of annealing temperatures) and 72° for 30 sec. Products were visualized with Rox-400 size standard on an ABI 3130xl sequencer

We identified 16 polymorphic microsatellite loci that could be amplified and scored consistently. All tissue samples were analyzed using a 2-primer PCR. Reactions included 10 µL of a PCR mixture containing ThermoScientific® PCR Master Mix, 0.2 µM of each primer

(unlabeled and dye-labeled), and approximately 20 ng of genomic DNA. Reactions were subjected to 30 cycles of 94° for 30 sec, 58° for 30 sec, and 72° for 30 sec. and products were visualized with Rox-400 size standard on an ABI 3130xl sequencer. The program MICROCHECKER (Van Oosterhout et al. 2004) indicated no evidence of null alleles at any locus.

Fecal pellet samples were extracted with the Zymo Research Fecal DNA Mini Prep Kit. Samples were genotyped at a subset of reliable loci. Samples that produced a product for the subset of loci were genotyped for the full set of 16 loci. Reaction conditions consisted of a 20 μL PCR mixture of ThermoScientific® 2X PCR Master Mix, 0.4 μM of each primer, 0.2 mg/mL of bovine serum albumin (BSA), and approximately 10 ng of genomic DNA or a 20 μL PCR mixture containing 1.25 units AmpliTaq® Gold DNA Polymerase, 10X PCR Gold Buffer (150 mM Tris-HCl, 500 mM KCl), 2.0 mM $MgCl_2$, 0.2 mg/mL BSA, and 200 μM each dNTP. Cycling conditions and fragment visualization were identical to those described above except that 40 cycles were performed for the 2-primer PCR. At least 2 PCR reactions were carried out and analyzed for each fecal pellet sample to minimize error due to allelic dropout (Taberlet et al. 1999).

Genetic analysis. We tested for Hardy-Weinberg equilibrium and linkage disequilibrium within subpopulations using the methods of Guo and Thompson (1992) and Raymond and Rousset (1995) with the program GENEPOP v. 4 (Rousset 2008). Bonferroni adjustments were made for multiple comparisons (Rice 1989). The probability of identity, the probability that 2 siblings share the same genotype, was calculated for each subpopulation with the program GenAlEx v. 6.2 (Peakall and Smouse 2006). If 2 samples had matching genotypes at all loci or all but 1 locus and were obtained in the same sampling area, we removed 1 from the analysis.

To determine the potential degree of genetic differentiation, we grouped swamp rabbit samples according to their proximity into 8 subpopulations (Figure 6). Samples at Pumphouse Plant, East Unity and Sandusky were combined to form the Sandusky population; samples at Tamms Rd. and Ullin were combined into the Ullin subpopulation; samples collected at Bellrose and Cache Chapel formed the Bellrose subpopulation; and all Hickory sites were grouped into the Hickory subpopulation (Table 4). The sample collected in Ballard County, Kentucky was not included in F_{ST} estimates but was included in the Bayesian analysis of population structure as a 9th putative subpopulation. We calculated global and pairwise F statistics (Weir and Cockerham 1984) and 95% confidence intervals with the program FSTAT v. 2 (Goudet 2002). We assessed genetic structure within swamp rabbits of the Cache River using aspatial and spatial Bayesian approaches. Analysis with K =1 to K = 8 were performed with STRUCTURE using 200,000 MCMC steps and 50,000 burn-in steps assuming a correlated allele frequency model with admixture (Falush et al. 2003). The K with the highest ln likelihood of the data (L (K)) suggested the most likely number of genetic groups. We calculated the ad hoc statistic ΔK, which is related to the greatest improvement in L(K) with a change in K, to corroborate results (Evanno et al. 2005). The proportion of membership in each population (Q) was determined and its graphical representation of Q was determined for each individual and sorted by the individuals' location, southwest to northeast. GENELAND was implemented according to the developers instructions (Guillot et al. 2005): the model was run with increasing numbers of K_{MAX} until results indicate the most likely K was less than K_{MAX}. The spatial option of BAPS (Corander et al. 2008) was also employed to detect the most likely number of interbreeding groups.

RESULTS

Sample collection. Tissue samples were obtained from trapped animals ($n = 82$) and hunter harvests ($n = 13$) (Figure 6). Although we collected pellets from >30 sites during 2006-10, many samples could not be genotyped or could only be partially genotyped. For this analysis, genotypes from 9 pellet samples were included (Table 4).

Genotyping. Departure from Hardy-Weinberg equilibrium was detected at locus sfl008 (Berkman et al. 2009) in 3 subpopulations ($P < 0.05$). This departure was not significant following Bonferroni correction but the locus was dropped from further analysis. Linkage disequilibrium was not significant between any pair of loci in any group after Bonferroni correction ($P > 0.05$). The remaining 15 loci had an average polymorphism of 4.2 alleles per locus (Appendix F). The probability that 2 siblings shared genotypes at all 16 loci was less than 1 in 55,000.

Genetic analysis. Global F_{ST} was 0.077 (CI: 0.056-0.097) and global F_{IS} was 0.019 (CI: -0.019-0.06). Pairwise F_{ST} ranged from 0.034 to 0.159 (Table 5). Analysis with STRUCTURE indicated that K = 4 was the most likely number of populations (Figure 7) and a modal value of ΔK also occurred at K = 4. Individuals sorted by location displayed varying proportions of membership in each of 4 genetic clusters (Figure 8). Assignment to a genetic cluster corresponded loosely with geographic location and subpopulation designation (Figure 8). Individuals appeared to sort by location (Figure 9) with those in the southwest associating with cluster 1, intermediate individuals with other clusters, and individuals in the northeast with cluster 3. Few intermediate individuals existed between the southwest and northeast cluster that did not associate with other clusters.

Results obtained with BAPS indicated 2 was the most likely number of populations with a posterior probability of 1.0 (Figure 10). Results of analysis with GENELAND varied each run

and indicated K= 8, K= 9, and K= 10 were the most likely number of populations in roughly

equal proportions. However, most samples could not definitely be assigned to any 1 group when

these high numbers of populations were considered. Analysis with $K_{MAX} = 4$, the most likely

number of distinct groups as chosen by STRUCTURE, was chosen to depict the spatial

structuring of populations (Figure 11). Genetic clusters 1 and 2 included spatially disjunct

members along the main channel of the Cache River and included the individual in Kentucky and

individuals outside of the Cache River watershed. Cluster 3 was composed of groups near the

mouth of the Cache River, and cluster 4 included swamp rabbits from Cypress Creek, a tributary

of the Cache River.

DISCUSSION

Spatial analysis with GENELAND (Guillot et al. 2005) suggested that 2 genetic groups of

swamp rabbits are intermingled along the Cache River, in Kentucky, and outside of the Cache

River watershed while 2 others appear to originate from single locations: Miller and Horseshoe

subpopulations near the mouth of the Cache River and Hickory subpopulation on the Cypress

Creek tributary (Figures 6, 11). Whether the apparent isolation of the latter 2 genetic clusters is

due to distance or landscape features bears further scrutiny.

Our investigation of genetic differentiation of swamp rabbits indicated a moderate level

of gene flow ($0.05 < F_{ST} < 0.25$) among putative groups and conflicting results of the most likely

number of populations. The differing results for K despite observing low-enough levels of gene

flow between the putative subpopulations to detect potential genetic structure (Latch et al. 2006)

may have been due to isolation by distance and a continuous sampling distribution (Pritchard et

al. 2000, Schwartz and McKelvey 2009). Sampling constraints (i.e., the ability to obtain either

many tissues from trapped animals or large numbers of reliable genotypes from different rabbits

in a distinct area) may have precluded the ability to identify distinct genetic groups in this study. Nonetheless, it is noteworthy that swamp rabbits were differentiated into as many as 4 distinct populations along 50 km of the Cache River.

MANAGEMENT IMPLICATIONS

Our results from analysis with STRUCTURE (Figures 8 and 9) and the values of pair-wise gene flow (Table 5) indicate that sites in the lower Cache River are relatively isolated from those in the far upper Cache River. To prevent further isolation, which may be more likely in northern populations, managers should focus on improving and maintaining connectivity along the Cache River. Sites in the Bay Creek watershed appear to receive migrants from the Cache River as evidenced by the similarity of their genetic make-up (Table 5, Figures 8 and 11). We suggest that upland forested corridors may be important for maintaining the relatively sparse populations that occur in watersheds adjoining the Cache River in Illinois.

JOB R-3.2: COMBINING GENETIC ANALYSIS AND HABITAT INFORMATION FOR BOBWHITE AND SWAMP RABBITS

Objectives: (1) examine the relationships among genetic diversity within a patch, time since isolation, and fragment size; and (2) integrate previous habitat maps and genetic analyses for a new understanding of population dynamics.

Patterns of diversity in neutral genetic markers are a result of contemporary and historical population dynamics of a species, particularly population size and migration among subpopulations. The consequences of genetic drift, specifically the loss of genetic diversity, increase with decreasing population size. Without migration from other subpopulations, small isolated subpopulations may lose genetic diversity and experience increased extinction risk (Frankham et al. 2002). Reduced subpopulation diversity is a concern for both bobwhite and swamp rabbits due to their reliance on patchy habitat in Illinois (Roseberry and Sudkamp 1998, Barbour et al. 2001). Subpopulations with lower diversity indicate they may be isolated and habitat modifications or other management techniques to improve gene flow may be warranted.

Subdivided populations can be mapped onto the fragmented landscape with spatially variable attributes such as habitat type, water sources, slope, and anthropogenic influences. Spatial relationships between the subdivided populations and habitat variables can then be determined. This method of identifying the influence of landscape features on organisms using population genetic analysis is termed landscape genetics (Manel et al. 2003). We sought to investigate how specific landscape features may influence the genetic structure of bobwhite and swamp rabbits; as in the previous Job, bobwhites and swamp rabbits are discussed separately.

Bobwhite

INTRODUCTION

Suitable habitat models suggest bobwhite habitat is relatively contiguous in the southern

and western portions of Illinois (Roseberry and Sudkamp 1998, Thogmartin 2002). However, the surrounding areas including northern, eastern and extreme southern Illinois contain large expanses of habitat that support relatively few bobwhites. Northeastern Illinois is dominated by intense agriculture and urban land use and extreme southern Illinois is composed of large forested tracts. Bobwhite in Illinois occupy portions of the state that contain moderate amounts of row crop agriculture, and woody edges rather than contiguous canopy (Roseberry and Sudkamp 1998)

Subpopulations at the edge of their range are generally expected to have lower diversity than those in the center (Eckert et al. 2008). Because the Saline and Scott subpopulations are at the edge of Illinois' largest expanse of suitable habitat, it was expected that they would have lower diversity than subpopulations in the interior of the study area.

In Job R-3.2, we found very little genetic structure between bobwhite subpopulations and inconsistent pattern of differentiation. We concluded that fragmentation of habitat in Illinois was insufficient to produce lasting genetic differentiation among habitat patches and the scale of our study. Consequently, we limited our investigation of bobwhite in this Job to the question of diversity and did not pursue an analysis of landscape influences on genetic differentiation.

METHODS

Bobwhite sampling and genotyping procedures are presented in Job R-3.1. We examined the relationship between bobwhite subpopulation location and genetic diversity by calculating allelic richness. We calculated allelic richness using rarefaction, which accounts for unequal subpopulation sizes by estimating the expected allele count in a given sample size (Kalinowski 2004). In this case, we estimated the allele count for a sample size equal to that of our smallest sample ($n = 19$). The calculation was performed using the program HP RARE v. 1.0

(Kalinowski 2005). We calculated jackknife estimates of mean allelic richness and 95% confidence intervals for each subpopulation.

RESULTS

Allelic richness ranged from 7.47 in the Wayne subpopulation to 8.38 in the Marion and Washington subpopulations. Confidence intervals of the jackknife estimates of mean allelic richness all overlapped indicating a lack of significant difference between any 2 subpopulations (Figure 12).

DISCUSSION AND MANAGEMENT IMPLICATIONS

Our results, which indicate no difference in diversity of subpopulations, support the assertion that bobwhite in southern and central Illinois are 1 panmictic population. This conclusion was also indicated from our genetic structure investigation (Job R.3-1). The lack of a difference precluded an analysis of diversity in relation to differences among the subpopulations such as location, total area of highly suitable habitat, or other variables. Therefore, management implications from this Job are similar to those from Job R.3-1.

<center>**Swamp Rabbits**</center>

INTRODUCTION

In the northernmost portion of their range, swamp rabbits exist in a patchy distribution due to fragmentation of their preferred habitat (Terrel 1972, Barbour et al. 2001). Because swamp rabbits occupy habitat patches along floodplains, demes along floodplain corridors and drainage systems may exhibit greater similarity than those that would require upland travel to connect. A species with similar cover preferences (Allen 1985), the marsh rabbit, was reluctant to travel through open areas between patches (Forys and Humphrey 1996). Swamp rabbits inhabiting a network of preferred bottomland habitat fragmented by agricultural fields and other

open land may be effectively isolated with limited movement between forested patches due to a reluctance to cross upland habitats. For a clearer understanding of the population dynamics of swamp rabbits in fragmented habitat, we assessed differences in genetic diversity among subpopulations in the Cache River basin and investigated the influence of landscape, particularly watercourses, on gene flow.

METHODS

Swamp rabbit sampling and genotyping procedures were provided in Job R-3.1. We examined the relationship between swamp rabbits groups and genetic diversity by calculating allelic richness. Rarefaction (Kalinowski 2004) was used to adjust for unequal sample sizes an implemented with the program FSTAT (Goudet 2002). We calculated jackknife estimates of mean allelic richness and 95% confidence intervals for each subpopulation.

The influence of watercourse on genetic structure was examined with a partial Mantel test (Smouse et al. 1986). In this test, the effect of genetic distance was regressed against watercourse distance while controlling for the effect of Euclidean distance. We included all samples analyzed in Job R-3.1 except those outside the Cache River watershed, which consisted of the individual in Ballard County, Kentucky, and those in the East subpopulation from the Bay Creek watershed. This resulted in a square matrix of size $n = 96$.

We calculated individual genetic relatedness using Rousset's â (Rousset 2000) with the program SpaGeDi (Hardy and Vekemans 2002). Distance along a watercourse was calculated by measuring a segment of stream beginning and ending at the closest distance to an individual's sample point. Measurements were calculated in ArcGIS v.9.2 (ESRI 2004). Significance of the relationship between genetic distance and watercourse distance was assessed using with 9,999 permutations of the partial residuals to simulate a distribution under the null hypothesis

(Anderson and Legendre 1999) as implemented in the program zt (Bonnet and Van de Peer 2002).

RESULTS

Allelic richness ranged from 2.39 in the Hickory subpopulation to 2.91 in the Containment Basin. According to the overlap of jackknife 95% confidence intervals, differences in allelic richness among subpopulations were not significantly different (Figure 13). The partial Mantel test (Smouse et al. 1986) indicated that swamp rabbit genetic distance could be attributed to distance over watercourses while controlling for the effect of Euclidean distance ($r = 0.18$, $P = 0.0001$).

DISCUSSION AND MANAGEMENT IMPLICATIONS

We noted that the Hickory and Miller subpopulations, which appeared isolated in our Bayesian analysis of genetic structure (see Job R-3.1), also had the lowest diversity. Additionally, the largest difference in diversity occurred between neighboring subpopulations, Hickory and Containment Basin (see Job R-3.1, Figure 6). An analysis of genetic structure indicated some differentiation existed between these 2 subpopulations but less than most of the pair-wise comparisons of subpopulations (see Job R-3.1, Table 4). This type of a relationship between 2 subpopulations, a similar genetic make-up with different diversity, may arise from metapopulation dynamics (Slatkin 1977). Large mainland or source populations are expected to maintain a higher genetic diversity either due to the relationship between population size and genetic diversity or due to persistent immigration from other sources (Eckert et al. 2008). In this case, the Containment Basin subpopulation may have fit the role of the larger, more diverse mainland/source. The mainland/source produces dispersers that move to the island/sink (Boorman and Levitt 1973, Brown and Kodric-Brown 1977), the Hickory subpopulation.

Consequently, they maintain some genetic similarity but express differences in diversity (Slatkin 1977). The sum total of these results suggests that the Hickory subpopulation, which lies on a Cache River tributary, was relatively isolated from other subpopulations on the main channel of the Cache River and may have received migrants from the Containment Basin subpopulation.

Despite the isolation of some subpopulations, the lack of significant difference in allelic richness suggested diversity among swamp rabbit subpopulations generally remained level. Although some subpopulations appeared to be isolated as indicated by an analysis of genetic structure and a general trend in diversity, differences in diversity were not drastic. Isolated swamp rabbit subpopulations may experience low but continuous gene flow or the loss of diversity may be incipient and may become more drastic in time. Regardless, our study identified isolated populations, which may benefit from management actions to mitigate extinction risk.

We also found a general pattern that watercourses influenced gene flow. This suggests that swamp rabbits, like marsh rabbits, may be reluctant to disperse across upland habitat relying on river corridors to access suitable habitat patches. Managers can, therefore, regard subpopulations as networks connected by river corridors, and watershed boundaries may coincide with population boundaries. Management actions intended to promote swamp rabbit colonization should be in areas connected to occupied patches by watercourse. Finally, increased forested habitat in riparian corridors may improve connectivity and decrease extinction risk for isolated populations.

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Table 1. Occupancy status of the swamp rabbit (*Sylvilagus aquaticus*) during Winter 2009 and Winter 2010 in sites among the southernmost counties of Illinois, USA. Sites were classified as swamp rabbits absent (A), swamp rabbits present (P), not surveyed (N), or flooded at the time of the visit (F) for the year of the survey.

County	Site Name	Township	Range	Section(s)	Ownership/ Management	2009	2010
Alexander	Bumgard Island	17S	2W	6, 7	Private	P	P
	Clear Creek Levee	14S	3W	14	USFS	A	A
	Cape Ben d	14S	3W	21	USFS	A	N
	Horseshoe Lake	16S	2W	8, 15, 16, 17, 20, 21, 22	State	P	P
	Horseshoe Lake Island	16S	2W	4, 5, 9	State	A	A
	Moses Rd	16S	1W	29	USFWS	A	N
	Promised Land Rd	16S	2W	11	State	A	N
	Pumphouse Plant*	15S	1W	6	USFWS	P	P
	Sandusky 6*	15S	1W	30	USFWS	A	A
Jackson	Oakwood Bottoms Rd	10S	3W	2, 3	USFS	A	A
	Pomona	10S	2W	16, 21	USFS	A	A
	Rattlesnake Ferry Rd	10S	3W	21	USFS	A	A
	Skeeter Park Rd	9S	3W	20	USFS	A	A
Johnson	Bell Pond	13S	4E	11	USFS	P	P
	Briggs	12S	2E	28	Private	P	P
	Cypress Pond	12S	2E	17, 18	State and Private	P	P
	Heron Pond	13S	3E	30	State	P	P
	Little Black Slough	13S	2E	23, 26	State	A	A
	McAllister	12S	2E	8	Private	A	N
	North Main Access	14S	2E	8	State	N	A

Table 1. Continued

County	Site Name	Township	Range	Section(s)	Ownership/ Management	2009	2010
	Old Town Lake	12S	3E	4,9	USFS	A	F
	Reevesville	14S	4E	23, 24	USFS	A	A
	Reevesville Levee	13S	4E	25	Private/USFS	N	P
	Rose Plant 1*	14S	2E	11	Private	N	A
	Vienna Penitentiary	13S	4E	10	State	N	A
	Wildcat Bluff	13S	3E	19	State	A	A
Massac	Fort Massac State Park	16S	5E	9, 10	State	A	A
	Mermet Lake	14-15S	3E	26, 34, 1	State	A	A
	Sielbeck Forest	15S	4E	10	State	A	A
Pope	Bates**	13S	5E	20	Private	A	P
	Broadway	14S	6E	7	USFS	P	N
	Robnett Creek	14S	5E	13	USFS	A	N
	Stafford Bluff	14S	5E	6	USFS	A	N
Pulaski	Bellrose*	14S	1E	19, 20	USFWS	P	P
	Cache Chapel*	14S	1E	21	USFWS	P	P
	Containment Basin*	14S	2E	19	USFWS	N	P
	East Unity	16S	1W	6	USFWS	P	P
	Hodges Creek	16S	1E	4	Private	N	P
	Lower Cache Access	14S	1E	13	State	A	A
	Miller Plant*	16S	1W	20	USFWS	P	P

Table 1. Continued.

County	Site Name	Township	Range	Section(s)	Ownership/ Management	2009	2010
	Post Creek Cutoff	14S	2E	14	State	P	P
	Sandusky 5*	15S	1W	19	USFWS	N	P
	Sandusky 7*	15S	1W	19	USFWS	P	P
	Sandusky Rd	15S	1W	19	USFWS	P	P
	Tamms Rd*	14S	1W	33	USFWS	P	P
	Ullin	14S	1W	26	USFWS	N	P
	Warren Rd	15S	1W	7	USFWS	N	P
Union	Hickory 3*	13S	3E	26	USFWS	P	P
	Hickory 5*	13S	1E	22	USFWS	P	P
	Hickory 6*	13S	1E	22	USFWS	A	A
	Hickory Bottoms	13S	1E	35	USFWS	P	P
	Union County Conservation Area	13S	2W	17	State	A	A

* Denotes sites that contain artificial latrine logs (Schauber et al. 2008)

Table 2. Northern bobwhite (*Colinus virginianus*) samples submitted by quail hunters and designated by their season and county of harvest in Illinois, USA.

County	2006-07	2007-08	2008-09
Bond	4	14	9
Cass	0	2	0
Coles	0	4	0
Effingham	2	3	5
Fayette	7	14	17
Franklin	8	0	0
Greene	7	10	23
Hamilton	3	19	12
Jackson	1	7	9
Jasper	40	0	54
Jefferson	3	2	26
Jersey	0	4	14
Logan	0	11	0
Macoupin	0	26	2
Marion	54	142	88
McLean	0	3	0
Menard	0	4	0
Montgomery	5	0	0

Table 2. Continued.

County	2006-07	2007-08	2008-09
Perry	3	27	63
Pike	1	3	12
Saline	35	138	86
Scott	21	20	13
Shelby	0	10	8
Tazewell	0	3	0
Wabash	51	0	112
Washington	25	79	62
Wayne	2	53	40
White	31	31	33
Total	303	629	688

Table 3. Pairwise F_{ST} values, the probability (P) that this value was greater than FST from random permutations, and the number of migrants exchanged between the subpopulations each generation (Nm) obtained from F_{ST} and from private alleles (Slatkin 1985). Values obtained from 11 microsatellite loci analyzed for populations of northern bobwhite (*Colinus virginianus*) in Illinois, USA.

		All samples	Related samples removed		
Subpopulation 1	Subpopulation 2	F_{ST}(P)	F_{ST}(P)	Nm (F_{ST})	Nm (Private alleles)
Marion	Saline	0.012(<0.001)	0.009(<0.0010)	28.2	5.75
Marion	Washington	0.009(<0.001)	0.007(<0.00)	37.0	4.87
Saline	Washington	0.008(<0.001)	0.005(0.001)	47.9	5.76
Marion	Wayne	0.008(<0.001)	0.009(<0.001)	28.7	7.10
Saline	Wayne	0.016(<0.001)	0.015(<0.001)	16.3	3.99
Washington	Wayne	0.012(<0.001)	0.011(<0.001)	22.4	4.75
Marion	Scott	0.017(<0.001)	0.016(<0.001)	15.6	3.51
Saline	Scott	0.006(0.028)	0.006(0.039)	43.0	4.54
Washington	Scott	0.007(0.021)	0.006(0.037)	40.1	3.65
Wayne	Scott	0.017(0.001)	0.017(0.001)	14.1	3.42
Marion	Perry	0.014(0.001)	0.013(0.002)	19.5	4.54
Saline	Perry	0.011(0.003)	0.008(0.013)	30.3	3.49
Washington	Perry	0.007(0.026)	0.008(0.015)	30.1	3.36
Wayne	Perry	0.018(0.001)	0.008(<0.001)	13.5	2.46
Scott	Perry	0.013(0.023)	0.012(0.025)	20.6	3.30

Table 4. Political locations where swamp rabbit (*Sylvilagus aquaticus*) samples were obtained for genetic analysis in Illinois and Kentucky, USA. Sample number (N) and type (T= tissue, P = fecal pellet) were indicated.

County	Site Name	Political Location	*n*	Sample Type
Alexander	Horseshoe Lake	16S 2W 21	17	T & P
	Pumphouse Plant	15S 1W 6	10	T
Ballard (KY)	Ballard WMA	15S 1E 26	1	P
Johnson	Bell Pond	13S 4E 11	3	T
	Heron Pond	13S 3E 30	1	T
	Reevesville Levee	13S 4E 25	1	P
	Rose Plant 1	14S 2E 11	1	T
Pulaski	Bellrose	14S 1E 19	4	T
	Cache Chapel	14S 1E 21	8	T
	Containment Basin	14S 2E 19	4	T
	East Unity	16S 1W 6	2	P
	Miller Plant	16S 1W 20	4	T
	Sandusky	15S 1W 19	4	T & P
	Tamms Rd	14S 1W 33	9	T
	Ullin	14S 1W 26	7	T

Table 4. Continued.

County	Site Name	Political Location	N	Sample Type
Union	Hickory 3	13S 3E 26	12	T & P
	Hickory 5	13S 1E 22	7	T
	Hickory Bottoms	13S 1E 35	9	T

Table 5. Pairwise F_{ST} values (below diagonal) and their probabilities determined through 9,999 random permutations (above diagonal) obtained from 15 microsatellite loci analyzed in swamp rabbit (*Sylvilagus aquaticus*).

	Bellrose	East	Containment Basin	Hickory	Horseshoe Lake	Miller	Sandusky	Ullin
Bellrose		0.001	0.057	0.001	0.001	0.001	0.001	0.001
East	0.084		0.118	0.016	0.001	0.001	0.001	0.001
Containment Basin	0.044	0.038		0.023	0.004	0.013	0.002	0.002
Hickory	0.075	0.038	0.046		0.001	0.001	0.001	0.001
Horseshoe Lake	0.107	0.065	0.062	0.098		0.016	0.003	0.001
Miller	0.159	0.116	0.098	0.135	0.052		0.001	0.001
Sandusky	0.070	0.076	0.077	0.083	0.034	0.096		0.002
Ullin	0.060	0.064	0.082	0.085	0.058	0.130	0.044	
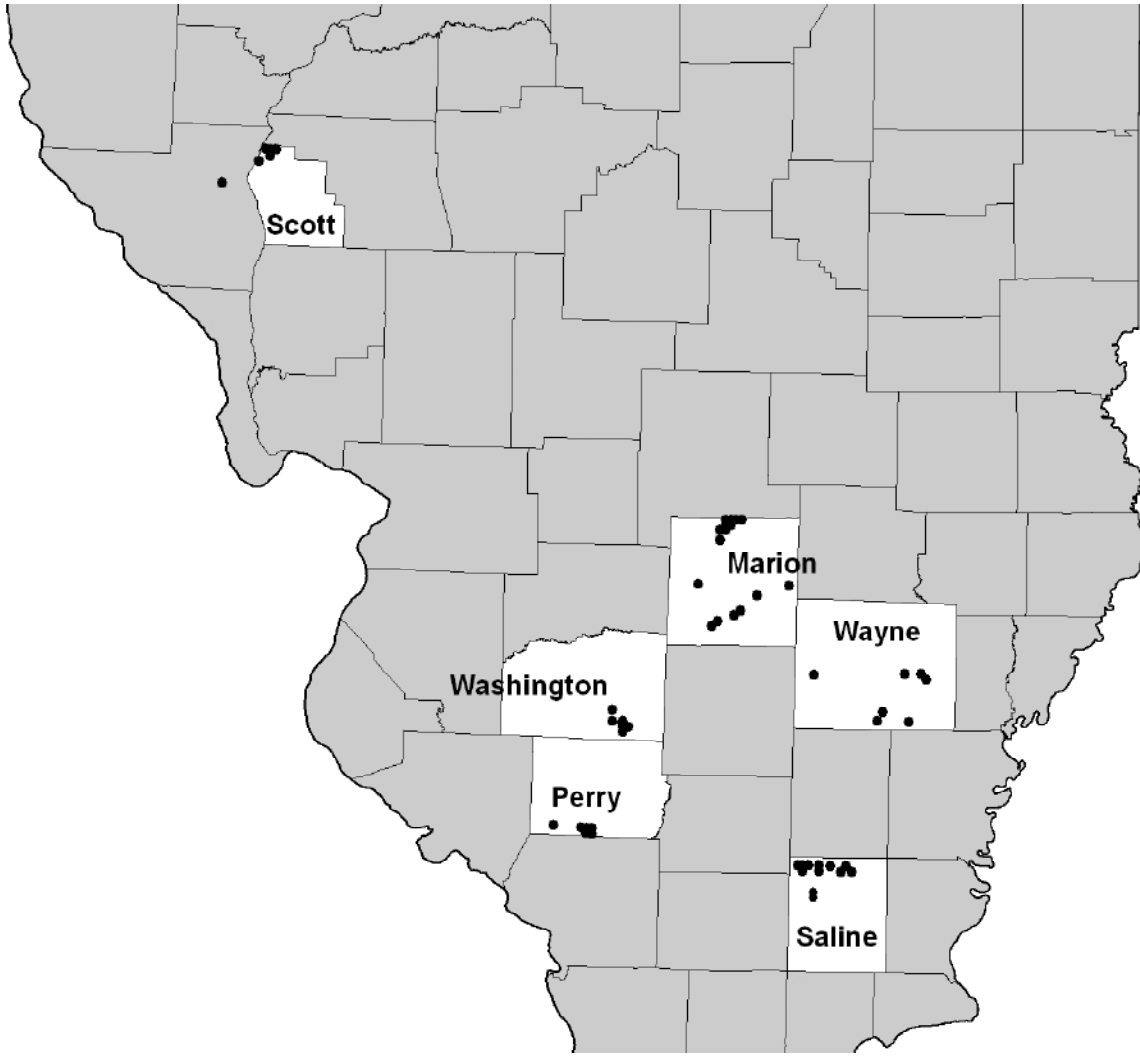
Figure 1. Northern bobwhite (*Colinus virginianus*) sample locations obtained in 2007-08 from the central and southern counties of Illinois, USA.
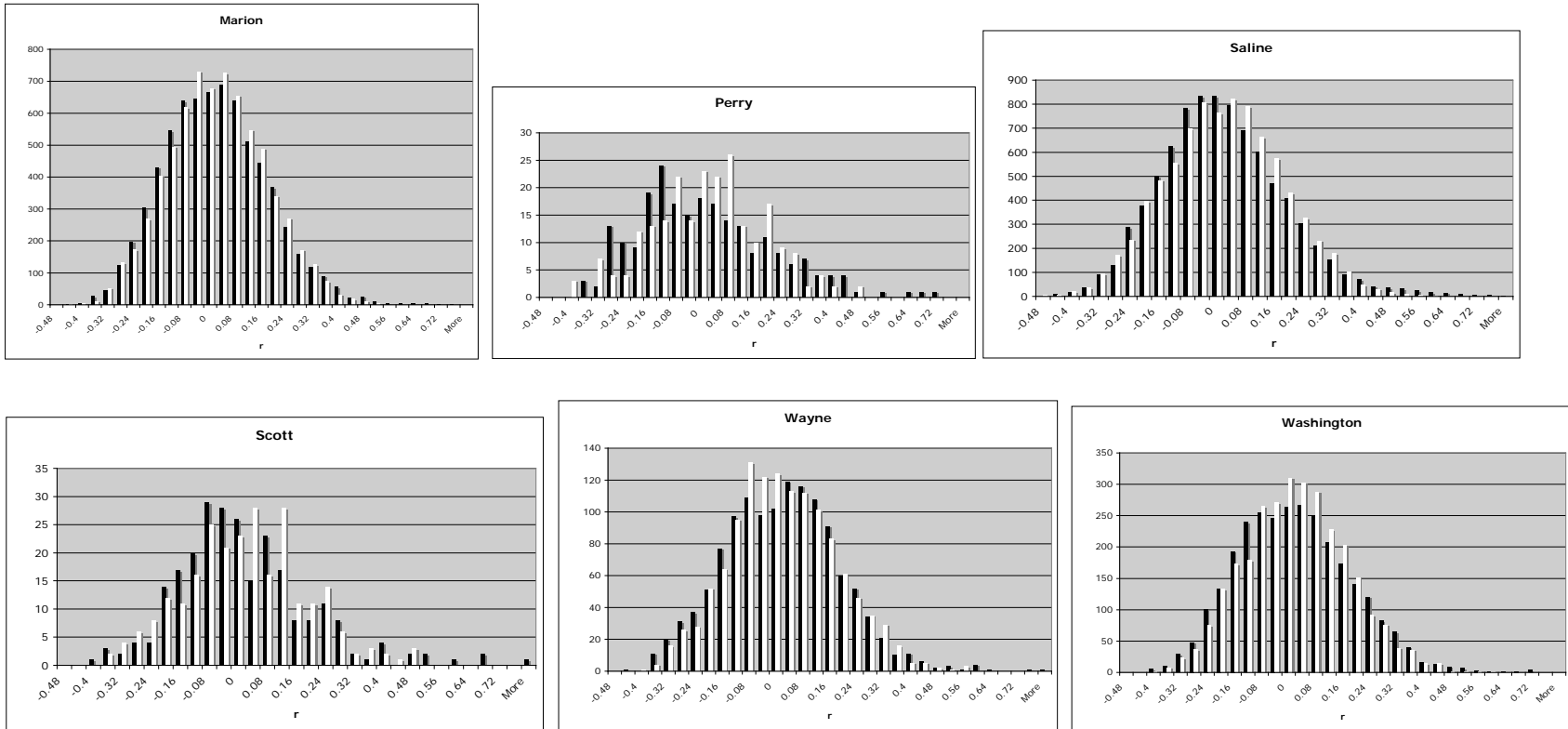
Figure 2. Frequencies of relatedness values (r) determined from pairs of northern bobwhite (*Colinus virginianus*) are indicated with black bars. Relatedness values of simulated pairs (the null distribution), which were generated using allele frequencies in each subpopulation, were indicated by white bars. Subpopulations were designated based on the county in the central counties of Illinois, USA.
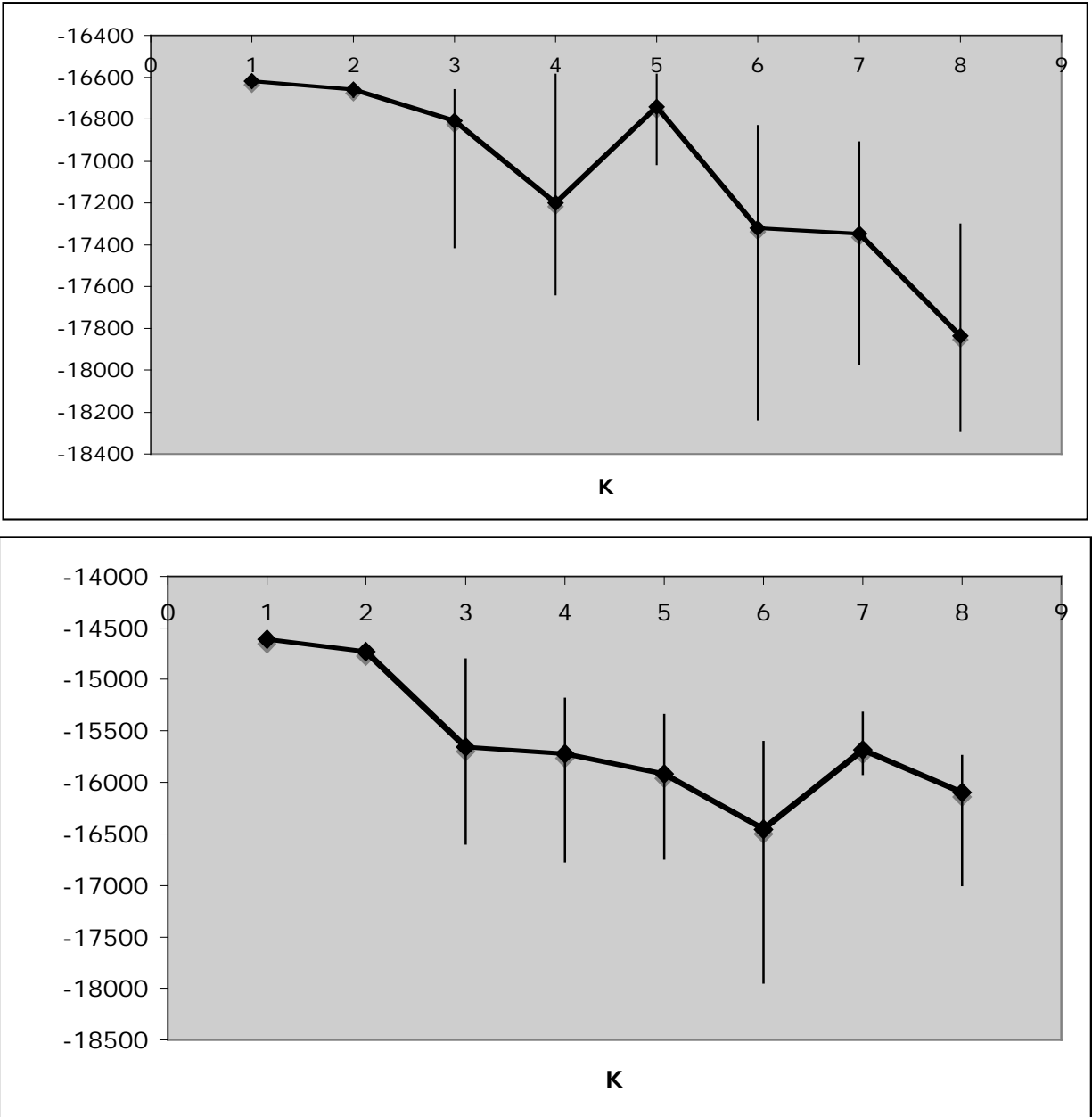
Figure 3. Ln probability of data from an average of 5 runs of STRUCTURE v. 2.3 (Pritchard et al. 2000) with the number of expected groups (K) ranging from 1-8. Error bars correspond to the range of Ln probability of the data achieved from individual runs. Analysis was performed with all northern bobwhite (*Colinus virginianus*) samples (top) and with highly related individuals removed (bottom). Samples were obtained from 6 putative subpopulations during 2007-08 in central Illinois, USA.
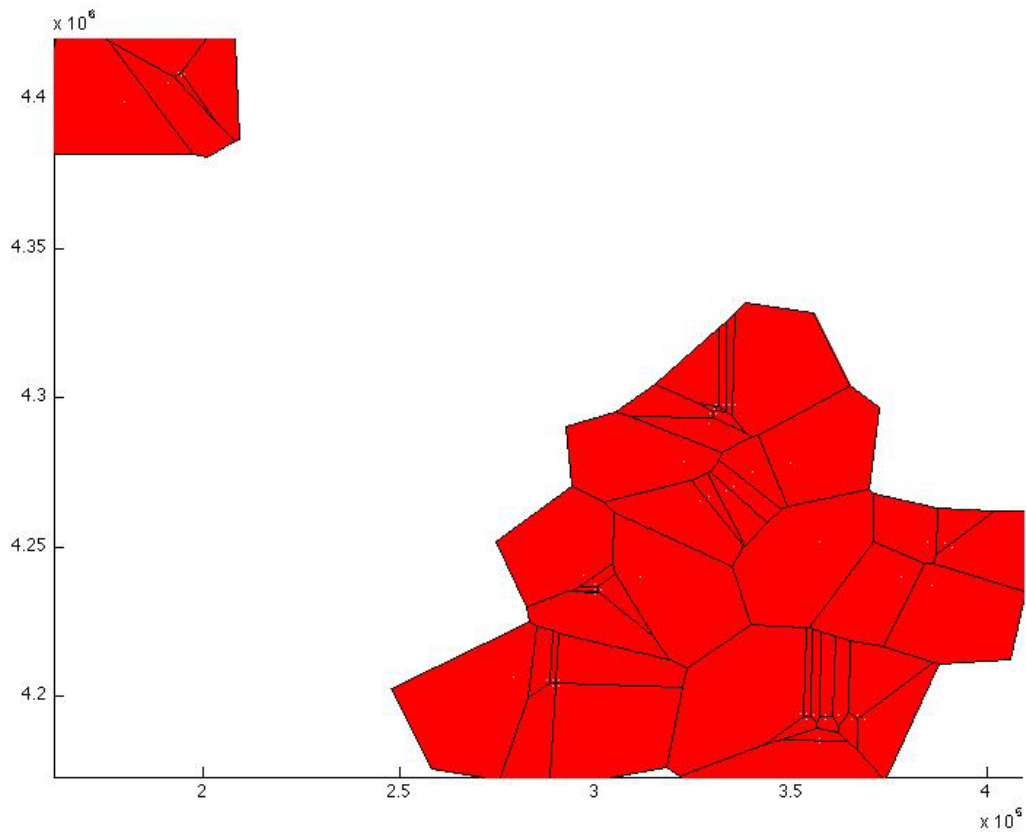
Figure 4. Voronoi tessellation (a polygon representation of sample points) created by the program BAPS v. 5 (Corander et al. 2008) of northern bobwhite (*Colinus virginianus*) sample locations from central Illinois, USA.
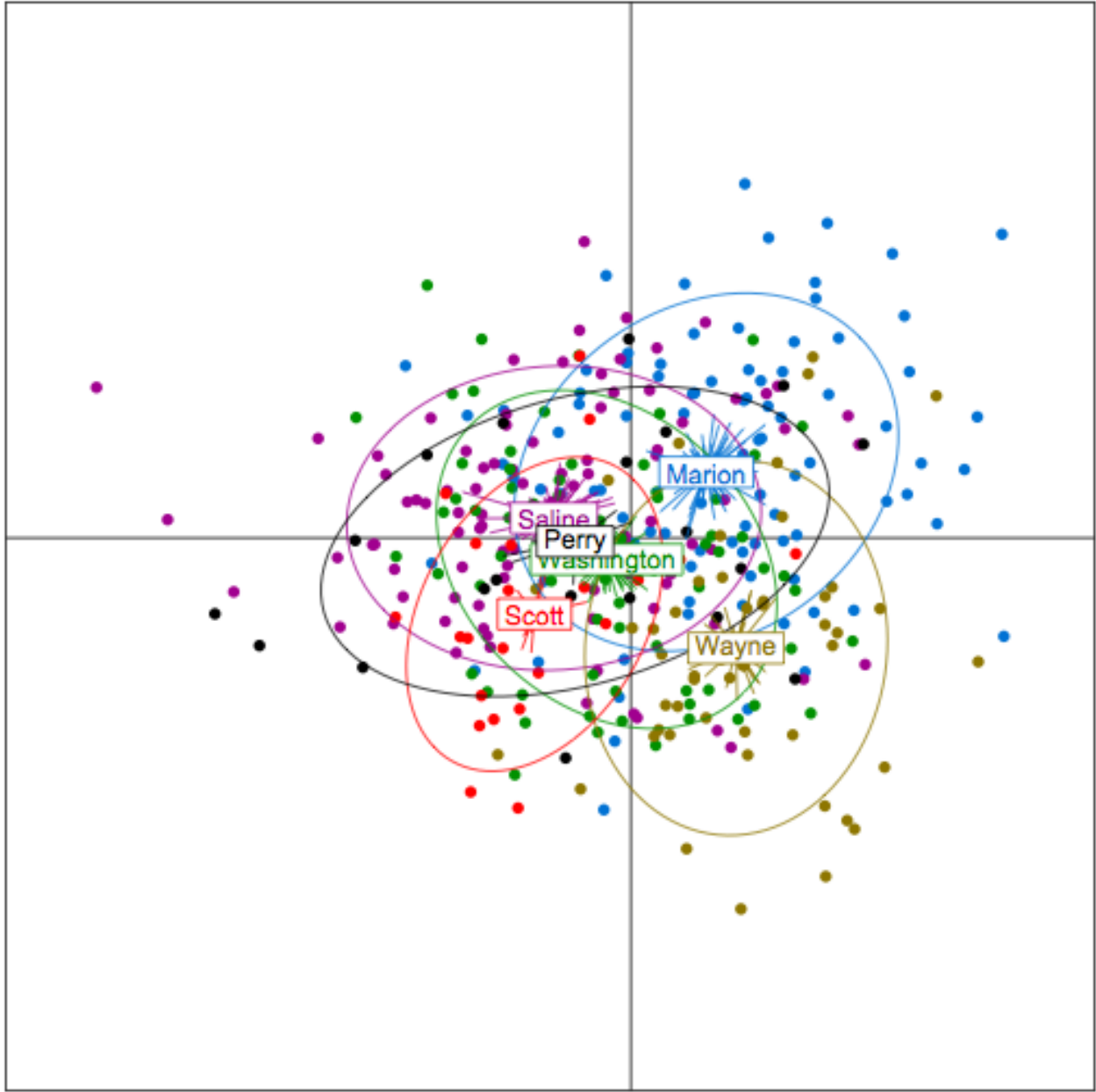
Figure 5. Principal component scores for individual bobwhite (*Colinus virginianus*) genotypes along the first 2 axes, which accounted for 57% of the variance among subpopulations. Stars at the subpopulation means were encircled by 95% inertial ellipses.
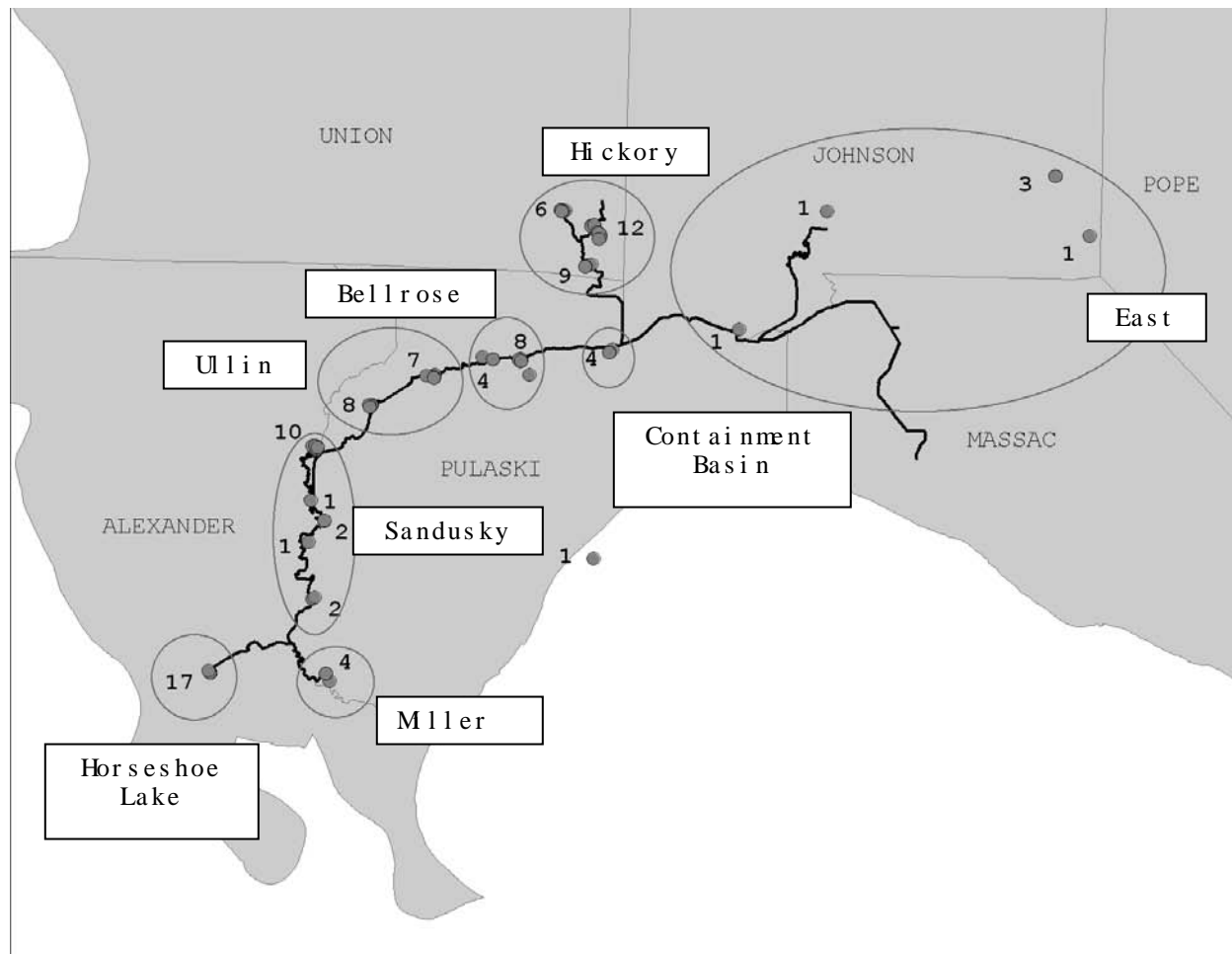
Figure 6. Swamp rabbit (*Sylvilagus aquaticus*) sample locations for a study of gene flow in the southernmost counties of Illinois, USA. Putative sample groups (*n* = 8) were indicated by grey ellipses and names of groups were indicated in white boxes.
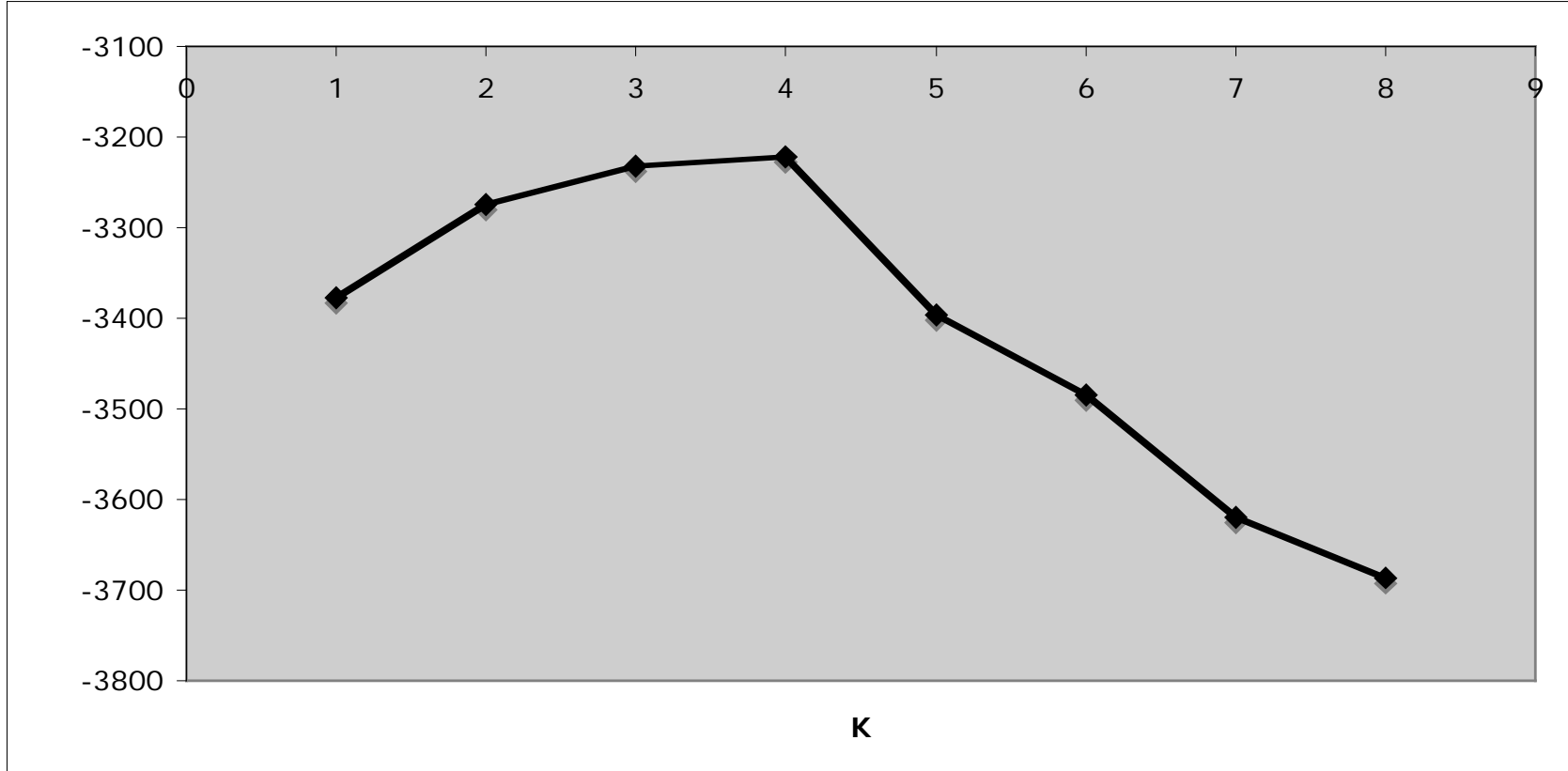
Figure 7. Ln probability of data from an average of 5 runs of STRUCTURE v. 2.3 (Pritchard et al. 2000) with the number of expected groups (K) ranging from 1-8. Analysis was performed on data from 16 microsatellite loci amplified from swamp rabbits (*Sylvilagus aquaticus*) obtained during 2007-10 in southern Illinois, USA.
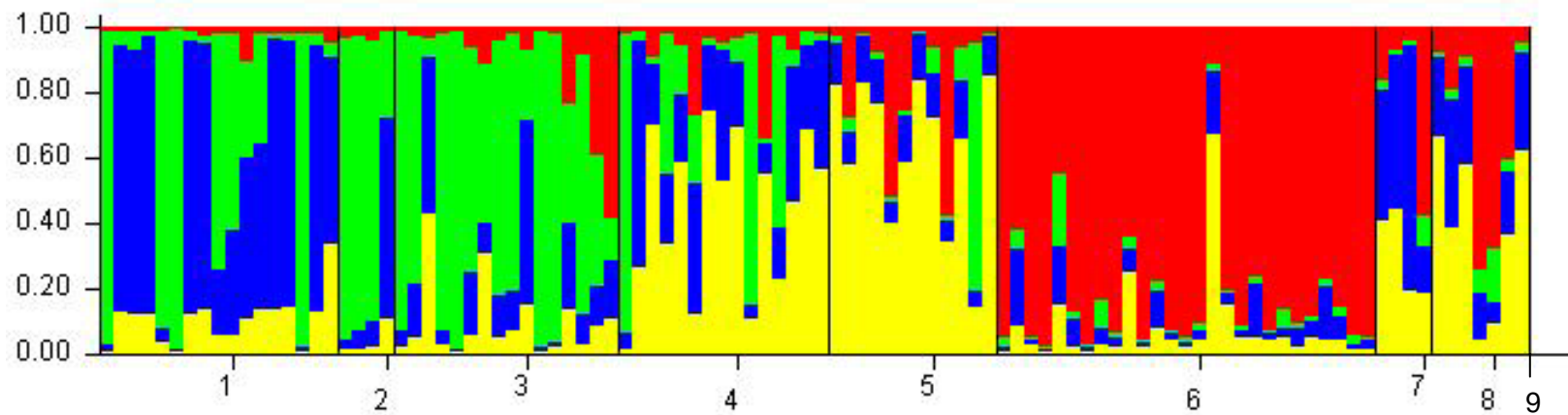
Figure 8. Proportion of membership in 1 of 4 genetic clusters as determined by STRUCTURE v 2.3 (Pritchard et al. 2000) for swamp rabbits (*Sylvilagus aquaticus*) found in southern Illinois and western Kentucky, USA. Individuals were sorted by their location on the Cache River, from southwest to northeast, and grouped according to putative subpopulation (1= Horseshoe Lake, 2= Miller, 3= Sandusky, 4= Ullin 5= Bellrose, 6 = Hickory, 7 = Containment Basin, 8 = East, 9 = Ballard County, KY).
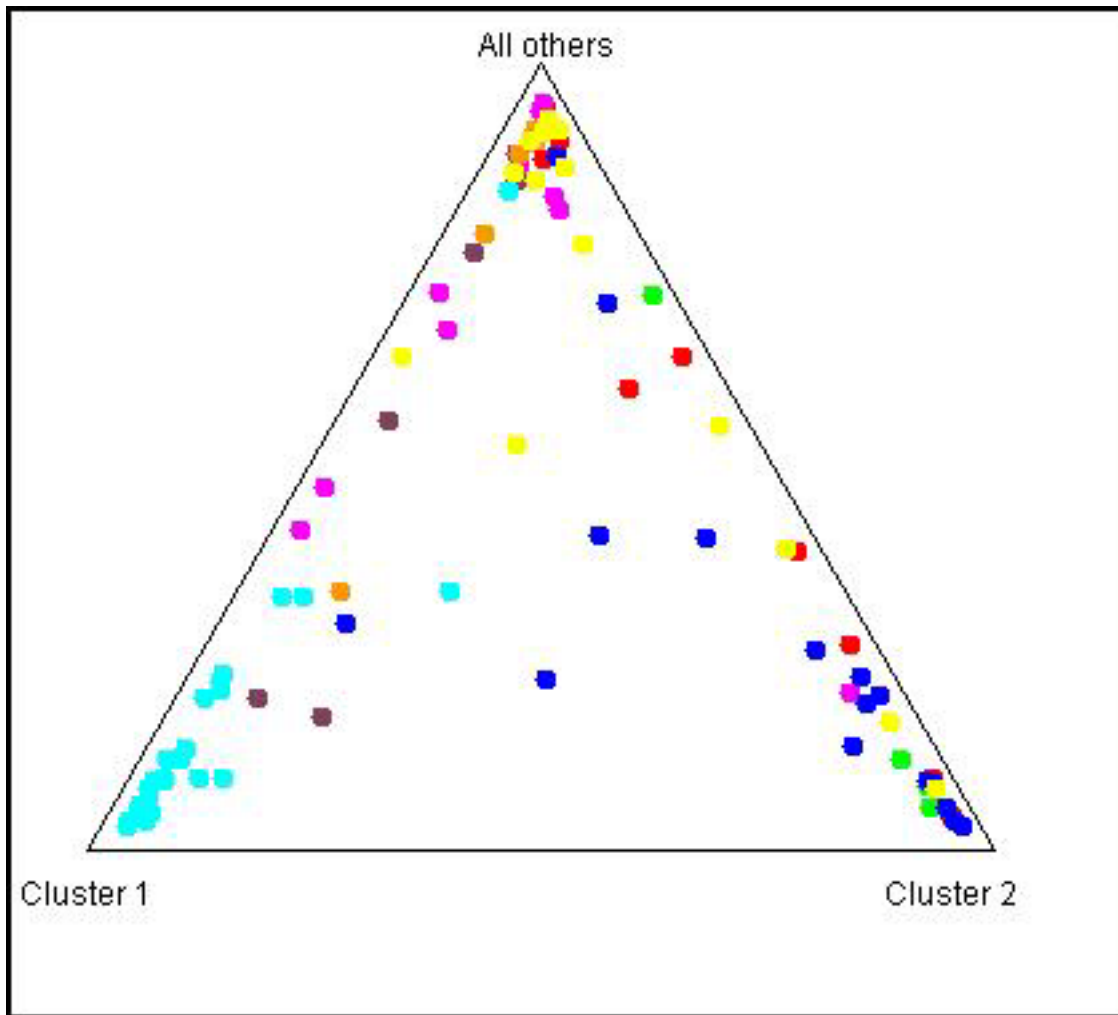
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Figure 9. Tri-plot of individual swamp rabbits (*Sylvilagus aquaticus*) represented as dots and their proportion of membership in 1 genetic cluster (distance to a triangle corner) relative to their membership in another genetic cluster (distance to another corner) as determined by the program STRUCTURE v 2.3 (Pritchard et al. 2000). Swamp rabbits were sampled from the southernmost counties of Illinois and western Kentucky, USA. Colors of dots indicate membership in one of 9 putative subpopulations.
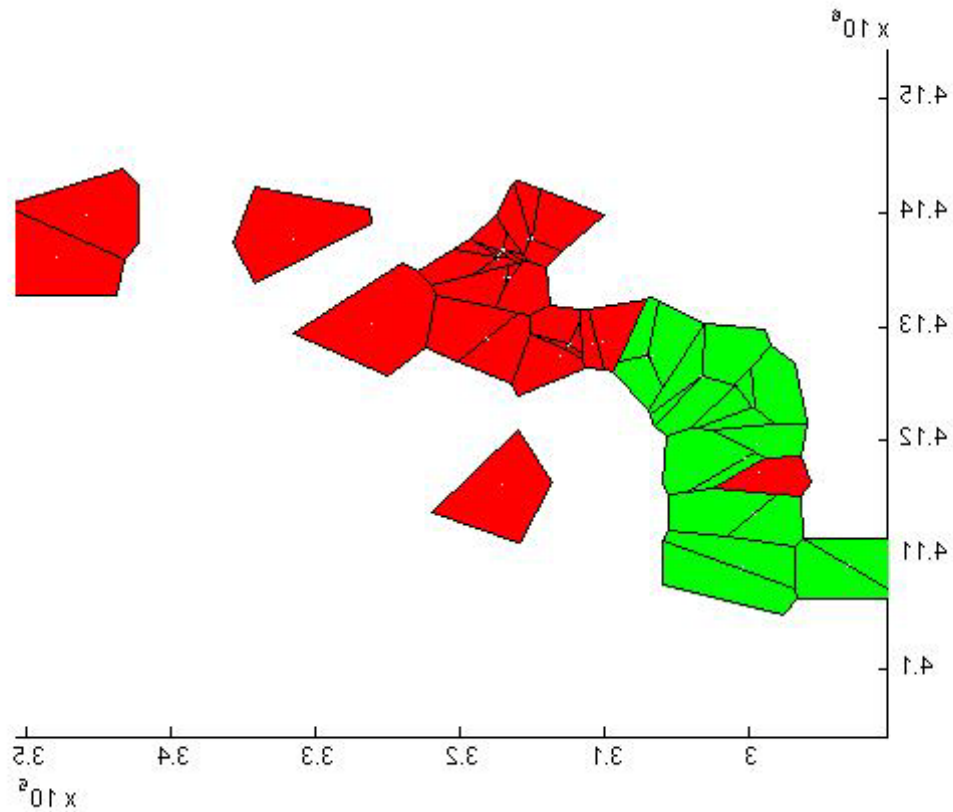
Figure 10. Voronoi tessellation (a polygon representation of sample points) created by the program BAPS v. 5 (Corander et al. 2008) of swamp rabbit (*Sylvilagus aquaticus*) sample locations from southern Illinois and western Kentucky, USA. Different shades indicate assignment to different genetic clusters.
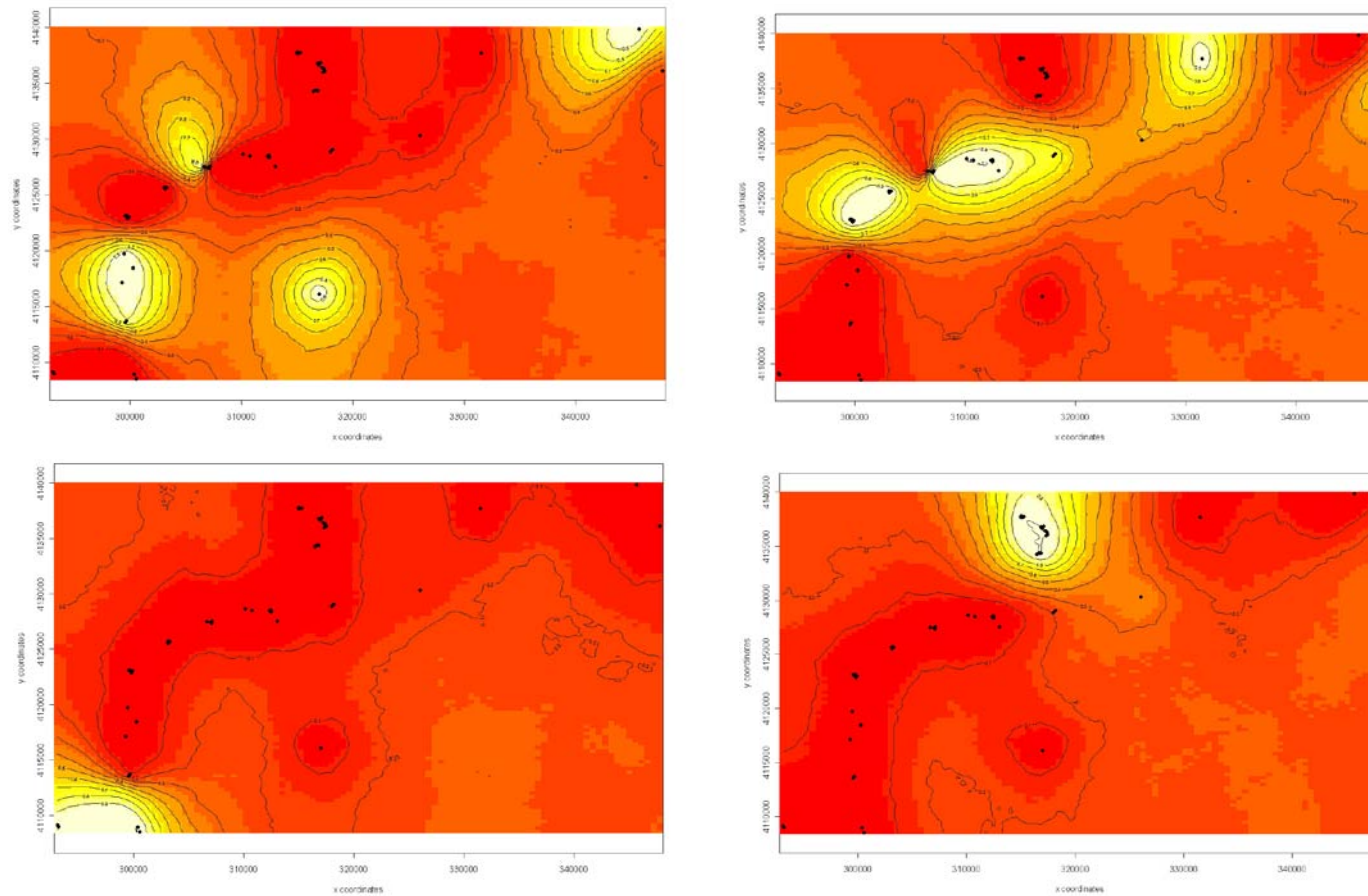
Figure 11. Posterior probability of membership in 1 of 4 genetic clusters as determined by GENELAND v. 6.2 (Guillot et al. 2005) for individual swamp rabbits (*Sylvilagus aquaticus*). Locations of swamp rabbit samples appear as black dots. The space around each sample point was interpolated to produce a spatial distribution of the probability of belonging to 1 of the 4 genetic clusters. Light shading of the space indicated a high posterior probability of membership and dark shading a low probability

Figure 12. Jackknife estimates of mean allelic richness and 95% confidence intervals (error bars) for 6 subpopulations of northern bobwhite (*Colinus viriginianus*) from Illinois, USA.
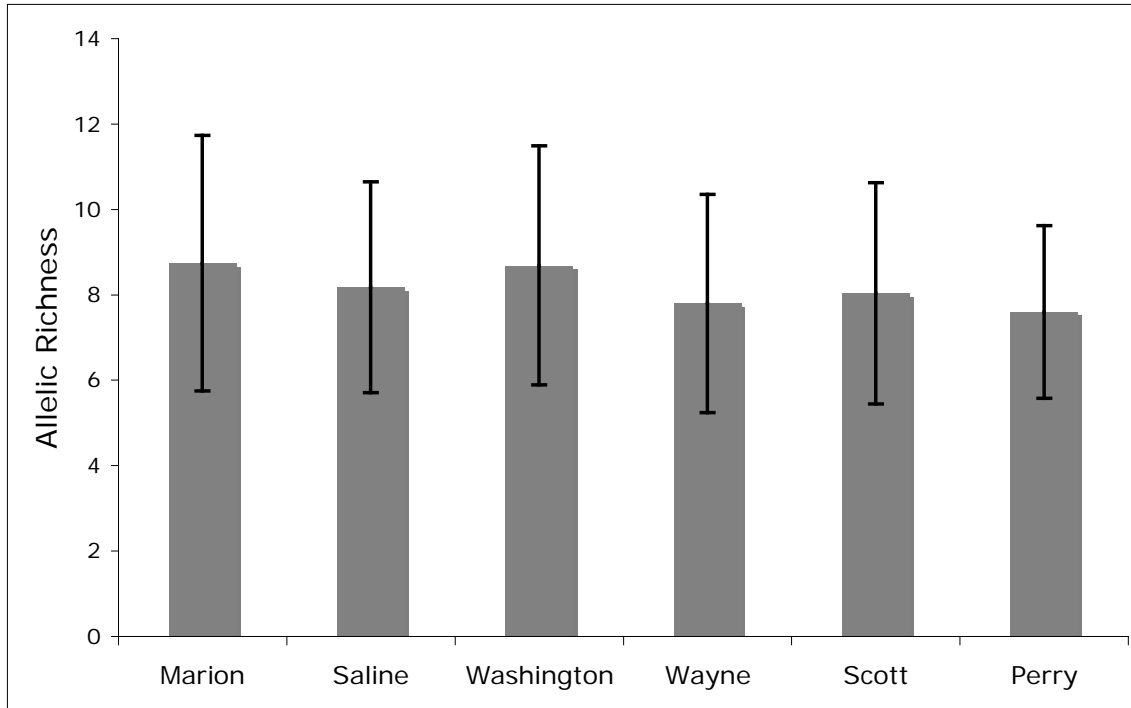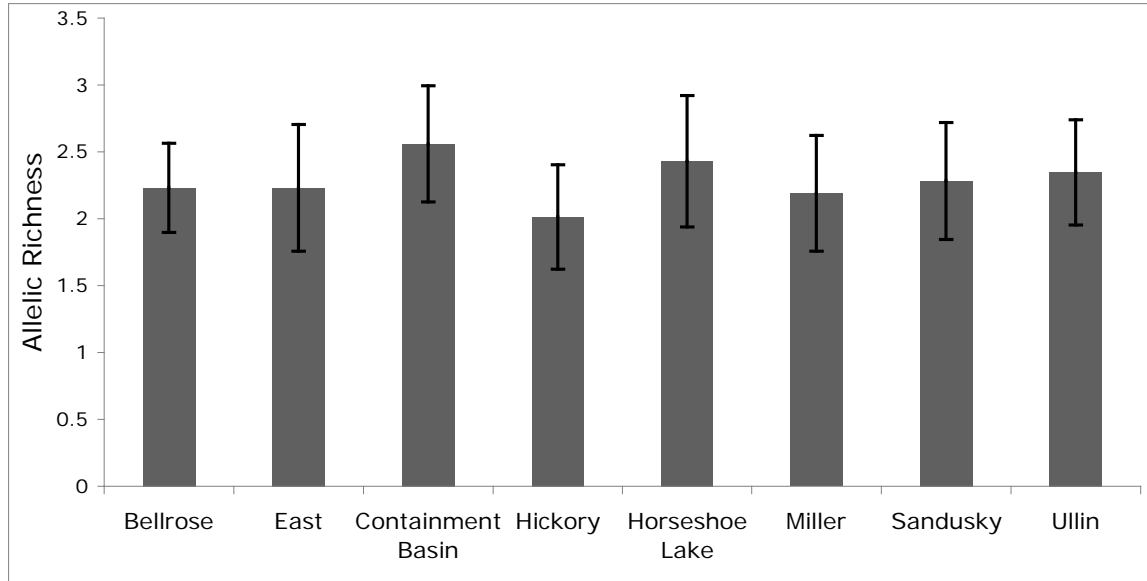
Figure 13. Jackknife estimates of mean allelic richness and 95% confidence intervals (error bars) for 8 subpopulations of swamp rabbits (*Sylvilagus aquaticus*) in southern Illinois, USA.

STUDY R-4. EFFECTS OF URBANIZATION ON RECRUITMENT AND HARVEST OF MOURNING DOVES

JOB R-4.1: EFFECTS OF URBANIZATION ON MOURNING DOVE NESTING SUCCESS, BEHAVIOR, MOVEMENTS, AND HOME RANGE

<u>Objective</u>: determine if nesting success dates and cover, movements during nesting season and early fall, and home range size vary with degree of urbanization.

INTRODUCTION

See Stoelb (2009; Appendix D).

METHODS

Study Area

We conducted research in urban and rural communities in Franklin and Williamson counties in southern Illinois, USA. Study sites ($n = 12$) were characterized on an urban–rural gradient based on human population. Human population sizes ranged from less than 121 to 16,035 people (U.S. Census Bureau 2000; Table 6).

All residential study sites had streets lined with utility poles and wires, alleyways, and sidewalks. Businesses, historic centers, and schools were interspersed throughout the more populated study sites. Noise levels and traffic varied with the day of the week, and time of day. Parks, woodlots, and bodies of water were excluded from study sites. Many residential study sites were built upon reclaimed minelands.

The amount of vegetation varied throughout each study site. Urban landscapes and lawns were decorated with ornamental plantings and shrubs. Trees such as maples (*Acer spp.*), oaks (*Quercus spp.*), elms (*Ulmus spp.*), cedars (*Juniperus spp.*), and pines (*Pinus spp.*) were found throughout the residential areas. Rural areas consisted of agricultural tracts dominated by soybean and corn, and woodlots of mixed forests.

The southern Illinois physiographic region can be characterized as the central lowland till

plains (U.S. Geological Survey 2003). In Franklin County, major land uses and areas were delineated as agricultural land–763.8 km^2, forested land–98.2 km^2, urban and developed land– 51.3 km^2, wetlands–141.9 km^2, and other land (e.g., barren and exposed land without vegetation or structures, quarries, and bare soil surfaces)–62.7 km^2. Williamson County, land uses and areas were delineated as agricultural land–606.3 km^2, forested land–217.3 km^2, urban and built-up land–83.1 km^2, wetlands–169.1 km^2, and other land–74.1 km^2 (Gustafson et al. 1997).

Capture and Handling

Urban sites were located $\geq$16 km from rural sites to reduce the possibility that captured doves were using both urban and rural areas. We used a combination of Kniffin modified funnel traps, Thompson traps, fall traps, and a modified rocket-net to capture mourning doves (*Zenaida macroura*) and Eurasian collared-doves (*Streptopelia decaocto*) during May-July, 2007-09. We randomly selected trap sites (*n* = 10/study site) from locations where doves were previously detected during dove abundance surveys, contingent upon receiving landowner permission. We prebaited traps with milo, white proso millet, and black-oil sunflower on bare ground prior to setting traps (Keeler and Winston 1951). We set traps when doves were observed feeding consistently. We ended capture efforts when all available radiotransmitters were implanted (see below).

We checked traps at mid-morning and dusk, and closed traps overnight to avoid nocturnal predation. We used the Bird Banding Laboratory (BBL) aging and sexing key (Cannell 1983, Schulz et al. 1995) to determine the age and sex of captured doves. We determined the mass of birds to the nearest gram with a Pesola® spring scale (Ben Meadows Company, Janesville, Wisconsin, USA). We measured and recorded wing length; tail length; culmen length; beak length, depth and width; and tarsus, toe, and total body length with Mitutoyo® digimatic plastic

calipers (Tyler Tool Company, Tylertown, Mississippi, USA). We visually inspected doves for

signs of diseases such as trichomoniasis and avian pox, as well as parasites.

We surgically implanted subcutaneous radiotransmitters (Schulz et al. 1998, 2001) in

mourning doves and Eurasian collared-doves from each study site. We used model PD-2

radiotransmitters (3 g, 23 x 12 x 6 mm, Holohil Systems Ltd., Carp, Ontario, Canada) with a

frequency range of 138-235 MHz, a nominal life of 4 months, and a line-of-sight range of

approximately 0.5-2.0 km. Transmitters were approximately 2.3% and 1.7% of mourning doves

and Eurasian collared-doves body weights, respectively. Each radiotransmitter was connected to

a 21.6-cm whip antenna made of stainless steel wire coated with nylon.

We followed published techniques for surgical procedures (Schulz et al. 1998, 2001) and

surgery took place in IACUC-approved (protocol # 07-006) facilities at Southern Illinois

University Carbondale. We anesthetized doves with an anesthetizing machine (Quantiflex® by

Fraser Harlake) with 5% isoflurane per 1.5 liters of oxygen through a gas mask in which half of

the dove's beak was inserted. We considered doves anesthetized when the eyelids remained

completely closed. We plucked feathers at the base of the neck to expose the incision site, and

along the right lateral hip region where the antennae exited. We cleansed exposed areas with a

2% chlorohexidine solution. We made an incision approximately 2.5-cm wide and 2.5-cm long

between the shoulders to create a subcutaneous pocket at the base of the neck to accommodate

the radiotransmitter. We reduced the flow of isoflurane to 3% after a successful incision was

made. We threaded a sterile epidural needle from the right lateral hip region to the medial part of

the surgical incision. We threaded the radiotransmitter antenna from the anterior end of the

epidural needle to the posterior end. We placed the radiotransmitter into the subcutaneous

pocket. We sutured the incision and the flow of anesthetic is slowly reduced from 1.5% to 0%

upon the final suture. We positioned the remaining feathers to cover the surgical site. We

stimulated doves to consciousness by gently exercising the wings and softly blowing in the face.

We transported fully recovered doves to the site of capture for release. Doves remained in

captivity for approximately 2 hrs.

Radiotelemetry and Nest Sampling

We located doves by homing and triangulation at least once per week. We rotated the

scheduled day of the week and time of day when each group was tracked on a weekly basis.

Tracking ended when the radiotransmitter was dead or when hunting season began. We recorded

$\geq$30 locations for each radioed dove to determine home range (Seaman et al. 1999). We used a

vehicle-mounted omnidirectional magnetic base whip antenna, a hand-held 3-element Yagi

directional antenna, a Garmin Etrex Legend GPS unit, a R-1000 digital receiver, and a Silva

Ranger compass to track the location of radio-marked doves.

We estimated home-range size during the breeding season (May-Nov) for all telemetered

birds for which we had $\geq$5, $\geq$10, $\geq$15, and $\geq$20 locations. Range size was estimated by the 100%

minimum convex polygon method. In addition, we calculated movement distances between each

pair of consecutive locations. Because the majority of birds were monitored during the 2009

season (29 of 39), we pooled data from all 3 years (2007–09) in our analysis.

We calculated annual survival rates of mourning doves using the Kaplan-Meier estimator

with staggered entry of individuals (Pollock et al. 1989) for all doves that were tracked by

telemetry for $\geq$10 days during the breeding seasons of 2007–09 in urban areas. The fate of many

doves during the study period was undetermined; therefore, we estimated 2 different survival

rates. The first, termed Category 1, assumed that doves with undetermined fates were alive.

Category 2 assumed that doves with undetermined fates were dead. Research-caused mortalities

($n = 2$ residents, $n = 1$ translocation) were not considered deaths in the survival estimates and these doves were censored from the analysis at the last date at which they were known to be alive.

We used data from radiotransmitters, surveys, and behavioral observations to locate nest sites. Radiotelemetry reduced bias in nest searching (Powell et al. 2005). We recorded nest and site characteristics such as genera of tree or details of man-made structures. If the nest was in vegetation, we recorded the height of the vegetation, diameter at breast height (DBH), and placement of nest in the limbs. We measured height of nest and height of nest tree with a clinometer. We recorded type of nesting material, description of surrounding vegetation, and the amount of cover for all nest sites. We measured characteristics of the nearest-neighbor tree (of a suitable size) to the nest tree in a randomly selected direction in 2009 only. We compared dimensions of nest trees to random trees with paired t-tests. We also compared the frequencies of used vs. random trees.

RESULTS

We surgically implanted 59 mourning doves (33 M, 26 F) in urban areas and 14 in rural and exurban areas with radiotransmitters during the 2007-09 breeding seasons. Of these birds, 41 (24 M, 17 F) were tracked until they disappeared, 7 (4 M, 3 F) were never relocated, 2 (1 M, 1 F) died, 1 (1 F) had transmitter failure, and 8 (3 M, 5 F) transmitters were found with an unknown fate.

Doves were tracked for 1,932 (M) and 1,473 (F) radiodays. Breeding-season survival of doves (May-Oct) was estimated to be 0.95 (95% CI: 0.86-1.0) for females and 0.92 (0.76-1.0) for males, if doves for which we found transmitters were assumed to be alive; and 0.68 (0.47-0.90) and 0.76 (0.55-1.0) for females and males, respectively, if those doves were assumed to be dead.

Based on numbers of telemetered birds at risk, 9 of 20 females were censored from analyses during 17–31 July, whereas 11 of 19 males were censored during 12–31 (Figure 14).

Telemetered mourning doves were monitored in the 4 largest urban sites (Figures 15-18). Most birds were always located ($n = 839$ total radiolocations) within city limits, although a few individuals made forays into rural area (Figures 15-18). Breeding home ranges of mourning doves during 2007-09 varied little between the sexes (Table 7), and generally averaged 10-15 ha, regardless of the number of locations that were used to calculate estimates. Movements between consecutive locations averaged 144.2 ± 12.4 m for females ($n = 365$ movements) and 159.5 ± 8.5 m for males ($n = 355$ movements). A single Eurasian collared-dove was relocated 30 times, and had a home range estimated to be 2.67 ha (Figure 16); this bird was monitored in 2008.

Telemetry locations used to develop home ranges in rural and exurban sites were gathered from July to September 2007. We estimated home ranges for 3 of the 14 mourning doves that were fitted with transmitters in these sites. We were unable to obtain >10 locations for 11 doves, and therefore home ranges for these doves were not estimated. Estimates for 2 male mourning dove home ranges in Pittsburg, Illinois, were 4.36 ha (16 locations) and 7.63 ha (27 locations). A male dove captured in a rural site outside of Pittsburg, Illinois, had a home range estimated at 30.06 ha (22 locations). We did not estimate home ranges for rural doves in 2008 because research efforts were focused towards other objectives.

We found 46 nests of mourning doves in 21 species of trees and 1 man-made object in 2008 (Table 8), and 83 nests in 31 species of trees in 2009 in urban sites (Table 9). After accounting for nest trees that were destroyed in storms or otherwise removed, we sampled 76 pairs of trees in 2009 (nest trees vs. random trees; Table 10). Nest trees were taller ($t_{75} = 4.45$, $P < 0.001$) and had larger DBH ($t_{56} = 2.46$, $P = 0.02$) than random trees, but were similarly

distanced to buildings ($t_{75} = 0.06$, $P = 0.98$) and roads ($t_{75} = 1.34$, $P = 0.19$). Trees could be categorized into 6 species or generic groups based on frequency (*Acer* spp., *Pinus* spp., *Quercus* spp., *Juniperus virginana*, *Liquidambar styraciflua*, and other). A total of 75% ($n = 57$) of nest trees and 75% of random trees could be placed into a species or generic group. Use and availability of nest and random trees were nearly identical: *Acer* spp: $n = 20$ each for nest and random trees; *Quercus* spp: $n = 7$ each for nest and random trees; *Pinus* spp: $n = 13$ for nest trees, $n = 12$ for random trees; *Liquidambar*: $n = 13$ each for nest and random trees; *Juniperus*: n = 4 for nest trees, $n = 5$ for random trees. See Stoelb (2009; Appendix D) for results on nesting success in exurban sites and nest-site use and selection along the rural-urban cline.

DISCUSSION

Survival of urban doves during the breeding season was high (0.68-0.76 or 0.92–0.95, depending on assumptions), although 69.5% (41 of 59) birds were right-censored. An additional 11.9% (7 of 59) were never relocated. Previous work with rural doves carrying implantable transmitters (Berdeen and Otis 2006) or back-mounted transmitters (Schulz et al. 1996) reported similar survival rates for this time period, but also noted high censoring rates. Berdeen and Otis (2006) attributed these censoring rates to the difficulty in monitoring such a mobile species while using a small transmitter with limited range, the scale of movements by mourning doves (especially late in the breeding season and just prior to migration), and the use of antenna lengths that were less than optimal for radio reception. They recommended productive survey methods and appropriate equipment to locate telemetered birds. A consequence of the high censoring rates is that survival estimates may be biased high because some assumptions of survival analysis using telemetry are violated; i.e., death times are exactly known and censoring is random and independent of fate (Berdeen and Otis 2006). Nevertheless, we concur with Schulz et al. (1996)

that mortality of doves during the nesting season is not a key limiting factor, and we conclude that the urban environment does not negatively affect dove survival.

Mourning dove movements in our urban environments were constrained relative to movements by rural doves in previous studies. In Missouri, daily movements for nesting males ranged from 0.8 to 7.8 km and nesting females could be found 5.3 km away from nest. During the breeding season, home ranges for mated males ranged from 482 to 1,674 ha. Unmated males had smaller home ranges varying from 342 to 1,123 ha (Sayre et al. 1980). In southeastern Idaho, the average distance a mourning dove moved from its nest site was 3.7 km, and the mean daily maximum movements ranged from 1.1 to 3.8 km (Howe and Flake 1988). In Alabama, daily home ranges for juvenile mourning doves averaged 218 ha, and the daily maximum distance traveled between 2 locations averaged 3.4 km (Losito and Mirarchi 1991). There were no habitat preferences found for hatching-year mourning doves (Losito and Mirarchi 1991).

The scale of movements and ranging behavior that we observed in urban doves may be due to a number of factors. The reduced movements and small home ranges in urban areas compared to rural sites may have been due to high-resource density for doves in the urban environment, allowing doves to fulfill food and habitat needs in small areas. Alternatively, our estimates of ranging behavior may have been biased low due to a low probability of locating doves once they moved >1 km from a nesting site. Doves are highly mobile but can carry a transmitter with limited line-of-sight range (ca. 400-800 m), thus, when they move distances several km, as seen in rural studies (Sayre et al. 1980), our ability to locate the telemetered individuals was reduced.

Mourning doves nested in a variety of trees in urban environments in southern Illinois, but did not appear to select trees by species. A similar diversity of trees was noted in an earlier

study in Williamson County, Illinois, which reported 36 dove nests in 15 different tree and shrub

species and 4 nests on the ground (Hanson and Kossack 1963). Our results conflicted with

earlier studies conducted in the Eastern Management Unit that suggested mourning doves prefer

conifers and orchard trees (Sayre and Silvy 1993). In Illinois, they preferred blue spruce (*Picea*

pungens) and Norway spruce (*Picea abies*) in comparison to other conifers, being able to build a

secure nesting platform in the stiff needles and branches in spruces (Hanson and Kossack 1963).

Mourning doves in Minnesota preferred white spruce (*Picea glauca*) and blue spruce to other

conifers and deciduous trees (Harris et al. 1963).

Size of nest trees were similar to those seen at an urban campus in Texas, where doves

preferred live oaks (*Quercus virginiana*) with an average DBH of 46 cm to other trees and

ornamentals (Munoz 2004). These nests were found in close proximity to open fields and a

further distance from buildings (Munoz 2004). In urban areas in Texas, Ludwick (2008) found

286 mourning dove nests in 25 species of trees. Of the 25 species of nesting trees, they preferred

to nest in sugar hackberry (*Celtis laevigata*), live oak, and Rio Grande ash (*Fraxinum*

berlandieriana).

Mourning doves nest in such a variety of habitats (Sayre and Silvy 1993) that defining

which variables most influence the selection of a nest site and the success of that nest is a

challenge (Stoelb 2009). We suspect that developed areas are in no way inferior habitats for

nesting mourning doves, and in fact may be more productive than those in rural areas (see

Discussion in Stoelb 2009:19-25) . Additional data are required to analyze this assumption to

accurately assess the role urbanization plays in the reproductive success and nest-site selection of

mourning doves in southern Illinois. The same methodology can and should be applied in other

areas of the United States to compare and contrast trends in both nest success and nest-site

selection along urban-rural gradients (Stoelb 2009).

JOB R-4.2: IMPACTS OF URBANIZATION ON MOURNING DOVE ABUNDANCE AND HARVESTABLE SURPLUS

Objective: use band return data to estimate the proportion of annual harvest coming from urban, suburban, and exurban sites compared to rural areas.

INTRODUCTION

The population of mourning doves is estimated to be approximately 350 million in the United States (Otis et al. 2008b). Mourning doves are harvested more than any other migratory game bird in the United States (Otis et al. 2008b). During the 2008 hunting season, >17 million mourning doves were harvested in the U.S., with approximately 7,671,800 mourning doves harvested in the Eastern Management Unit (EMU) and 683,100 harvested in Illinois (Dolton et al. 2009). According to the U.S. Fish and Wildlife Service (2006), 2.3 million migratory bird hunters spent $1.3 billion on hunting trips and equipment, with 1.2 million sportspersons hunting doves on a combined 6 million days. Hunting expenditures totaled $451 million in Illinois alone (U.S. Fish and Wildlife Service 2001). Money generated from dove hunting contributes toward wildlife conservation and research programs through the Pittman-Robertson Act.

Urban areas can provide a potential refuge for this hunted species (Scott et al. 2004). In Ohio, the harvest rate of banded mourning doves from rural areas was greater than from urban areas (Scott et al. 2004). It was hypothesized that this result may be due to urban doves having a smaller home range and a decreased tendency to migrate than in rural doves. Both of these scenarios reduce the chances of an urban dove being harvested (Scott et al. 2004). Wildlife managers need additional information to understand the contribution of urban doves to harvest and to efficiently predict the effects of harvest on this species. In this study, we used band-return data to estimate the proportion of annual harvest coming from urban, suburban, and exurban sites compared to rural areas in southern Illinois.

METHODS

Study Area – See Job R-4.1 description.

Capture and Banding – See Job R-4.1 description of trapping

We checked traps at mid-morning and dusk, and closed traps overnight to avoid nocturnal predation. We used the BBL aging and sexing key (Cannell 1983, Schulz et al. 1995) to determine the age and sex of captured doves. We determined the mass of birds to the nearest gram with a Pesola® spring scale (Ben Meadows Company, Janesville, Wisconsin, USA). We measured and recorded wing length; tail length; culmen length; beak length, depth and width; and tarsus, toe, and total body length with Mitutoyo® digimatic plastic calipers (Tyler Tool Company, Tylertown, Mississippi, USA). We visually inspected doves for signs of diseases such as trichomoniasis and avian pox, as well as parasites. We banded doves at each location with federally-issued aluminum leg bands following BBL protocols (Gustafson et al. 1997) and released doves at the capture site. We received band-return data from the U.S. Geological Survey bird-banding laboratory in Laurel, Maryland, USA.

RESULTS

We banded 458 mourning doves in urban areas and 168 doves in rural areas during the 3 years of study (Tables 11-14). The sex ratio of urban and rural doves was both biased toward males (Table 11). We captured 2 Eurasian collared-doves in Herrin in 2007 (1 M, 1 F) and 2 in 2008 (1 F, 1 immature).

We received reports of 44 band recoveries of the 626 banded doves (Table 15). A similar percentage of mourning doves banded was recovered in urban areas (7.42%) as in rural areas (5.95%) during the 2007-09 seasons ($\chi^2 = 0.32$, 1 df, $P > 0.5$). All recovered birds were banded in 2007 (Table 16). The sex ratio of recovered birds was 25 M:11 F: 8 unknown, similar to the

sex composition of birds banded in 2007 ($\chi^2 = 0.68$, 2 df, $P > 0.7$). The age ratio (age at banding)

of recovered birds was 33 after-hatching-year (AHY):11 hatching-year (HY), which provided

suggestive evidence that hatch-year birds were overrepresented in the recovered sample relative

to the age composition of birds banded in 2007 ($\chi^2 = 3.17$, 1 df, $P = 0.07$) Recovered birds were

banded in Carterville ($n = 3$), Herrin ($n = 4$), Marion ($n = 4$), Pittsburg ($n = 7$), rural Zeigler ($n = 3$),

West Frankfort ($n = 13$), and Zeigler ($n = 10$). Forty-two of the recovered mourning doves

were shot and 2 were reported found dead (Table 15). All finders of the bands were persons who

found or shot the mourning dove and were not conservation agency employees. Mourning doves

were recovered in Illinois ($n = 41$), Texas ($n = 2$), and Mississippi ($n = 1$; Table 15).

DISCUSSION

Our results show that urban doves contribute to harvest in southern Illinois, with the

proportion of recovered birds not differing between urban and rural areas. These results differ

from the findings from the Ohio study (Scott et al. 2004), where harvest rates were higher for

rural doves than urban doves. Doves in the Ohio study (Scott et al. 2004) were banded in large

urbanized counties with human populations 10-100 times larger than in our urban sites, and those

urban birds may have had reduced pressure to migrate and thus, reduced vulnerability to harvest.

Notably, 2 trapping sites in the Scott et al. (2004) study were in rural areas adjacent to towns of

20,000-25,000 inhabitants. These towns were larger than our largest urban site (Table 6), yet

were classified as rural sites because the towns were deemed too small to serve as year-round

refugia (Scott et al. 2004). The greater harvest rate for urban doves that we observed could result

from home-range size, daily movement patterns, and migratory behavior of urban doves in our

study system that put them at an increased risk during the hunting season. Flocking behavior in

autumn may have brought urban birds to rural areas in preparation for migration, increasing their

chances of mortality by hunters, especially if fall flocking occurred in huntable rural areas adjacent to the banding locations in small cities.

Knowing the harvest rate of urban doves will aid in the status of mourning doves and enable managers to make informed management decisions, as hunting-season regulations will likely have a strong influence on Illinois dove population parameters. In Illinois a large-scale, long-term banding effort would improve our understanding of the contribution of urban doves to harvest. A critical need regarding harvest of urban doves is understanding the relationship between urban population size (of humans), migratory propensity of doves, and rate of harvest of urban-banded doves. Consistent urban banding along with monitoring efforts would reveal if urban areas are indeed providing a haven for doves during the hunting season. Patterns of migration and harvest location revealed by banding efforts in urban areas may help address our concerns of why mourning doves are declining across the U.S.

JOB R-4.3: DISTRIBUTION OF EURASIAN COLLARED-DOVES IN ILLINOIS

Objective: develop baseline data on the occurrence of Eurasian collared doves in southern Illinois and on interactions between Eurasian collared doves and mourning doves.

INTRODUCTION

Wildlife managers across the nation are concerned about the status of the mourning dove and have limited data to make appropriate decisions on managing mourning doves (2003 Mourning Dove National Strategic Harvest Management Plan, Dolton et al. 2009). The Call Count Survey (CCS), conducted annually between 20 May and 5 June on a national scale, is designed to monitor mourning dove populations and to inform harvest regulations (Dolton 1993, Dolton et al. 2007). Previous CCS reports (1966-2006) indicated that mourning dove populations across all management units are decreasing (Dolton and Rau 2006), with a significant decline of mourning doves heard in the hunting states of the EMU during the 1966-2009 period (Dolton et al. 2009). However, surveys reporting population changes for mourning doves in the past 10 years for the EMU exhibit inconsistent results and no significant trend in mourning doves heard (Otis et al. 2008b, Dolton et al. 2009). According to the results of the 2008-09 CCS, there was no significant change in the population status of mourning doves based on birds heard per route in the EMU (Dolton et al. 2009). Within Illinois, wildlife managers are concerned about the overall decline on mourning doves, although CCS results for mourning doves heard in Illinois showed a 13.5% increase over the most recent 2-year period (2008-09), a 0.9% decrease in the 10-year period (2000-09), and a non-significant increase of 0.2% in the 44-year period (1966-2009).

A potentially complicating factor affecting future mourning dove trends in Illinois is the invading presence of the exotic Eurasian collared-dove, which arrived in the U.S. in southeastern

Florida in 1986 (Smith and Kale 1986). In the U.S., Eurasian collared-doves are found in urban and agricultural areas where roosting, nesting sites, and food sources are available (Romagosa 2002). Some exotic species can exclude native species from resources, potentially displacing them from their preferred habitat (Smith and Smith 2001). Biologists speculate that collared-doves have the potential to become a competitor of the native mourning dove. Resource and habitat requirements such as food selection, nest sites, and nesting materials are analogous between these 2 species (Romagosa and McEneaney 1999, Romagosa and Labisky 2000). Temple (1992) recognized the lack of information on life histories and ecological relationships concerning exotic birds, and stressed the need to educate the public on these issues. The first Eurasian collared-dove recorded in Illinois was in Clinton County in 1997 (Johnson et al. 1998), and the species presently occupies 94 of 102 Illinois counties (J. Walk, The Nature Conservancy, personal communication). The Eurasian collared-dove often lives in close proximity to humans (Smith 1987), and generally in urban and agricultural areas where roosting, nesting sites, and food sources are available (Coombs et al. 1981, Romagosa 2002).

The CCS has provided historic information of population trends and a useful comparison of regional populations. However, there is current debate suggesting that this method is inadequate to provide dove abundance or density information, or to provide information needed to identify necessary changes in harvest regulations (National Mourning Dove Planning Committee 2003). Additional problems with the methodology of the CCS are related to dove behavior and urban-rural distribution. Unmated males perch coo more often than mated males (Frankel and Baskett 1961, Irby 1964, Sayre et al. 1980, Otis et al. 2008a). This factor can potentially affect the results of the CCS by overestimating the number of paired doves found along the survey route (Irby 1964, Baskett 1993, Dolton 1993). The CCS excludes Midwestern

urban areas when surveying populations of mourning doves (Braun et al. 1993). Mourning doves are numerous in urban areas (Emlen 1974, Otis et al. 2008a), and typically nest in a variety of tree species, plantings, and manmade structures found in urban areas. Breeding males can be observed on utility wires advertising their mating status. Therefore, excluding urban areas in surveys can underestimate the number of mourning doves in a given region.

Survey techniques that were designed for rural areas often fail in urban areas due to obstacles such as noise and obstructed visibility, traffic, interruption from pedestrians, lack of access to private property, and the large quantity of non-territorial birds such as house sparrows (*Passer domesticus*) (DeGraff et al. 1991). Urban areas, railroads, airports, and major highways have noise disturbances that make it difficult to hear cooing doves (Foote et al. 1958) and may bias auditory surveys (Breeden et al. 2008). Additional studies in urban environments are necessary to gain a better understanding of urban habitats and the wildlife residing there (DeGraff et al. 1991).

Surveying doves in urban areas is important to document population changes for mourning doves and Eurasian collared-doves (Braun et al. 1993), especially given the lack of information on how to successfully survey and study populations of Eurasian collared-doves (Beckett et al. 2007). Our overall objective was to develop baseline data on the occurrence of Eurasian collared doves in southern Illinois and on interactions between Eurasian collared doves and mourning doves. We used data from call-count and relative abundance surveys modified for the urban environment to meet this goal. Specifically, we (1) estimated the relative abundance of mourning doves and Eurasian collared-doves during the breeding season over an urban-rural gradient; (2) examined seasonal changes in relative abundance of doves along the urban-rural gradient; (3) examined relationships between dove relative abundance and measures of

urbanization; and (4) compared nest characteristics of mourning doves and Eurasian collared-doves.

METHODS

Study Area – See Job R-4.1 description.

Capture and Handling – See Jobs R-4.1 and 4.2 for description of capture and handling.

Dove Surveys

We conducted visual dove surveys in March, June, and September during 2007-09. Our 4 main urban sites (Carterville, Herrin, Marion, and West Frankfort; Table 6) were sampled in all 3 years. Beginning in June 2008, we sampled 7 additional rural sites and another urban site (Johnson City; Table 6). We assumed that both dove species were equally detectable. We conducted visual surveys between 30 min after sunrise and 1000 CST on days with no rain and wind speeds <20 km/hr. We located study sites at the core of each town and each site was partitioned into 4 quadrants. Each north-south road within each quadrant was surveyed by driving ≤8 km/hr. We conducted surveys on main roads, not alleyways. We recorded the location and vegetation type or structure occupied for each dove detected by sight (DeGraff et al. 1991). We did not record doves in flight. We documented the start and finish time and temperature for each survey.

We manually mapped the width of each transect on an aerial photograph, and used ArcGIS 9.0 (Environmental Systems Research Institute, Redlands, California, USA) to compute the width of each transect (Mills et al. 1989). Transect widths varied due to visual obstructions consistent in urban areas such as homes, garages, and other structures. For example, rooftops of houses defined the maximum transect width for doves recorded on residential streets. We manually measured the length of each transect on an aerial photograph. We calculated transect

area as the product of transect width and length.

In southern Illinois, CCS routes are not officially established. For the purpose of this study, we modified and conducted CCS in 8 sites along the urban–rural gradient. We used 3-4 stops 1.6 km apart per transect as listening stations in each of the 4 urban areas, and used 8-10 stops 1.6 km apart per transect as listening stations in each of 4 rural areas (See Stoelb 2009 for a full description of CCS methodology).

Radiotelemetry and Nest Sampling

We located telemetered doves (Job R-4.1) by homing and triangulation at least once per week. We rotated the scheduled day of the week and time of day when each group were tracked on a weekly basis. Tracking ended when the radiotransmitter is dead or when hunting season begins. We recorded a minimum of 30 location points for each radioed dove to determine home range (Seaman et al. 1999). We used a vehicle-mounted omnidirectional magnetic base whip antenna, a hand-held 3-element Yagi directional antenna, a Garmin Etrex Legend GPS unit, a R-1000 digital receiver, and a Silva Ranger compass to track the location of radio-marked doves.

We used data from radiotransmitters, surveys, and behavioral observations to locate nest sites. Radiotelemetry reduced bias in nest searching (Powell et al. 2005). We recorded nest and site characteristics such as genera of tree or details of man-made structures. If the nest was in vegetation, we recorded the height of the vegetation, DBH, and placement of nest in the limbs. We measured height of nest and height of nest tree with a clinometer. We recorded type of nesting material, description of surrounding vegetation, and the amount of cover for all nest sites. If collared-dove nests were in a suitable place for an observer to examine the eggs, we recorded characteristics such as length and breadth, shape, weight, color, surface texture, and eggshell thickness.

Statistical Analyses

We estimated relative density of doves (doves/ha) for each species in each quadrant by dividing total number of birds seen within a quadrant by total area surveyed. We used mixed-model repeated measures ANOVA to test whether relative abundance of mourning doves differed by site type (urban vs. rural) and season (Mar-Jun-Sep) in 2008 and 2009. We did not compare relative densities of Eurasian collared-doves between urban and rural sites because only 1 of 7 rural sites contained this species. We also conducted a separate analysis of densities of both dove species for urban sites (>4,000 inhabitants) for the full 2007-09 study period to examine seasonal and yearly patterns. We regressed relative-density estimates of mourning doves and Eurasian collared-doves on metrics of urbanization (site population size, population density, housing density, and land area) for each season and year. We compared characteristics of collared-dove and mourning dove nest sites with *t*-tests. We conducted all statistical analyses using SAS software (SAS/STAT Version 9.2; SAS Institute, Cary, North Carolina, USA).

RESULTS

Relative Abundance and Call-Count Surveys

We surveyed 110.1 km^2 of transects over the 3 years of study. Relative abundance surveys were not conducted at study sites containing <4,000 people in 2007 or during spring 2008 (Tables 17-19). During 2008, relative densities of mourning doves varied between site types ($F_{1, 10} = 10.56$, $P = < 0.01$) and among months ($F_{1, 10} = 4.87$, $P = 0.05$) with no type-month interaction ($F_{1, 10} = 1.69$, $P = 0.22$). Relative densities were higher in urban areas and during summer (Table 20). During 2009, relative densities of mourning doves did not vary between site types ($F_{1, 10} = 2.35$, $P = 0.16$), by months ($F_{2, 19} = 0.30$, $P = 0.74$), or by the type-month interaction ($F_{2,19} = 2.13$, $P = 0.15$).

A separate analysis involving only the 4 largest urban areas in 2007-09 for relative

densities of mourning doves showed variation among the 4 individual sites ($F_{3, 6}= 7.48$, $P =$

0.019), years ($F_{2, 6}= 16.18$, $P = 0.004$) and months ($F_{2, 6} = 14.56$, $P = 0.005$), but no interaction

effect (Table 20). Densities were highest in summer and in 2007. Relative densities of Eurasian

collared-doves varied among study sites ($F_{3, 6} = 19.79$, $P = 0.002$), and years ($F_{2, 6}= 7.22$, $P =$

0.025), with highest numbers seen in 2007 (Table 20). Overall, the ratio of mourning doves to

collared-doves averaged >10:1 in all seasons and years in study sites where collared-doves

occurred (Table 20).

We detected mourning doves in 2007 in all study sites during all survey seasons, whereas

Eurasian collared-doves were detected in 75% (3 of 4) of urban study sites, including Herrin,

Marion, and West Frankfort (Table 17). In fall 2007, relative densities of Eurasian collared-

doves were positively related ($F_{1, 2} = 70.7$, $P = 0.014$, $r^2 = 0.973$; Figure 19) with number of

human inhabitants at study sites. There were no significant relationships in any season in 2007

between relative densities of mourning doves and the number of people at study sites. There

were no significant relationships in any season in 2007 between relative densities of mourning

doves and Eurasian collared-doves and human population density, housing density, or land area.

We detected mourning doves in all study sites during all survey seasons during 2008,

whereas Eurasian collared-doves were detected in 33.3% (4 of 12) of study sites, including

Herrin, Marion, West Frankfort, and Zeigler (Table 18). Relative density of mourning doves was

positively related to the human population size at study sites in summer ($F_{1, 10} = 5.86$, $P = 0.036$,

$r^2 = 0.369$; Figure 20), human population density at study sites in summer ($F_{1, 10} = 5.36$, $P =$

0.043, $r^2 = 0.350$; Figure 21), and fall 2008 ($F_{1, 10} = 66.28$, $P < 0.001$, $r^2 = 0.869$; Figure 21), and

housing density at study sites in summer ($F_{1, 10} = 6.34$, $P = 0.031$, $r^2 = 0.388$; Figure 22), and fall

2008 ($F_{1, 10} = 34.6$, $P < 0.001$, $r^2 = 0.776$; Figure 22). There were no significant relationships in any season in 2008 between mourning doves and urban land area.   Relative density of Eurasian collared-doves was positively related to human population size in fall ($F_{1, 10} = 18.61$, $P = 0.002$, $r^2 = 0.651$; Figure 23) and to land area in fall ($F_{1, 10} = 15.3$, $P = 0.003$, $r^2 = 0.605$; Figure 24). There were no significant relationships in any season in 2008 between relative densities of Eurasian collared-doves and human population density or housing density.

We detected mourning doves in 92% (11 of 12) of study sites during all survey seasons in 2009, whereas the Eurasian collared-dove were detected in 33.3% (4 of 12) of the study sites, including Herrin, Marion, West Frankfort, and Zeigler (Table 19). In summer, relative density of mourning doves was positively related to the human population size at study sites ($F_{1, 10} = 24.32$, $P < 0.001$, $r^2 = 0.709$; Figure 25) and to urban land area at study sites ($F_{1, 10} = 9.83$, $P = 0.011$, $r^2 = 0.496$; Figure 26).   There were no significant relationships in any season in 2009 between relative densities of mourning doves and human population densities or housing density. Relative density of Eurasian collared-doves was positively related to human population size in fall ($F_{1, 10} = 8.01$, $P = 0.018$, $r^2 = 0.445$; Figure 27), human population density in spring ($F_{1, 9} = 5.50$, $P = 0.044$, $r^2 = 0.380$; Figure 28), and urban land area in spring ($F_{1, 10} = 4.72$, $P = 0.055$, $r^2 = 0.321$; Figure 29). There were no significant relationships in any season in 2009 between relative densities of Eurasian collared-doves and housing density.

Results of the CCS in 2007 and 2008 are reported by Stoelb (2009). Generally, there was an increase in number of doves heard as human population size increased; i.e., doves heard increased along the rural–urban gradient.

Nest Comparisons between Dove Species

We found 46 mourning dove nests in 21 different tree species and on 1 man-made object

(Table 8) in the 2008 nesting season. We also found 17 collared-dove nests in 10 different tree species and on 2 man-made objects (Table 21). Three nest-tree variables, DBH ($t = 0.84$, $P = 0.406$), tree height ($t = 1.21$, $P = 0.23$), and crown density ($t = -0.51$, $P = 0.614$), did not vary between species. However, collared-dove nests were higher ($t_{15, 44} = 3.14$, $P = 0.003$) than those of mourning doves (Table 22).

We found 83 mourning dove nests in 31 different species of trees (Table 9) and 10 collared-dove nests in 6 different species of tree and on 1 man-made object (Table 23) in 2009. Seven of 10 (70%) collared-dove nests were in evergreen species (*Ilex opaca*, *Pinus* spp., *Juniperus virginiana*) compared to only 19 of 83 (23.8%) of mourning dove nests. The most commonly used trees by mourning doves were *Acer* spp. ($n = 19$) and *Liquidambar styraciflua* ($n = 13$). Nest trees of collared-doves did not differ from random trees in height ($t_8 = 0.12$, $P = 0.91$), DBH ($t_6 = 0.50$, $P = 0.64$), distance to buildings ($t_9 = 1.25$, $P = 0.24$) and distance to roads ($t_9 = 0.01$, $P = 0.99$). Between species, nest trees of mourning doves were taller ($t_{31.9} = 4.64$, $P < 0.001$) and tended to be farther from buildings ($t_{84} = 1.77$, $P = 0.08$) than those of collared doves (Table 23). However, DBH of nest trees ($t_{75} = 1.43$, $P = 0.16$) and distance of nests to roads ($t_{84} = 1.53$, $P = 0.13$) did not vary between species (Table 23).

DISCUSSION

The relative density of both species of doves was positively related to metrics of urbanization at various times during the study. For mourning doves, these relationships were strongest in summer, and consistent with the higher number of birds seen in the larger urban areas during that season. These findings are similar to those of work conducted in the western U.S. In Tucson, Arizona, mourning dove abundance in 50-m fixed-radius plots was correlated positively to housing density, percent of area paved or graded, and percent of urban land in open

exotic cover (Germaine et al. 1998). Similarly, Crooks et al. (2004) classified mourning doves as urbanization-enhanced species in coastal southern California based on their abundance on urban transects compared to either fragmented or unfragmented natural habitat. Blair (1996) found mourning doves to be a suburban adaptable species that can be found in developed areas such as residential areas, business districts, and clusters of office buildings. Species richness may be high in urban environments; however, synanthropic species typically dominate (Lancaster and Rees 1979, Beissinger and Osborne 1982, Marzluff 2001).

Many amenities of urban areas can attract doves. Doves are highly adaptable and opportunistic (Emlen 1974) and will nest in a variety of habitats including man-made structures such as ledges, chimneys, rainspouts, house columns, and air conditioners (Sayre and Silvy 1993). Roofing of houses, television antennas, and utility poles and wires provide for advertising and resting perches (Emlen 1974). Winters are milder than in nearby rural areas, and bird feeders and bird baths provide for the dove needs (Romagosa 2002, Otis et al. 2008a). Ornamental species can provide seed for granivorous birds (Beissinger and Osborne 1982). In Maryland, as farmland was being developed into a city, mourning doves declined in the surrounding agricultural area, due to a less attractive feeding ground (Geis 1974).

Because doves appear to do well in urban environments, increasing urbanization may indicate that the urban component of the population is likely to increase over time. For that reason, reliable methods for surveying urban dove populations are needed. The proclivity of doves toward perching on wires and other highly conspicuous locations, coupled with high road density, make visual surveys a promising approach in urban environments. Visual surveys also avoid specific issues related to CCS in urban environments (especially noise disturbance reducing detection distances; Foote et al. 1958, Breeden et al. 2008), as well as issues intrinsic to

CCS (e.g., low calling frequency during parts of the breeding cycle; Frankel and Baskett 1961, Irby 1964, Sayre et al. 1980, Otis et al. 2008a). However, a close assessment of transect width, as determined by the visible distance from the road, is necessary to correctly calculate relative densities.

It is uncertain if populations of southern Illinois doves seasonally migrate. We found generally higher relative densities of mourning doves in summer than spring and fall for our urban sites, which suggests that mourning doves breeding in urban areas in southern Illinois do migrate. Scott et al. (2004) classified 2 trapping sites that were adjacent to towns of 20,000-25,000 inhabitants as rural because the towns were deemed too small to serve as year-round refugia (Scott et al. 2004). These towns were larger than our largest urban site (Table 6). The implication of Scott et al. (2004) is that birds trapped in these areas were indeed migratory. In addition, the steep decline in telemetered birds at risk in late July-early August (Figure 14), which resulted from disappearances, and the decline in relative densities of mourning doves in September may have been due to premigratory movements from urban areas to fall flocking areas in rural areas.

It has been documented that Eurasian collared-doves are non-migratory, but when necessary, their dispersal patterns are in deliberate search of food and roosting sites (Coombs et al. 1981, Romagosa 2002). The lack of a seasonal difference in the relative abundance of Eurasian collared-doves in the larger towns of our study also suggests non-migratory behavior. Some Eurasian collared-doves disperse long distances from their natal site and fill in gaps where suitable habitat is available, whereas others disperse shorter distances and stay very close to the natal site when sexually mature (Smith 1987, Hengeveld 1993).

Eurasian collared-doves likely are not having a negative impact on mourning doves in

this region due to their low numbers (>10:1 ratio of mourning doves to collared-doves in all sites where collared-doves occurred) and constrained distribution (only 4 of 12 study sites). Our results also indicate that the Eurasian collared-dove appears to have a more restricted nesting niche (mainly evergreen trees) than that of mourning doves, further reducing the potential for direct competition. Duncan (2004) used Audubon Christmas Bird Count data to assess mourning dove population trends before and after the Eurasian collared-dove invasion in northwest Florida and coastal counties in Alabama. No evidence was found that Eurasian collared-dove had a deleterious effect on mourning dove populations.   Orr and Hayslette (2007) analyzed the North American Breeding Bird Survey and Christmas Bird Count data in Florida and suggested that Eurasian collared-doves impacts on mourning dove populations may be less severe than biologists originally indicated (Romagosa 2002). Their study suggested that changes in mourning dove populations are due to ecological factors other than Eurasian collared-doves.

MANAGEMENT IMPLICATIONS

Results from the CCS will continue to indicate a downward trend if resident doves are becoming an increasing fraction of the mourning dove population and the overall population is stationary or even moderately increasing. Currently, CCS routes do not contain urban areas, and thus do not account for the fraction of the mourning dove population living in urban settings (Dolton 1993). It would be useful to develop standardized methods to census mourning doves in urban and rural areas, as both fractions of the population need to be monitored to accurately assess population viability. This standardization would allow wildlife managers to discover how populations are fluctuating in all habitat types, whether they are highly developed or not. We recommend our survey technique as a repeatable method to assess relative abundance of mourning doves in urban areas.

Wildlife managers do not have immediate concerns about negative effects of Eurasioan collared-doves on mourning dove populations in southern Illinois. However, if Eurasian collared-doves follow the longterm trends of many other non-native bird species, such as the rock dove (*Columbia livia*), European Starling (*Sturnus vulgaris*) , and house sparrow, and increase to high densities in urban areas, they may have a negative effect on mourning doves. The Eurasian collared-dove has characteristics of a potentially successful invader (Ehrlich 1986, Pimentel et al. 2000) and needs to be closely monitored.

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Table 6. Population size, population density, housing density, and land area of 12 study sites in Williamson and Franklin counties in southern Illinois, USA, that were sampled for relative densities of mourning doves (*Zenaida macroura*) and Eurasian collared-doves (*Streptopelia decaocto*) during 2007-09.

County	Site	Population Size	Population Density (people/km^2)	Housing Density (homes/km^2)	Land Area (km^2)
Williamson	Marion	16,035	482.6	227.4	33.23
	Herrin	11,298	532.0	244.9	21.24
	Carterville	4,616	409.7	185.8	11.27
	Johnston City	3,557	704.3	345.5	5.05
	Cambria	1,330	374.8	182.9	3.5
	Pittsburg	575	106.2	45.4	5.41
	Freeman Spur	273	263.5	118.7	1.04
	Colp	224	617.8	308.9	0.36
	Rural Pittsburg	158	18.4	7.3	8.64
Franklin	West Frankfort	12,949	666.2	488.0	12.3
	Zeigler	1,669	749.3	363.2	2.23
	Rural Zeigler	121	20.9	9.1	5.80

Table 7. Home-range size of male and female mourning doves in urban areas in southern Illinois, 2007-2009. Estimates calculated by the minimum convex polygon method.

Minimum Number of Locations	Sex	Home-range Size (ha)		
		n	Mean	SE
≥ 5	Female	17	11.12	3.63
	Male	22	10.51	5.38
≥ 10	Female	13	14.13	4.44
	Male	13	15.81	8.90
≥ 15	Female	12	15.05	4.72
	Male	8	23.86	13.94
≥ 20	Female	10	14.92	5.67
	Male	6	11.76	4.67

Table 8. Trees containing nests of mourning doves (*Zenaida macroura*) in southern Illinois, 2008.

Common Name	Scientific Name	Nests (*n*)	Percentage
American elm	*Ulmus americana L.*	1	2.2
Bald cypress	*Taxodium distichum* (*L.*) *Rich.*	1	2.2
Black locust	*Robinia pseudoacacia L.*	1	2.2
Box elder	*Acer negundo L.*	6	13.0
Colorado spruce	*Picea pungens*	2	4.3
Crabapple spp.	*Malus* spp.	3	6.5
Japanese maple	*Acer palmatuni*	1	2.2
Landscape holly	*Ilex x altenuata'Fosteri'*	1	2.2
Lily magnolia	*Magnolia liliiflora*	3	6.5
Norway spruce	*Picea abies (L.) Karst*	1	2.2
Red cedar	*Juniperus virginiana L.*	3	6.5
Red maple	*Acer rubrum L.*	2	4.3
River birch	*Betula nigra*	1	2.2
Shingle oak	*Quercus imbricaria*	1	2.2
Shortleaf pine	*Pinus echinata Mill*	3	6.5
Silver maple	*Acer saccharinum L.*	2	4.3
Sweet gum	*Liquidambar styraciflua L.*	5	11.0
Tulip tree	*Liriodendron tulipifera L.*	1	2.2
White mulberry	*Morus alba L.*	2	4.3

Table 8. Continued.

Common Name	Scientific Name	Nests (*n*)	Percentage
White oak	*Quercus alba L.*	2	4.3
White pine	*Pinus strobus L.*	3	6.5
House column		1	2.2
Total nests		46	100.0

Table 9. Trees containing nests of mourning doves and paired random trees sampled in urban sites in southern Illinois, 2009.

Species of Tree	Scientific Name	n nests	n random trees
Bald cypress	*Taxodium distichum L.*	1	0
Black locust	*Robinia pseudoacacia L.*	1	1
Black walnut	*Juglans nigra L.*	2	1
Box elder	*Acer negundo L.*	5	1
Bradford pear	*Pyrus calleryana*	2	2
Colorado spruce	*Picea pungens*	1	0
Cottonwood	*Populus deltoides*	1	0
Crabapple spp.	*Malus spp.*	2	0
Eastern redcedar	*Juniperus virginiana L.*	4	5
Gingko biloba	*Gingko biloba*	1	0
Hackberry	*Celtis occidentalis*	1	0
Japanese maple	*Acer palmatuni*	1	2
Mimosa	*Albizia julibrissin Durz.*	1	1
Norway spruce	*Picea abies L.*	1	0
Post oak	*Quercus stellata*	1	1
Red bud	*Cercis canadensis*	1	0
Red maple	*Acer rubrum L.*	1	7
Red mulberry	*Morus rubra*	1	0
Red oak	*Quercus rubra L.*	3	2

Table 9. Continued.

Species of Tree	Scientific Name	n nests	n random trees
River birch	*Betula nigra L.*	1	1
Shingle oak	*Quercus imbricaria Michx.*	2	0
Shortleaf pine	*Pinus echinata Mill.*	1	0
Silver maple	*Acer saccharinum*	12	6
Sugar maple	*Acer saccharum*	1	5
Sweetgum	*Liquidambar styraciflua L.*	13	13
Sycamore	*Platanus occidentalis*	1	0
Tulip tree	*Liriodendron tulipifera L.*	2	3
Weeping cherry	*Prunus subhirtella var. pendula*	1	0
White ash	*Fraxinus americana L.*	4	0
White oak	*Quercus alba*	2	1
White pine	*Pinus strobus L.*	12	9
Total nests		83	61[a]

[a] Other random trees sampled included Virginia pine (*Pinus virginiana*; $n = 2$), loblolly pine (*Pinus taeda*; 1), American holly (*Ilex opaca*; 3), pin oak (*Quercus palustris*; 4), green ash (*Fraxinus pennsylvanicus*; 3), flowering dogwood (*Cornus florida*; 1), white spruce (*Picea glauca*; 1).

Table 10. Characteristics of nest trees of mourning doves (*Zenaida macroura*) and paired random trees (*n* = 76) sampled during the 2009 breeding season in southern Illinois in urban areas.

Characteristic	Nest Trees		Random Trees	
	Mean	SD	Mean	SD
Tree height (m)	14.9	8.2	10.5	5.3
DBH (cm)	51.0	23.8	42.8	21.6
Distance to building (m)	8.4	6.0	8.3	7.5
Distance to road (m)	10.0	10.2	11.5	10.4

Table 11. Overall summary of mourning dove (*Zenaida macroura*) banding in urban and rural sites in southern Illinois, USA, 2007-09.

Site	Year	After-hatching Year	Hatching Year	Males	Females	Unknown
Urban	2007	129	24	75	48	30
Urban	2008	218	39	156	56	45
Urban	2009	44	4	24	20	4
Urban	Total	391	67	255	124	79
Rural	2007	57	10	35	18	13
Rural	2008	87	14	71	13	14
Rural	Total	144	24	106	31	27

Table 12. Capture summary of mourning doves (*Zenaida macroura*) at individual urban sites in southern Illinois, USA, 2007-09.

Year	Town	After-hatching year	Hatching Year	Males	Females	UK
2007	Carterville	14	1	9	5	1
	Herrin	34	6	17	15	8
	Marion	35	6	23	9	9
	West Frankfurt	41	10	24	17	10
	Zeigler	5	1	2	2	2
	Totals	129	24	75	48	30
2008	Carterville	20	3	14	6	3
	Herrin	41	3	31	9	4
	Marion	61	14	40	19	16
	W. Frankfurt	59	8	39	17	11
	Zeigler	37	11	32	5	11
	Totals	218	39	156	56	45
2009	Carterville	10	0	5	5	0
	Herrin	12	0	6	6	0
	Marion	15	2	10	5	2
	W. Frankfort	7	2	3	4	2
	Totals	44	4	24	20	4

Table 13. Capture summary of mourning doves (*Zenaida macroura*) at individual rural sites in southern Illinois, USA, 2007-2008.

Year	Location	After-hatching Year	Hatching Year	Males	Females	UK
2007	Pittsburg	20	3	12	7	4
	Rural Pittsburg	21	1	14	6	2
	Rural Zeigler	16	6	10	5	7
	Totals	57	10	36	18	13
2008	Pittsburg	43	2	36	7	2
	Rural Pittsburg	16	1	14	2	1
	Rural Zeigler	28	11	21	4	11
	Totals	87	14	71	13	14

Table 14. After-hatching-year (AHY) and hatching-year (HY) mourning doves (*Zenaida macroura*) captured and leg-banded at rural and urban sites in southern Illinois, USA, and recovered in the USA, 2007-09.

Site	Age	Reward Band	Year	No. Banded	No. recovered 2007	2008	2009
Rural	AHY	No	2007	57	2	2	4
			2008	87	0	0	0
			2009	0	0	0	0
Rural	HY	No	2007	10	2	0	0
			2008	14	0	0	0
			2009	0	0	0	0
Urban	AHY	No	2007	129	7	14	4
			2008	218	0	0	0
			2009	44	0	0	0
Urban	HY	No	2007	24	4	2	3
			2008	39	0	0	0
			2009	4	0	0	0

Table 15. Harvest summary for returns of banded mourning doves in southern Illinois, USA, 2007-2009.

Date Harvested	Town Banded	Age	Sex	Harvest Location	How Obtained	Hunting Seasons Survived
1-Sep-07	Herrin	AHY	Female	Texas	Shot	1
1-Sep-07	Herrin	AHY	UK	Illinois	Shot	1
1-Sep-07	Marion	AHY	Female	Illinois	Shot	1
1-Sep-07	Pittsburg	HY	UK	Illinois	Shot	1
1-Sep-07	West Frankfort	AHY	Female	Mississippi	Shot	1
1-Sep-07	West Frankfort	AHY	Male	Illinois	Shot	1
1-Sep-07	West Frankfort	HY	UK	Illinois	Shot	1
2-Sep-07	Carterville	HY	UK	Illinois	Shot	1
2-Sep-07	Zeigler	AHY	UK	Illinois	Shot	1
7-Sep-07	Pittsburg	HY	UK	Illinois	Shot	1
9-Sep-07	Pittsburg	AHY	Female	Illinois	Shot	1
9-Sep-07	West Frankfort	AHY	Female	Illinois	Shot	1

Table 15. Continued.

Date Harvested	Town Banded	Age	Sex	Harvest Location	How Obtained	Hunting Seasons Survived
13-Sep-07	Marion	HY	UK	Illinois	Shot	1
20-Sep-07	West Frankfort	HY	UK	Illinois	Shot	1
24-Oct-07	Pittsburg	AHY	Male	Texas	Shot	1
1-Sep-08	Carterville	AHY	Female	Illinois	Shot	1
1-Sep-08	Marion	HY	Male	Illinois	Shot	1
1-Sep-08	West Frankfort	AHY	Male	Illinois	Shot	1
1-Sep-08	West Frankfort	HY	Male	Illinois	Shot	1
1-Sep-08	West Frankfort	AHY	Male	Illinois	Shot	1
1-Sep-08	West Frankfort	AHY	Male	Illinois	Shot	1
1-Sep-08	Zeigler	AHY	Male	Illinois	Shot	1
1-Sep-08	Zeigler	AHY	Male	Illinois	Shot	1
3-Sep-08	Pittsburg	AHY	Male	Illinois	Shot	1

Table 15. Continued.

Date Harvested	Town Banded	Age	Sex	Harvest Location	How Obtained	Hunting Seasons Survived
3-Sep-08	West Frankfort	AHY	Male	Illinois	Shot	1
5-Sep-08	Zeigler	AHY	Male	Illinois	Shot	2
7-Sep-08	Marion	AHY	Female	Illinois	Shot	1
7-Sep-08	Zeigler	AHY	Male	Illinois	Shot	1
11-Sep-08	Carterville	AHY	Male	Illinois	Shot	1
11-Sep-08	Pittsburg	AHY	Male	Illinois	Shot	1
13-Sep-08	Zeigler	AHY	Male	Illinois	Shot	1
15-Sep-08	West Frankfort	AHY	Female	Illinois	Shot	1
20-Sep-08	Zeigler	AHY	Male	Illinois	Shot	1
1-Sep-09	Rural Zeigler	AHY	Male	Illinois	Shot	2
5-Sep-09	Pittsburg	AHY	Female	Illinois	Shot	3
5-Sep-09	Rural Zeigler	AHY	Male	Illinois	Shot	2

Table 15. Continued.

Date Harvested	Town Banded	Age	Sex	Harvest Location	How Obtained	Hunting Seasons Survived
5-Sep-09	West Frankfort	HY	Female	Illinois	Shot	1
9-Sep-09	West Frankfort	HY	Female	Illinois	Shot	1
12-Sep-09	Rural Zeigler	AHY	Male	Illinois	Shot	2
16-Sep-09	Zeigler	AHY	Male	Illinois	Found Dead	2
1-Oct-09	Zeigler	AHY	Male	Illinois	Shot	2
4-Oct-09	Zeigler	AHY	Male	Illinois	Shot	1
6-Oct-09	Herrin	AHY	Male	Illinois	Found Dead	2
16-Oct-09	Herrin	HY	Male	Illinois	Shot	2

Table 16. Band returns from the 2009 hunting season for mourning doves (*Zenaida macroura*) captured in southern Illinois, USA, 2007-09.

Date Harvested	Town Banded	Age	Sex	Harvest Location	Source	Hunting Seasons Survived
1 Sep 2009	Rural Ziegler	AHY	male	Illinois	harvest	2
5 Sep 2009	Pittsburg	AHY	female	Illinois	harvest	3
5 Sep 2009	Rural Ziegler	AHY	male	Illinois	harvest	2
5 Sep 2009	West Frankfort	HY	female	Illinois	harvest	1
9 Sep 2009	West Frankfort	HY	female	Illinois	harvest	1
12 Sep 2009	Rural Ziegler	AHY	male	Illinois	harvest	2
16 Sep 2009	Ziegler	AHY	male	Illinois	found dead	2
1 Oct 2009	Ziegler	AHY	male	Illinois	harvest	2
4 Oct 2009	Ziegler	AHY	male	Illinois	harvest	1
6 Oct 2009	Herrin	AHY	male	Illinois	found dead	2
16 Oct 2009	Herrin	HY	male	Illinois	harvest	2

Table 17. Relative densities of doves (doves/km^2; MODO = mourning doves [*Zenaida macroura*]; ECDO = Eurasian collared doves [*Streptopelia decaocto*]) observed during visual surveys during 2007 in southern Illinois study sites. Density based on doves observed/transect area.

	March		June		September	
Study Site	MODO	ECDO	MODO	ECDO	MODO	ECDO
Carterville	44.4	0.0	105.5	0.0	26.0	0.0
Herrin	64.0	6.7	118.0	14.7	78.7	5.3
Marion	60.9	6.9	111.3	2.8	37.1	7.3
West Frankfort	35.6	0.9	112.7	3.1	60.7	5.3

Table 18. Relative densities of doves (doves/km^2; MODO = mourning doves [*Zenaida macroura*]; ECDO = Eurasian collared-doves[*Streptopelia decaocto*]) observed during visual surveys during 2008 in southern Illinois study sites. Density based on doves observed/transect area.

	March		June		September	
Study Site	MODO	ECDO	MODO	ECDO	MODO	ECDO
Cambria			51.9	0.0	33.0	0.0
Carterville	19.9	0.0	42.8	0.0	35.2	0.0
Colp			24.8	0.0	42.5	0.0
Freeman Spur			18.7	0.0	28.1	0.0
Herrin	41.3	4.0	92.7	4.7	48.7	5.3
Johnston City			93.7	0.0	50.8	0.0
Marion	37.6	1.8	62.3	5.0	50.4	5.0
Rural Pittsburg			18.5	0.0	18.5	0.0
Pittsburg			47.2	0.0	16.7	0.0
West Frankfort	40.9	2.2	84.9	1.3	55.0	2.2
Rural Zeigler			49.7	0.0	16.6	0.0
Zeigler			68.6	15.6	74.8	3.1

Table 19. Dove relative densities (doves/km^2; MODO = mourning doves[*Zenaida macroura*]; ECDO = Eurasian collared-doves [*Streptopelia decaocto*]) observed during visual surveys during 2009 in southern Illinois study sites. Density based on doves observed/transect area.

Study Site	March MODO	March ECDO	June MODO	June ECDO	September MODO	September ECDO
Cambria	18.8	0.0	14.2	0.0	42.5	0.0
Carterville	13.8	0.0	29.1	0.0	16.8	0.0
Colp	21.2	0.0	0.0	0.0	3.5	0.0
Freeman Spur	56.2	0.0	28.1	0.0	0.0	0.0
Herrin	54.0	3.3	61.3	4.7	18.7	5.3
Johnston City			45.2	0.0	41.8	0.0
Marion	46.7	3.2	63.2	4.6	48.5	2.3
Rural Pittsburg	18.5	0.0	11.1	0.0	40.7	0.0
Pittsburg	30.6	0.0	22.2	0.0	22.2	0.0
West Frankfort	43.6	0.9	59.9	2.2	22.5	2.2
Rural Zeigler	38.7	0.0	33.1	0.0	22.1	0.0
Zeigler	59.2	6.2	40.5	9.4	96.6	3.1

Table 20. Relative densities of mourning doves (MODO) and Eurasian collared-doves (ECDO) in urban ($n = 4$-5) and rural ($n = 7$) sites seen on driving transects in southern Illinois in 2007–2009.

| | | | Relative Density (birds/km^2) | | | | | |
| | | | March | | June | | September | |
Year	Site Type	Species	Mean	SE	Mean	SE	Mean	SE
2007	Rural	MODO						
		ECDO						
	Urban	MODO	51.2	6.8	111.9	2.6	50.6	11.8
		ECDO	3.6	1.8	5.2	3.3	4.5	1.6
2008	Rural	MODO			39.9	7.3	32.9	7.9
		ECDO			2.2	2.2	0.4	0.4
	Urban	MODO	34.9	5.1	75.3	9.9	48.0	3.4
		ECDO	2.0	0.8	2.2	1.1	2.5	1.1
2009	Rural	MODO	34.7	6.5	21.3	5.3	32.5	12.3
		ECDO	0.9	0.9	1.3	1.3	0.4	0.4
	Urban	MODO	39.5	8.8	51.7	6.5	29.7	6.5
		ECDO	1.9	0.8	2.3	1.0	2.0	1.0

Table 21. Trees containing nests of Eurasian collared-doves (*Streptopelia decaocto*) in southern Illinois, 2008.

Common Name	Scientific Name	Nests (*n*)
Bald cypress	*Taxodium distichum (L.)*	2
Black maple	*Acer nigrum Michx.*	1
Box elder	*Acer negundo L.*	1
Higan cherry	*Prunus subhirtella*	1
Pin oak	*Quercus palustris muench.*	1
Shingle oak	*Quercus imbricaria*	2
Silver maple	*Acer saccharinum L.*	2
Sugar maple	*Acer saccharinum L.*	1
Sweet gum	*Liquidambar styraciflua L.*	1
White pine	*Pinus strobus L.*	2
Ameren transformer		1
Utility pole		2
Total nests		17

Table 22. Characteristics of nest trees used by mourning doves (*Zenaida macroura*) and Eurasian collared-doves (*Streptopelia decaocto*)in urban areas in southern Illinois during the 2008 and 2009 breeding seasons.

Year	Characteristic	Mourning Dove		Eurasian Collared-dove	
		Mean	SD	Mean	SD
2008					
	Tree height (m)	13.7	8.1	16.5	7.6
	DBH (cm)	50.8	23.0	56.4	18.8
	Nest height (m)	4.0	3.2	7.0	3.6
	Crown density (%)	26.4	22.1	23.1	20.8
2009					
	Tree height (m)	14.9	8.2	9.1	2.6
	DBH (cm)	51.0	23.8	38.6	15.4
	Nest height (m)	4.4	2.8	4.5	2.4
	Crown density (%)	30.4	29.8	34.7	33.8
	Distance to building (m)	8.4	6.0	4.9	4.9
	Distance to road (m)	10.0	10.2	15.2	10.9

Table 23. Trees containing nests of Eurasian collared-doves (*Streptopelia decaocto*) and random paired trees in urban sites in southern Illinois, 2009.

Species	Scientific Name	*n* nests	*n* random
American holly	*Ilex opaca*	1	2
Eastern red cedar	*Juniperus virginiana L.*	3	1
Shortleaf pine	*Pinus echinata Mill.*	1	0
Sugar maple	*Acer saccharinum L.*	1	2
Sweet gum	*Liquidambar styraciflua L.*	1	1
White pine	*Pinus strobus L.*	2	0
Air conditioning unit		1	0
Total nests		10	[a]

[a] Other random trees sampled included red maple (*Acer rubrum*; *n* = 2), southern magnolia (*Magnolia grandiflora*; 1), and sycamore (*Plantanus occidentalis*; 1).
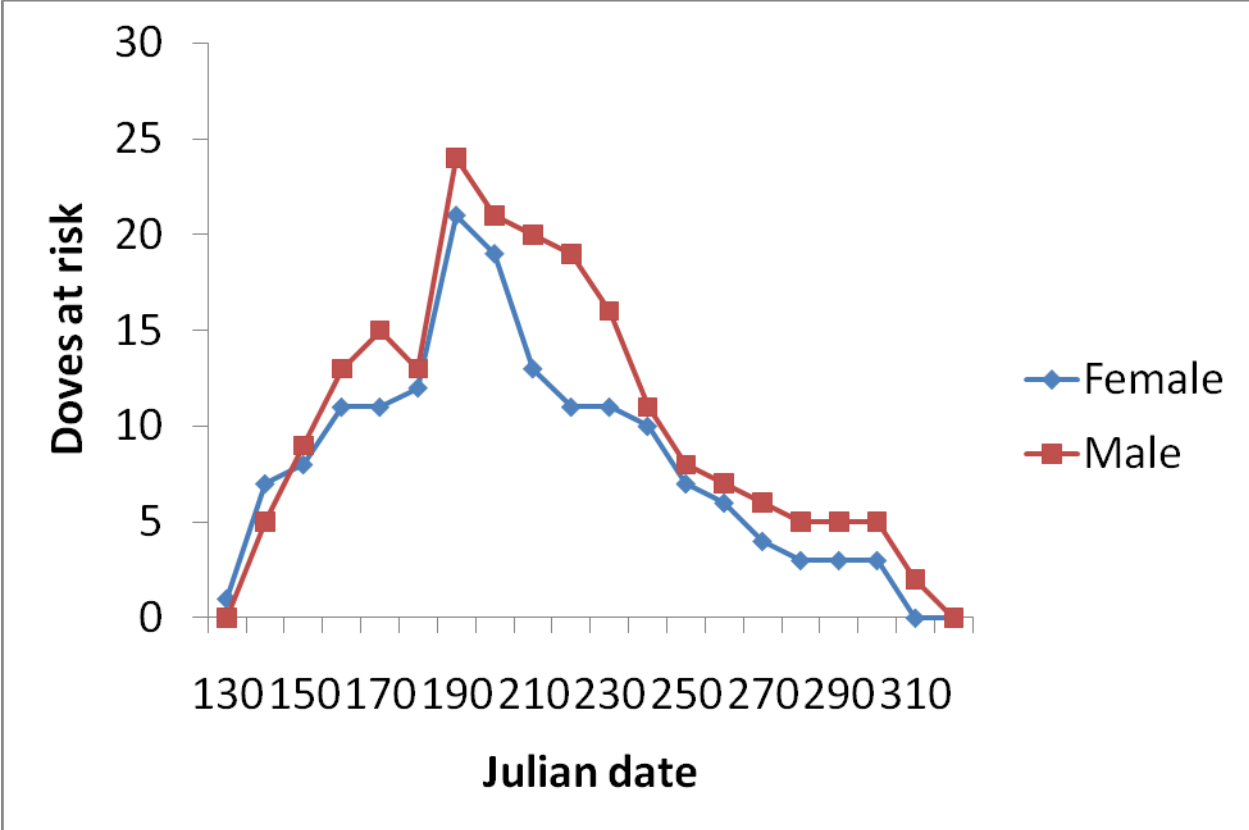
Figure 14. Number of telemetered mourning doves (*Zenaida macroura*) at risk during nesting season in urban areas in southern Illinois, May-November 2007-09.

Figure 15. Home ranges of mourning doves (*Zenaida macroura*; female: solid lines; male: dashed lines) in Carterville, Illinois in 2007-09.
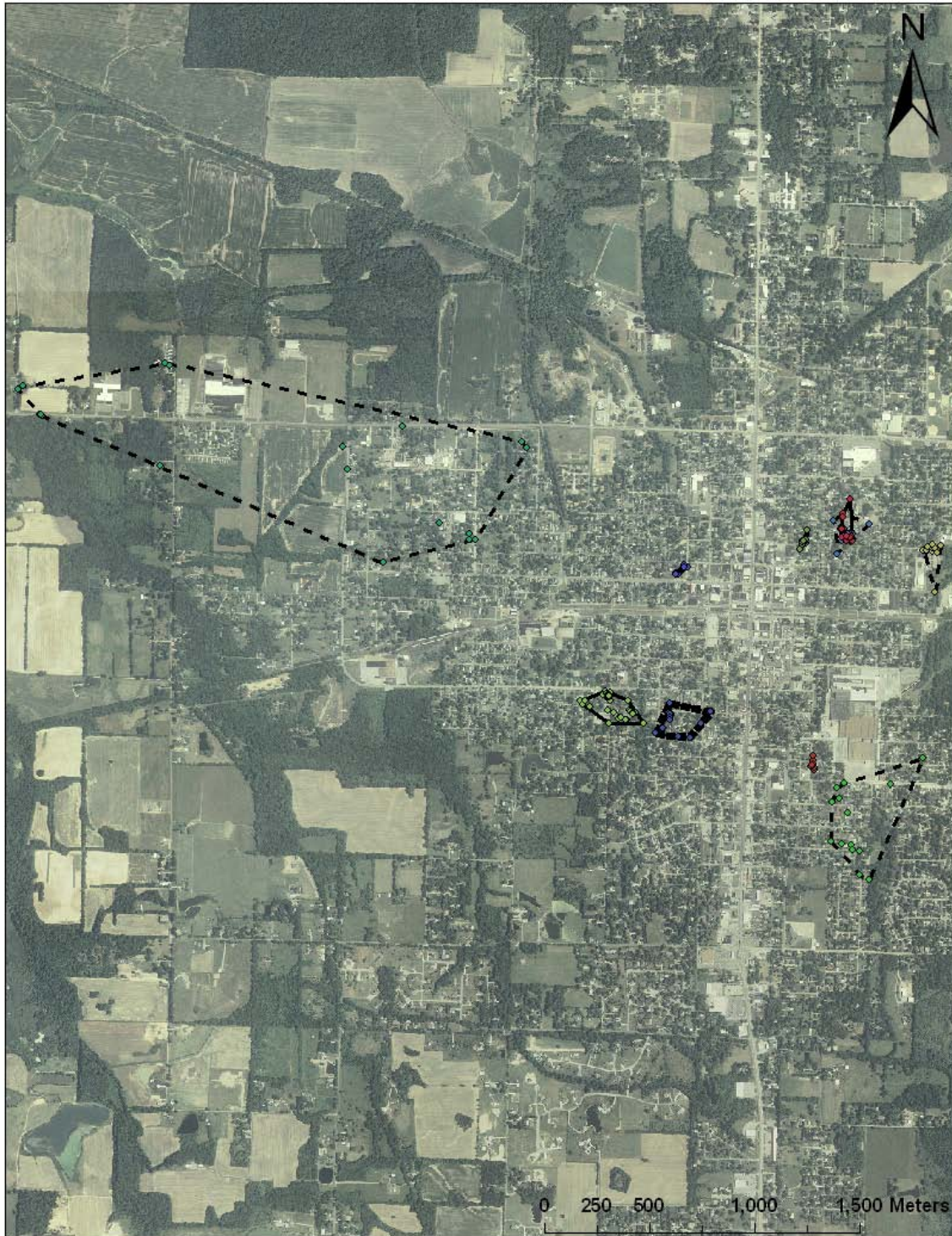
Figure 16. Home ranges of mourning doves (*Zenaida macroura*; female: solid lines; male: dashed lines) in Herrin, Illinois in 2007-09. The individual range with doubly-thickened dashed line represents the home range of a single Eurasian collared-dove (*Streptopelia decaocto*).
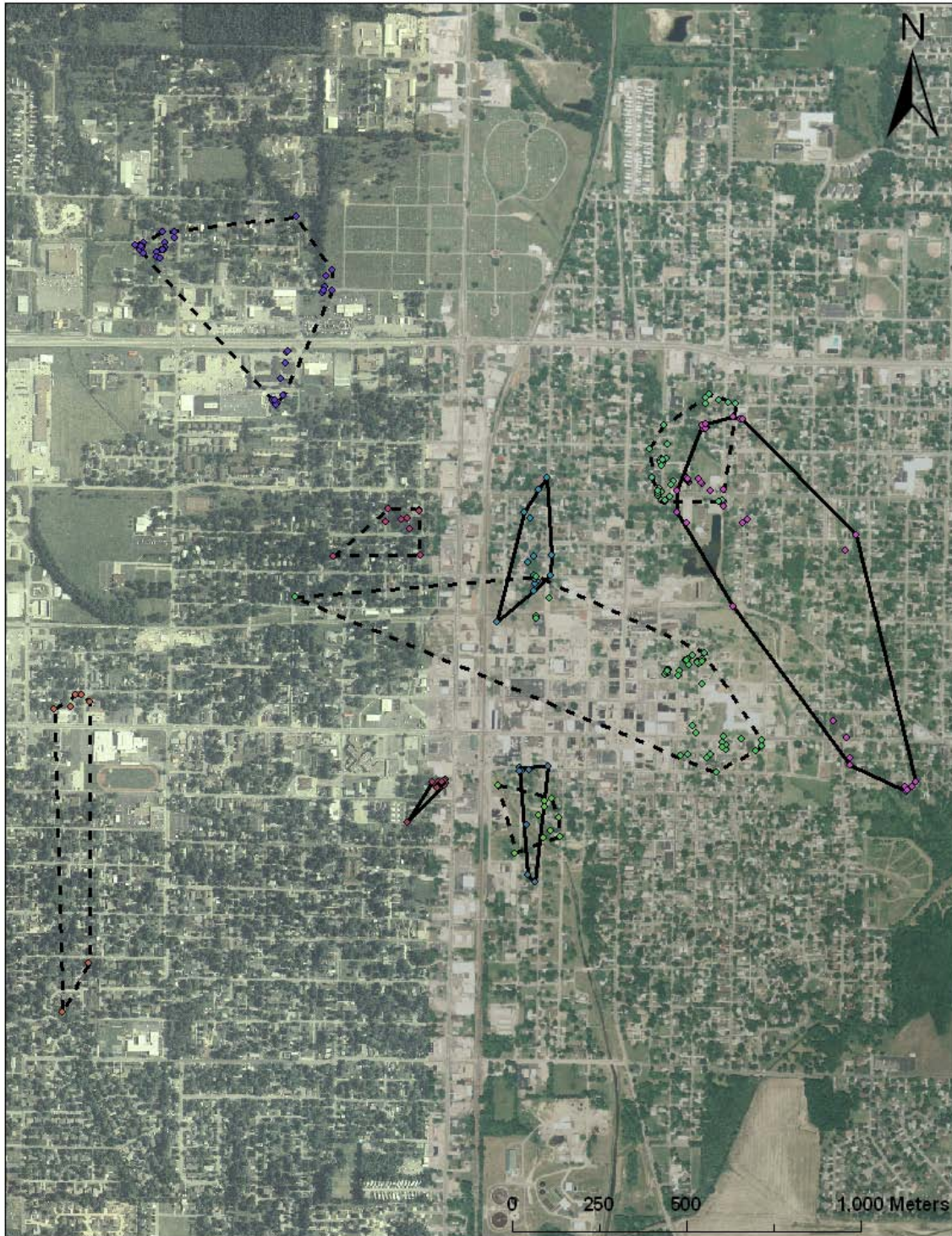
Figure 17. Home ranges of mourning doves (*Zenaida macroura*; female: solid lines; male: dashed lines) in Marion, Illinois in 2007-09.
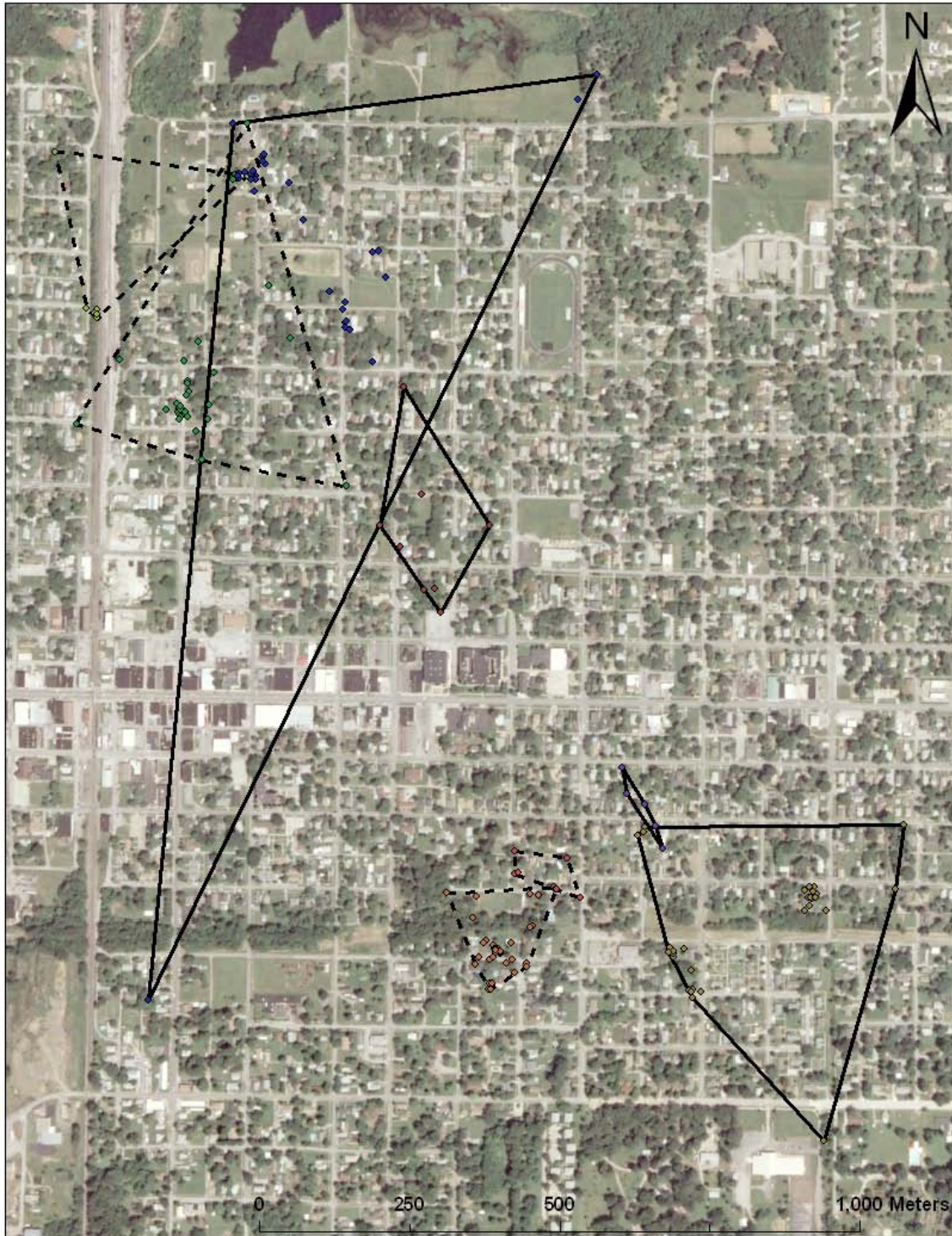
Figure 18. Home ranges of mourning doves (*Zenaida macroura*; female: solid lines; male: dashed lines) in West Frankfort, Illinois in 2007-09.
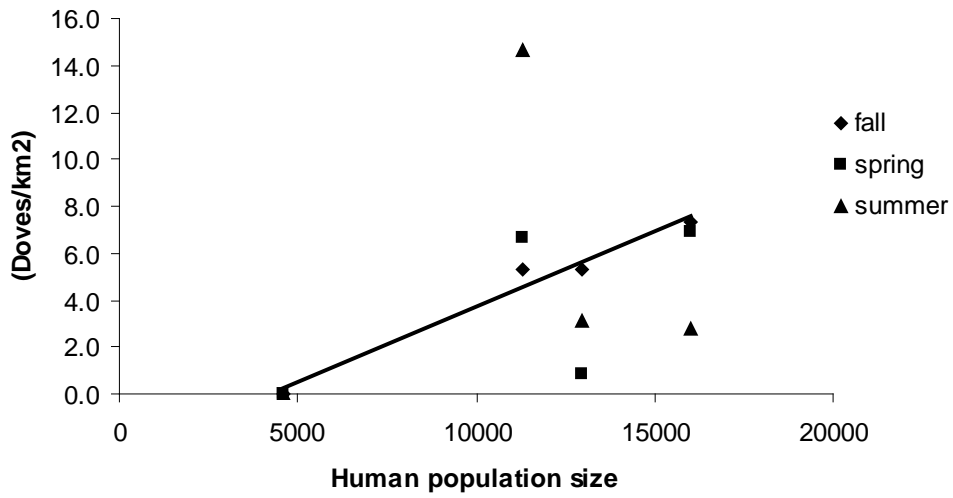
Figure 19. Relative density of Eurasian collared-doves (*Streptopelia decaocto*) in relationship to human population size in southern Illinois during 2007. Line represents positive relationship (*P* = 0.011) in fall.
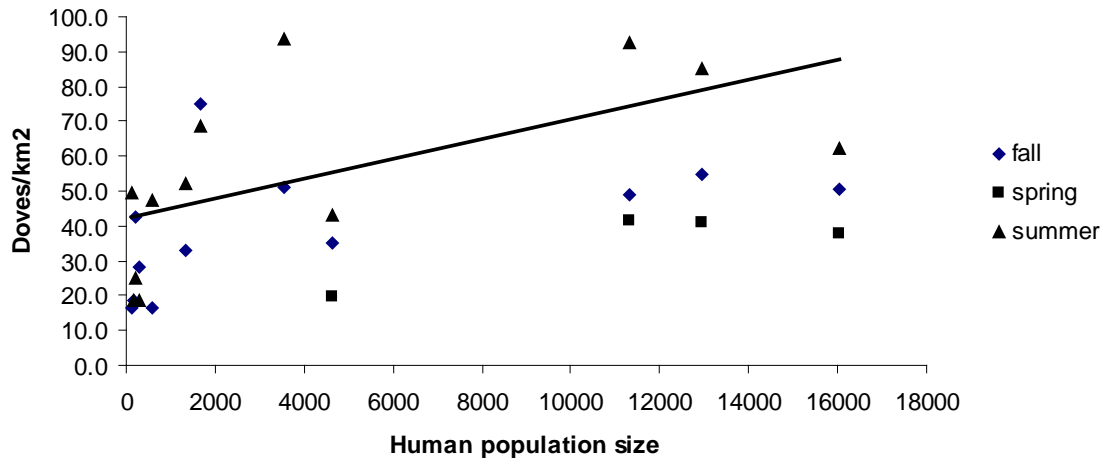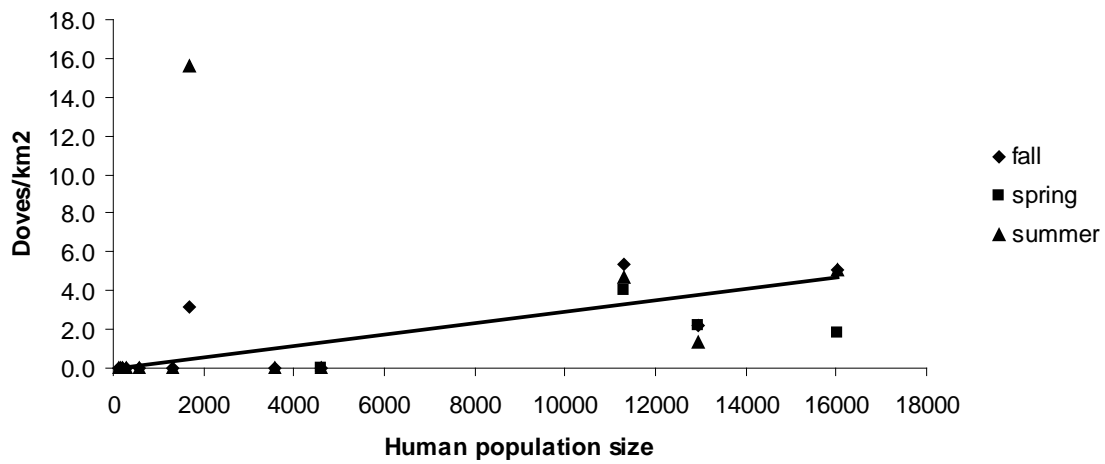
Figure 20. Relative density of mourning doves (*Zenaida macroura*) in relationship to human population size in southern Illinois during 2008. Line represents positive relationship ($P = 0.036$) in summer.
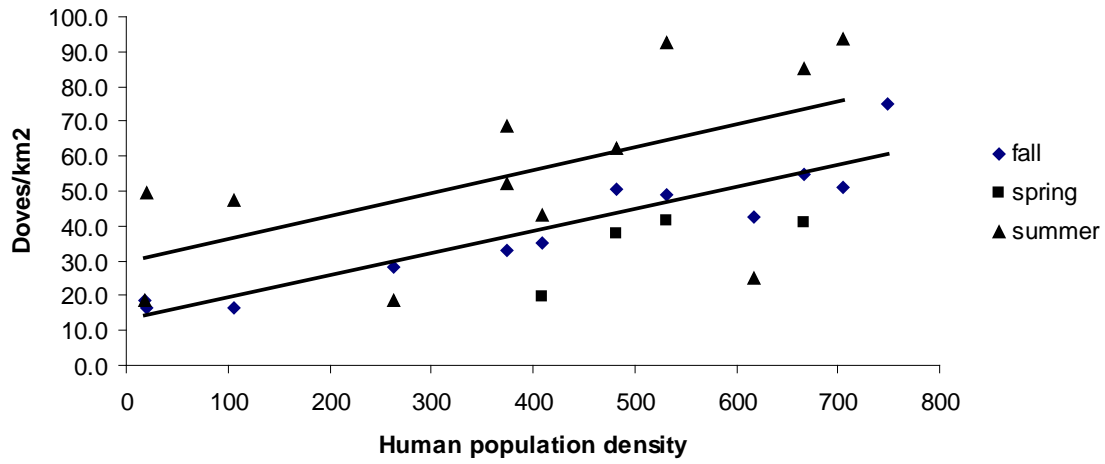
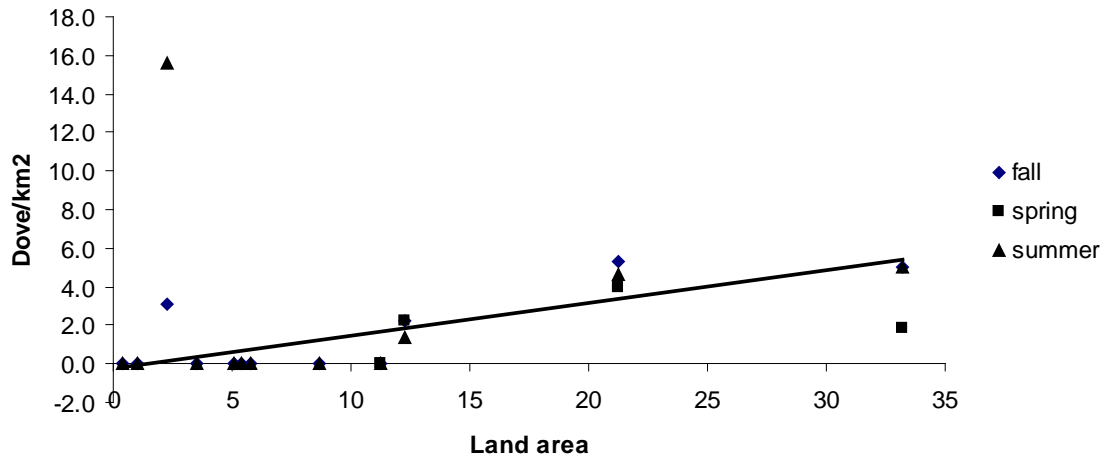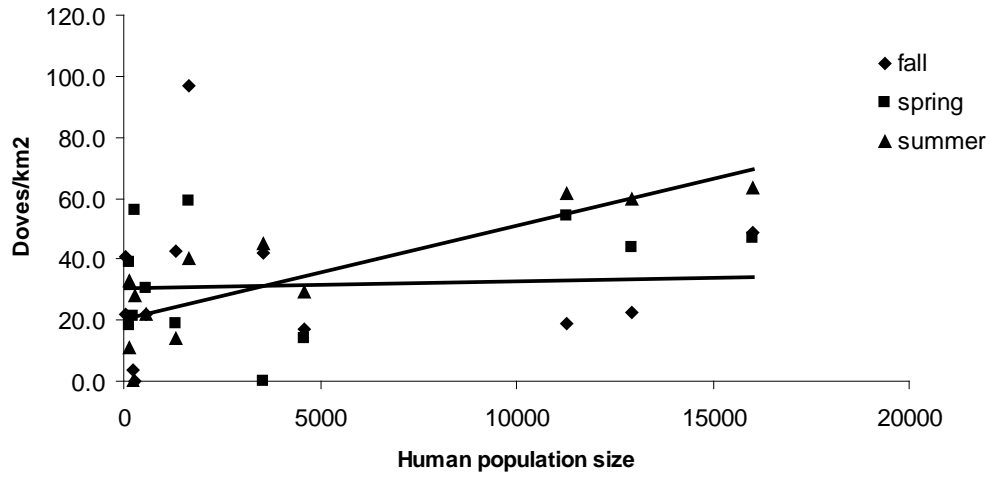Figure 21. Relative density of mourning doves (*Zenaida macroura*) in relationship to human population density in southern Illinois during 2008. Line represents positive relationships in summer (top: $P = 0.043$) and fall (bottom; $P < 0.001$).
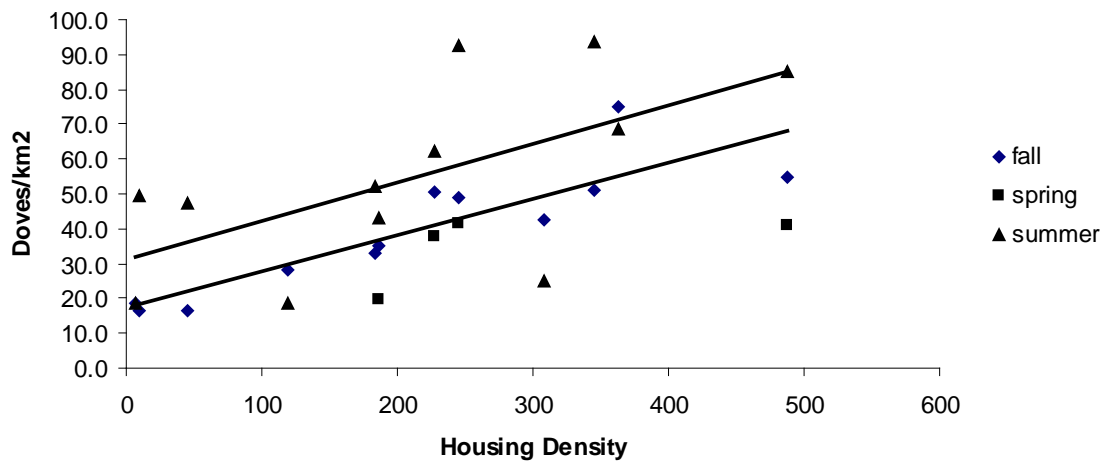
Figure 22. Relative density of mourning doves (*Zenaida macroura*) in relationship to housing density in southern Illinois during 2008. Lines represent positive relationships in summer (top; *P* = 0.031) and fall (bottom; *P* < 0.001).

Figure 23. Relative density of Eurasian collared-doves (*Streptopelia decaocto*) in relationship to human population size in southern Illinois during 2008. Line represents positive relationship in fall (*P* = 0.002).

Figure 24. Relative density of Eurasian collared-doves (*Streptopelia decaocto*) in relationship to urban land area (km^2) in southern Illinois during 2008. Line represents positive relationship in fall ($P = 0.003$).
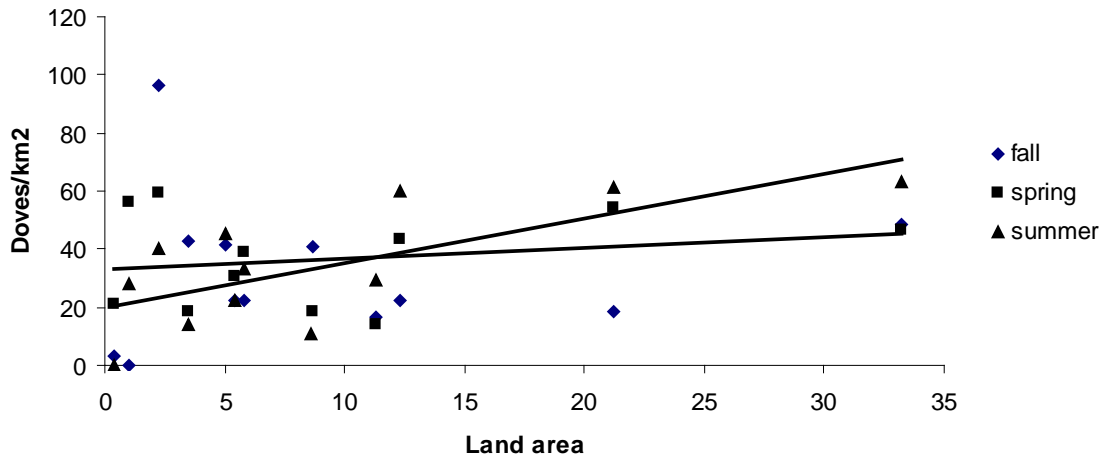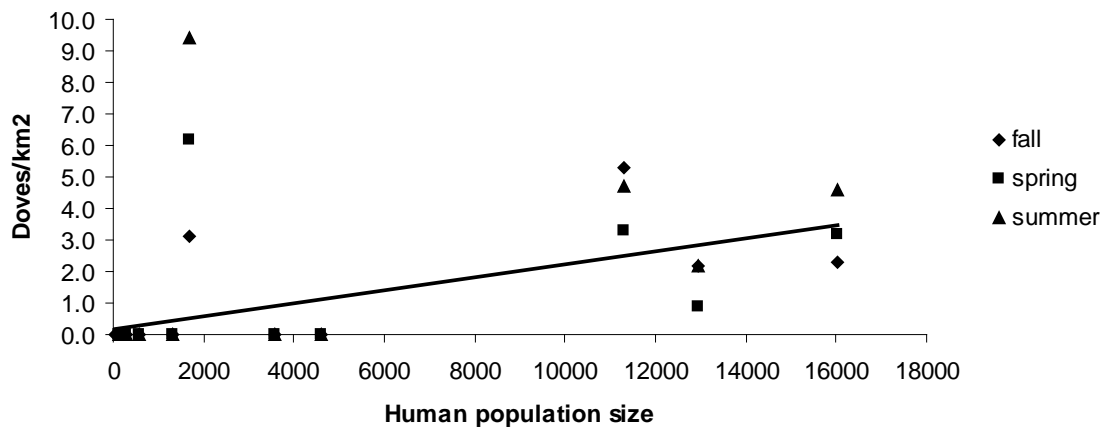
Figure 25. Relative density of mourning doves (*Zenaida macroura*) in relationship to human population size in southern Illinois during 2009. Line represents positive relationship in summer ($P < 0.001$). Flat line represents non-significant relationship in fall.

Figure 26. Relative density of mourning doves (*Zenaida macroura*) in relationship to urban land area (km^2) in southern Illinois during 2009. Line represents positive relationship in summer (P = 0.011). Flat line represents non-significant relationship in fall.

Figure 27. Relative density of Eurasian collared-doves (*Streptopelia decaocto*) in relationship to human population size in southern Illinois during 2009. Line represents positive relationship in fall ($P = 0.018$).
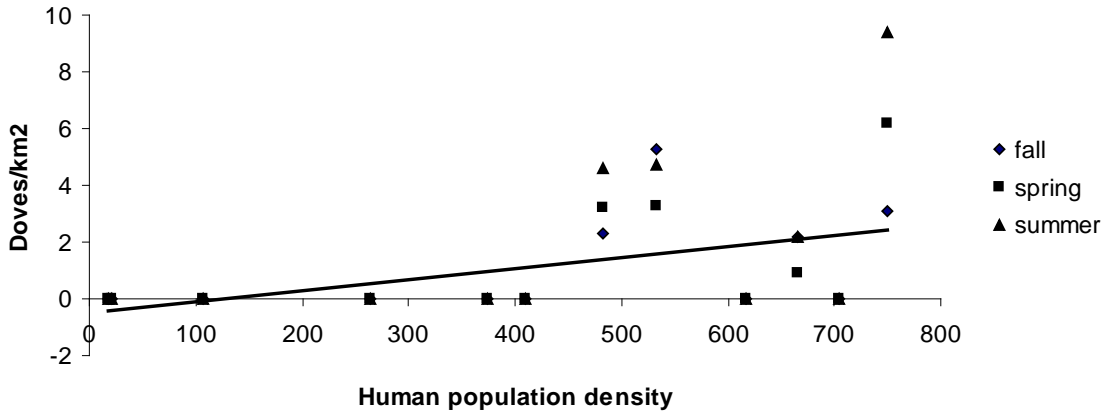
Figure 28. Relative density of Eurasian collared-doves (*Streptopelia decaocto*) in relationship to human population density in southern Illinois during 2009. Line represents positive relationship in spring ($P = 0.044$).
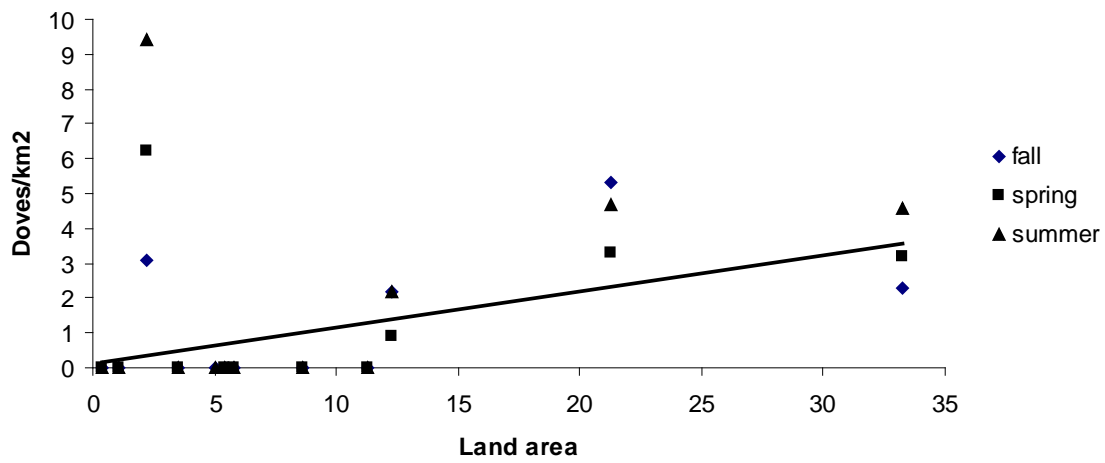
Figure 29. Relative density of Eurasian collared-doves (*Streptopelia decaocto*) in relationship to urban land area (km^2) in southern Illinois during 2009. Line represents positive relationship in spring (*P* = 0.055).

Appendix A. Osborne (2010) dissertation.

Appendix B. Rubert (2007) thesis.

Appendix C. Scharine (2008) thesis.

Appendix D. Stoelb (2009) thesis.

Appendices E, F. Bobwhite and swamp rabbit raw genetics data.