NORTHERN BOBWHITE WINTER ECOLOGY IN SOUTHERN NEW JERSEY

by

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ABSTRACT

Over the past 40 years, northern bobwhite (*Colinus virginianus*) populations have experienced range-wide declines. Population parameters have been gathered throughout most of the range but Mid-Atlantic populations have been largely ignored. In my study, I sought not only to gather data on winter habitat, movement, and selection, but also examine the relationship between these metrics and survival. I captured and radiotracked bobwhites between October and April, 2006-2007 and 2007-2008 non-breeding seasons on a 125km2 area of Cumberland County, New Jersey, USA. Chi-square analysis with Bonferroni confidence intervals revealed third order selection of Grassland and Scrub-Shrub habitat classes more often than expected while Agriculture and Other habitat classes were used less than in proportion to their availability. The relationship between coveys and Forest habitat appears to be more complex. Cox proportional hazard analysis revealed that risk of mortality was increased by use of Grassland habitat, low movement rates, and increased proximity to occupied buildings and barns. These results indicate that bobwhite coveys may be isolated in small fragments of usable habitat without sufficient travel corridors to maintain large enough winter home ranges to meet their biological needs. Additionally, my data suggests that predators may be forming a preferred search image on these fragmented habitats, thereby increasing mortality. It is possible bobwhite suffer from both low quantity and quality of habitat on the landscape. Increased interspersion of Woody cover on Grasslands as well as land management that increases Grassland and Scrub-Shrub habitat on the landscape level could increase bobwhite winter survival and ultimately aid in stabilizing the population in southern

New Jersey. House cat predation and window collisions are possible causative factors for the correlation between mortality risk and distance to occupied buildings and barns and their potential impacts on bobwhite populations should be investigated in future studies.

INTRODUCTION

The northern bobwhite (*Colinus virginianus*; hereafter bobwhite) is a widely distributed gamebird in eastern North American, historically found in early-successional habitats ranging from southeastern Canada to Guatemala and some Caribbean islands. However, bobwhites have experienced precipitous rangewide declines in abundance since the 1960's (Sauer et al 2008). These declines have been attributed to urban/suburban sprawl, "clean" agriculture, and habitat fragmentation (Brennan 1991, Church and Taylor 1992, Fies et al. 1992, Roseberry and Sudkamp 1998, Peterson et al. 2002, Williams et al. 2004). Although declines have occurred rangewide, Mid-Atlantic populations have experienced especially serious declines (Figure 1). For example, populations in New Jersey have declined 6.3%/year between 1966-2007 and 13.0%/year between 1980-2007 (Sauer et al. 2008) as compared to a rangewide decline of 3.0%/year and 3.9%/year over the same time periods.

According to the construct of the "abundant center" hypothesis (where populations are more robust at the core of their range: Andrewartha and Birch 1954, Hengeveld and Haeck 1982), as range-wide populations decline, peripheral populations are more likely to go extinct and geographic ranges will contract (Goel and Richter-Dyn 1974, Pimm et al. 1988, Tracy and George 1992, Lawton 1995, Mehlman 1997, Vucetich et al. 2000). This prediction is of concern for declining bobwhite along the northern edge of their range. Researching the causes of this decline may prove to be useful in understanding the demographics of low abundances before such phenomena begin to affect core areas of the bobwhite range. Despite this need, bobwhite research and management have historically focused on core populations in the Southeastern and Midwestern regions of the United States ignoring the once robust Mid-Atlantic region (Figure 1).

Through a meta-analysis population model, Sandercock et al. (2008) recently predicted that winter survival of adults was the most important variable affecting bobwhite population growth. While many studies have reported bobwhite winter survival, habitat selection, and behavior (e.g. Dixon et al. 1996, Williams et al. 2000, Sisson et al. 2000, Seckinger et al. 2008), few attempts have been made to link specific behavior and habitat metrics to survival (Williams et al. 2000, Flock 2006). Assuming Sandercock's prediction that winter survival is paramount, understanding factors (e.g. habitat use) that affect winter survival has the potential to clarify the causation of the bobwhite decline.

This research attempted to identify factors limiting the abundance of a northern peripheral population of bobwhite in southern New Jersey during winter by examining: 1) covey movement rates and home range sizes, 2) patterns of covey habitat selection at the 3rd order (Johnson 1980), 3) relationship between risk of mortality and factors such as percent habitat use, individual movement rates, and distance to barns and occupied buildings, and 4) factors influencing 4th order microhabitat selection of diurnal use sites and nocturnal roost sites. Understanding these relationships could ultimately lead to the development of land management practices that might enhance non-breeding survival in southern New Jersey bobwhite populations and stabilize or reverse local declining population trends.

METHODS

Study Area

I conducted my research in western and central Cumberland County in southern New Jersey, USA (Figure 2). The dominant habitats within the county were Forest (44.0%), Agriculture (e.g. soybeans, corn, winter wheat, tomatoes, lettuce, and cabbage: 13.8%), Scrub-Shrub (5.5%), and Grassland (3.2%). Other habitat categories not typically used by bobwhite made up 33.5% of the county. The most prevalent of these were wetlands and open water (17.8%), and urban, suburban, or industrial development (11.9%; NJDEP 2008). Dominant canopy species included: Virginia pine (*Pinus virginiana*), pitch pine (*Pinus rigida*), white oak (*Quercus alba*), southern red oak (*Quercus falcata*), black oak (Quercus velutina), and red maple (*Acer rubrum*) and an understory of blueberry (*Vaccinium* spp.), mountain laurel (*Kalmia latifolia*), and greenbriar (*Smilax* spp.). Common species in shrub-scrub habitat were autumn olive (*Elaeagnus umbellata*), multiflora rose (*Rosa multiflora*), blackberry (*Rubus alleghaniensis*), raspberry (*Rubus occidentalis*), sassafras (*Sassafras albidum*), sweetgum (*Liquidambar styraciflua*), and sumac (*Rhus* spp.). Grasses commonly found in study area include: broom sedge (*Andropogon virginicus*), Indian grass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), wavy hairgrass (*Deschampsia flexuosa*), orchard grass (*Dactylis glomerata*), foxtail (*Setaria* spp.), timothy (*Phleum pretense*), big bluestem (*Andropogon gerardi*), purple top (*Triodia flava*), and deer tongue grass (*Panicum clandestinum*).

Temperatures recorded at the nearby Millville Municipal Airport (MMA; 39°22’N, 75° 05’W) ranged from -17.8°C to 28.9°C during 1 October – 30 April, 2006-2007 season with an average temperature of 6.1°C (NOAA 2008). During the

2007-2008 season, temperatures ranged from -12.8°C to 31.7°C with an average temperature of 7.1°C (NOAA 2008). The 30 year average (1971-2000) temperature was 6.1°C (NOAA 2008). Total precipitation adjusted for water equivalence was 80.9 cm from 1 October 2006 to 30 April 2007 and 64.8 cm from 1 October 2007 to 30 April 2008 compared to a 30 year average (1971-2000) of 62.4 cm (NOAA 2008). Yearly snowfall totals were 9.7 cm during the 2006-2007 season and 22.8 cm in the 2007-2008 season (ONJSC 2008).

Within Cumberland County, I identified a study area of 125 km2 in west-central Cumberland County that potentially contained bobwhite (Figure 2). I used rapid habitat evaluation, road surveys, fall covey call surveys, and historical observations by landowners and members of New Jersey Division of Fish and Wildlife) to determine the extent of this area. The study area was comprised predominantly of private land, but also included a 1.5 km2 state Wildlife Management Area (WMA) that had mixed habitat and included managed grassland and savannah. In 2007, a prescribed burn occurred on 37 ha of the WMA's grassland and savannah habitats. The WMA was open for bobwhite hunting which occurred approximately between 10 November and 31 January. Only one private landowner allowed bobwhite hunting.

General Methods

I captured bobwhites from 1 October through 30 April using funnel traps (Stoddard 1931) baited with corn (Zea mays) and red millet (Sorghum sp.). Funnel traps were placed in locations with dense vegetation overhead to avoid detection by avian predators. I also captured bobwhite via night-lighting (Labisky 1968) when weather and roosting vegetation allowed. Following capture, all birds were aged, sexed, (Rosene 1969) fitted with an individually numbered aluminum leg band, and weighed to the nearest gram. If a bird weighed ≥150 g, I fitted it with a 6 g necklace-mounted radiocollar (Burger et al. 1995). Bobwhites weighing ≤150 g were not radio-collared to avoid stress from radiocollars weighing ≥5% of an individual's body mass (Samuel and Fuller 1994). If no other flight feathers were missing, I collected the first primary on each wing for future genetic and stable isotope analysis. I then released all bobwhites at their location of capture. The Institutional Animal Care and Use Committee at the University of Delaware (IACUC; Approval No.1142) approved the capture and handling procedures used in this study.

Telemetry

I located all bobwhites 4 to 7 times per week using handheld VHF and H-antennas between 1 October – 30 April, 2006 – 2008 until mortality, collar-loss, collar-failure, or end of study season. I obtained locations by homing (White and Garrott 1990) where I fully or partially encircled radiomarked individuals or coveys to within 25-50 m (Burger et al. 1995, Townsend et al. 2003, Terhune et al. 2006). Subsequent locations were never taken on the same day to avoid autocorrelation. I varied location times throughout the day to capture a full range of behavioral variation. I recorded bobwhite locations on aerial maps of 1 km2 quadrats overlaid with Universal Transverse Mercator (UTM, NAD83 Zone18) gridlines. I subsequently entered all location points into ArcMAP as UTM coordinates. If bobwhites were flushed, I used a Garmin etrex GPS unit to record the location's UTM coordinates to within 5 m.

To classify habitat types of all locations, I first used ArcMap to combine 2002 New Jersey land use/land cover data from Watershed Management Areas 15

(Great Egg Harbor), 16 (Cape May), and 17 (Maurice, Salem, and Cohansey; NJDEP 2008). These Watershed Management areas covered all of Cumberland County. I reclassified existing habitat categories as Forest, Grassland, Agriculture, Scrub-Shrub, or Other. The Forest category consisted of all patches of coniferous and deciduous forest with a canopy $\geq$7 m. Grasslands included early-successional old-field habitat, planted warm season grasses, and areas managed as grassy oak savannah. Agriculture was composed of row crops (primarily harvested corn and soybean fields as well as growing winter wheat), truck crops (vegetables and herbaceous ornamental plants), and food plots (standing corn and sorghum). Scrub-Shrub habitats were composed of hedgerows, late-successional brushy areas, treelines, and other odd areas with a canopy <7 m. The Other category included areas believed to be unsuitable for bobwhite such as urban and suburban development, wetlands, open water, and frequently mowed tree farms. In instances where habitat categories had changed since 2002, I reclassified these areas in ArcMap. In a few instances, habitat category changes required ground truthing with a Garmin etrex GPS unit prior to reclassification. I observed little change in habitat categories between years, however, to account for minor differences, separate classification files were used for habitat analyses in the 2006-2007 and 2007-2008 seasons.

Covey Home Range

A covey was defined as a group of 2 or more birds that were located together consecutively at least 7 times after October 1. When covey membership changed as a result of 2 coveys merging, the resulting group of birds was treated as a distinct covey. For the purpose of home range and covey movement calculations, covey locations only included observations where all radio marked covey members were tracked to the same location. Observations where coveys were broken up were excluded from home range and movement calculations.

Covey locations were imported into ArcMap. Using the HOME RANGE extension for ArcMap, I calculated a 95% adaptive kernel home range for each covey. I selected smoothing parameters using least squares cross validation. I only conducted analysis on coveys with ≥30 telemetry locations (Seaman et al. 1999). The number of locations used in the analysis per covey varied from 35 to 124. In addition to home range size, I also calculated mean daily movement for coveys. I used ArcMap to calculate the Euclidean distance between covey telemetry locations on consecutive days.

Habitat Selection

I calculated percent habitat use for each covey's telemetry locations. Percent available habitat was defined as the percent area of a given habitat type within a covey's home range. I used a modified Chi-squared goodness of fit test with Bonferroni confidence intervals (White and Garrett 1990 from Neu et al 1974) to examine resource selection of individual coveys at the third order (Johnson 1980). This modification allows for a conversion of a Design I radio-telemetry study (where animals are not uniquely identified and availability is defined at the population level, as Neu et al. 1974 originally proposed) to a Design III radio telemetry study (where both resource use and resource availability are identified for each radiomarked animal) (e.g. Broomhall et al. 2003, D'Eon and Serrouya 2005, Nicholson et al. 2006). This modified methodology allowed me to examine the relationship between habitat use and habitat availability when not all habitat types were present in the home range of each covey (White and Garrott 1990) and has been shown to produce similar results to compositional analysis (Manley et al. 2000). I applied Neu's methodology to test the null hypothesis that habitat was used in proportion to its availability. If the null was rejected, I placed 90% Bonferroni confidence intervals around the percent use value for each habitat type. If the expected percent habitat use value fell outside the 90% confidence intervals, that habitat was said to be used either more or less than in proportion to its availability. If a habitat was not present in a covey's homerange, we were not able to determine selection for that habitat type for that specific covey. Therefore the tally of habitat type selection would not always equal the total coveys observed.

Microhabitat Selection

I took microhabitat measurements at both diurnal flush sites and nocturnal roost sites. Coveys were flushed at varying times during daylight hours no more than once per week to obtain vegetation measurements. Microhabitat measurements were centered on the perceived center location of all flushed birds. Roosting coveys were located between an hour after sunset and an hour before sunrise no more than once per week. Nocturnal roost locations were marked with flagging tape at approximately 30 m in three cardinal directions to facilitate location of the roost location the following day and to avoid flushing roosting coveys. Roost locations were determined by the presence of a fecal pile. I also took microhabitat measurements at novel fecal piles found while radio tracking, provided that they appeared recent. For this analysis, I also included fecal piles located in a pilot study during January 2006 – April 2006.

At every flush or roost site, I recorded the general habitat type that the measurements were taken in (i.e. Grassland, Forest, etc.). I estimated relative cover percentages of forbs, cool season grass, litter, bare ground, and woody vegetation within a 50x50 cm sampling Daubenmire frame (Daubenmire 1959) at the center of each nocturnal roost and flush site and at 3.5 m from the center point in 4 cardinal directions. I measured vegetation height (excluding woody plants >2 m tall) at center points and at 3.5 m in all cardinal directions. Next, I placed a visual obstruction pole (Robel et al. 1970) at the center of all flush and roost sites and measured the visual obstruction of vegetation from 3.5 m away in each cardinal direction. The pole was divided into 0.1 m strata. I recorded the lowermost strata dividing line that was ≥50% visible. Paired random points were selected at a random distance and direction within 100 m of the flush or roost point. All paired random points were kept within the same habitat type as their paired point. I measured paired random points using the same methodology as roost and flush points except that vegetation height and ground cover measurements were not taken at center points. I compared the averages of ground cover percentages, vegetation heights, and visual obstruction at flush or roost sites to their paired random averages with a paired t-test ($P \leq 0.10$, program SPSS).

Survival

Individual bobwhites were allowed to adjust to radiocollars for 7 days before being included in survival analysis to reduce radiocollar bias (Tsai et al. 1999). Bobwhites were censored because of unknown fate, collar loss, or survival beyond the end of the study season. If exact dates of collar loss or disappearance were unknown, the midpoint between the last unique location and the day the collar stopped moving or was not locatable was used as the censor date. In the first year of the study, I visually confirmed potential mortalities following 3 consecutive locations at the same point. In the second year, radiocollars contained a mortality sensor that doubled the transmitter's pulse rate after 12 hours of inactivity, allowing for more prompt investigation of mortality events. I recorded likely mortality causes as avian predation, mammalian predation, hunter harvest, study related mortality, unknown source, or other based on evidence present at the mortality site. When exact mortality dates were not know, I used the midpoint between the last day known alive and the date that the mortality was discovered as the mortality date. I used the program MICROMORT (Heisey and Fuller 1985) to calculate period survival rates during both non-breeding seasons using all bobwhites that survived past the 7-day censor period. For the sake of comparison to other studies, I adjusted each season's survival rate to a 6 month period using methods outlined in Sandercock et al. (2008) and averaged the resulting rates.

I used likelihood-ratio tests ($P \leq 0.10$) within Cox's proportional hazard models (Cox 1972) to test the null hypotheses that risk of individual mortality was not influenced by the main effect of the individual's distance to occupied buildings and barns or relative habitat use of five habitat classes (Grassland, Scrub-Shrub, Forest, Other, and Agriculture). I used ArcMap to calculate the percent relative habitat use and average Euclidean distance to the closest inhabited building or barn for individual bobwhites. Relative habitat use was defined as the percentage of times that an individual bobwhite was located in a given habitat category.

RESULTS

Forty-eight bobwhites were available for survival during the October 2006-April 2007 season. My analysis does not include 4 bobwhites that were removed because they did not survive past the 7-day censor period, a bobwhite that lost its collar during the censor period, and 2 bobwhites that died as a result of the study. In the October 2007-April 2008 season, 13 bobwhites were available for survival analysis. One bobwhite was not included in the analysis because it did not survive beyond the 7-day censor period. Period survival during the 2006-2007 non-breeding season was 0.2618 (SD = 0.0688) while during the 2007-2008 season it was 0.2429 (SD = 0.1146). Across years, mortalities of bobwhites available for survival analysis were attributed to avian predation (46%, n = 16), unknown source (17%, n = 6), unidentified mammal predation (17%, n = 6), house cat predation (14%, n = 5), window collision (3%, n = 1), and hunter harvest (3%, n = 1).

For covey home range, covey movement, and habitat use analysis, 3 coveys were removed because <30 locations were available for analysis. All of the removed coveys were relatively small and merged with other coveys early in the non-breeding season. The mean home range size of the 13 remaining coveys was 29.18 ha (SE = 4.85; Table 1). Mean daily movement for the 13 coveys was 157.78 m (SE = 15.75). At the individual level (n = 38), Cox proportional hazards analysis identified that the risk of mortality increased with decreased movement (Likelihood ratio test= 6.18 on 1 df, p=0.01).

The percentage of covey telemetry locations in Grassland was similar to percent area of Grasslands within home ranges (Figure 3). However, both greatly exceeded the total percentage of grassland present in Cumberland County. In Shrub-Scrub habitat, the percentage of locations was greater than average percent home range area and percent county area. Forested habitat percentages were similar in all 3 categories but were greater at the county level than for covey telemetry locations. Only an incidental percentage of covey locations occurred in the Other habitat category. A higher percentage of Other was present in home range areas, but this value was lower than the percent area present in the county as a whole. The percentage of locations in Agriculture was also low relative to both home range area and county area (Figure 3).

Chi-square analysis revealed that selection occurred in all coveys ($P < 0.10$). Comparison of expected percent use to actual percent use bounded by 90% Bonferroni confidence intervals revealed that, overall, the number of coveys located more frequently than expected was greatest in Grassland and Scrub-Shrub habitats (Figure 4) and the number of coveys located less frequently than expected was greatest in Other and Agriculture habitat categories. However, Chi-square analysis also revealed differences in the patterns of habitat selection among coveys. Two coveys used Forest more than expected and Grassland less than expected (Figure 4). Of the 5 habitat categories tested against individual mortality, only increased use of Grassland was related to increased risk of mortality ($n = 48$, Likelihood ratio test= 2.79 on 1 df, $p=0.10$). Risk of mortality increased significantly with decreased distance from occupied buildings and barns ($n = 61$, Likelihood ratio test= 3.22 on 1 df, $p=0.07$).

Covey roost sites in grassland habitat had less bare ground, more woody cover, greater vegetation height, and greater visual obstruction readings than at random (Table 2). However, covey roost sites in forest habitat did not differ significantly from paired random forest points in any of the measured categories (Table 2). Grassland diurnal flush sites had taller vegetation and higher visual obstruction than random paired points (Table 3). Forest flush sites also had higher vegetation than paired random forest points (Table 3). Though not significant, forest diurnal flush sites also had greater visual obscurity than paired random points (Table 3).

DISCUSSION

Recently, Sandercock et al. (2008), in creating a meta-analysis population model of northern bobwhite, found that winter survival was one of the most influential demographic parameters. Because New Jersey bobwhite populations have been declining at an alarming rate, Sandercock et al.'s (2008) findings may provide a substantive explanation for this decline. My estimated winter survival rates, when adjusted for a six-month period to correspond to Sandercock et al.'s (2008) model (0.30), were approximately average for recent bobwhite studies (median = 0.26, Figure 5). Because Sandercock et al. (2008) predicted that a winter survival rate of 0.47 was necessary for a stable population, New Jersey populations would be expected to be declining at a similar rate to the range-wide average. This finding is initially surprising when considering the 13.0%/year declines in New Jersey shown by the Breeding Bird Survey (BBS, 1980-2007) as compared to those across the bobwhite range (3.9%/year; Sauer et al. 2008). Several factors may account for this disparity between survival rates and continuing statewide declines. First, my non-random selection of a study area, where bobwhite density was relatively high, may not have been representative of bobwhite elsewhere in the state. Therefore there is a strong possibility that BBS trends are picking up local extinctions at a landscape scale, whereas my investigation supported a more robust local population.

Second, another explanation for this discrepancy is the limited timeframe of my study. There was little snowfall in southern New Jersey during my two study seasons and what snow there was did not persist on the ground for more than a few days at a time. In the northern portion of their range, bobwhites are known to experience increased mortality from starvation and exposure during severe winter weather events (Leopold 1937, Guthery et al. 2000). Higher rates of mortality may occur in New Jersey during winters with more snowfall and longer durations of snow cover persistence and my study did not capture this type of event. However, because bobwhite populations in New Jersey have declined nearly every year since 1980 (Sauer et al. 2007), such a pattern is inconsistent with the rationale that the winters I measured were less severe than on average.

The third and most likely explanation for continuing bobwhite declines, despite approximately average winter survival, is that other parameters affecting population growth are equally or perhaps more important in causing bobwhite declines in southern New Jersey. Roseberry and Klimstra (1984) documented a negative correlation between early winter population density and overwinter survival. Thus, if bobwhite densities are consistently low at the beginning of the non-breeding season because of deficiencies in population parameters occurring during the breeding season, bobwhites should exhibit higher winter survival.

The average covey home range size over the entire winter in my study (29.18 ha, range 5.05ha to 54.21ha) well exceeded reports by Roseberry and Klimstra (1984) that home ranges were typically smaller than 10ha in Illinois. Covey home range sizes in southern New Jersey were more similar to those reported by Madison et al. (40.6 ± 5.0 and 42.7 ± 4.7; 2000) in Kansas and Bell et al. (18.4 - 58.4; 1985) in Louisiana. Both of these studies concluded that poor habitat quality was the factor responsible for their large covey home range sizes (Madison et al. 2000; Bell et al. 1985). If this is the case in southern New Jersey, efforts to improve habitat quality as well as quantity may also be warranted. However, another hypothesis that could explain the relatively large home range sizes is that covey home ranges may be larger overall because of low covey density on the landscape. Sociobiological factors influencing covey distributions are not entirely understood (Ellis et al. 1969) but Stokes (1967) believed that covey calls functioned as a method of establishing the locations of other nearby coveys. This behavior was viewed by Roseberry and Klimstra (1984) as territorial. If bobwhite coveys are to some degree territorial, home ranges would be larger if uncontested by other coveys. Further investigation of the relationship between covey size and habitat quality is warranted before making habitat management decisions based on covey home range size alone.

Despite the large winter home ranges, the mean daily covey movement rate of 157.8 m/day (range: 49.2m/day to 195.3m/day) observed in this study was low relative to other studies: 390 m/day in Tenneseee (Yoho and Dimmick 1972); 242m/day in Illinois (Roseberry 1964); and 218-275m/day in Kansas (Madison et al. 2000, Williams et al. 2000). However, unlike the other studies listed, my study was conducted on a forest dominated landscape. In the study by Williams et al. (2000), decreased movement was also associated with increased use of woody vegetation (with study areas containing only 3-4% woody cover on cropland and rangeland ecosystems within Kansas). This contrasts starkly with the high percentage of forest and scrub-shrub habitat both in Cumberland County and in the home ranges of my observed coveys. High availability of woody cover on both the landscape and home range scale could have facilitated the low daily movement rates seen in this study by allowing bobwhites to move throughout their home range without necessitating relatively fast movements across open areas where they would be vulnerable to predation.

Interestingly, the positive correlation between lower movement within their home range and higher risk of mortality was unexpected, based on previous hypotheses that lower rates of covey movement would result in lower mortality from decreased vulnerability to predation and hunting (Scott and Klimstra 1954, Roseberry 1964, Williams et al. 2000). However, this paradox may have been caused by intense fragmentation of usable space by vast areas of agriculture, salt marsh, urban development and other seldom-utilized habitat types, effectively confining movement within their home range to small patches of suitable habitat. For example, the three coveys with mean daily movement rates <70m/day were found in areas that fit this description. These coveys also exhibited the smallest home ranges in my study (all were ~10ha). Coveys in small isolated patches of habitat would be especially vulnerable to localized changes in the availability of food resources and escape cover if their ability to move to another patch of suitable habitat was limited. Additionally, Roseberry (1979) noted that quail hunting is not a random searching process, as experienced hunters concentrate their efforts in habitat that quail use most often. This relationship is also likely for predators that form search images for available prey. Therefore, coveys relegated to isolated patches of habitat may face higher mortality from both hunting and predation. Consequently, increasing the amount of usable space on the landscape (Guthery et al. 2000, Williams et al. 2004) with connectivity between areas of usable space holds the most promise for minimizing the likelihood of local extinction events.

Traditionally, grassland and early successional Scrub-Shrub habitat has been seen as "good bobwhite habitat" (Edminster 1954, Roseberry and Klimstra 1984). Thus, the overall use of grassland and scrub-shrub habitats greater than or equal to their availability within home ranges was expected. However, individual use of grassland was correlated with an increased risk of mortality. Bobwhites are known to avoid open grasslands if woody escape cover is not nearby (Casey 1965), probably because of increased susceptibility to diurnal avian predators. Williams et al. (2000) found that wintering bobwhites experienced higher mortality associated with the use of pasture. In my study area, some of the grassland areas used by bobwhites contained tree lines, hedgerows, and other patches of woody vegetation, while others contained none. The use of fine scale habitat management to improve interspersion of early successional woody cover on open grasslands has the potential to improve bobwhite winter survival in southern New Jersey and reduce or eliminate the correlation between grassland use and mortality risk.

Bobwhite coveys in my study area had a mixed relationship with Forest habitat. Given that the use of Forest habitat was not significantly correlated with mortality risk and no clear trend existed in selection for the habitat (2 coveys used Forest more than expected, 5 equal to expected, and 5 less than expected), home ranges containing large amounts of forest habitat appear to be sufficient but not optimal during winter. Large areas of forested habitat on the landscape are probably more detrimental to bobwhite populations during the breeding season, when grassland becomes a more necessary component of home ranges as a result of breeding requirements. Nonetheless, Guthery (1999) postulated that beyond an unknown critical threshold, too much woody cover on a landscape will cause a “redundancy in edge and loss of usable space for bobwhites”. I believe this to be the case in southern New Jersey.

Interestingly, 2 of my coveys used Forest habitat more than expected, supporting an observation noted in eastern Maryland (Wilson and Vaughn 1944) that three out of 71 coveys spent most of their time in the forest. Anecdotally, locals have sometimes referred to “wood coveys,” indicating an occasional preference for this habitat type. The greater use of forest habitat by some coveys may represent a facultative response to low food availability or herbaceous cover in grassland habitat. The summer preceding my second study season (2007-2008) was very dry (19.7cm of rainfall compared to 48.6cm in the previous year and an average of 47.3cm from 1971-2000 (NOAA 2008)) and caused some weedy forb species to die before flowering and setting seed. However, both southern red oaks and white oaks produced large mast crops. Errington (1936) observed bobwhites feeding on squirrel-opened acorns in wooded areas following a dry summer with poor seed production by weedy herbaceous plants. Partially eaten acorns that appeared to have been opened by rodents were found at many flush locations and fully eaten acorns with identical marks were often found immediately adjacent to roost sites. Additionally, small pieces of acorn meat were found in the crops of several partially intact bobwhites that were recovered from mortality sites in the 2007-2008 season. Though it is probably not a major component of an optimal bobwhite home range, closed-canopy pine-hardwood forest appears to provide some level of food and cover in winters following extremely dry growing seasons.

Agriculture was used less than expected by most coveys and no coveys used it greater than expected. This is likely a reflection of the differences between the types of agriculture found in southern New Jersey versus other areas where bobwhite habitat use has been studied. Fields in which vegetables were grown were often completely devoid of vegetation for the majority of the non-breeding season. Likewise, conventional row-crops were often rotated with winter wheat, which provided little or no food or cover during the non-breeding season. Even in fields where this was not the case, rowcrops were almost never left standing along field edges and corners. One exception to this trend occurred during the 2006-2007 season on an intensively managed semi-wild game farm where a 1.4ha food plot of sorghum was left standing all winter. Locations of a single covey within that specific food plot accounted for 65% of all covey locations in agriculture. At present, the type of agriculture practiced in southern New Jersey appears to be almost entirely unsuitable for bobwhite coveys during winter.

As expected, the Other habitat category was used only incidentally by bobwhite coveys during the non-breeding season. However, under different management regimes, some cover types currently in the Other category could be made functionally available to bobwhites. Tree nurseries in particular show some promise as potential bobwhite habitat for several reasons. First, a decrease in the intensity of mowing schedules around large established trees could potentially decrease costs to nurseries while increasing the landscape-level availability of grassland habitat. Nurseries especially focused on large pines could be managed to mimic the savannahs and open woodlands that likely supported bobwhite populations in the past. Second, because of their large size and proximity to areas currently supporting bobwhite coveys, tree nurseries have the potential to rapidly increase local abundance of bobwhites in some areas with relatively small changes in management practices. Two large nurseries (97.3 ha and 432.4ha) were located immediately adjacent to several covey home ranges in both years.

Traditionally, bobwhite managers have viewed loss and fragmentation of usable space as the primary threat associated with increasing urban and suburban development. Supporting this, Flock (2006) found a negative relationship between human development and bobwhite survival during the breeding season. My data support his finding and suggest that the presence of occupied buildings and barns has a deleterious effect on bobwhite winter survival in addition to loss and fragmentation of usable space. The correlation between proximity to occupied buildings and increased risk of mortality has several potential explanations.

Friesen et al. (1995) found that diversity of forest-nesting neotropical migrant songbirds shared an inverse relationship with the number of houses surrounding forest fragment, independent of the fragment's size. They believed that high rates of cat predation or nest predation by gray squirrels may have played a role in locally decreasing songbird populations. Bock et al. (2002) observed a similar trend in abundances of small native rodents in grasslands adjacent to suburban areas. Barratt (1997) suggested that predation by house cats associated with homes in residential areas could significantly impact populations of small native fauna in relatively undisturbed adjacent natural land. This is consistent with Seckinger's (2008) assertion that "habitat quality for bobwhite may be influenced by factors at the spatial scale of the predator and not solely determined by vegetation structure and usable space."

It is likely that some of the housecat mortalities recorded during my study were caused by feral cats, however, on several occasions I observed bobwhite coveys being flushed by collared housecats. In one instance, a bobwhite radiocollar was recovered from inside a crawlspace of a private residence immediately adjacent to a mature housecat and a litter of kittens. The remains of at least two bobwhites were present in the crawlspace. As early as 1931, Stoddard asserted that housecats posed a serious threat to bobwhites of all ages and proposed licensing requirements for owners and fines if cats caused the deaths of "valuable bird life." Additionally, housecats that are fed by humans may pose a disproportionately large threat to wildlife, including bobwhites, as they are less constrained by prey availability than other predators and can exist at artificially high densities (Lepczyk et al 2003).

Window collisions are also a possible risk for bobwhites in close proximity to buildings. I observed one mortality event attributed to window collision during my study, a phenomenon which has been previously documented for bobwhites (Stoddard 1931, Veltri and Klem 2005). Stoddard (1931) documented bobwhite collisions with other anthropogenic structures such as telephone wires, fences, and white buildings and suggested that in aggregate they caused “considerable loss of life”. Although the frequency and significance of window collisions and similar collisions with anthropogenic structures is not known for bobwhites, it has been implicated as an important source of mortality impacting many bird species (Klem 1990). For example, collision with fences and power lines are known to be an important source of mortality affecting lesser prairie-chickens (*Tympanuchus pallidicinctus*), another grassland-associated galliform species (Wolfe et al. 2007).

Despite the 3rd order selection of habitat variables that may affect bobwhite fitness, it is also important to recognize the selection of 4th order habitat variables. For example, Klimstra and Ziccardi (1963) noted microhabitat properties such as slope aspect, drainage, vegetation height, and stem density, could be important in bobwhite covey selection of nocturnal roost sites to reduce thermoregulatory costs. They also noted a trend toward more frequent roosting in heavy cover in the northern portion of the bobwhite range. Supporting this, Hiller and Guthery (2005) speculated that in regions with roost sites below thermoneutral temperatures, microclimate should logically be an important selection criterion but reasoned that other factors like covey dynamics and risk of predation might have confounding effects on selection. The selection of grassland roost sites with higher visual obscurity, taller vegetation, more woody cover, and less bare ground supports Hiller and Guthery's (2005) hypothesis that coveys seek microclimates that improve thermoregulatory efficiency. This relationship could also explain the relatively high frequency with which coveys in my study area roosted in forest habitat. In diurnal flush locations, selection of points with greater vegetation height in both forests and grasslands and more visual obstruction in grasslands likely reflects a preference for areas with thicker overhead cover that decrease vulnerability to avian predation.

Overall, the data presented supports previous hypotheses about causes of bobwhite decline across their range (e.g. changes in agricultural practices, advancing succession of abandoned farms) and emphasizes the role of urban and suburban development as a threat to bobwhite populations. These threats are present range-wide to varying degrees but bobwhite populations in New Jersey appear to have declined disproportionately. The abundant center hypothesis provides a possible explanation for this pattern. Bobwhite populations at the northern edge of their geographic range are susceptible to high levels of winter mortality, resulting from severe winter storms and prolonged snow cover (Guthery et al. 2000). Aldo Leopold documented the contraction of the bobwhite's range in Wisconsin as a result of two successive severe winters (1937). Following such an event, bobwhites on a relatively well connected landscape can re-colonize areas where they were extirpated due to severe weather. However, when small populations exist in isolated patches of suitable habitat with low connectivity, the likelihood of local extirpation increases while the likelihood of re-colonization decreases. This phenomenon is not only of concern to northern parts of the bobwhite's range, but also to areas of the southern United States susceptible to severe drought. Biologists have noted that nest and subsequent chick survival are important factors in predicting population growth (Sandercock et al. 2008) and that catastrophic droughts can impact these parameters (Guthery et al. 2000). Therefore, southern populations have the potential to exhibit range border fluctuations similar to northern populations if numbers decline below a certain threshold. Given current predictions regarding climate change in the American South and Southwest, preserving connectivity of suitable bobwhite habitat could become even more important in maintaining the historic distribution of bobwhites into the future.

MANAGEMENT IMPLICATIONS

If bobwhite populations continue to decline at their present rate and the historical range continues to contract, I believe this study provides a cautionary tale for future bobwhite populations elsewhere in their range. Overall, bobwhites in my study area exhibited above average winter survival but home range size and habitat use patterns indicated that populations currently suffer from inadequate quantity, quality, and connectivity of habitat. According to modeling by Guthery et al. (2000), decreases in the amount of usable space on a landscape will increase the likelihood of extinction in bobwhite populations.

Practically, increasing usable space to the level suggested by Guthery et al. (2000) for a population in an extreme environment with a reasonable harvest (800-1600) would most likely require drastically increasing the proportion of early-successional habitat on the landscape. The high use proportions and low county-wide availability of Grassland and Scrub-Shrub habitat relative to their availability within home ranges indicates that these habitat types are particularly important to bobwhites in winter. Increasing the proportions and interspersion of these habitat types (e.g. implementation of Farm Bill Conservation Program 33) at the landscape level should result in an increase in usable space and increase winter survival.

Another recommendation to achieve this goal is to promote pine-oak savannahs through thinning and burning of existing forests. A model for this type of management already exists within my study area and could be looked to as a successful bobwhite management effort. A 37ha portion of the Buckshutem Wildlife Management Area is currently being managed as a pine-oak savannah and supported several coveys of bobwhites during my study. The creation of this savannah involved extensive thinning of dense timber stands, planting with native grasses, and burning on a 2-5 year basis. Similar open woodland or savannah habitat was probably common in some areas of eastern North America, including southern New Jersey, prior to European settlement (Lorimer 2001). Periodic burning by Native Americans would have maintained a patchwork of early successional habitats that supported a variety of grassland bird species including bobwhites (Hunter et al. 2001). One account by an early European colonist describes woodlands in eastern New Jersey as having tree densities of 10-30/acre (Whitney 1994). However, such elaborate management practices may be unnecessary if managing strictly for increased bobwhite abundance. Seckinger et al. (2008) documented a significant increase in bobwhite winter survival as a result of converting 33% of closed canopy forest to early successional herbaceous habitat on a 52% forested landscape.

Of particular concern in New Jersey bobwhite, as is the case in many parts of their range, is the dramatic increase in urban and suburban development that in turn is causing habitat loss and fragmentation. In addition, increasing urban and suburban development in areas near otherwise suitable habitat could lead to the creation of ecological traps. It is for this reason that I recommend future studies explore not only the causes but also the spatial relationship between distance to houses and increased mortality risk. A better understanding of this phenomenon will enable better prioritization of conservation efforts and increase managers' ability to mitigate negative effects on bobwhite populations.

Appendix A

FALL COVEY CALL COUNTS

In the first two years of covey call counts, listening points were located in areas known to contain bobwhite coveys or suspected to contain coveys based on habitat. Counts were conducted following methodology from (Wellendorf et al. 2004) but also included playing of previously recorded bobwhite covey calls. In the 2005 season, volunteers conducted 15 counts. Single coveys were detected in 2 counts. In 2 other counts, volunteers detected two coveys, however, subsequent trapping and radio-telemetry in these areas indicates that most likely these were just individual bobwhites from single coveys that were split up. In the 2006 season, volunteers detected single bobwhite coveys in 4 out of 21 attempts.

As a response to low detection rates, during the 2007 season, volunteers conducted covey call counts 30-60m from known, radio-marked coveys. Radio-marked coveys responded to callers in 9 out of 27 counts. Of these 9 responses, 5 were from a covey containing only two bobwhites and three were from coveys known to be split up, based on disjunct telemetry locations of individuals. The remaining response is believed to be from a covey that was split up based on an observation that the call heard did not come from the same direction as the radio-marked individuals in the covey. No coveys were known or suspected to be split up in any of the counts where no coveys were detected. Though not statistically testable, these data seem to indicate that morning covey calls serve mainly to re-unite coveys that are broken up during the night, or help small coveys locate other bobwhites. The low detection rates observed for larger coveys and coveys that had not broken up during the night indicate that this method is not useful as an index of abundance. In fact, it may prove somewhat hazardous to bobwhites. In several instances, the covey comprised of 2 birds did not merely call in response to recorded covey calls, but actually flew toward the caller. On 2 occasions, house cats also appeared to be attracted to the caller and approached to within 10 yards. In instances where bobwhites respond to the caller, this technique might expose bobwhites to additional predation risk.

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Table 1 - Areas of five habitat types within home ranges and numbers of locations by habitat type for thirteen coveys in Cumberland County, New Jersey.

		Area in Homerange (ha)						Number of Locations					
Season	Covey	Grassland	Scrub-Shrub	Forest	Agriculture	Other	Total	Grassland	Scrub-Shrub	Forest	Agriculture	Other	Total
2006-2007	1	2.71	4.98	5.90	3.50	1.80	18.89	13	67	38	5	1	124
2006-2007	2	2.75	0.00	2.95	2.66	1.35	9.71	10	0	98	5	1	114
2006-2007	3	11.64	1.99	6.89	0.75	0.00	21.28	25	17	18	1	0	61
2006-2007	4	15.09	3.09	33.15	2.63	0.25	54.21	34	12	14	0	0	60
2006-2007	5	17.50	2.22	30.41	2.99	1.01	54.13	22	23	24	1	0	70
2006-2007	6	9.11	2.67	9.98	0.00	0.00	21.76	22	16	6	0	0	44
2006-2007	7	18.01	1.11	18.57	0.00	0.00	37.68	36	7	19	0	0	62
2006-2007	8	11.82	1.69	8.45	0.00	0.00	21.96	17	12	17	0	0	46
2006-2007	9	3.37	1.10	0.61	0.36	2.09	7.53	93	11	14	0	3	121
2006-2007	10	4.47	5.90	5.86	14.23	3.75	34.21	27	39	5	22	0	93
2007-2008	11	2.66	0.66	0.45	0.01	1.28	5.05	24	7	4	0	0	35
2007-2008	12	26.91	1.30	21.62	0.00	0.03	49.86	78	5	37	0	0	120
2007-2008	13	5.88	1.51	33.36	1.77	0.48	43.00	5	2	106	0	0	113
Average		10.15	2.17	13.71	2.22	0.93	29.18	31.23	16.77	30.77	2.62	0.38	81.77

Table 2 - Comparison of microhabitat measurement means and standard errors at bobwhite covey nocturnal roost points and paired random points in forest and grassland habitat in Southern New Jersey during February 2006–April 2006, November 2006 –April 2007, and November 2007 –April 2008.

	Variable	Roost	Random	t	df	P
Grassland	Bare Ground*	8.71 ± 1.14	12.84 ± 2.23	-2.21	51	0.03
	Litter	64.98 ± 2.26	65.04 ± 2.78	-0.02	51	0.99
	Cool Grass	9.23 ± 1.49	9.62 ± 1.76	-0.22	51	0.83
	Forbs	3.48 ± 0.83	5.34 ± 1.64	-1.58	51	0.12
	Woody Vegetation*	13.41 ± 2.63	6.88 ± 1.56	2.36	51	0.02
	Robel*	15.93 ± 2.41	8.94 ± 1.53	2.35	51	0.02
	Vegetation Height*	80.26 ± 3.61	66.86 ± 4.67	2.46	51	0.02
Forest	Bare Ground	1.41 ± 0.67	1.35 ± 0.94	0.05	26	0.96
	Litter	70.85 ± 3.74	72.18 ± 3.35	-0.42	26	0.68
	Cool Grass	0.22 ± 0.19	0.09 ± 0.06	0.67	26	0.51
	Woody Vegetation	27.52 ± 3.77	26.25 ± 3.41	0.42	26	0.68
	Robel	21.96 ± 3.94	20.19 ± 4.60	0.45	26	0.66
	Vegetation Height	80.39 ± 4.39	78.31 ± 6.95	0.30	26	0.77

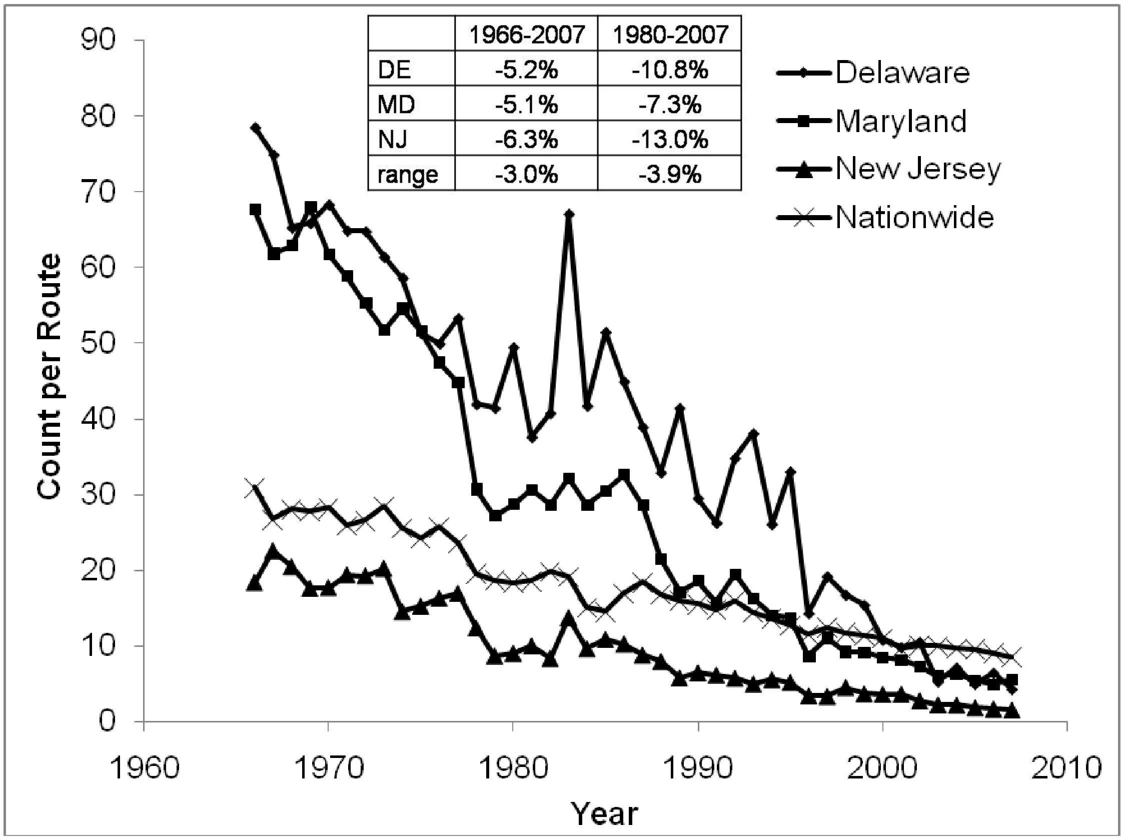
*significant values $P \leq 0.10$

Table 3 - Comparison of microhabitat measurement means and standard errors at bobwhite covey diurnal flush points and paired random points in forest and grassland habitat in Southern New Jersey during February 2006–April 2006, November 2006 – April 2007, and November 2007 –April 2008.

	Variable	Flush	Random	*t*	df	P
Grassland	Bare Ground	11.18 ± 2.42	11.70 ± 2.13	-0.27	27	0.79
	Litter	66.46 ± 3.19	63.80 ± 4.36	0.70	27	0.49
	Cool Grass	6.36 ± 1.58	7.10 ± 2.07	-0.36	27	0.72
	Forbs	6.39 ± 1.53	7.90 ± 3.06	-0.45	27	0.65
	Woody Vegetation	9.26 ± 1.81	8.84 ± 2.03	0.24	27	0.81
	Robel*	27.86 ± 4.31	14.46 ± 3.67	2.53	27	0.02
	Vegetation Height*	89.80 ± 6.05	70.64 ± 6.09	3.10	27	0.01
Forest	Bare Ground	1.31 ± 0.71	0.87 ± 0.44	0.59	25	0.56
	Litter	68.66 ± 3.22	72.45 ± 4.03	-0.94	25	0.36
	Cool Grass	0.15 ± 0.12	0.05 ± 0.05	0.80	25	0.43
	Woody Vegetation	29.72 ± 3.11	26.64 ± 4.00	0.77	25	0.45
	Robel	27.60 ± 4.21	19.01 ± 4.31	1.43	25	0.17
	Vegetation Height*	101.84 ± 7.92	88.63 ± 8.51	1.81	25	0.08

*significant values $P \leq 0.10$

Figure 1. Northern bobwhite population trends in three Mid-Atlantic states (New Jersey, Delaware, and Maryland) between 1966-1979 and 1980-2007 as estimated from the Breeding Bird Survey (Sauer et al. 2008).



	1966-2007	1980-2007
DE	-5.2%	-10.8%
MD	-5.1%	-7.3%
NJ	-6.3%	-13.0%
range	-3.0%	-3.9%

Figure 2 - Map of Cumberland County, New Jersey with focal areas outlined in white and an inset of New Jersey with Cumberland County shaded.

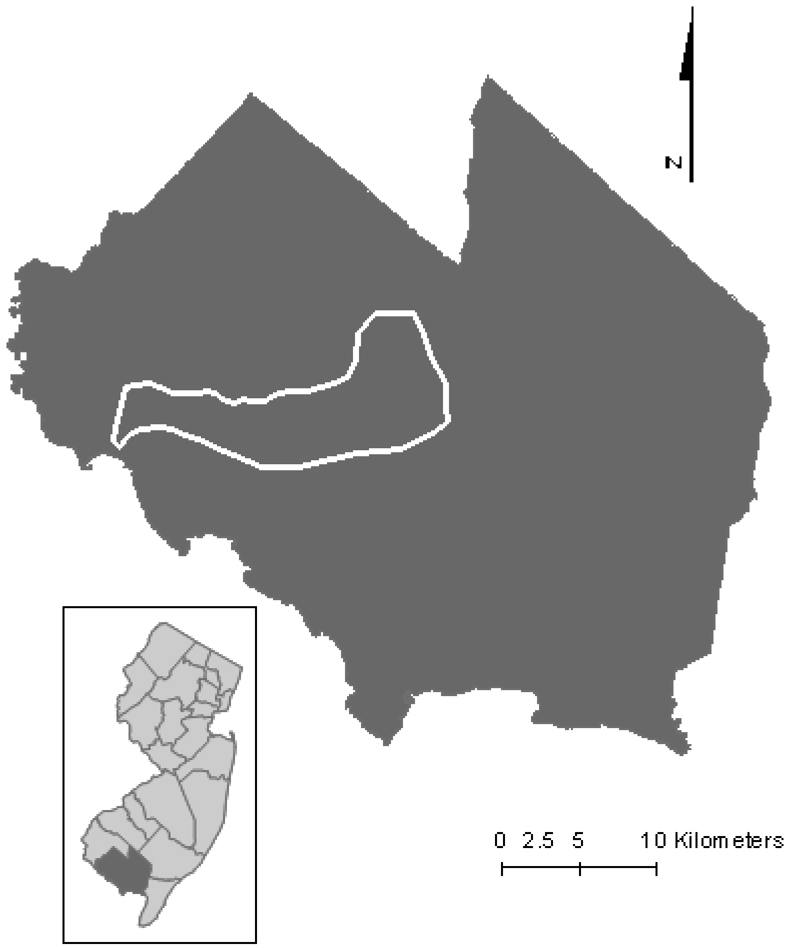


Figure 3 - Percent habitat category in Cumberland County, NJ, compared to average percent habitat category in home range area and telemetry locations of thirteen bobwhite coveys in Cumberland County, New Jersey October 2006 – April 2007 and October 2007 – April 2008.

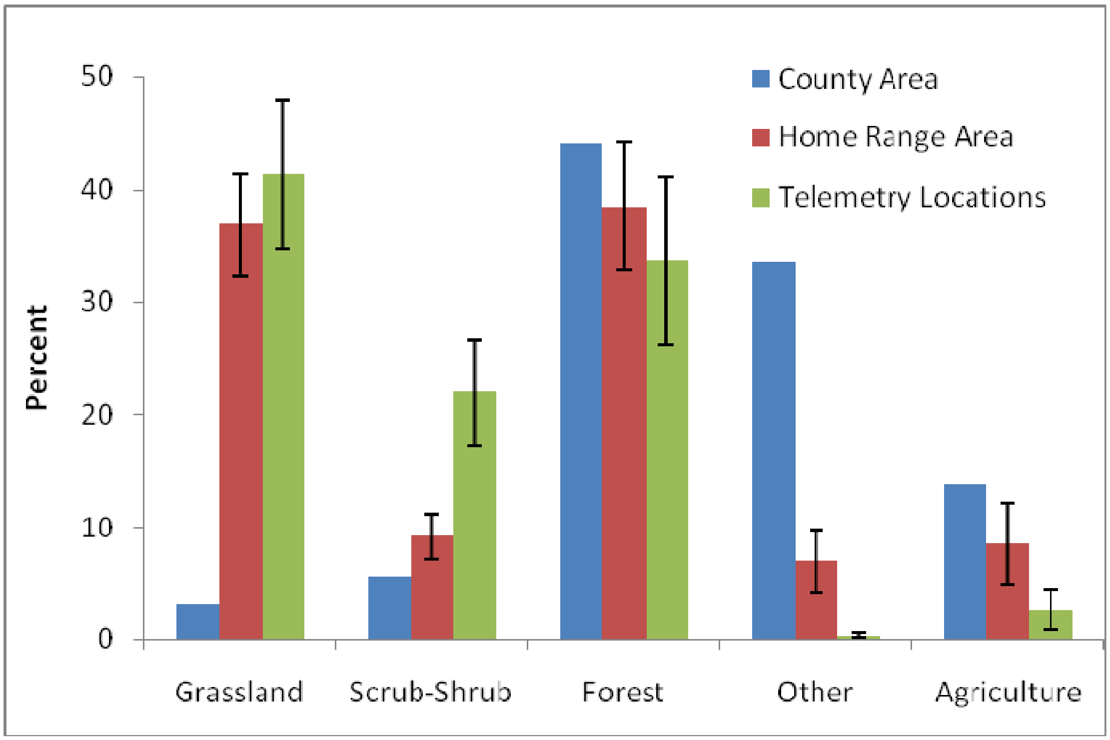


Figure 4 – Number of bobwhite coveys that used habitat classes more than expected, not different from expected, or less than expected based on chi-square analysis with Bonferroni confidence intervals, during October 2006 – April 2007 and October 2007 – April 2008. Note, because some covey's home range did not have all habitat types, the number of coveys represented for each habitat type does not equal 13.

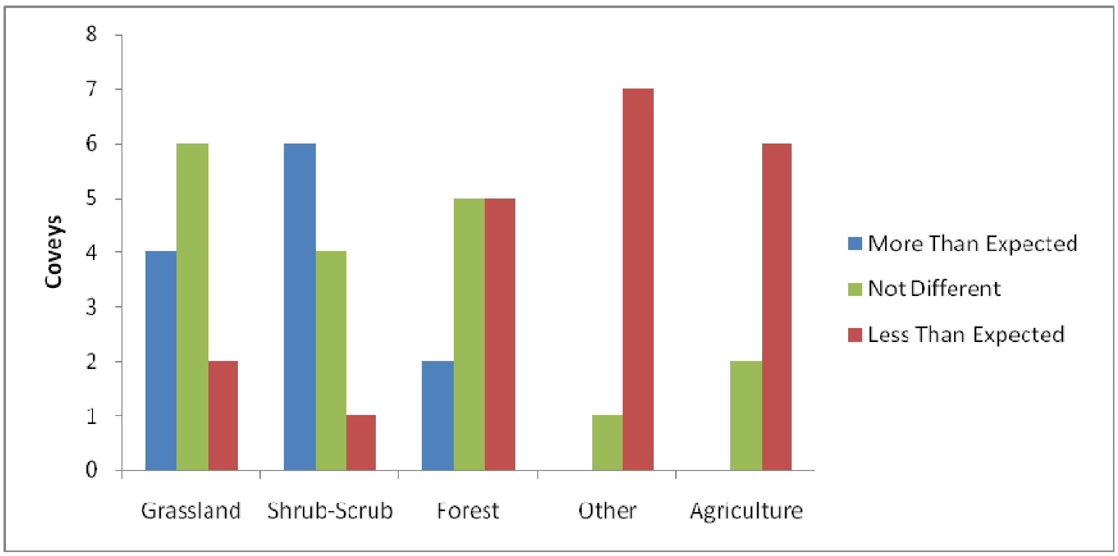


Figure 5 - Geographical comparison of current estimated winter survival rate (0.30) to reported bobwhite winter survival rates published between 1984 and 2007 (from Sandercock et al. 2008). All rates are adjusted to a 6-month interval from October – March. Inset of 166 winter survival rates from studies reported by Sandercock et al. (2008) with emphasis added to the range representing my combined survival estimate.