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STOPOVER ECOLOGY OF AUTUMN-MIGRATING RAPTORS IN THE CENTRAL APPALACHIANS

A Dissertation in Ecology

By

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ABSTRACT

Migration can be the most hazardous period of a bird's life cycle. Conditions at stopover sites may influence individual condition, survival, and affect future reproductive potential and population numbers. Availability of suitable habitat for resting and feeding en route can be an important component determining the success of migration for many birds. In eastern North America, raptors follow two main corridors during autumn migration, the Atlantic coast and the Appalachian Mountains. In the Central Appalachians, the Kittatinny Ridge is a key autumn corridor for eastern raptors. However, little is known about how migrants use the ridge and associated habitats en route. To better understand migration behavior and habitat use by raptors along an inland flyway, I studied migrating raptors during autumn along the Kittatinny Ridge. My objectives included to assess the frequency of travel and stopover in individual raptors and document behavior during stopover to understand the role and importance of stopover in migration in raptors. I also studied which habitats were used by raptors during stopover and the frequency of use of the Kittatinny Ridge to determine the importance of habitat to raptors and whether a flyway corridor could be identified

In one part of the study, I radio-tagged and followed 34 Sharp-shinned (*Accipiter striatus)* and 14 Cooper's Hawks (*A. cooperii*) during autumn migration 2003 and 2004. Birds were trapped on the Kittatinny Ridge, and followed for one to 12 days each through Pennsylvania and neighboring states. Both species spent 1-5 days on stopover between travel periods (mean= 2 d.). Sharp-shinned Hawks spent an average of 33.6% of daylight foraging (± 24.5 SD) and 32.6% of day roosting (±27.4), and Cooper's Hawks spent 33.8% (± 6.8) of day foraging and 47.2% (±26.2) roosting. Sharp-shinned Hawks spent less time roosting than Cooper's Hawks; however, neither species differed in behavior by age, except that adults spent more time in non-migrating flight. On travel days, migrant Cooper's and Sharp-shinned hawks spent an average of 45% and 35% of daylight in migratory flight respectively, reducing time spent roosting and foraging. Travel days were not strongly associated with cold front passage, but were associated with days of low cloud cover and for Sharp-shinned Hawks, northerly winds, and higher temperature. Travel time was longer on days with northerly (tail) winds for both species. The ratio of hours in travel to hours on stopover per bird during tracking was 1:7 (including night hours) suggesting that rest and foraging periods are an integral aspect of their migration journey.

The two species traveled in different compass directions with Sharp-shinned Hawks flying to the southwest (mean= 216.5º ±5.8 SE) and Cooper's Hawks traveling more to the south (mean= 190.2º ±8.3 SE). Direction did not vary by age, region, or date. Cooper's Hawks spent more time per day traveling on migratory travel days than Sharp-shinned Hawks. Adult Cooper's Hawks flew farther and faster on average than Sharp-shinned Hawks and hatch-year Cooper's Hawks. Both species spent more time in active travel flight on the Kittatinny Ridge than in the adjacent valley or other regions, although the valley and northern ridges were equally available. When in the Piedmont and Coastal Plain region both displayed longer, faster flights than in Ridge and Valley region. Both species exhibited faster travel on days with tail winds, and Cooper's Hawks also flew faster on days with strong thermals and light winds. Headwinds appeared to shorten the migration distance for hatch-year Sharp-shinned Hawks whereas adults compensated by flying longer to cover a similar distance.

Cooper's and Sharp-shinned hawks may use different strategies to migrate through the Central Appalachians. Cooper's Hawks exhibited short travel periods with longer stopovers along the Kittatinny Ridge followed by long-distance 'power' flights with short stopovers when traveling south across the more open and developed Plain and Piedmont region. Sharp-shinned Hawks appeared less likely to undertake long flights and more consistently flew close to the Appalachians where more abundant forest habitat could be found. Both species seemed to use thermals and updrafts to aid their migration and save energy.

Forest patch size was one of the most important factors in stopover site selection with both species choosing larger forests more than occurred at random at both the landscape scale and near scale. At a regional scale, both species selected more rural areas for stopover sites, selecting areas with more mixed forest and pasture. Sharp-shinned Hawks avoided suburban areas as well. Hatch-year Sharp-shinned Hawks used contiguous forest, wetlands, and evergreen forest less than adults. Nearly half of all roosts of both species were on the Kittatinny Ridge suggesting either an affinity to large forests or the flyway itself. Both species combined roosted at an average of 6.9 km from the ridge flyway when found within the Ridge and Valley region. Hatch-year birds roosted farther from the ridge than adults in both species and Sharp-shinned Hawks roosted farther from the ridge than Cooper's Hawks.

Cooper's Hawks were more selective in their habitat choice during migration than during nesting, choosing large forests in more rural landscapes. The selection of roosts by Sharp-shinned Hawks near wetlands may indicate that the opportunity to drink is important during migration or that wetlands concentrate their songbird prey. Evergreen stands could provide important protective cover to roosting Sharp-shinned Hawks, as they may be more vulnerable to avian predation and more likely to seek out evergreen forest during stopover than the Cooper's Hawk.

During road surveys of all raptors on stopover, birds were most abundant within 1 to 6 km of the ridge and less numerous farther from the ridge or on the ridge itself. The lowest abundance was observed at the farthest distance from the ridge, 16 km. The pattern of higher abundance near the base of the ridge remained consistent regardless of changes in forest cover . The abundance near the Ridge indicates that distance to the flyway could be an important factor influencing migrant distribution. Habitat influenced distribution of migrants on stopover as well. Forest raptors were more numerous on the north side where forest cover was more abundant, and open habitat raptors, e.g. Red-tailed Hawk and Northern Harrier, were more numerous on the south slope where farmland predominates. Although age influences patterns of migration, no age difference was observed in habitat or distance of migrant raptors surveyed during road surveys.

The road survey results together with the radio-tracking data on two accipiters suggests that migrant raptors may prefer to roost near the migration flyway during stopover, but will move away from the flyway to find appropriate habitat when necessary. Although songbirds demonstrate greater flexibility in habitat use on migration as compared the breeding season (Petit 2000, Rodewald and Brittingham 2004, Keller et al. 2009), raptors appear more conservative in their habitat selection during migration.

Migrating raptors expend considerable energy to travel between breeding and wintering areas. As part of their migration strategy, many utilize updrafts along ridges, to save energy en route. In this study, accipiters relied extensively on thermal lift to aid

their migration south but also used the Ridge for energy-savings and stopover. Migration travel occurred in a wide variety of weather conditions, excluding days of heavy cloud cover or rain. Migrant raptors appear to prioritize replenishing energy and finding safe areas to rest during their journey. Migrating accipiters regularly integrated stopover into their migration journey, perhaps following an energy-minimization strategy of migration (Newton 2008). Raptors settled preferentially near the migration route during stopover, a behavior that is also supportive of an energy minimization strategy of migration.

Long-term conservation of North American raptor populations may rely on the protection of a rural mix of habitats along key migration corridors including large patches of contiguous forests, rural fields, and wetlands. Although more research is needed, raptors appear to show more conservative habitat selection patterns during migration than during breeding or wintering periods. The avoidance of suburban areas by migrant accipiters also suggests that conservation planning should limit suburban and urban development within important migration corridors.

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Chapter 1. Stopover Ecology of Autumn-migrating Raptors in the Central Appalachians: background.

INTRODUCTION

Migration, the regular journey of birds between their breeding grounds and non-breeding grounds (Dingle 1996), occurs in 183 of 292 species (62%) of birds of prey worldwide (Zalles and Bildstein 2000). Many species aggregate in large numbers along established corridors during migration with concentrations ranging from thousands of birds to millions at some locations (Bildstein 2006, Newton 2008). Migration behavior is a product of natural selection and varies widely among species and populations (Alerstam 1990, Berthold 1996, Alerstam et al. 2003).

Most North American migratory raptors are partial migrants in which a portion, but not all members, of the species migrates (Kerlinger 1989, Bildstein 2006). Attributes of migration behavior, e.g., timing and distance, may vary within a species, among populations, by age, and by sex (Kerlinger 1989). Individuals also may vary their migration patterns among years, affecting their annual survival and reproduction (Newton 2008). Late-arriving individuals in the spring may have less time to prepare for nesting and produce less young, and be relegated to lower-quality territories. Early arriving birds may be subject to stress of severe weather and reduced foraging opportunities but can have better choice of breeding territories. The timing and pace of the migration journey and the choices made during the journey can have immediate consequences on survival (Berthold 1999, Alerstam et al. 2003).

Choices about when to fly and when to not fly during migration are poorly understood, particularly for raptors. Weather suitability for migration and seasonal timing are suggested to influence individual decisions (Kerlinger 1989); however, a bird may also be influenced by need to refuel or replenish food stores and rest (Alerstam and Lindstrom 1990, Carmi et al. 1992, Moore et al. 1995).

The challenges of migration represent a significant selective force which has shaped behavioral strategies of raptor populations (Kerlinger 1989, Moore et al. 1995, Bildstein 2006, Newton 2008). Migrants can face water crossings, inclement weather, long journeys over unfamiliar terrain, predators, and many other hazards (Moore et al. 1995, Hutto 2000). Recent research suggests that much of the adult mortality in songbirds occurs during the migration and not during breeding and wintering periods (Sillett and Holmes 2002, Newton 2008). Mass mortality of migrant songbirds has been documented during water crossings (Kerlinger 1989) and at radio towers and other lighted structures (e.g., Shire et al. 1999). Some raptors are reported to arrive at migration roost sites emaciated and near death, and mortality at water crossings numbering over 1,000 birds has been noted (Smith et al. 1986, Kerlinger 1989).

If migration is challenging for raptors, then finding adequate migration stopover habitat and opportunities to rest and feed could be pivotal to their survival. Moore et al. (1995) posit that the lack of suitable stopover habitat, or “areas with the combination of resources and environmental conditions that promotes occupancy by individuals of a given species and allows those individuals to survive during passage” could result in substantial population declines as migration places birds at their physiological limit in an unfamiliar landscape.

Feeding on Migration

Food supply can influence patterns of migration within and between years (Newton 1979). In partial migrants, e.g., the Red-tailed Hawk (*Buteo jamaicensis*) some individuals may not migrate if the winter is mild and prey are plentiful (Craighead and Craighead 1969). Food resources and feeding opportunities along the migration route may be as critical in shaping migration patterns and behavior en route as it is in non-breeding periods, however very little research has been conducted on foraging or food requirements of raptor migrants. Although long-distance migrants e.g., the Broad-winged Hawk (*Buteo platypterus*) and Swainson's Hawk (*B. swainsoni*) build up fat prior to migration and may not need to forage regularly, anecdotal observations suggest most raptors forage consistently during migration at northern latitudes (Shelley and Benz 1985, Nicoletti 1997). Even long-distance migrants forage during migration, as 6 to 15% of Broad-winged Hawks had distended crops as they migrated past Hawk Mountain Sanctuary during three autumns (Shelley and Benz 1985, HMS unpubl. data).

In shorebirds, researchers have found that migration is timed to maximize feeding opportunities during stopover, e.g., Red Knot at Delaware Bay, New Jersey (Kerlinger 1995). The timing of migration of some raptor species, e.g., American Kestrel (*Falco sparverius*) and Sharp-shinned Hawk, has been hypothesized to be coordinated with the timing of the migration of their prey as well (Kerlinger 1989, Nicoletti 1997).

Stopover Habitat Selection

How migrants select stopover habitat is still unclear. Moreover, what types of habitats are important and how individuals locate them is relatively unstudied (Moore and Aborn 2000). Migrant songbirds appear to select habitats for stopover based on availability of food and protective cover (Hutto 1985, Moore and Yong 1991, Moore et al. 1995, Keller et al. 2009). If a stopover site is unsuitable a migrant may depart with less fat reserves than needed, and risk mortality or require additional stops which could lead to late arrival to the breeding or non-breeding sites or poor condition (Moore and Yong 1991).

Some migratory songbirds may seek out certain habitats during migration stopover (Moore et al. 1990, Rodewald and Brittingham 2004). Habitat area or size may contribute to suitability for migration stopover and the ability for replenishing fat stores (Moore et al. 1995, Petit 2000, Buler et al. 2007, Keller et al. 2009). The habitat used, however, may vary from the habitat used during the breeding season. Forest-nesting birds have been found concentrated along edges or in shrubland, perhaps because invertebrate prey were more abundant in such habitats (Rodewald and Brittingham 2004). Birds may also vary their habitat choices geographically suggesting stopover site selection may be complicated by ecological and physiological requirements that may vary with migration progress and landscapes (Petit 2000). Birds in need of sleep may also seek out flocks to take advantage of others alertness to predators during their rest period (Nemeth 2009). Migrants with fat stores may select different habitats than lean birds (Petit 2000).

In the few studies of migrant raptor habitat use that have been conducted, birds appear to seek out habitats similar to their breeding habitat types. A study of 34 radio-tagged Sharp-shinned Hawks (*Accipiter striatus*) during migration stopover in Cape May, New Jersey, suggested that this woodland raptor selected woodlands on migration over other habitat types (Holthuijzen et al. 1985). Niles et al. (1996) found that raptors in

Cape May flew over habitats similar to their breeding habitats as they moved along the Cape May Peninsula. Selecting habitat similar to familiar habitats may assist migrants in finding prey, however because prey abundance and habitat components may vary, some flexibility in selection could be an appropriate strategy (Moore and Aborn 2000).

Sampling of habitats or sites in the first hours of stopover within a landscape may be important mechanisms birds use to select certain stopover sites (Petit 2000, Moore and Aborn 2000). However, time spent searching may need to be minimized when fat stores are depleted. Distances raptors travel from their migration corridor or flyway in search of suitable stopover sites is unknown. If suitable habitat is rare near migration pathways, migrants may be forced to settle in less suitable sites or expend energy seeking appropriate habitat.

Young birds on migration may be particularly challenged when habitat is limited, with some species exhibiting differences in foraging behavior and fat stores by age (Yong and Moore 1993, Woodrey 2000). First-year raptors suffer high rates of mortality post-fledging (70%) presumably because learning to capture live prey is difficult (Newton 1979). Foraging in unfamiliar terrain and habitats along migration routes may be particularly challenging for inexperienced, immature hawks. Longer stopover periods by immature age classes have been noted for several wading birds and Steller's Eagle (*Haliaeetus pelagicus*) and could reflect lower foraging efficiency or possibly a reduced migration urgency compared to adults (Newton 2008).

Weather, Migration, and Stopover Timing

Stopover behavior of individual birds may be influenced by an individual's internal conditions (i.e., need for feeding and resting, migration urgency) as well as environmental conditions, i.e., habitat, weather, prey availability, date (Wlasberg 1990, Alerstam and Lindstrom 1990). Most studies of raptor migration have examined when birds are seen migrating in relation to weather or seasonal progression (Kerlinger 1989, Titus and Mosher 1982). For example, pulses of raptor migration at migration watch-sites in the eastern United States have been correlated to the passage of cold fronts and northerly winds (Broun 1939, Richardson 1978, Titus and Mosher 1982, Allen et al. 1996, Maransky et al. 1997). During rain and snow, migrants are suspected to roost and wait for clearer conditions, although satellite-telemetry techniques have revealed a few species may migrate even during inclement conditions (Newton 2008). Because most studies of raptor migration have focused on ground-based counts, our understanding of weather and migration behavior may be biased (Titus and Mosher 1982, Kerlinger 1989). Weather can enhance or inhibit conditions for migration and may have considerable influence over stopover decisions by an individual as well. Observations on individual birds during both stopover and travel periods can provide more complete and unbiased data on migration choices and patterns in response to different weather conditions.

Habitat Conservation

Availability of roosting and foraging habitat along the migration pathway may directly affect migrant survival. Biologists suggest that large, undeveloped areas with a diverse habitat array may be needed along key migration corridors although small patches in urbanized landscapes are also important (Moore et al. 1995, Hutto 2000, Mehlman et al. 2005).

The Kittatinny or Blue Mountain, is the eastern-most ridge of the central Appalachians, and has been recognized as a major migration corridor for southbound migrating raptors and songbirds since the 1930s (Broun 1939). It was recognized as a state, national and global Important Bird Area because of its importance as a flyway for migratory raptors (Crossley 1999, Commission on Environmental Cooperation 1999, Bildstein 2006), yet little is known about the use of the Ridge and associated habitats by raptors during stopover periods and whether they require certain habitats for foraging and resting.

Suburban sprawl has reduced available wildlife habitat in southeastern Pennsylvania with the last large patches of continuous forest (greater than 10,000 acres) occurring only on the Blue Mountain itself (Goodrich et al. 2002, Bishop 2008). As sprawl and development continue to encroach along the base and slopes of the Appalachian Mountains, a better understanding of habitat use by migrant raptors using this corridor may be important to future conservation efforts in the region.

Raptor Stopover Ecology Questions

To better understand the stopover ecology of migrating raptors, I examined behavior and habitat use of migrating raptors along the Kittatinny Ridge in the Central Appalachians using both intensive and extensive approaches. Intensive data were collected on a forest-dependent raptor, the Sharp-shinned Hawk and a closely related forest generalist species, the Cooper's Hawk (*Accipiter cooperii*), by radio-tracking individual birds and quantifying their stopover and migration behavior daily, and studying the natural history of their migration, e.g., timing, cadence, and the influence of weather on their behavior. I also examine how accipiters travel through the Appalachian landscape, documenting the time spent in different regions, as well as the direction of flight and travel characteristics in response to weather factors.

With better knowledge of the role of stopover periods in migration journey and a better understanding of individual migration behavior, I studied the stopover habitat use by the two accipiter species to understand if migrants are selecting habitats or using habitats as they occur in the landscape. Because the two species have dissimilar nesting habitats and diets (Bildstein and Meyer 2000, Curtis et al. 2006), I hypothesized they may differ in stopover habitat use but display similar migration behavior patterns. I hypothesized that the Sharp-shinned Hawk would exhibit more selective use of habitats than the Cooper's Hawk, because Sharp-shinned Hawks nest nearly exclusively in large forests away from people and Cooper's Hawks nest in a wide array of habitats from urban parks to large forests (Bildstein and Meyer 2000, Curtis et al. 2006). Because immature raptors are more variable in their migration behavior overall (Kerlinger 1989), I hypothesized that hatch-year birds will exhibit less selection in habitats used during stopover. I evaluated the use and importance of the Kittatinny Ridge as a flyway and stopover site by measuring the distance of stopover roost sites from the ridge for each species and age group and examine how often birds used the ridge for stopover as well as migration.

Because some researchers have suggested habitat selection during migration may begin by selection of the migration pathway and that migrants may cue in on different habitat components at different scales (Hutto 2000, Buler et al 2007), I examined habitat selection at three scales to try to understand what aspects of the landscape may be important to migrating raptors in the Central Appalachian region and at which scale habitat attributes are selected.

For the intensive portion of the research, I compared the Sharp-shinned Hawk and the Cooper's Hawk, two widespread North American raptors. Sharp-shinned Hawks nest in large evergreen or mixed forests from Alaska east across Canada and south through southern Pennsylvania and south through Appalachian ridges (Bildstein and Meyer 2000). Considered a partial migrant, Sharp-shinned Hawks migrate in large numbers each autumn to winter throughout the central and southern United States and into Mexico and Central America. Numbers sighted at Hawk Mountain Sanctuary on the Kittatinny Ridge each autumn average 3,988 annually. Eastern birds winter primarily from Pennsylvania south through Florida and Texas (Goodrich and Smith 2008). Because they nest in large stands of forest in temperate regions I predict they may seek out large forests during migration. The Cooper's Hawk breeds in a wide variety of forest types from extensive forest to small woodlots, hedgerows and single trees in rural or suburban and urban landscapes (Curtis et al. 2006). They breed across southern Canada south through the southern United States and northern Mexico (Curtis et al. 2006). They are also partial migrants with northern birds migrating to greater extent than southern birds. Annual counts of Cooper's Hawks at Hawk Mountain Sanctuary on the Kittatinny Ridge in Pennsylvania average 503 birds per year (Curtis et al. 2006, Goodrich and Smith 2008). Most birds winter within the United States, although western populations move into Mexico during non-breeding periods (Curtis et al 2006).

To compare behavior and habitat use of these closely-related accipiters, I trapped and tracked 48 birds (34 Sharp-shinned Hawks, 14 Cooper's Hawks) during autumn migration on the Kittatinny Ridge in 2003 and 2004. Of these 48 birds, four did not migrate and several were not followed for an adequate period of time for behavioral analyses. As a result, our sample size varies depending on the question from 44 to 39 birds.

I used a more extensive sampling method to examine stopover distribution and behavior of all migrant raptors detected using the Kittatinny corridor across Pennsylvania. I established road-side surveys on the Kittatinny Ridge and at three radial distances at five sites to assess the behavior and distribution of migrants in relation to this major landscape feature. Transect surveys quantified the stopover behavior of birds, the abundance of avian prey along transects, and habitat associations of raptors observed in stopover. Fifteen species were detected during surveys and included in the data analyses. Species studied included open-habitat raptors, e.g., Red-tailed Hawk and American Kestrel, and forest raptors, e.g., Broad-winged Hawk and Sharp-shinned Hawk. I examined how far from the ridge do raptors concentrate and whether the north slope was used to a greater extent than the south slope. Habitat associations and availability along the ridge were mapped to determine if habitat or ridge affinity, or both, influenced migrant concentrations. Surveys were conducted at several distances from the ridge to assess if a corridor of higher use by migrants could be defined and how far it might extend from the ridge.

Chapter 2. Stopover behavior of Sharp-shinned (*Accipiter striatus)* and Cooper's Hawks *(A. cooperii*) during autumn migration through the Central Appalachians

ABSTRACT

In autumn 2003 and 2004, I studied the stopover behavior of 39 radio-tagged Sharp-shinned and Cooper's hawks (*Accipiter striatus, A. cooperii)* migrating through the central Appalachians. Migrants were tracked for 1 to 12 days each and their behavior recorded from sunrise to sunset. Both species spent 1-5 days on stopover between migration travel days (mean=2 d.) and spent more time in stopover than in travel during the study (hours 7:1). Sharp-shinned Hawks spent an average of 33.6% of their day foraging (SD=24.5) and 32.6% of day roosting (SD=27.4). Cooper's Hawks spent 33.8% (SD=6.8) of day foraging and 47.2% (SD=26.2) roosting. Foraging occurred on 98.8% of the study days whereas migration travel occurred on 45% of days only. On travel days, migrating Sharp-shinned and Cooper's hawks spent an average of 45% and 35% of day traveling respectively, with less time roosting and foraging than on stopover days. Hatch-year birds differed from adults in proportion of time spent foraging and roosting, but the direction of difference varied by species. Travel days were not associated with cold front passage, but were associated with days of less cloud cover, tail winds, and warmer temperature for Sharp-shinned Hawks and days of less cloud cover for Cooper's Hawks. These data suggest that stopover periods are integral to a successful migration for these species and the availability of stopover habitat within migration corridors may be important to their long-term conservation.

INTRODUCTION

Migration is one of the most challenging segments of the avian life cycle (Sillett and Holmes 2002). Birds may lose up to 40% of their body weight during the journey and more than 50% may not survive (Hutto 2000, Munro 2003, Newton 2008). Individual migration patterns reflect a balance of internal and external influences (Alerstam 1990). And, the mortality can be higher than during other periods of the life cycle (Sillett and Holmes 2002). Migrants may strive to minimize time spent in their migration journeys as early arrival to breeding or non-breeding territories can bring competitive advantage, i.e., ‘time-minimization hypothesis’ (Alerstam and Lindstrom 1990). Minimizing energy expenditure also may be important with birds traveling more when weather conditions allow less energy use during flight, i.e., ‘the energy-minimization hypothesis’ (Alerstam 1990, Newton 2008). Replenishing fuel, finding suitable sites to rest, and avoiding hazards en route also may be important in determining migration patterns and behavior (Hedenstrom 2007, Buler et al. 2007, Newton 2008).

Research on migrating songbirds suggests that stopover and travel timing and duration can be a function of food availability, individual condition, weather, and location quality (Bairlein 1992, Berthold 1996, Mehlman et al. 2005, Hedenstrom 2007). If migrants seek to minimize energy needed for flight, they may feed more often for shorter periods to enhance daily flight performance, and migrants may feed for longer periods when faced with a migration barrier (Newton 2008). A migrant that has selected a less suitable habitat for stopover may have to spend more time foraging and resting (Petit 2000, Newton 2008). If refueling is necessary yet unpredictable, birds may spend more time foraging when located in food-rich habitats and more time traveling when prey are scarce. If this is true, weather may show less influence on migration timing or behavior.

Behavior of migrating raptors, particularly the frequency of foraging, and patterns of stopover and travel are little understood and may vary with latitude, migration progress, and migration length (Kerlinger 1989, Bildstein 2006, Newton 2008). Scientists suggest that some long-distance raptor migrants may fast during several weeks of their migration and spend very little time foraging during most of their migration (Hofslund 1973, Smith et al. 1986, Harmata 2002). For example, raptors regularly cross large areas of inhospitable terrain during migration (e.g., water, deserts) where foraging opportunities are presumably rare (Martell et al. 2001, Fuller et al. 1998, Bildstein 2006) and some species are known to limit feeding during parts of their migration (Newton 2008). In contrast, raptors are observed hunting during migration at northern latitude watch-sites regularly and are seen migrating past with full crops (Holthuijzen et al. 1985, Shelley and Benz 1985).

If foraging is a priority for migrating raptors, migration patterns could be influenced by abundance of prey populations. Kerlinger (1989) suggested that concentrations of migrating accipiters along the Atlantic coast during late September may be a response to the large numbers of prey, e.g., migrating songbirds, concentrating in coastal habitats during that time period.

Young birds may be particularly challenged on migration and exhibit different refueling behaviors than adults during stopover. Immature songbirds trapped during migration have less fat than adults (Woodrey 2000) and often spend more time foraging on stopover (Woodrey 2000, Petit 2000, Deutshchlander and Muheim 2009). Hatch-year raptors suffer high rates of mortality after fledging and are less adept at obtaining prey (Roth et al. 2005, Newton 2008). Similar to songbirds, hatch-year raptors may need more time on stopover sites to adequately refuel and continue on their migration (Woodrey 2000). Their inexperience also may result in hatch-year birds selecting less suitable sites.

Weather can influence migration behavior in raptors. Cold front passage and tail winds have been documented to concentrate raptor migration flights along leading or diversion lines during autumn (Titus and Mosher 1982, Allen et al. 1996, Woltmann and Cimprich 2003). Further, individual raptors have been shown to adjust their migration heading to maximize efficiency of migration and compensate for prevailing winds (Kerlinger 1989, Klaassen et al. 2008). Heavy cloud cover has been shown to inhibit Bald Eagle (*Haliaetus leucocephalus*) migration in the west (Harmata 2002) and soaring birds are known to use thermals extensively during long-distance migration (Shamoun-Baranes et al. 2003, Bildstein 2006). Because highest counts of accipiter migrants during autumn are seen at watch-sites following a cold front passage on days with north or northwest winds (Allen et al. 2006), they are assumed to spend more time migrating under such conditions. However, influence of weather on migration and stopover choices of individual migrants has not been investigated.

I examined the stopover behavior of two species of forest raptors, the Sharp-shinned (*Accipiter striatus)* and Cooper's Hawk (*A. cooperii)*, as they move south along the Kittatinny Ridge in the Central Appalachians, a key migration corridor for eastern North American raptors (Crossley 1999, Bildstein 2006, Goodrich and Smith 2008). Specifically, I compared stopover behavior and stopover and migration frequency by age and species, and evaluated their behavior in relation to weather, fat levels, stopover forest patch size, and seasonal progression.

METHODS

Study Area

Birds were trapped on the Kittatinny Ridge, or Blue Mountain, located in the Ridge and Valley Province (www.dcnr.pa.us/topogeo) of eastern Pennsylvania, and followed south through Pennsylvania and areas south through Maryland, West Virginia, Virginia, and North Carolina. The study area, which was defined by the paths taken by the migrants from the Kittatinny Ridge, included parts of the Piedmont and Atlantic Coastal Plain topographic provinces within the Pennsylvania, Maryland, Virginia, New Jersey and Delaware.

The Kittatinny Ridge of the central Appalachians in Pennsylvania extends over 300 km with few breaks from the border of New Jersey to just north of Maryland (Crossley 1999). The Kittatinny Ridge is designated a Pennsylvania Important Bird Area because of the migration of raptors and songbirds it attracts during autumn (Crossley 1999, Bildstein 2006). More than 20,000 raptors are sighted at several locations along the Kittatinny Ridge each autumn season, and some species concentrate here in higher numbers than elsewhere in eastern North America (Goodrich and Smith 2008).

Sharp-shinned and Cooper's hawks were trapped at Little Gap Banding Station (40˚ 04", 75˚ 30", 455 m above sea level) on the Kittatinny Ridge in eastern Pennsylvania, east of Palmerton, Northampton County, Pennsylvania. The banding station is located northeast of Hawk Mountain Sanctuary and Bake Oven Knob, two internationally-recognized watch sites on the ridge. Birds were radio-tracked from Little Gap to wherever they chose to travel.

Trapping

Between 2 September and 22 November in 2003 and 2004 48 accipiters (34 Sharp-shinned and 14 Cooper's Hawks) were banded and radio-tagged. The birds were caught by a volunteer team between 0830-1630 h EST under federal banding permit 21371 (Pennsylvania State permit 00032, Penn State University IACUC permit # 19240). Males and females of both species were targeted for capture using mist-nets or bow traps, and none of the birds were held for longer than 45 min. Of the Sharp-shinned Hawks tagged, 32 were female and two were males , and of the 14 Cooper's Hawks tagged, seven were female and seven were males (most male Sharp-shinned Hawks I trapped were too small to carry a transmitter).

Of the birds I tagged, 21 were hatch-year Sharp-shinned Hawks and 13 were after-hatch-year (adult) Sharp-shinned Hawks, whereas 8 were hatch-year and 6 were adult Cooper's Hawks. More hatch-year birds were trapped earlier in the autumn than after-hatch year birds (HY date range September 2 to November 22; adult date range October 2 to November 17) due to their earlier migration timing (Rosenfield and Evans 1980, DeLong and Hoffman 1999, Mueller et al. 2000).

I tagged only birds appearing in good health, of suitable weight, and not undergoing active molt of wing or tail feathers. I banded each bird with a United States Geological Service (USGS) aluminum band and took the standard morphometric measurements.. The measurements included: wing chord (mm), fat at axillaries and tail (on scale of 1-5), crop distention, tarsus length (mm), tail length (mm), hallux length (mm) and body mass (g). The field team assessed fat in migrants using methods described in Delong and Gessamen (2001). The crop is an expanded pouch-like area of the esophageal region found in many birds (Gill1995). When full with food, it distends and this distension can be palpated and seen visually. We ranked crop distension on qualitative scale of appearing empty to appearing full.

A light-weight, tail-mounted radio transmitter (Holohil model RI-2CP) was affixed to migrants on the two central rectrices. The Sharp-shinned Hawk female transmitter weighed 2.9 g with a battery life expectancy of 10 weeks whereas the male Sharp-shinned Hawk transmitter was 2.6 g with a battery life expectancy of 9 weeks. Transmitters for the Cooper's Hawks weighed 3.8 g and had a battery life greater than 10 weeks. The weight of each radio transmitter was less than 3% total body mass to minimize the influence of transmitters on flight behavior (Kenward 2001, Woltmann 2001, Hiraldo et al. 1994). In 2004, the transmitters had mercury position sensors installed that gave faster signal cadence when the tail was held horizontal. This allowed us to better assess behavior of birds, i.e., flying birds had faster signal cadence than sitting birds.

Radio-tracking Methods

Birds were followed using two four-wheel drive vehicles equipped with four-element yagi antennas mounted on a 4 m telescoping pole attached to the vehicle through the sunroof, allowing 360 º rotation and tracking while driving. Some birds were followed using only one vehicle due to personnel constraints.

Tests of the radio transmitter signal strength indicated that the maximum range of reception was approximately 1.6 km for birds within forest and up to 8 km in open areas.

These range tests were performed using transmitters placed approximately 1.5 m above ground, placed in trees. Surrounding vegetation and topography (i.e., mountains) caused a definite and predictable decline in signal range. If a bird was in flight above treetop level or if the tracker was in an airplane, the signal range increased significantly to 15 to 20 km. If a bird perched in thick cover, the range was reduced to <1 km. All field observers were trained prior to the migration to improve their ability to take bearings accurately and to decrease inter-observer differences in tracking (White and Garrott 1990, Garrott et al. 1986).

Tracking of each bird began pre-dawn (<0600 EST) to ensure that the birds were still within the previous night's roost site. The birds were followed until they went into their roost site at dusk (~1730 EST), and for one half hour after dark to ensure the bird did not move after they were left. Only hawks that exhibited migratory movements during radio-tracking were considered in this study to exclude resident birds. Four birds exhibited no migration flights during tracking and were excluded from the study, three Cooper's and one Sharp-shinned Hawk. If the bird was lost by ground vehicles for longer than two h, an antenna-equipped airplane was used to relocate the bird. The yagi antenna system for the plane conformed to that described in Gilmer et al. (1981) and used a special aircraft receiver (R2100—Advanced Telemetry Systems, Inc.). If a bird was relocated, bearings were taken by ground vehicles and radio-tracking resumed.

Behavior of Migrants

The field team recorded the behavior of each bird every 15 min from sunrise to sunset or whenever the behavior changed. Behaviors were recorded based on the transmitter signal strength and pattern using six pre-defined behavioral categories: 1) roosting (bird stationary for >30 min); 2) perched (bird stationary for <30 min with no flying behavior); 3) migration travel or migratory flight (bird flying in one direction above the canopy for >3 km distance); 4) flying (bird flying for short distance, less than 3 km, above or below the tree canopy); 5) perch-flying or foraging (bird alternating short perches and short flights (<5 min each) in quick succession of movements; and, 6) no signal or unknown behavior (bird out of range or signal temporarily lost due to an obstruction). Perch-flying was assumed to represent foraging based on previous research and observations of accipiter hunting techniques (e.g., Holthuijzen et al. 1985, Palmer 1988, Squires and Kennedy 2006). I also recorded the location of the bird, the general habitat, and weather conditions throughout each tracking day. Locations were estimated from bearings taken during movements and for every roost location, diurnal and nocturnal, using triangulation and Locate II software (Pacer 2000). Maps of migrant tracks are shown in Appendix A.

I truncated our data to consider the bird's behavior only for the period between sunrise and sunset for the geographic latitude of the bird's location (www.sunrisesunset.com). Thus, in this study I only examined diurnal behavior. Based on the lack of change between locations at night and the following morning, I assumed that raptor migrants spent their nocturnal hours roosting in one location.

Because I monitored birds for different numbers of days and min per day and because daylight varied through the autumn, I compared stopover behavior by species, age class, or other groups by comparing the proportions of daytime min spent in different activities. I also recorded the timing of activities, such as when study birds began moving off their night roost and when they began nocturnal roosting as minutes after sunrise and minutes prior to sunset. Because study birds were tracked for partial days at the beginning and end of tracking periods, sample sizes for timing of activities were less than total days monitored.

No signal periods averaged 10 to 17% of average daily tracking periods for each species (Table 1). Because no signal periods occurred sporadically and during all behaviors, e.g., migratory flights, low flights, roosting, and hunting, and during all times of the day, I assumed that excluding the no signal periods from analyses did not affect the results. Daily behavioral data was included in analyses for any day where the no signal period represented <40% of day. On the first and last day of tracking an individual, partial days of tracking were possible. For such days I only included a day's behavior if I tracked the bird for >60% of the daylight period. However, roosting and lift off times were used where possible, regardless of tracking period.

Weather Data

Weather has been shown to be an important predictor of raptor flights at ground-based migration watch-sites (Titus and Mosher 1982, Kerlinger 1989, Allen et al. 1996). Hourly weather data was obtained from the National Climatic Data Center for cities near to where birds were located (www.ncdc.noaa.gov; accessed 1/2005). Stations in Pennsylvania, New Jersey, Maryland, Virginia, West Virginia, and North Carolina were used to obtain data on average daily temperature, daily precipitation, daily resultant wind direction, daily resultant wind speed, sea level pressure, and percent cloud cover.

To estimate thermal strength I used daily forecast maps of 'thermal updraft velocity' (W_* or TUV) in units of ft per min (fpm) developed by meteorologists for use by glider pilots (Glendening 2002, Summerskill 2003). TUV represents the average dry thermal strength at mid-boundary layer level of atmosphere and uses temperature, boundary layer height, and clouds, to derive an estimate of thermal strength for each day at midday (e.g., 1 p.m. EST). Higher TUV values represent stronger thermal activity and better soaring conditions. I divided the local study area into six regions based on topography and landscape attributes (Appendix A). For each of the six regions, I calculated a thermal strength per day by multiplying the TUV values within a region by the proportion of the region covered by each TUV value (measured in ArcMap 8.3). I then computed an adjusted TUV value for each region per day by summing the proportional values. The TUV for each day a bird was followed was assigned based on the region where a bird was located on that day. If a bird traversed more than one region, I averaged the TUV values among the regions used by the bird.

Wind speed and wind direction were taken from the National Climatic Data Center of National Oceanographic and Atmospheric Administration (http://www.ncdc.noaa.gov; accessed 1/2005). I used daily resultant wind speed and direction (or daily average) taken from the closest weather station to each bird on each tracking day. Because northwest winds are associated with large migration flights at ridge-top watch-sites in the eastern United States (Broun 1939), I classified the resultant wind direction for each day into four 90° sectors centered on northwest, southwest, southeast, and northeast directions.

I used the changes in sea level barometric pressure, rain, temperature and wind direction and speed to determine on which days cold fronts passed over the Appalachians Cold front passage days were defined by a drop in barometric pressure followed by rise, an increase in winds, and often by periods of rain (Grenci and Nese 2006, Young G., pers. comm.). For each tracking day I noted the number of days since cold front passage starting with 0 for day of the front, 1 for the day following the front, etc. Behavior was compared by cold front day number to see if travel or other activities varied with frontal passage. Weather attributes and thermal strength estimates were compared to daily behavior proportions to determine if weather affected migrant stopover behavior.

Habitat and Behavior

To assess if migrant behavior varied among habitats I compared the behavior of migrants by the size of the forest patch used for the evening roost location. Size of forest patch used for stopover was categorized by creating a sequence of seven circular buffers of increasing area and comparing the buffers to each forest patch used in ArcMap 8.3. The seven buffers from largest to smallest were: Contiguous Forest = forest > 400 ha, Very Large forest included forest area from 200-400 ha, Large forest =100-200 ha, Medium forest= 40-100 ha, Small forest= 10-40 ha, Tiny forest = wooded area <10 ha, or Non-forest habitat, e.g., hedgerows or forest strips <1 ha.

Stopover Length and Behavior

Stopover days were defined as any day where travel did not occur, whereas travel days were defined as days where at least some migration travel occurred. To examine behavior and stopover length, stopover days were numbered, with any day that a bird exhibited migratory travel was designated as day 0, and subsequent days during tracking spent in stopover without migratory travel were numbered sequentially one, two or more. Days prior to an observed travel period were numbered sequentially to represent days before travel, coded -1 through -4. Few birds were observed on stopover for more than four days, so only days 0, 1, 2, 3 were analysed post-migration and only days 0,-1, -2, -3 were analyzed for pre-migration comparisons. The day of trapping was omitted from stopover analyses because I could not know if a bird migrated or not prior to trapping.

Migrant behavior was compared by the average stopover duration and average travel duration (i.e., mean number of sequential days). Length of stopover was only measured after a travel day was observed, resulting in 0, 1, or 2 stopover periods measured per study bird. If the stopover length averaged less than two days, an individual was classified as exhibiting short stopover periods. If the average stopover length was two days or greater, it was classified as having long stopover periods. Each bird's mean travel period length was classified similarly into two categories, short or long.

Recent Feeding and Behavior

Behavior and stopover length of birds that had visible fat on trapping or showed evidence of recent feeding by showing a bulging crop when trapped were compared to birds without fat or bulging crops on trapping to examine if internal resources influenced migrant stopover patterns. Mean stopover length was compared between birds with fat and without fat and with full crops and without by species and age to see if birds with fat behaved differently than others. Fat and crop status were only assessed when each bird was first encountered using standard fat assessment methods as described in Delong and Hoffman (2004).

Statistical Analyses

Because daily migration behavior is strongly influenced by external factors (e.g., weather, habitat, landscape context, season) (Alerstam 1990, Petit 2000, Newton 2008) and because study birds moved regularly and often long distances, I considered each day as a separate sample (Klaassen et al. 2008). Thus, I examined daily behavior for in relation to external and internal factors (i.e., fed recently, age, species). Sample days were reduced for some questions or analyses where tracking data were insufficient. For example, roost entry and exit times were not recorded for all days of tracking, e.g., when a bird was lost or started moving prior to field team arrival.

Because the behavior data were not normally distributed for most variables due to large number of zeros, I used non-parametric Mann Whitney U tests or Kruskal Wallis tests to compare behaviors among groups (Zar 2010). I used standard t-test to compare minutes post-sunrise or minutes pre-sunset that behaviors occurred as minutes were normally-distributed (Zar 2010). To evaluate the influence of body condition on behavior, birds were coded into dichotomous categories of body condition according to whether they displayed any subcutaneous fat (Yes or No) or any crop distention on the trapping day (Yes or No) and behavior proportions and stopover patterns compared between the two groups.

I conducted a stepwise logistic regression both backwards and forwards with p value to enter at 0.15 (SYSTAT 13.0, Zar 2010). I compared travel days to non-travel days to determine which external or internal factors may be important in determining travel days for each species. Variables considered included date, days since cold front passage, rain, thermal updraft velocity (TUV fpm), cloud cover, temperature, wind direction, and the presence of a crop or subcutaneous fat on trapping.

RESULTS

The field team recorded behavior on 39 migrant accipiters on 170 autumn days in 2003 and 2004. I eliminated from consideration four birds that did not migrate during our tracking and five birds that were tracked for less than 12 h. The reduced sample included behavioral data from 62 Cooper's Hawk and 108 Sharp-shinned Hawk tracking days (n=11 Cooper's Hawks and 28 Sharp-shinned Hawks). The number of tracking days per individual ranged from 1 to 12 (mean 4.5 for Sharp-shinned Hawk, 5.6 for Cooper's Hawk), with days per bird representing 0.6% to 7.5% of total sample. Approximately half of the days from each species were from adult and half from hatch-year birds (Table 2.1).

Day length available to the birds during tracking varied through the season and across latitudes ranging from 593 to 762 min. Lost signal or non-tracking periods excluded in behavior analyses averaged 14.6% of daylight period (SD=23.7) on the 170 study days.

Daily Rhythm and Behavior Frequency

Both species began moving off their night roost early in the day. Sharp-shinned Hawks began daily movements at an average of 34.8 min (SD=51.4) after sunrise (n=75 days) whereas Cooper's Hawks began moving at an average of 17.8 min (SD=45.9) after sunrise (n=47). Both species went into night roosts before sunset, with Sharp-shinned Hawks entering the roost site an average 98.9 min (SD=95.2, n=81) prior to sunset and Cooper's Hawks entering night roosts an average of 110.4 min before sunset (SD=79.8, n=54).

Birds usually began foraging immediately after leaving the roost in the morning (>90% of days). Migration travel, if it occurred, began an average of 210.2 min (SD=131.6, n=52) post-sunrise for Sharp-shinned Hawks, and an average of 233.3 min (SD=99.1, n=27) post-sunrise for Cooper's Hawks. Most birds had a maximum of one travel period per day but others exhibited 'hops' of flight on some days where periods of migrating were broken up by short periods of stopover (14.8% of Cooper's Hawk and 20.8% of Sharp-shinned Hawk migration days).

Hatch-year birds began migration travel later in the day than adults for both Sharp-shinned Hawk (hatch-year mean=241.3 min post-sunrise, SD=151.2; adult mean=165.6 min post-sunrise, SD=81.3; t=2.307, df=51, p=0.026) and Cooper's Hawk (hatch-year mean=279.0 min post sunrise, SD=109.5; adult mean=196.7 min post sunrise, SD=74.9; t=2.221, df=27, p=0.039). Sharp-shinned Hawk hatch-year birds went to roost earlier than adults (hatch-year mean=126.2 min, SD=94.8 pre-sunset and adult mean=73.5 min, SD=89.2 pre-sunset; t=2.576, df=79, p=0.012). Cooper's Hawks showed no age difference in roost times.

On rainy days, both species selected night roosts earlier than on non-rainy days. Sharp-shinned Hawks on rainy days roosted an average of 154.6 min prior to sunset (SD= 65.7) and on non-rainy days they roosted an average of 75.4 min prior to sunset (SD=127.9; t =3.678, df=79, p=0.000). Cooper's Hawks roosted an average of 170.4 min prior to sunset on rainy days (SD=123.8) whereas on non-rainy days birds roosted an average of 95.1 min (SD=65.7) prior to sunset (t=2.992, df=52, p=0.004).

Both species spent more of the daylight period roosting and foraging than actively traveling south (i.e., migrating) during autumn (Table 2.1). On travel days, more time on average was spent migrating than in other activities but some time was spent in roosting or foraging before and after migrating each day (Fig. 2.1a & b). On travel days, Sharp-shinned Hawks spent an average of 207.0 (± 128.8) min migrating each day and Cooper's Hawks spent 209.3 (± 129.1) min migrating. The maximum number of min of travel in one day by any bird was 548 min by a hatch-year Sharp-shinned Hawk. The maximum travel period per day for Cooper's Hawks was 490 min, undertaken by an adult Cooper's Hawk.

Foraging was a common daily activity of both species regardless of travel periods (Table 2.1). Radioed birds foraged on all but two of the 170 days studied (98.8% of days). The two days that birds did not forage included a day of torrential rain associated with hurricane Ivan (2004) where a study bird roosted all day in thick cover and a second day when a bird migrated for greater than 300 min and went directly to roost without foraging.

Diurnal roosting occurred regularly, i.e., 98.8% of the days (Table 2.1). Migrating travel occurred on only 77 of the 170 autumn tracking days (45.3%). Sharp-shinned Hawks migrated on 49.1% of total days monitored and Cooper's Hawks migrated on 43.5 % of days (Table 2.1).

Accipiters exhibited non-travel flying periods, possibly used for surveying the landscape or searching for prey, occasionally throughout the study (52 of 170 days, 30.6%). Non-migrating flying events averaged 10-15 min each with daily totals ranging from 0 to 71 min encompassing less than 5% of the daylight (Sharp-shinned Hawk mean = 22.1 ± 32.5 min; Cooper's Hawk mean=12.3 ± 37.9 min) (Table 2.1). Perching occurred regularly each day as well (Sharp-shinned Hawk mean=8.5 min (SD=16.6); Cooper's Hawk mean =9.5 (SD=16.3) min; 2.0% of days) (Table 2.1).

Species and Age Comparisons

Sharp-shinned Hawks spent less of their day roosting than Cooper's Hawks for all days observed (Table 1; Sharp-shinned Hawk mean=167.6 min/day (SD=148.7), Cooper's Hawk mean=257.7 min/day (SD=165.2) U=4.147, df=1, p=0.007). Other behaviors did not vary between species (p>0.1) (Table 2.1).

Adults spent more time in non-migrating flight than hatch-year birds (Table 2.1, U=1.706, df=1, p=0.04) (Table 1). Other diurnal behaviors did not vary significantly by age (Table 2.1).

Hatch-year Cooper's Hawks spent significantly more time foraging than adults (U=282.00, df =1, p=0.006) (Table 2.1). Adult Cooper's Hawks spent more time in non-migrating flying behavior than hatch-year birds (Table 2.1) (U=616.00, df =1, p=0.025). The proportion of time spent roosting, perching, and migrating did not differ by age (Table 2.1).

Migration Travel and Daily Behavior

Both Sharp-shinned and Cooper's Hawks spent less time roosting on travel days compared to non-travel days (Fig. 2.1a, 2.1b; Cooper's Hawk U=679.0, df=1, p=0.003; Sharp-shinned Hawk U=266.0, df=1, p=0.000). Sharp-shinned Hawks spent less time foraging on travel days (Fig. 2.1a, 2.1b; U=1777.0, df=1, p=0.03) and less time on local flights on travel days as well (U=1756.0, df=1, p=0.02). Cooper's Hawks foraging and flying was not significantly reduced on travel days (Fig. 2.1a, 2.1b).

Recent Feeding, Fat, and Behavior

Adult Sharp-shinned Hawks that had fed recently (food present in crop on trapping) spent less time roosting during subsequent tracking days (n=40, U=399.0, df=1, p=0.006) and more time foraging (U=1709.5, df=1, p=0.05), but showed no difference in behavior if they had subcutaneous fat stores. In contrast, hatch-year birds spent less time foraging if they had visible fat when trapped (U= 380.0, df=1, p=0.013).

Adult Cooper's Hawks roosted less during daylight hours if captured with food in their crop (U= 151.0, df=1, p=0.03). Hatch-year Cooper's Hawks with visible subcutaneous fat at capture spent less time roosting than birds without fat (n=19, U=88.0, df=1, p=0.016). None of the adult Cooper's Hawks had detectable fat on trapping, and none of the hatch-year Cooper's Hawks had food in their crop on capture preventing those comparisons.

Stopover and Travel Duration

Both stopover and travel periods ranged from 1 to 5 consecutive days in length. The pattern varied among individuals. Some birds alternated single migration travel days and single stopover days, and others had several days of stopover and then several consecutive travel days (Table 2.2). Overall, the time study birds spent in diurnal and nocturnal stopover surpassed the time spent in travel during the migration journey. For birds followed for at least five consecutive days (Table 2.2), I found that the ratio of total h in migration travel to total h on stopover was 1:7 (including the roosting time at night, was 1:7) suggesting that stopover periods are integral to migration.

The stopover period length of all study birds of both species combined averaged 1.89 days (SD=1.15) and periods of migration averaged 1.70 consecutive days

(SD=0.93). Cooper's Hawks exhibited slightly longer stopover periods (mean=2.00 ± 1.07 days) than Sharp-shinned Hawks (mean=1.79 ± 1.19 days) (U=2148.0, df =1, p=0.05,). Mean travel period durations were similar between species (Cooper's Hawk mean=1.71 consecutive travel days (SD=0.73), Sharp-shinned Hawk mean= 1.71 days (SD=0.98)). Stopover length did not vary by age for either species.

Sharp-shinned Hawks that undertook long stopovers (two days or more) foraged more per day (n=44 days, mean=44.6%, SE=3.8%) and roosted less per stopover day (mean=32.9%, SE=3.7%) than Sharp-shinned Hawks that had short stopovers, i.e., less than two days (n=41, foraging=24.1%, SE=3.0%; roosting 45.0%, SE=4.7%): H=16.45, df =1, p=0.000; roosting: H=3.643, df=1, p=0.05). Sharp-shinned Hawks with short duration travel periods also roosted for longer during stopover days than birds that traveled for two days or more (longer travel roosting =27.2% , SE=4.2, shorter travel roosting=42.1%, SE=3.7 (H=7.9, df=1, p=0.005). Cooper's Hawks showed no difference in behavior with long or short stopover or travel periods although the sample size was small.

Cooper's Hawks with food in their crop on capture showed shorter stopover length than those without food (H=13.432, df=1, p=0.000). Travel length did not vary by crop status for Cooper's Hawks and small numbers of Cooper's Hawks showed fat stores on capture precluding analysis. I failed to detect any difference in Sharp-shinned Hawk stopover or travel length whether trapped with food or not and between birds with and without distended crops (p>0.1).

Seasonal Progression and Behavior

Number of days spent in stopover was positively correlated to date for both species, with longer stopover periods later in the autumn (Cooper's Hawk, Pearson r=0.412, p=0.024; Sharp-shinned Hawk r=0.429, p=0.001). Cooper's Hawks increased the proportion of time spent foraging during November compared to September and October months (H=8.322, df=2, p=0.02). Sharp-shinned Hawk foraging did not vary among months (H=3.94, df=2, p=0.14). No other behaviors varied among months for either species.

Weather and Stopover Behavior

Wind: Cooper's Hawks showed no difference in the proportion of time spent in travel per day under varying wind directions (p>0.1). Sharp-shinned Hawks spent more time in traveling per day on northwest winds, a mean of 35.5% (±28.6%) of their day, as compared to 13% to 23% of their day with other winds (Pearson X^2=7.842, df=3, p=0.05). I was unable to detect any influence of wind speed on daily travel duration or the incidence of travel among days for either species (p>0.1).

Cold Fronts, Rain and Clouds: The daily behavior and incidence of migratory travel did not vary with the timing of cold front passage for either species (p>0.1). However, both species avoided travel on rainy days (Coopers: Pearson X^2=9.003, df= 3, p=0.03; Sharp-shinned Hawk: Pearson X^2=11.792. df= 3, p=0.008). Although no birds traveled during steady rain, migrants did travel occasionally on days with light drizzle or when rainfall was followed by clearing in the same day. For Cooper's, 91.7% of travel days were rain-free whereas 85.7% of Sharp-shinned Hawk travel days were without rain.

The proportion of day spent roosting was significantly higher on rainy days for both species (Cooper's Hawks mean % roosting on non rainy days= 42.0 ±24.5% (SD) versus rain days= 69.0 ± 22.0%; H= 123.0, df= 1, p= 0.002; Sharp-shinned Hawk % roosting: means % non rainy days= 30.8 ± 24.1%, mean % rainy days= 50.8 ± 30.3%; H= 707.5, p=0.007). Cooper's Hawks spent a greater proportion of their day foraging on non-rainy days (non-rainy day mean% = 36.6 ± 23.9% versus rainy day mean %= 22.2 ±22.7%; H=409.0, p=0.052) whereas Sharp-shinned Hawks exhibited no reduction in foraging time on rainy days (p>0.1).

Excluding rain days, both species were more likely to migrate on days with less cloud cover (Cooper's Hawk t=1.798, df = 1, p=0.08; Sharp-shinned Hawk t=2.407, df=1, p=0.02; Fig. 2).

Thermal Strength and Temperature: Daily thermal strength (TUV) decreased with date across all regions during the study (Pearson r= -0.297, p=0.029) and was inversely correlated to cloud cover (Pearson r=-0.225, p=0.003). Thermal strength was significantly higher on travel days compared to non-travel days (mean TUV on travel days= 323.0 ±124.3 fpm; mean TUV on non-travel days= 270.5 ±140.3 fpm; t=-2.562, df =167, p=0.011). Thermal updraft velocity was inversely correlated to days since cold front passage (0-9) as well (Pearson r=-0.404, p=0.000) which suggests that lift from thermals was higher on the first days after a front. Mean daily temperature was higher on travel days than non-travel days for Sharp-shinned Hawks but not for Cooper's Hawks (SS mean temperature on travel days =57.4 (SD=9.2) ˚F, and non-travel mean= 53.3 ˚F (SD=12.0); t=1.996, df=106, p=0.05).

Predicting Travel Days and Weather

The best model of weather variables to predict travel days for Sharp-shinned Hawks included cloud cover, temperature, and wind direction (LL=-44.712, df=25, p=0.000, r^2=0.398). Only cloud cover (β = - 0.026 ±0.007 (SE), t=-2.937, p=0.003), temperature (β =0.088 ± 0.034 (SE), t=2.525, p=0.01), and variable winds (β = 4.442 ± 1.137, t= 2.456, p= 0.014) had significant influence on travel. Less cloud cover and higher daily temperatures were associated with greater travel probability (odds ratio: cloud cover=0.976 ±0.007 (SE, 95% confidence interval (95% c.i.).=0.988-0.963); temperature odds ratio= 1.039± 0.028, 95% c.i=1.076-1.003) and variable winds significantly increased the travel probability (variable wind odds ratio= 84.979 ±19.961; 95% c.i. = 2710.5-2.664).

For Cooper's Hawks the best model predicting travel days included cloud cover and temperature (LL= -103.371, r^2=0.111, p=0.021). Travel probability was higher on days with less % cloud cover (β= -0.019 ± 0.007 SE, t=--4.537, p=0.000, odds ratio=0.985 ±0.006 SE, 95% c.i.=0.989-0.973) and higher temperature (β=-0.038+0.018 SE, odds ratio=1.039, 95% c.i.=1.076-1.003). Wind direction and speed had no detectable influence on travel days for either species.

Habitat Patch Size and Behavior

Both species combined roosted longer on average per day in contiguous forest sites (>400 ha) compared to smaller forest patches (both species combined mean % roosting=51.4% in contiguous forest; mean % roosting in smaller forests= 20% to 40%; H=15.5, df=4, p=0.004). The also foraged less (mean=28% in contiguous forest versus 30 to 43% in smaller forests; H=9.283, df=4, p=0.05). Adult accipiters showed more diurnal roosting (mean=51.4%, SE=4.5%) in the contiguous forest and the least amount within non-forest habitats (mean=2.4%, SE=6.1%) (H=16.425, df=4, p=0,002). No other behaviors among forest types for age groups, although the sample sizes for smaller forests were low.

DISCUSSION

Autumn-migrating Sharp-shinned and Cooper's hawks spent a larger proportion of their days occupied in refueling and in rest than in travel. Cooper's Hawks showed no reduction in time spent foraging on travel days compared to stopover days suggesting that refueling remained a priority regardless of migration travel. Although raptors have been suggested to fast, or feed opportunistically, during migration (Smith et al 1986), I found that migrants actively foraged on a daily basis and that migrants that had not fed recently spent more days in stopover, perhaps delaying travel until adequately refueled. Research on other species of raptors using satellite tracking also shows more time spent in stopover than in travel during migration (Newton 2008).

The importance of stopover periods and quality of stopover habitat to completing a successful migration for other bird groups has been confirmed in recent studies (Mehlman et al. 2005, Moore et al. 2005, Deutschlander and Muheim 2009). Songbirds have been observed to spend more time foraging on the first day of stopover than individuals later in a stopover period suggesting the need for refueling after a migratory flight (Finch and Yong 2000, Woodrey 2000). Accipiters in this study also spent considerable time each day resting, indicating that diurnal rest may also be an important component of migration.

The large proportion of time spent in stopover by both species supports the hypothesis that stopover periods are as important to the survival and health of migrant raptors as has been found for other migratory birds. In this study, raptors did not face any substantial geographic barriers to migration and still spent several days in stopover regularly. Migration barriers may extend stopover periods as radio-tagged Sharp-shinned Hawks adjacent to a water barrier in New Jersey spent up to 96 h on stopover before departing, longer than average stopover periods in this study (Holtijuizen et al. 1985).

The behavioral patterns shown by autumn-migrating accipiters in the Central Appalachians appear to follow an energy-minimization strategy of migration rather than a time-minimization strategy (Alerstam 1990, Alerstam and Lindstrom 1990, Newton 2008). Neither species carried large fat stores and both foraged daily to maintain energy, consistent with the energy or load minimization hypothesis (Alerstam 1990). Migration timing in accipiters seemed more closely tied to individual rhythm or stopover needs rather than weather. As short-distance individual migrants, Cooper's and Sharp-shinned hawks may not need to follow a schedule as closely as long-distance flocking migrants and they may be able to migrate when both weather and internal energy stores are optimum (Smith et al. 1986). Regular stopover during travel may allow each individual to establish its own pace and forage longer when necessary.

That both species travel days were best predicted by a lack of cloud cover and warmer temperature indicates that availability of thermals may be important to accipiter travel decisions. The influence of variable winds on predicting travel days in Sharp-shinned Hawks also suggests they are less responsive to tail winds than thermal availability. Variable winds are usually light and have can produce minimal disruption to thermal development, whereas winds from other directions can be strong and disruptive to thermal development (Grenci and Nese 2006).

Diurnal roosting occurred regularly in both species and may be used for digestion, predation avoidance, and rest (Newton 1979). Although diurnal roosting encompassed 30 to 50% of the day in this study, daytime roosting was less than found in coastal Alabama where three migrating Sharp-shinned Hawks roosted for greater than 56% of time observed on average and three Coopers Hawks roosted for 85% of daytime observed, with observation duration ranging from 2 to 17 h total (Woltmann 2001), and less than found in Wisconsin for one Sharp-shinned Hawk where the researcher estimated the bird was sitting for 80% of the day (Cochran 1972). The behavior of birds in Alabama may have been influenced by the water, or migration barrier, they faced. Overall, the autumn daytime roosting in this and all other studies were greater than noted for wintering hawks in Indiana which roosted primarily at night and foraged throughout the day (Roth and Lima 2003). Together, these studies indicate that accipiter diurnal roosting and foraging behavior may vary substantially across the life cycle and perhaps the migration route. Migrating accipiters may use an energy management strategy of migration including energy-minimization as a priority but also prioritizing adequate rest within the migration period. Further research may be needed to clarify how migrant behavior varies across landscapes and whether migration barriers influence behaviors substantially.

Migration watch-sites count migrating hawks throughout the day whenever wind and weather concentrates migrants. Observers presume migrants maximize travel on such days and use less conducive weather for resting and feeding. However, daily travel periods documented here encompassed less daily time on average than roosting and foraging periods and few birds flew more than half the day. Recent satellite-telemetry research suggests the distance between breeding and non-breeding areas may influence daily migratory behavior. Satellite-tagged Osprey (*Pandion halieatus*), a long-distance migrant, spent approximately 25% of their day in migrating flight (Martell et al. 2001) and a much less migratory species, the White-tailed Eagle (*Haliaeetus albicilla*) spent only 3.5% of their day on average in migration (Newton 2008). In the Central Appalachians, migrant accipiters travel from eastern Canada and New England to winter in the mid-Atlantic and southeastern states (Goodrich and Smith 2008). The eastern population of the Sharp-shinned Hawk derives from farther north and shows a greater propensity to migrate to southern latitudes compared to the Cooper's Hawks (Bildstein and Meyer 2000, Curtis et al. 2006). The longer daily travel interval found for Sharp-shinned Hawks may be a result of their more migratory nature. Alternatively, Cooper's Hawks are strong fliers and may be able to travel farther faster thus requiring less time to travel a similar distance (see Chapter 3).

Age class patterns in foraging varied by species however the prey size class and abundance also vary substantially between the two accipiters. The larger Cooper's Hawk may be better equipped to locate prey in unfamiliar stopover sites as they can take a variety of common mid-sized birds (i.e., robins, jays, doves) and small mammals, which may be more predictable than the smaller songbird prey taken by the Sharp-shinned Hawk (Bildstein and Meyer 2000, Roth and Lima 2003, Curtis et al. 2006). Fifty percent of the Cooper's Hawk diet can be small mammals (Fischer 1985, Curtis et al. 2006).

Adult Sharp-shinned Hawks spent more time foraging than hatch-year birds, however there is likely a lower availability of songbird prey during the later migration period of adult birds. The Sharp-shinned Hawk diet is comprised of 95% small songbirds, e.g., warblers, sparrows (Bildstein and Meyer 2000). The peak of songbird migration in Pennsylvania is during late September and early October (Buskirk et al. 2009). The median date of migration for hatch-year Sharp-shinned Hawks through Pennsylvania is October 3rd, coinciding with peak songbird flights, whereas the median date of adult passage is October 14th (Hawk Mountain unpubl. data). Therefore, adult birds are migrating when prey numbers are diminishing.

Most accipiters are not known to put on considerable fat prior to migration (Delong and Hoffman 2004) and few raptors will put on more than 20% of their body weight in fat (Bildstein 2006). Kjellan et al. (2001) found that raptors with more fat were less likely to forage, similar to the hatch-year birds in this study. Adult and hatch-year Sharp-shinned Hawks showed opposite patterns in this study, suggesting further research may be needed to clarify migration strategies and foraging behavior between age classes. Some studies have found that long-distance migrants may forage more prior to crossing areas where foraging opportunities are unlikely (Yosef 1996). Adult Sharp-shinned Hawks captured with distended crops may forage more, in contrast to hatch-year birds, because prey are more limited during their later travel period and thus maybe more infrequently encountered. Due to the earlier timing of their migration, hatch-year accipiters may find prey more easily and be able to feed more regularly than adults. Differences between the two species may arise from differences in migration destination, body size, prey availability or migration strength, as well.

Adults of both species exhibited slightly more non-migrating flight than hatch-year birds. Such flights may be used to survey for prey concentrations or potential new roost sites (e.g., Fischer 1986) however, flights also can expose the individual to predators or other hazards (Roth et al. 2005). On one occasion I observed a radio-tagged Sharp-shinned Hawk attacked by another accipiter during a high circling flight above its roost site, driving it back into roost for the remainder of the day. Young birds may fly less as they could be wary of leaving the safety of a stopover forest in an unfamiliar region (Woodrey 2000). Predator avoidance has been suggested to be an important part of stopover habitat selection (Moore and Aborn 2000). Also, if prey availability is lower during the later migration period of the adults,, adults may need to move more widely to find adequate prey.

Individual birds varied in intervals of migration travel and stopover. The interspersion of travel and stopover periods may depend on resource availability and individual differences (Loria and Moore 1990). The length of stopover is likely dependent on a migrant's success in replenishing energy reserves or fat stores (Walsberg 1990) but also may be influenced by conditions conducive to migration such lift from thermals or wind (Kerlinger 1989, Newton 2008). Accipiters appear to respond to both factors in setting their migration pace or pattern. Both showed longer stopover when they had not fed recently and more travel on days when thermals were strong. Because raptors fly singly they may be more apt to establish individual rhythms and cues than songbirds or shorebirds. The mean stopover length for accipiters in this study (i.e., two days) was similar to that found for songbirds in some studies (Loria and Moore 1990, Finch and Yong 2000). The periodicity of migration and stopover may vary with general migration strategy, body condition, distance from wintering areas, experience, and deserves further investigation.

Cold front passage was not related to travel initiation in this study in contrast to research using migration counts (Broun 1939, Allen et al 2006), although, longer travel periods occurred on northwest winds for Sharp-shinned Hawks, Cooper's Hawk's travel appeared most strongly influenced by low cloud cover, suggesting they may be a more 'broad-front' migrant than previously thought (Bildstein 2006). The heavier body of the Cooper's Hawk may give it an advantage over the smaller Sharp-shinned Hawk during thermal-soaring (Kerlinger 1989, Bildstein and Meyer 2000, Curtis et al. 2006). Thermal lift can help birds save energy in flight and could be an important component of an energy-minimization strategy (Kerlinger 1989).

Accipiters avoided travel on days of heavy cloud cover or rain. Harmata (2002) also found that Bald Eagles avoided migration travel on days of total overcast, and cloud cover has been noted to inhibit migration take-off in raptors in Texas (Kerlinger and Gauthreaux 1984). Because thermal strength is inversely related to cloud cover, these results emphasize the importance of thermals to migrating raptors, consistent with radar studies in eastern New York (Kerlinger and Gauthreaux 1984). Cloud cover can also inhibit sun-compass orientation in birds, although it is not clear if raptors use this method of navigation (Berthold 1996).

The behavior of radio-tracked accipiters in this study indicates that weather may concentrate migration, but other factors are important in individual travel decisions (i.e., energy refueling and rest). Strong thermals may allow for efficient travel on days when migrants are not likely to be seen along leading or diversion lines.

Holthuijzen et al. (1985) found that Sharp-shinned Hawks roosted most when in woodland with more flying conducted in open habitats. Edge habitats can offer greater densities of autumn-migrating songbirds (Rodewald and Brittingham 2002, Keller et al. 2009), a popular prey of accipiters. Although Keller et al. (2009) found more forest-interior songbirds within forest-interior habitats during autumn migration in southern Pennsylvania. I suggest that accipiters selected contiguous forest for stopover when they need to prioritize rest and avoidance of predators, similar to migrating tanagers (Moore and Aborn 2000). These sites can provide appropriate prey in some circumstances as well (Keller et al. 2009). Songbirds on stopover often move beyond their preferred habitats in search of prey when they are fat-depleted (Petit 2000, Barrow et al. 2000). Adult accipiters may choose smaller forests when prey have been difficult to find in larger forests and when they are hungry and thus spend more time foraging in these habitat types as that is their priority. I suspect this may be why the study noted higher levels of foraging in accipiters using small or non-forest habitats.

In summary, migrant raptors may follow a more flexible and complex migration strategy than previously understood. Stopover periods appear to be important components of the migration journey for both Sharp-shinned and Cooper’s hawks, and the availability of suitable stopover forests along migration routes could be critical. Weather appears less important in migration travel choices than refueling opportunities and energy management, although further research is needed. Further radio-tracking studies comparing behavior patterns of long-distance and short-distance migrant raptors at different latitudes could be useful in clarifying how fat levels, destination, and energy needs affect behavior and stopover and travel choices during raptor migration.

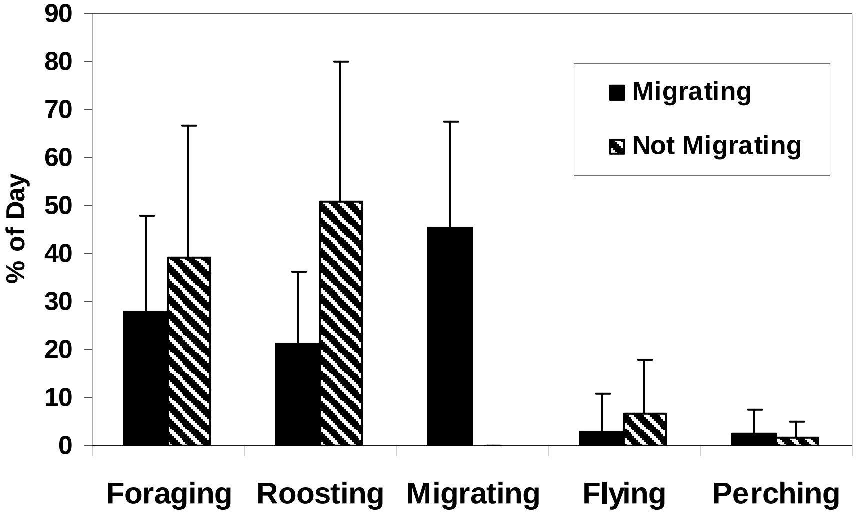

Figure 2.1a. Mean proportion of day (±SD) Sharp-shinned Hawks spent in different behaviors when migrating and not migrating in autumn 2003 and 2004 (n=29 birds, 107 days).

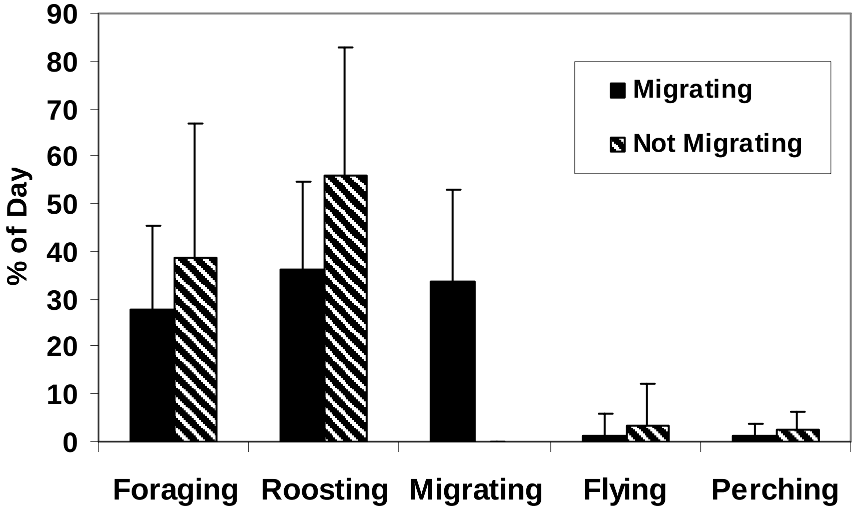

Figure 2.1b. Mean proportion of day (±SD) that Coopers Hawks spent in different behaviors on migration and non migration days in autumn 2004 (n=11 birds, 62 days).

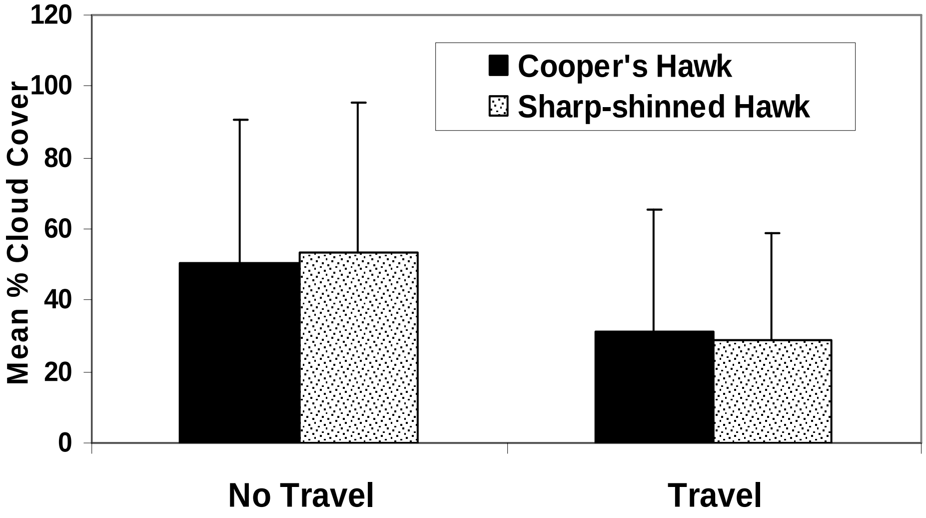

Figure 2.2. Mean (±SD) % cloud cover on non-travel days and travel days for migrating Cooper's (t=2.362, df=1, p=0.02) and Sharp-shinned hawks (t=4.591, df=1, p=0.000), excluding rain days.

Table 2.1. Proportion of day migrant accipiters spent in different activities during autumn, 2003-2004.

				Mean % of Day (SD)[a]					
Species	Age	# Birds	# Days	Perching	Flying	Foraging	Migrating	Roosting	No Signal[b]
Sharp-shinned Hawk	All	28	108	2.0 (4.2)	4.7 (11.3)	33.6 (24.5)	23.4 (28.3)	32.6 (27.4)	17.1 (26.1)
	Adult	13	52	2.0 (4.4)	6.4 (11.5)	39.2 (28.2)	19.8 (28.5)	32.7 (27.3)	14.1 (24.8)
	Immature	15	56	2.1 (4.1)	3.2 (8.1)	28.3 (19.1)	26.9 (27.9)	39.7 (27.2)	20.8 (28.2)
Cooper's Hawk	All	11	62	1.8 (3.0)	2.5 (6.4)	33.8 (6.8)	14.6 (21.4)	47.2 (26.2)	9.8 (20.9)
	Adult	6	33	1.9 (3.4)	3.2 (8.1)	26.1 (21.2)	17.9 (25.0)	50.9 (27.4)	6.7 (16.6)
	Immature	5	29	1.7 (2.7)	1.8 (7.2)	42.7 (24.7)	10.8 (16.0)	43.0 (24.5)	13.2 (24.9)

[a] Perching=perching for <30 min; flying=non-migrating flight; foraging=intermittent perch-flight periods; migrating=traveling in one direction for >3 km; roosting=perching for $\geq$30 min; no signal=transmitter signal lost;

[b] No signal time derived from total daily minutes, proportions of other behaviors based on total minutes minus no signal period.

Table 2.2. Periodicity of travel and stopover days in migrating Sharp-shinned and Cooper’s hawks tracked for more than five days, during autumn 2003-2004 in the Central Appalachians.

		Days Since Capture											
Species	Bird ID	1	2	3	4	5	6	7	8	9	10	11	12
Sharp-shinned Hawk (*Accipiter striatus*)	856	N	N	N	N	N	Y	Y	Y	Y			
	126	N	Y	Y	N	N	Y						
	961	N	Y	N	Y	N	Y						
	387	N	N	N	Y	Y	Y						
	740	N	Y	N	N	Y	N	Y	Y				
	794	Y	N	N	Y	N	Y						
	805	N	N	Y	N	N	Y						
	611	N	Y	N	N	Y							
	856	N	N	N	N	N	Y	Y	Y	Y			
	896	N	Y	N	N	N	N	N					
Cooper's Hawk (*A. cooperii*)	395	N	N	N	N	Y	Y	Y	N	Y			
	418	Y	Y	N	N	N	Y	Y	N	N	N	Y	Y
	547	N	Y	N	N	Y	N						
	99	Y	N	N	N	N	N						
	180	N	N	N	N	Y							
	606	N	Y	N	Y	Y							
	697	N	N	Y	N	N							

[1]‘Y’ = travel day, ‘N’=stopover day, Day 1= capture day, birds were tracked until they were lost or left.

Chapter 3. Flight Behavior of Autumn-migrating Accipiters in the Central Appalachians.

ABSTRACT

Understanding migration patterns and the influence of landscape and weather on the choices migrants make en route may be critical to effective conservation of migratory bird populations. The Kittatinny Ridge of the Central Appalachians is one of the most important corridors for autumn-migrating raptors in the eastern United States. How migrants use the Ridge or adjacent regions and how that varies with weather is largely unknown. In this study, I trapped and radio-tracked two species of accipiters on the Kittatinny Ridge during the autumn migration and mapped and measured their daily migration direction, distance, speed, and ridge-fidelity. I compared patterns among species, age classes, regions, and by weather variables including wind direction, wind speed, cloud cover, thermal strength, and the timing of cold front passage. Data was collected for 89 autumn migration days from 44 individuals, including 30 migration days from 12 Cooper's Hawks (*Accipiter cooperii*) and 59 days from 32 Sharp-shinned Hawks (*A. striatus*) tagged between 2 September and 22 November, 2003 and 2004. The proportion of migration time each bird spent in four topographic regions was compared (e.g., the Kittatinny Ridge, the adjacent southern valley, the northern ridges, and Plain and Piedmont region). The two species followed different migration directions with Sharp-shinned Hawks migrating to the southwest (mean=216º) and Cooper's migrated more to the south (mean=190º). Direction did not vary by age or region. Adult Cooper's Hawks flew farther and faster on average than both adult and hatch-year Sharp-shinned

Hawks and hatch-year Cooper's Hawks. Both species spent more time migrating on the Kittatinny Ridge than in the adjacent valley or other regions, but flew faster in the Coastal Plain.. Several Cooper's Hawks crossed bays and inlets during radio-tracking when traversing the Plain region south.

Migration travel days occurred under a wide variety of weather conditions. Accipiters appeared to use both tail winds and thermals to aid their migration journey. Flight directions differed with cross winds in both species. Birds tracked slightly more westerly with northeast and southeast winds, suggesting some compensation for wind drift may occur. Northwest winds and tail winds resulted in farther or faster daily migrations for Coopers Hawks. Sharp-shinned Hawks spent less time migrating on northwest winds but other flight characteristics did not vary with wind direction. Both species flew longer and faster on days with strong thermals and less clouds. Sharp-shinned Hawks migrated faster on the day of frontal passage and Coopers Hawks migrated farther. Migrants appear to alter their flight behavior to achieve similar migratory distances under a variety of weather conditions. Although both Cooper's Hawks and Sharp-shinned Hawks appear to utilize an energy-minimization strategy of migration with shorter flights allowing extensive diurnal feeding time. Cooper's Hawks also seemed to incorporate a time-minimization strategy south of the Appalachians, prioritizing short migration flights with longer stopovers on the Kittatinny Ridge followed by long-distance 'power' flights with minimal stopover time when flying across the Coastal Plain and Piedmont region. The larger Cooper's Hawk may be better suited than the Sharp-shinned Hawk for using thermals for soaring flight and for spending days in power flights where feeding is minimal during passage over inhospitable terrain.

Adults and hatch-year birds showed few differences in migration travel behavior within Central Appalachians. Additional studies in regions without leading or diversions lines would be helpful in determining if the lack of age differences were due to landscape restraints. Further research on flight behavior of radio-tagged migratory raptors is encouraged to build a better understanding of raptor migration behavior and ecology.

INTRODUCTION

The bi-annual seasonal migration of birds between breeding and non-breeding areas plays a critical role in their long-term survival and fitness (Berthold 1996, Sillett and Holmes 2002, Holmes 2007). Estimated annual mortality is highest during this period of the life cycle (Sillett and Holmes 2002) and many birds face unknown landscapes and threats (e.g., Brown et al. 2000). As landscapes and habitats encountered by North American migrants change, understanding migration behavior and the factors that challenge and influence a successful migration and migrant survival is important for long-term conservation of migratory bird populations.

Migration has both genetic and learned components (Berthold 1996, Alerstam and Hederstrom 1998). Many species have been shown to harbor an internal migration drive, migration direction, and for some, a sense of the total migration distance or duration (Berthold 1999, Newton 2008). This innate ‘time-distance’ knowledge allows inexperienced autumn migrants to arrive at an appropriate latitude or region to survive the non-breeding season. Adult birds are thought to have acquired a more exact ‘map’ of their journey so if displaced they make adjustments to their migration track to achieve their destination (Kerlinger 1989, Berthold, 1999, Newton 2008). For example, adults have been found to be better than hatch-year birds at compensating for cross winds that can push migrants off course (Thorup et al. 2003). Despite these findings there remains debate about how wind affects raptor migration and whether wind drift occurs and affects hatch-year birds to a greater extent than adults (Murray 1964, Kerlinger 1989, Bildstein 2006, Newton 2008).

Both individual condition and external factors can affect daily decisions by individual migrants (Schaub et al. 2004, Newton 2008). Fuel load, weather, and seasonality have been found to influence when a raptor initiates travel and its daily duration (Kerlinger 1989, Berthold 1996, Woltmann and Cimprich 2003). Potential risks also may influence the orientation and the route selected by migrating birds (Buler et al. 2007, Hedenstrom 2007, Deutschlander and Muheim 2009). Overall, migrants may strive to minimize time spent in their migration, i.e., ‘time-minimization hypothesis’, which would lead to heavy foraging followed by days of long migration travel with little foraging (Alerstam and Lindstrom 1990). Alternatively, migrants may strive to minimize energy expenditure during migration, the “energy minimization hypothesis or load-minimization hypothesis” (Newton 2008). These migrants may feed regularly and fly shorter distances to avoid gaining too much weight that could impinge on flight performance and predator avoidance ability. Such migrants might travel when weather conditions are optimal for flight to minimize energy cost but should also show regular foraging en route (Alerstam 1990, Newton 2008). Long-distance migrants such as the Peregrine Falcon (*Falco peregrinus*) may follow a time minimization strategy (see Fuller et al. 1998), however little is known about the patterns followed by short-distance migrants such as accipiters.

Recent advances in telemetry have allowed a greater understanding of migration routes and timing in long-distance migrants (Fuller et al. 1998, Mandel et al. 2008, Klaassen et al. 2008, Newton 2008). However, many of these studies have involved taking locations on migrants a few times a day at best. Few studies have examined the behavior and flight patterns of smaller raptors, such as accipiters (but see Cochran 1972). And, few studies have provided the detail to examine how raptors move through a landscape and respond to topographic changes on a daily basis.

One key aspect of migration behavior is direction of travel. Migration routes used by raptors may be influenced in part by the habitat and landscape context (Chapter 4, Niles et al. 1996). Yet in many cases raptors travel long distances over inhospitable terrain heading towards their non-breeding areas (e.g., Thorup et al. 2006). Kerlinger (1989) suggested that eastern Sharp-shinned Hawk populations have an inherited 'principle axis of migration' during autumn that is represented by a line from the center of their breeding to non-breeding areas, or along a hypothesized migration axis of 215º. Yet, birds tracked with radar in eastern New York followed a more southerly path, 193º (Kerlinger et al. 1985a) and Red-tailed Hawks following Central Appalachian ridges appear to be heading to the west or southwest, 230-270º (Kunkle et al. 2009). Individual migration direction may vary with latitude, landscape, weather, and possibly age and other internal factors (Niles et al. 1996, Fuller et al. 1998, Newton 2008). Understanding how migration direction decisions are made by raptors and what influences those decisions will enhance our understanding of migration ecology.

Weather has long been recognized to have major influence on migration behavior and patterns (Richardson 1978, Alerstam 1990). Diurnal raptors migrate at lower altitudes than nocturnal songbird migrants and regularly use lift from air currents such as thermals and updrafts to save energy during flight (Kerlinger and Gauthreaux 1984, Kerlinger 1989, Shamoun-Baranes et al. 2003, Bildstein 2006). The passage of cold fronts and north or northwest winds increases the numbers of raptors observed at diversion or leading lines such as coastlines and mountain ridges in eastern North America (Broun 1939, Titus and Mosher 1983, Allen et al. 1996, Maransky et al. 1997, Bildstein 2006). Raptor migration scientists presume more autumn-migrating raptors are traveling after a cold front and when tail winds are present than at other times because that is when counts at watch-sites are highest (Broun 1939, Kerlinger 1989). During inter-frontal periods, it is hypothesized that some may take time to rest and feed awaiting conducive tail winds or updrafts to assist their flight. Because few marked birds have been followed closely during migration until recently, the travel choices of individual raptors in relation to weather are little understood (Kerlinger 1989, Bildstein 2006).

Birds that can migrate more quickly and with less energy costs should realize greater overall fitness (Berthold 1996, Kerlinger 1989, Newton 2008). Accipiters usually fly with a powered flapping flight broken by intermittent glides. During windy days many are observed to use updrafts along Appalachian ridges, presumably to save energy en route (Broun 1939, Heintzelman 1986, Allen et al. 1996). Powered flight is more metabolically expensive than gliding flight and both are more energy consumptive than soaring, so finding a balance between a migration drive and energy savings could be important for these species (Kerlinger 1989). The strategy and flight pattern chosen may even vary among closely-related species. For example, the Cooper’s Hawk is larger than the Sharp-shinned Hawk and it feeds regularly on mammals (Curtis et al. 2006). The

Sharp-shinned Hawk feeds nearly exclusively on small birds, which may make refueling more challenging (Bildstein and Meyer 2000). The diet and size differences of these two species may allow Cooper's Hawks to remain farther north during the non-breeding season. The larger size of the Cooper's Hawk may allow it to exploit thermals more readily than the smaller Sharp-shinned Hawk (Kerlinger 1989).

Migration strategy may vary within a season and by latitude and topography as well. Although accipiters glide rapidly in ridge updrafts when winds are favorable (Broun and Goodwin 1943), they also use soaring flight for at least part of their annual migration journey (Cochran 1972, Kerlinger et al. 1985). The flight behavior used may affect migration speed and distance (Fuller et al. 1998, Thorup et al. 2007).

In the Central Appalachians, the Kittatinny Ridge has been identified as a key migration corridor for North American raptors and a state and national Important Bird Area (Crossley 1999, Van Fleet 2001, Bildstein 2006). Large numbers of hawks (>19,000/autumn) are counted at several sites along the ridge each autumn and several species are seen here in greater numbers than other sites in the eastern North America (Goodrich and Smith 2008).

Some Red-tailed Hawks (*Buteo jamaicensis*) will follow the Ridge for greater than 120 miles whereas others leave the ridge after following it for short distances (Kunkle et al. 2009). Although thousands of accipiters are sighted on the Kittatinny Ridge each autumn (Goodrich and Smith 2008), the degree to which birds follow the Ridge for long distances is unknown. Ridge-fidelity may also vary with age. Immature raptors have been suggested to be more likely to leave the Ridge, possibly due to wind drift and lack of experience (Murray 1964, Mueller and Berger 1967, Kerlinger 1989, Thorup et al. 2007). In contrast, adult and hatch-year Red-tailed Hawks did not differ in ridge affinity in a recent study (Kunkle et al. 2009). The degree of migrant fidelity to the Kittatinny Ridge, how migration patterns vary among species or age classes, and how migration patterns vary with weather is important to developing conservation plans for this important migration corridor and understanding trends derived from counts.

In this study, I examined the daily autumn migration behavior of two species of accipiter as they traveled along the Kittatinny Ridge and through the Central Appalachians. I radio-tagged migrant Sharp-shinned and Cooper's Hawks during autumn migration and followed them from dawn to dusk to study migration behavior, direction, distance, and speed and compared the patterns observed by species, age, topographic region, and weather.

METHODS

Study Area

Birds were trapped on the Kittatinny Ridge, or Blue Mountain, located in the Ridge and Valley Province (www.dcnr.pa.us/topogeo) of eastern Pennsylvania. For further description of the study area see Section 2.3.

Trapping

Between 2 September and 22 November in 2003 and 2004 48 accipiters (34 Sharp-shinned and 14 Cooper's Hawks) were banded and radio-tagged. The birds were caught by a volunteer team between 0830-1630 h under federal banding permit 21371 (Pennsylvania State permit 00032, Penn State University IACUC permit # 19240). For further details on trapping methods see Section 2.3.

Radio-tracking

Birds were followed using two four-wheel drive vehicles equipped with four-element yagi antennas mounted on a 4 m telescoping pole attached to the vehicle through the sunroof, allowing 360 º rotation and tracking while driving. For further details on radio-tracking see Section 2.3.

Migration Flight

Migration flights were defined as a bird flying in one direction for over three kilometers. Flight time was recorded as the time from when the bird left its perch to when it perched again. Signal quality and strength, time of day, and the bearing from the observer to the bird were recorded throughout each migratory flight and were used to estimate the bird's location and progression during travel periods. Both perch location before flight and perch location at end of flight were triangulated and mapped using at least three bearings entered into LOCATE II software, for a best estimate of the beginning and ending locations.

During tracking of each bird, the path the bird took was mapped in GIS ArcMap 8.3 software by mapping each bearing taken by the two tracking teams as a vector starting with the tracker's location and with the vector length reflecting the estimated distance to the bird based on signal strength and quality. Bearings were taken as frequently as possible as the bird traveled. The overlap of vectors from the two tracking teams allowed an approximate point estimate of the bird's location. Where two vectors were not available, the signal strength and quality, as well as subsequent field measurements and vectors mapped for the bird, allowed an approximation of bird's location or path.

Estimated locations were mapped into a GIS migration travel map for each bird for each day (see Appendix A). Other data collected for each travel point mapped included the date, time, topographic region, and weather variables for that day and time. To examine seasonal timing effects on travel parameters, I classified each observed travel day by day number (1-365) and early and late season periods (divided by October 15th based on the 95% passage period for accipiters on the Kittatinny Ridge (Bednarz et al. 1990). Regions were classified as on the Kittatinny Ridge in Pennsylvania (Kittatinny), in the valley directly south of Kittatinny Ridge but north of South Mountain (Valley), in the Appalachian ridges to the north or west of the Kittatinny (Ridges), or in the Plain or Piedmont topographic regions of southern Pennsylvania, New Jersey, Delaware, Maryland, Virginia, from the South Mountain south (Plain) (see Appendix B). For some analyses I grouped the Kittatinny with other ridges (Ridges-grouped) and compared them to valley and Plain regions.

Travel Parameters

Daily travel point estimates and the beginning and ending flight points for each bird were organized in date-time order in ArcMap 9.0 and used to create a time-based map of the daily movement of each bird. Only days where birds underwent migratory travel were considered in these analyses. Because most birds began and ended their days with low or high flying behaviors that would evolve into migration travel or devolve from migratory travel, I defined the daily travel initiation as the point when the bird began flying when beginning migratory flight behavior and the daily travel end as the point when they stopped flying for the day. This measure, the ‘daily travel distance and duration’, was longer than migratory periods identified during daily time budgets (see

Chapter 2) because during time budget analyses I separated low and high flight behaviors as distinctive from migratory travel behaviors. Low and high flights occurred on non-travel days as well as travel days, although on non-travel days movement was more often in non-specific directions as birds moved sporadically within or between forests. In assessing migratory travel, low or high flights could often be observed towards the end of a daily journey however, they were still part of daily travel so I included them in these analyses.

The Hawth's Tools spatial ecology add-on analysis package (www.spatialecology.com, ArcMap 9.0) was used to calculate the step length (m) between each daily travel point, the bearing or direction the bird traveled between each point, and the net displacement distance for each daily flight. The displacement distance between consecutive points was used for analyses as it measured the net distance traveled by the bird in one direction between two migration points, or net displacement, and did not include distance traveled in any circling, or lateral or reverse movement. Individual displacement distances were summed for each day between as many point locations as were available for a bird's migratory travel period. If the bird changed its direction during flight (i.e., a new step), I calculated a new bearing and displacement distance for that step or travel leg. Thus, the total daily displacement represented the sum distance of total migration steps for a bird in one day, which is a more accurate representation of total flight distance than the net displacement from start to finish only. Thus, the daily net displacement represented a conservative best estimate of total flight distance during one day.

For each travel day per bird I recorded the total minutes spent traveling (i.e., duration), the median direction of flight (i.e., the median bearing between all point locations derived for a day) and the distance traveled, (i.e., the sum of the net displacement distance (m) for that day). A daily travel rate was derived by dividing daily displacement distance by minutes lapsed from initiation of flight to its end. I also computed a mid-flight travel rate each day during a one hour period mid-way between flight beginning and ending to assess a flight rate not including the beginning and ending flight periods. Mid-flight rates were only derived for days when there was adequate point estimates of the bird's location throughout the day. The travel rates measured in this study represent ground speeds of the birds and not air speeds (Alerstam 1990, Kerlinger 1989). Flight speeds can be faster or slower than ground speeds depending on air movements.

To examine how birds used the landscape on migration, I derived the total duration of flight per bird as the sum of time (min) spent traveling during our observations summed over all days available for each bird. The total travel time was then used to compare the proportion of each bird's migratory travel that was spent flying within the different topographic regions.

Weather

For thermal strength and cold front passage timing estimation see Section 2.3. Hourly weather data (e.g., temperature, wind direction, wind speed, and cloud cover) was obtained from the National Climatic Data Center for cities nearest to where birds were located (www.ncdc.noaa.gov; accessed 1/2005). For each estimated location for each bird I gathered the weather from the nearest weather station to the bird for that hour. The weather parameters were then averaged for all hours spent in travel each day to provide the best estimate of the weather occurring for that bird during its daily journey. I designated days with measurable rain or fog using two dichotomous codes indicating days with rain and days without rain, and days with fog (including days with morning fog only) or not.

Statistical Analyses

Daily migration behavior can be influenced by several external factors (weather, habitat, landscape context, season; Alerstam 1990, Petit 2000, Newton 2008). And, study birds moved regularly and encountered different landscapes, weather, and habitats. Because the conditions encountered by study birds varied substantially and because travel days were usually separated by stopover days, I considered each travel day as a separate sample as has been done in other radio-tracking studies (e.g., Klaassen et al. 2008). The direction of daily migratory travel and the effects of other variables on travel direction (e.g., wind direction) were analyzed using circular statistics (Orianna software, version 3.0); Zar 2010). The Rayleigh test for Uniformity was used to assess if the travel vectors followed by species or age groups showed significant nonrandom directionality, and the V test was used to assess if the mean angle of flight followed the line of the Kittatinny Ridge (Zar 2010). The travel and wind directions were found to fit a von Mises distribution which allowed us to use the Watson-Williams test and other parametric circular statistics to compare among groups (Zar 2010).

A multiple ANOVA and t-tests were used to examine the linear normally-distributed variables including duration of travel, distance, and rate of travel in relation to weather and topographic variables and their interactions. Wind direction was transformed into radians for use in parametric analyses. Influence of weather parameters on migration patterns was examined first by species and then by age due to sample size constraints. Kruskal Wallis non-parametric statistics were used to compare the proportion of the total travel time spent in each of the topographic regions by each age and species group. Post-hoc comparisons among groups were made using Tukey's Honestly-Significant-Difference and Student-Newman-Keuls tests for parametric comparisons and using the Dwass-Steel-Chritchlow-Fligner Test for post-hoc non-parametric comparisons.

RESULTS

Migration travel data were collected on a total of 89 days from 44 individuals, including 30 days from 12 Cooper's Hawks (six adult) and 59 days from 32 Sharp-shinned Hawks (eleven adult). The 89 days included one to six per study bird, or an average of 1.88 (±1.15 SD) travel days per bird (Fig. 3.1 and 3.2). Mid-flight travel rates were derived for 20 Cooper's Hawk days and 51 Sharp-shinned Hawk days.

Birds travelled predominantly in the southwest to south direction for the duration of their flight path, although some exhibited movement to the east and west during part of their journey (Fig. 3.1 and 3.2). Four birds were followed to wintering locations within the study area which may have influenced their migration direction compared to study birds traversing the study area for destinations south of Delaware and Maryland. For instance, a bird wintering in southern New Jersey, eastern Maryland or Delaware would need to head south or southeast from the trapping location whereas birds heading to the southeastern United States would travel to the southwest to reach their destination and avoid crossing water (Kerlinger 1989). I included these data in the analyses because the wintering destination was unknown for other study birds. ‘Wintering’ was defined by birds remaining into January at one location.

Travel Direction

Travel patterns of both species during autumn migration exhibited significant non-random directionality (Rayleigh test: Cooper’s Hawk z=16.018, p=0.0003; Sharp-shinned Hawk z=32.40, p=0.0000) (Fig. 3.3). The two accipiters differed in their mean direction of travel through the study area with the Cooper’s Hawk exhibiting a mean flight direction predominantly to the south-southwest and the Sharp-shinned Hawk following a mean direction more to the southwest (Watson-William F=6.423, p=0.013, n=89) (Table 1, Fig. 3). No difference was found in mean direction by age class for either species (Watson Williams F-test, p>0.05) (Table 3.1).

The mean direction of travel also did not vary among the three main topographic regions for either species (Ridges-grouped, Valley, Plain) (Table 3.2). Moreover, although all birds were trapped on the Kittatinny Ridge and most birds followed the Kittatinny Ridge for part of their journey (Fig. 3.1, 3.2), the mean travel direction of both species over all days was significantly more southerly than the predominant direction of the Kittatinny Ridge in the study area (249º) (Cooper’s Hawk: V = 2.929, p= 0.002; Sharp-shinned Hawk: V = 6.785, p= 0.0000). Most study birds followed the Kittatinny Ridge through east-central Pennsylvania but veered to the south of the Ridge in south-central Pennsylvania (Fig. 3.1, 3.2).

Travel Duration

A total of 643.03 hours of travel behavior were observed on travel days including 380.67 hours for Sharp-shinned Hawks and 262.37 hours for Cooper’s Hawks. Although travel duration varied substantially among days (see Chapter 2), some birds in both species traveled for long periods per day (Cooper’s Hawks maximum travel=13.03 h; Sharp-shinned Hawk maximum=12.9 h).

Travel Distance

Sharp-shinned Hawks averaged 60.1 km daily travel distance (Table 3.1), and their maximum daily distance was 238.44 km (n=59). Adults and hatch-year Sharp-shinned Hawks did not differ significantly in their daily distance (Table 3.1). Cooper’s Hawks traveled for longer distances on average than the Sharp-shinned Hawk (Table 3.1; t= 2.19, df=1, p=0.035). Adult Cooper’s Hawk traveled three times longer on average during daily journeys compared to hatch-year birds (Table 3.1) (t=2.891, p=0.009). The longest one-day travel distance of a Cooper’s Hawk was 394.98 km (n=30).

Travel Speed

Adult Cooper’s Hawks flew significantly faster than hatch-year birds (Table 3.1; t=2.26, p=0.032). The Sharp-shinned Hawk rate did not vary by age (p>0.1). Mid-flight travel rates were higher than daily flight rates for both species, with Cooper’s Hawks traveling at a mean of 32.3 km/h (SD=16.7) and Sharp-shinned Hawks traveling at mean mid-flight rate of 16.2 km/h (SD=10.7). The Cooper’s Hawk mean mid-flight rate was faster than that of the Sharp-shinned Hawk (t=4.84, df=69, p=0.000). Maximum mid-flight rates recorded for each species respectively were 65.6 and 40.4 km/h respectively. Mid-flight rates did not vary by age or seasonal period for either species, although the sample sizes were small.

Travel within Topographic Regions

The total time observed in travel for each individual ranged from 0.62 to 44.47 h. Although birds were trapped on the Kittatinny Ridge, valley and northern ridge flight was equally available to birds as these regions bordered the Kittatinny Ridge. Some individuals made extended flights over the Plain region and others used Northern Ridges (Fig. 3.1 and 3.2). However, both species spent a greater mean proportion of the observed travel time flying on the Kittatinny Ridge compared to other regions (Table 3.2, Appendix C). A pair-wise comparison using the Dwass-Steel-Chritchlow-Fligner Test showed that the proportion of travel on the Kittatinny Ridge differed from all other regions ($p<0.001$ for all comparisons) but other regions did not differ from each other.

The distance traveled per day varied among regions for both species (Table 3.2). Cooper's Hawks traveled farther in the Plain region but showed no difference in distance between Kittatinny Ridge and nearby valley (Tukey's test difference Plain-Kittatinny Ridge=188.023, $p=0.001$; difference Plain-Valley=170.87, $p=0.002$). Sharp-shinned Hawks had longest flights in the Valley and shortest in Northern Ridges whereas no difference was seen in flights between Kittatinny and the Plain region (Tukey's northern ridges-Plain test difference= -69.57, 0.025) (Table 3.2).

The Cooper's Hawk daily rate of travel was faster in the Plain region compared to the Kittatinny Ridge or adjacent Valley (Tukey's difference Plain-Kittatinny=24.717, $p=0.0001$; difference Plain-Valley=20.855, $p=0.001$) (Table 3.2). Sharp-shinned Hawks also traveled faster when flying through the Plain and Valley regions and slower in Northern Ridges compared to the Kittatinny Ridge. The only difference among groups was found for northern ridges compared to Valley (Tukey's difference=-11.297, p=0.032) (Table 3.2).

Mid-flight rates by species did not vary among topographic regions; however, when species were pooled mid-flight rates were higher in the Plain region (mean=36.4 km/hr (SE=4.2) versus 18 to 23.4 km/hr; F=4.683, df=3, 56, p=0.005). Plain-flying birds flew faster than birds traveling on the Kittatinny Ridge (Tukey's Difference =18.006, p=0.002). Despite differences in flight parameters, the thermal updraft strength and wind direction did not vary significantly among regions on travel days.

Weather and Travel

On travel days, the thermal updraft strength varied from 50 to 550 ft/min across the region. Wind direction and speed varied widely among days with no predominant direction shown. Wind direction and thermal updraft velocity were correlated, with higher thermal updrafts on days of southwest to northwest winds (r=0.267, p=0.016). Thermal strength was also higher on the first days following a cold front passage (see Chapter 2).

Wind Direction and Speed

The Sharp-shinned Hawk travel direction differed significantly when winds were from the northwest as compared to the northeast. Northeasterly winds resulted in a more westerly travel track than with northwest winds (NE mean=240.0°±23.3° SD vs. NW mean = 210.2°±35°; F=4.336, p=0.05, df=20,7). Cooper's Hawks exhibited a more westerly flight direction on southeast winds compared to southwest winds (SE mean vector=215.8° ±14.6° vs. SW mean=165.9°±43.6°; F=6.786, p=0.02, df=6, 8). Flight direction did not differ among other wind sector pairs for either species but the sample size for some groups was small.

Sharp-shinned Hawks spent less time per day migrating on northwest winds (mean= 4.67 ± 2.65 h) compared to other wind directions (F=2.745, p=0.038, df=4, 52; Tukey's difference NW compared to NE, SE, SW =3. 498, -3.066, and -2.430 respectively, p<0.05). Mid-flight rate, daily travel rate, and daily distance did not vary by wind sector (Fig. 3.4a & b, Fig. 3.5). Cooper's Hawks exhibited no variation in time spent traveling per day by wind sector, however they flew farther on days with northwest winds (mean = 166.28 km, SD= 152.32 versus mean of 57.0 to 128.6 km on other wind sectors) (F=2.731, p=0.053, df= 4, 24).

To evaluate how head, cross and tail winds might affect travel for each age class, I regrouped wind direction into four categories including: head winds (S, SW, SE), tail winds (N, NW, NE), cross wind (E, W) or variable (i.e., no predominant direction or any winds less than 4 kph wind speed). No significant pattern was seen for Sharp-shinned Hawks pooled by age. Sharp-shinned Hawk adults flew longer on days with head winds (mean= 68.6 km, SD= 85.1) compared to other wind categories (mean=17.8 to 75.7 km; (F=3.903, p=0.023, df =11, 20) but distance and rate did not vary by wind sector for either age. No significant pattern was seen for Cooper's Hawks and wind direction by age, although sample size was small. When age groups were pooled, Cooper's Hawks migrated faster with tail winds (mean=20.5 km/h ±16.0 SD vs. 8.8 to 12.9 km/h) and farther (mean=169.6 km ±138.3 SD vs 61.9 to 71.8 km) than during flights on other wind conditions (distance F=6.512, df= 3,19, p=0.003; rate F=4.812, df= 3,19, p=0.012,). Wind speed considered separately from direction did not affect travel for either species and the interaction of wind speed and direction did not have effect on travel rate, duration or length for either species.

Thermals

Sharp-shinned Hawks spent less time traveling on days with stronger thermal strength (F=4.658, p=0.036, df=4, 52), but did not exhibit a difference with distance or rate of travel. Adult Sharp-shinned Hawks spent less time traveling on days of strong thermals (F=47.547, p=0.000, df=1, 16) but hatch-year birds showed no difference in travel duration with thermal strength.

In contrast, Cooper's Hawks flew farther and faster on days when thermal strength was higher, but exhibited no difference in daily travel duration (distance: F=5.749, p=0.03; rate: F=7.45, p=0.01, df= 1,19). Adult Cooper's Hawks also flew faster on days of stronger thermals whereas hatch-year birds showed no difference although the sample size was small (rate: F=9.236, p=0.019, df =1, 7).

Cloud Cover

Cooper's Hawk's daily travel distance and rate of travel was longer and faster when cloud cover was less (distance: F=8.073, p=0.000; rate F=4.704, p=0.006). The interaction of sky cover and thermal strength had significant influence on distance and rate of travel with days of less clouds and strong thermals exhibiting longer travel distance as well as faster daily travel rate (distance: F=8.628, p=0.000; rate: F=4.779, p=0.004, df=5, 19). Sky cover and the interaction of sky cover and thermal strength both had significant effect on Sharp-shinned Hawk rate of travel as well (sky: F=3.098, p=0.03; interaction sky and thermal: F=2.876, p=0.03, df=4, 40), with travel rate highest on clear days with strong thermals and lowest on overcast days associated with weaker thermals. When species were pooled, mid-flight rate of travel was faster when cloud cover was less (F=5.651, p=0.021, df=1, 49).

Although the average daily thermal strength declined in later season (r=-0.53, p=0.003), seasonal date did not significantly affect flight distance, duration, or rate during the study.

Days since Cold Front Passage

The distance and daily rate of travel varied significantly with day of cold front passage for Sharp-shinned Hawks but not the duration (distance F=3.57, p=0.029; rate F=4.04, df=3,24, p=0.018) (Fig. 3.6, 3.7). Cooper's Hawks showed no significant difference in travel distance, duration, or rate of with the timing of cold front passage, however sample size was small (Fig. 3.6, 3.7).

When travel parameters among cold front passage days were compared by age class (pooled across species) no significant differences were detected for adults, however hatch-year birds flew farther on the day of a cold front compared to other days (F=5.124, df=3, 16, p=0.011,) (Fig. 3.8). Adult Sharp-shinned Hawks had faster rate of travel on the day of cold front passage compared to other days (F=3.478, df=4, 20, p=0.026) but other parameters did not differ. Adult and hatch-year Cooper's Hawks travel behavior did not differ by cold front day (p>0.05) although the sample size was small.

DISCUSSION

Flight behavior and patterns of radio-tracked Cooper's and Sharp-shinned hawks in the central Appalachians suggest these closely-related species may pursue different strategies during autumn migration. Cooper's Hawks flew in a more southerly direction than Sharp-shinned Hawks and some birds undertook extended flights that crossed water bodies and large developed areas. Sharp-shinned Hawks moved predominantly to the southwest direction and flew closer to the Appalachian ridges and away from large urban areas and water. They also flew substantially slower and for shorter distances per day. The smaller Sharp-shinned Hawks may be less able to pursue long flights and cross areas of inhospitable habitats. They may fly closer to the Appalachians to ensure adequate stopover sites within the large forests of the ridges (see Chapter 4). Alternatively, they may be more prone to using updrafts on ridges and less likely to use thermal soaring as a migration strategy than the larger Cooper's Hawk (see Kerlinger 1989).

Migration Direction

The migration direction displayed by Sharp-shinned Hawks, 216º, corresponded to the hypothesized principle axis of migration, 215˚, suggested by Kerlinger (1989) for eastern Sharp-shinned Hawks, but differed from the mean track direction recorded for eastern New York southbound birds (193˚; Kerlinger et al. 1985, 1989). Kerlinger et al. (1985) reported that Sharp-shinned Hawks will adjust their heading to maintain a consistent migration track, suggesting that maintaining a certain direction may be important to autumn migrants. The difference in direction for the two studies suggests birds may travel in different directions at different latitudes or different parts of their migration journey depending on their ultimate destination, winds, or landscape attributes. Broad-winged Hawks (*Buteo platypterus*) follow an elliptical migration route from North American nesting areas to South American wintering areas and back (Kerlinger 1989). Accipiters may move more westerly in the Central Appalachians to avoid coastal bays, urban areas, or to take advantage of the Ridge-associated air currents.

I did not find any differences in track bearing within the regions or landscapes compared in this study, however our study birds had the same landscape barriers to negotiate, i.e., ridges and ocean bays, and may have behaved similarly as a result. One bird followed to a New Jersey wintering location did travel east and then south differing from most other birds in the study (Fig. 3.2).

The mean track direction for both Cooper's Hawks and Sharp-shinned Hawks was more southerly than the general track of the Kittatinny Ridge, and of the estimated track for a late-season migrant through the same region, the Red-tailed Hawk (Kunkle et al. 2009). Red-tailed Hawks captured on the Kittatinny Ridge flew more westerly during autumn migration (mean=230º) than birds in this study. However, early season Red-tailed Hawks traveling at a similar seasonal timing as the accipiters tracked more southerly, similar to directions in this study (mean=204º), which may indicate that early season raptors are more apt to take advantage of thermals during September and October than late season migrants as has been suggested earlier (Maransky et al. 1997) (Appendix C).

Travel direction did not vary with age as has been suggested in some previous studies. Several studies of songbirds and raptors have shown that hatch-year birds may follow a different track as they have no knowledge of a migration destination (Berthold 1996). Hatch-year birds also appear less able to adjust to wind displacement and exhibit more scattered migration patterns (Thorup et al. 2003, Thorup et al. 2007); however, Sharp-shinned and Cooper's hawks in this study exhibited no difference in daily direction by age. Marked Red-tailed Hawks on the Kittatinny Ridge also showed no difference in travel direction by age (Kunkle et al. 2009). Perhaps the mountain topography and landscape provide more structure to hatch-year migrants than other regions.

The more westerly direction found for birds flying under cross winds (with east component) suggests that accipiters may be displaced slightly from their preferred track by crosswinds in some conditions (Kerlinger 1989). It is possible that immature birds are more susceptible to scatter in open landscapes but not in mountains. Radio-tracking studies in areas without major leading or diversion lines could be useful in evaluating this question.

The more southerly track of the Cooper's Hawks may be partly due to their larger body size (Curtis et al. 2006) which makes them better equipped to take advantage of thermals to make long distance flights and water crossings when traveling through the Chesapeake Bay and coastal areas. None of the Sharp-shinned Hawks tracked in this study traveled across the Chesapeake Bay and the overall proportions of migrants heading towards likely water crossings when last seen were lower for Sharp-shinned than Cooper's hawks as well (12 vs. 33%). The Chesapeake Bay shoreline during mid-autumn can produce lines of strong updrafts oriented parallel to the coastline that can be ideal for soaring raptors, i.e., thermal streets (Smith et al. 1986, Sikora and Halerson 2002). These linear arrays of strong lift regularly develop following a cold front when a cold air mass overrides warm water, transported by light winds (Young and Sikora 2003). I suspect that these updraft arrays may be regularly used by raptors to save energy and accelerate their speed south. The higher travel speeds observed for birds in the Plain region may be partly a result of the migrants taking advantage of these atmospheric conditions.

Travel Distance, Duration, Speed

Cooper's Hawks appear to be stronger flyers than Sharp-shinned Hawks across all regions in this study. Broun and Goodwin (1943) found considerable variation in flight speed along the Kittatinny Ridge over a short distance under predominantly north or west winds. Both species averaged 18.75 km at Hawk Mountain (Broun and Goodwin 1943), faster than average day-long measured speeds recorded in this study, but not the mid-flight speeds. The birds likely vary their speed throughout their daily migration as they encounter differing topography. I also found slower flight was more likely at the beginning and end of a daily journey and some individuals flew much faster over the Plain and Piedmont regions. Golden Eagles (*Aquila chrysaetos*) displayed seasonal variation in migration speed, traveling more quickly during the early part of their migration and slower as they approached their destination (MacIntyre et al. 2008).

Newton (2008) reported daily migration speeds for satellite-tagged long-distance raptors ranging from 34 to 57 km/h. All were larger species than accipiters and some rates and distances were determined from locations taken once a day or every three days rather than regularly throughout a day. Osprey (*Pandion haliaetus*) were recorded to fly at 17.5 to 31.8 km/h with slower rates in flapping flight than when soaring (Klaassen et al. 2008). Fuller et al. (1998) found that Peregrine Falcons and Swainson's Hawks had a longer daily flight than in this study (160 to 188 km/d), but the rate varied with latitude. Differences shown in this study suggest accipiter travel rates may vary with topography and region and days of strong thermals appear to facilitate faster flights. Mid-flight rates were consistently higher than daily rates of travel as I predicted.

Regional Patterns

The importance of the Kittatinny Ridge as a migration flyway was further supported during this study. Both species spent more travel time per day on the Kittatinny Ridge than in the adjacent valley, and both the Ridge and the associated valley to the south were used more than the northern ridges of Central Appalachians. Most migrants followed the Ridge for at least part of their migration journey and adults spent more time on the ridge perhaps due to their experience level. Adults also use contiguous forest more often for stopover than hatch-year birds, which may influence their flight patterns (see Chapter 4). The proportion of time spent in the Plain or Piedmont by either species was low, but that pattern may have been partly influenced by the fewer number of birds tracked for several days, and the faster flight speed birds used to cross the region.

I suggest that migrants use slower days consisting of short flights along the ridge combined with extensive feeding and roosting time for several days prior to undertaking longer flights such as those traversing the Plain or Piedmont. The longer flights were usually associated with clear days with light tail winds, suggesting both thermals and favorable winds were used to aid their flight. Ospreys also were found to reduce their travel speed and duration in areas where feeding was more opportune and increase speed and duration where feeding was unlikely (Klaassen et al. 2008). Swainson’s Hawks and Peregrine Falcons also changed their rate across latitudes, moving more quickly during middle of the migration (Fuller et al. 1998).

Because both species use forests heavily during stopover for feeding and resting (Chapter 4), refueling was more predictable in the Ridge and Valley than in the more open Plain and Piedmont regions. Holthuizjen et al. (1985) found Sharp-shinned Hawks would feed or rest for several days in Cape May Point before crossing the Delaware Bay. And, songbirds are known to rest and feed for days prior to crossing the Gulf of Mexico or other inhospitable terrain where feeding may be difficult (Berthold 1996, Newton 2008).

Accipiters in this study appear to be following the energy-minimization strategy of migration rather than a time-minimization strategy or perhaps a hybrid of both (e.g., Newton 2008). Both species traveled in a wide variety of weather conditions but longer flights appeared correlated with energy-saving weather features, e.g., thermals. The observed short daily migration period is supportive of an energy minimization strategy, where birds use shorter flights to allow time for refueling daily. The longer flights shown by some Cooper's Hawks crossing the Plain and Piedmont regions and Chesapeake Bay suggests that this species may shift to a time-minimization approach in some segments of its migration, feeding heavily before undertaking several days of long flights.

The Sharp-shinned Hawk did not exhibit any strong difference in migration patterns by region, and may be following an energy minimization strategy predominantly. Sharp-shinned Hawks may be less able to endure long sustained flights and may be more dependent on finding forest for stopover each evening as has been found in songbirds (Carmi et al. 1992). Further research on migration patterns across several regions may be useful in fully understanding the differences in patterns exhibited by these two species.

Weather and Migration Travel

Despite the propensity of hawkwatch sites to observe larger numbers of raptors along leading and diversion lines in eastern North America on days of strong northwest winds (Titus and Mosher 1982, Kerlinger 1989, Allen et al. 1996, Maransky et al. 1997), accipiter travel days were not strongly related to wind or cold front passage. Sharp-shinned Hawks did spend more time in migratory travel on northwest winds but Cooper's Hawks showed similar travel regardless of winds. These data reinforce the caution that Kerlinger (1989) and others have made about using ground-based observations to study migration behavior and suggest the need for further study of radio-tagged birds.

Cross winds affected the daily migration track for both species, indicating some wind drift may occur. Partial drift compensation has been observed previously in the Sharp-shinned Hawk (Kerlinger et al. 1985) as well as in Osprey and Honey Buzzards (*Pernis apivorus*) in Europe (Thorup et al. 2003).

Both species used thermal soaring as an important component of their migration (Cochran 1972, Kerlinger et al. 1985). Both species flew farther and faster on days of low cloud cover and strong thermals. Golden Eagles in Alaska also used thermal-soaring flight frequently when tail winds were not present (MacIntyre et al. 2008). Thermals are a more predictable source of energy-saving flight across diverse landscapes than ridge-updrafts and may be more integral to raptor migration across the continent than previously realized.

The behavior of radio-tagged accipiters in this study indicates that raptors will migrate under a wide variety of weather conditions, and the increase in sightings at migration watch-sites located along leading and diversion lines under northwest winds is likely due to migrants converging to take advantage of the lift created along topographic features rather than more birds flying on such winds. Under this hypothesis, northwest winds may act to narrow a broad front migration movement to converge both horizontally and vertically (i.e., by altitude), bringing more birds in view of ground-based watch-sites, than might be seen passing on other wind conditions (Kerlinger 1989, Kerlinger and Gauthreaux 1984, Murray 1964). Strong winds can limit thermal altitude making migrants aloft more reliant on ridge updrafts for efficient travel (Kerlinger 1989). Although I found no evidence in this study that more birds migrated under northwest wind conditions (see Chapter 2), I did find that accipiters may fly faster and farther on such wind conditions which could also enhance numbers observed at ground based sites. Strong south winds may not produce these concentrations as they result on a head wind for the migrants. Southeast and northeast winds also occasionally produce migrant concentrations along the central Appalachians although such wind conditions can be associated with north moving fronts (VanFleet 2001). The weather least used by the migrating accipiters in this study was rain and heavy cloud cover supporting prior research findings (Chapter 2) and reinforcing the idea that lift from wind or thermals is key to the accipiter migration strategy (Kerlinger 1989). These findings suggest that migration monitoring stations may need to incorporate weather variables that concentrate flights into their long-term monitoring programs (i.e., wind direction, cloud cover).

Ridge watch-sites observe greater numbers of adults than hatch-year birds (60-70% adult; Hawk Mountain unpubl. data). In this study, hatch-year Sharp-shinned Hawks were less likely to fly on the Kittatinny Ridge than adults supporting watch-site's observations. I suspect that adults may be more adept at using ridge updrafts and therefore spend more time on the Ridge, although adults may be attracted to the large forests available for roosting as well (Chapter 4).

In summary, both Cooper's and Sharp-shinned Hawks migrated along the Kittatinny Ridge for a greater proportion of their migration through the Central

Appalachians than other nearby topographic regions. Migratory travel occurred on a variety of weather conditions and both species used ridge updrafts as well as thermals to aid their journey. Cooper's Hawks displayed a different flight behavior depending on the region they were crossing and flew more southerly than the Sharp-shinned Hawk. I suspect Cooper's Hawks may use a different strategy when migrating along the resource-rich Kittatinny Ridge compared to the areas of reduced or unpredictable resources to the south. In contrast, the smaller Sharp-shinned Hawk displayed shorter daily flights and appeared less likely to move away from rural areas with refueling opportunities (see Chapter 4). The slower flights observed along the Kittatinny Ridge and the flight direction of migrating Sharp-shinned Hawks suggest the importance of conserving stopover habitats along the Kittatinny Ridge and other key migration corridors for migratory birds. Migrant raptors appear to rely on these areas to replenish energy needed to complete their migration. Avian prey were also more abundant near the Ridge, suggesting prey concentrations may also influence accipiter behavior (Chapter 5). Our research suggests they may rely on the energy gained in this landscape to sustain their migration across areas to the south where refueling may be less predictable. Further intensive research on flight behavior of individual migratory raptors is encouraged as I begin to better understand migration behavior and its role in raptor conservation.

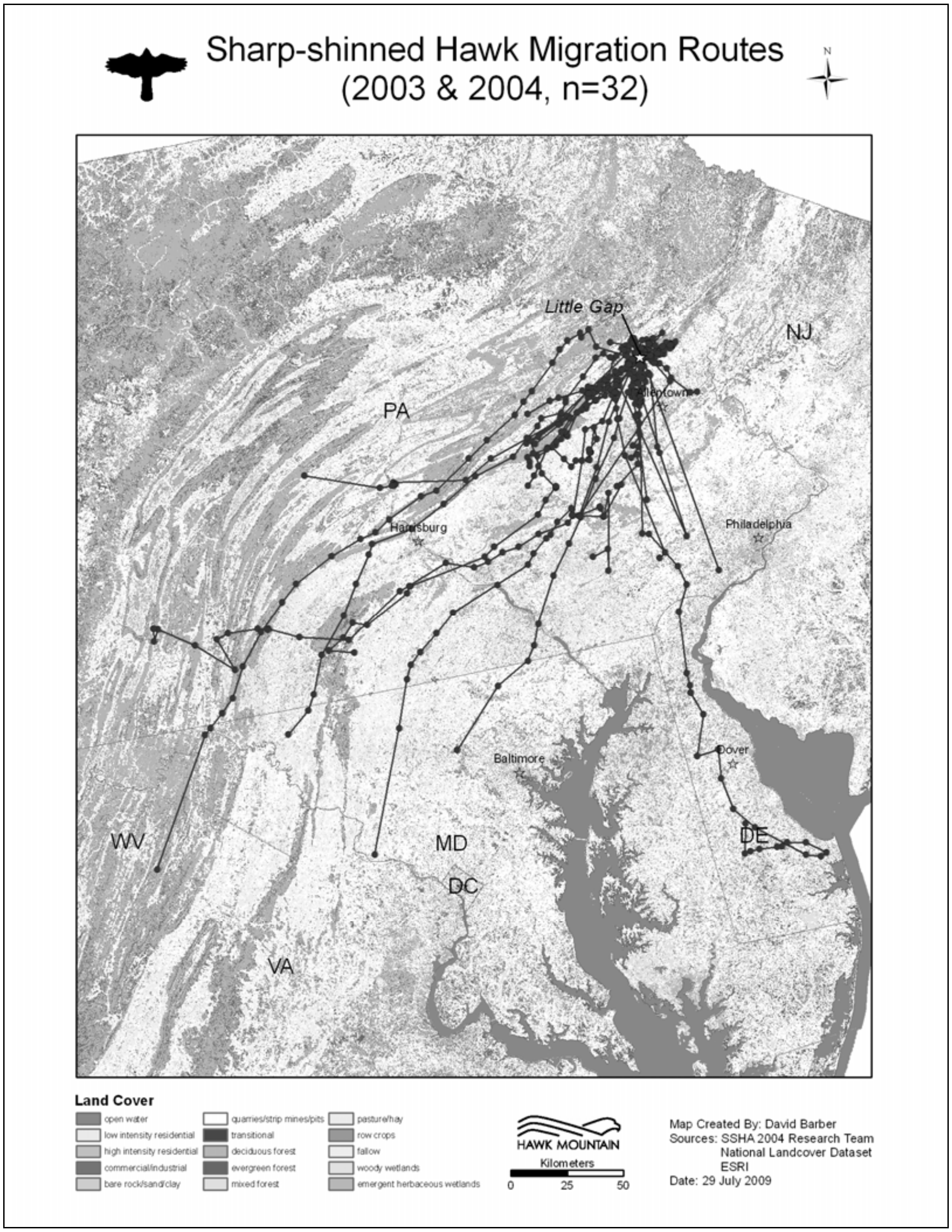

Figure 3.1. Migration tracks of radio-tagged Sharp-shinned Hawks (n=32) through Central Appalachians and areas south during autumn 2003 and 2004 (dots=estimated locations, lines = estimated track between locations) (individual tracks are shown in Appendix A).

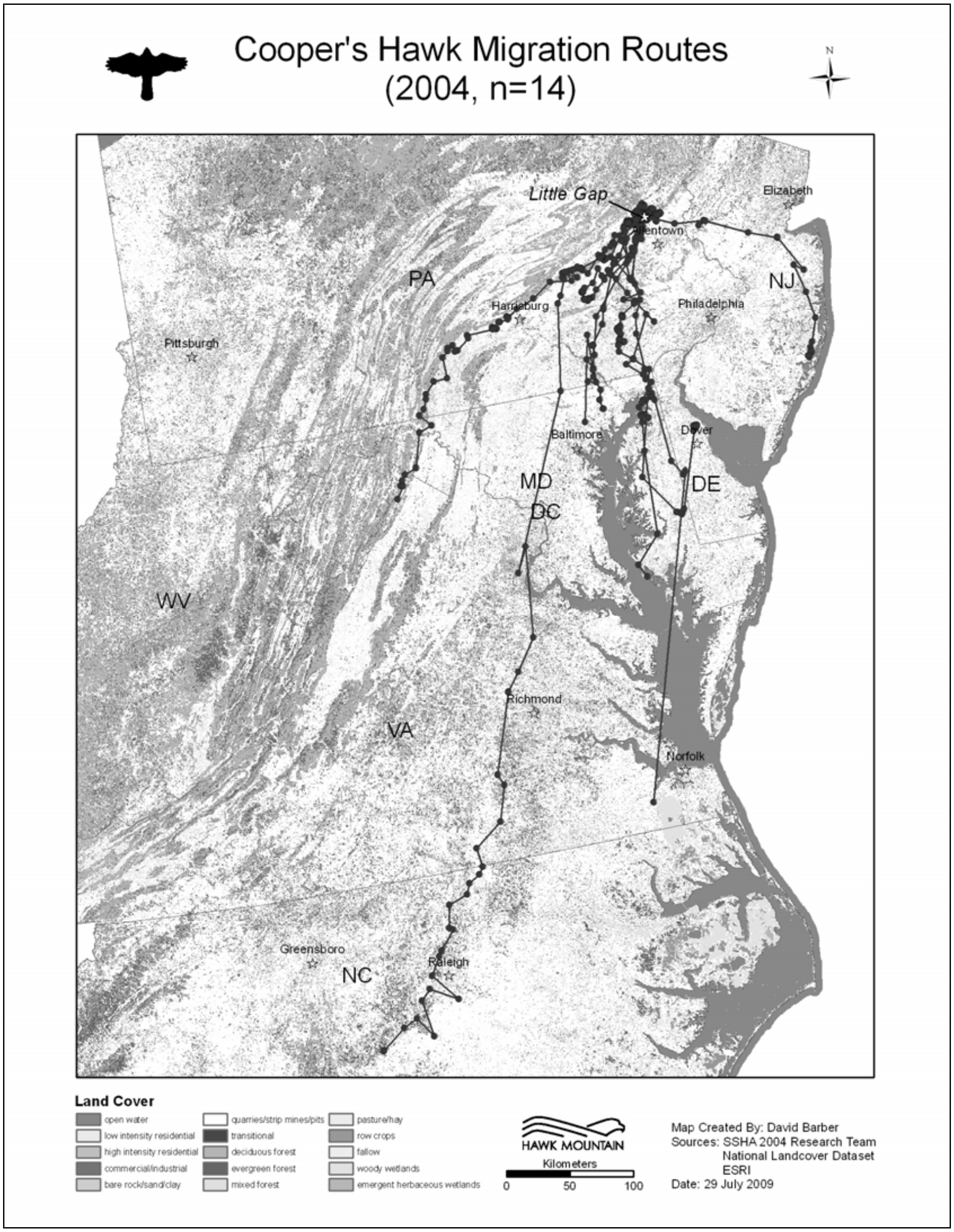

Figure 3.2. Migration tracks of radio-tagged Cooper's Hawks (n=14) through Central Appalachians and areas south during autumn 2004 (dots=estimated locations, lines = estimated track between locations) (individual tracks shown in Appendix A).

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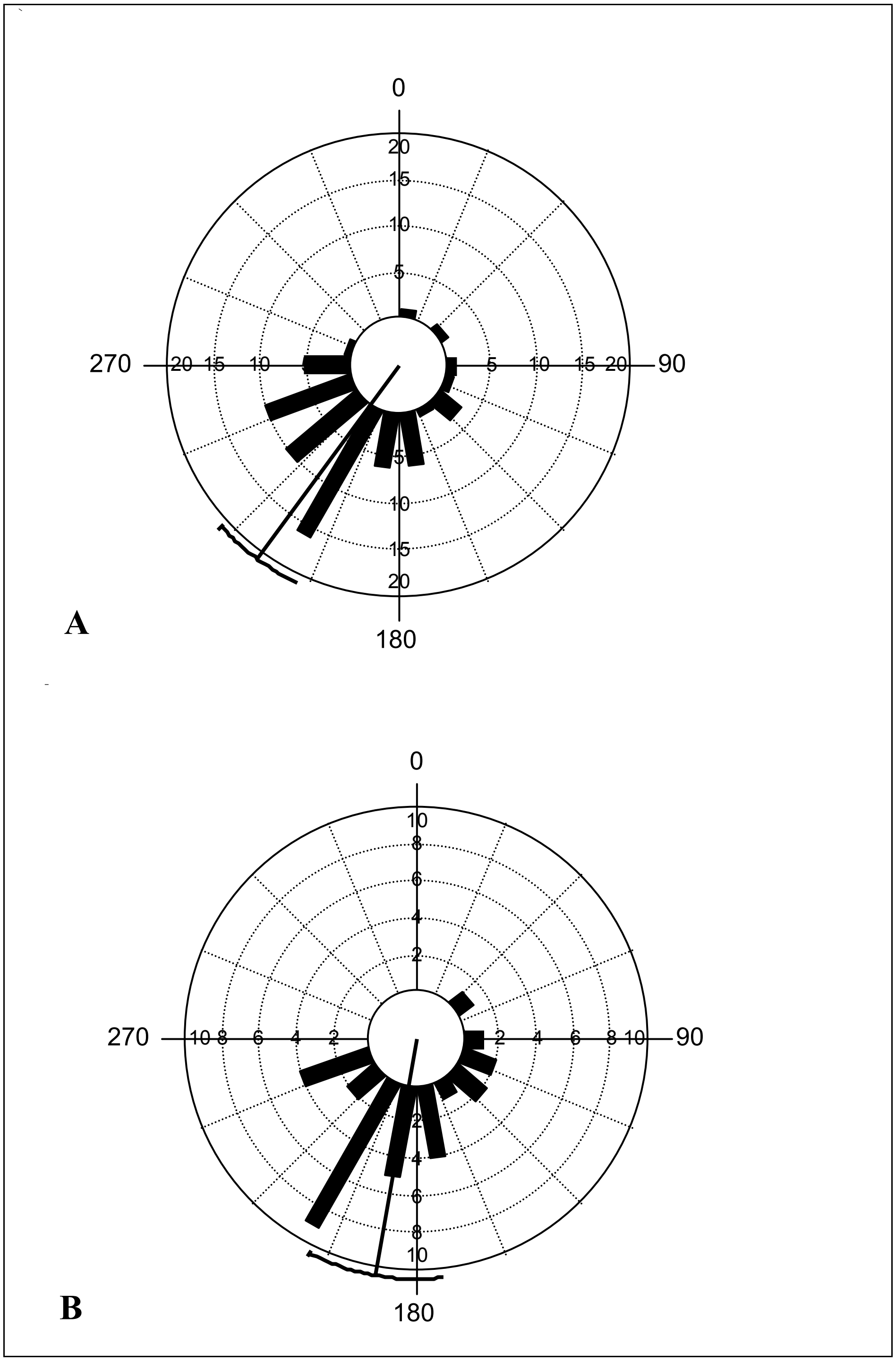

Figure 3.3. The mean migration direction (º) of 10 Sharp-shinned (A) and 32 Cooper's (B) hawks using the Central Appalachian corridor in autumn migration through Pennsylvania in 2003 and 2004 (line shows the mean & 95% CI).

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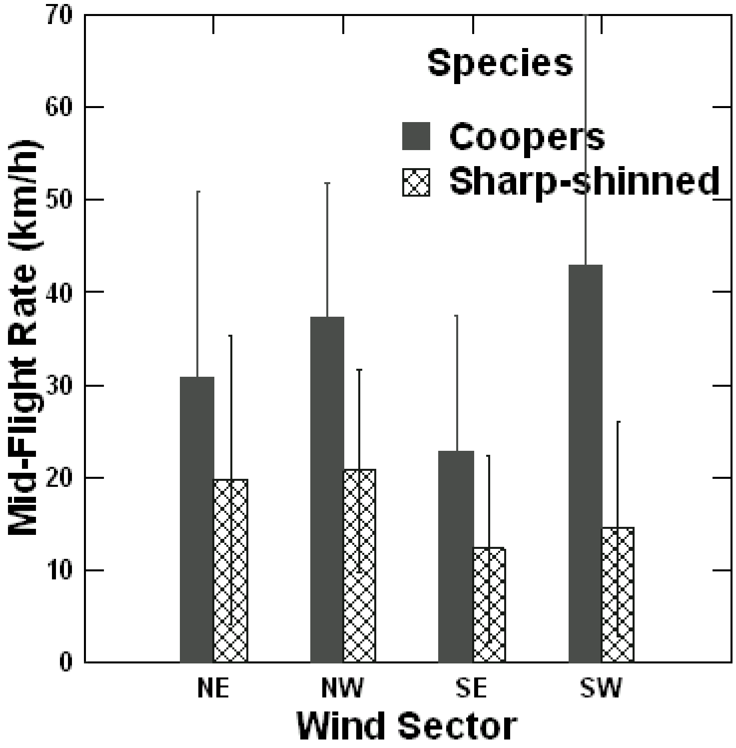

Figure 3.4a. Mean (SD) mid-flight travel rate (km/h) under differing winds for migrating Cooper's and Sharp-shinned hawks in Central Appalachians during autumn 2003 and 2004.

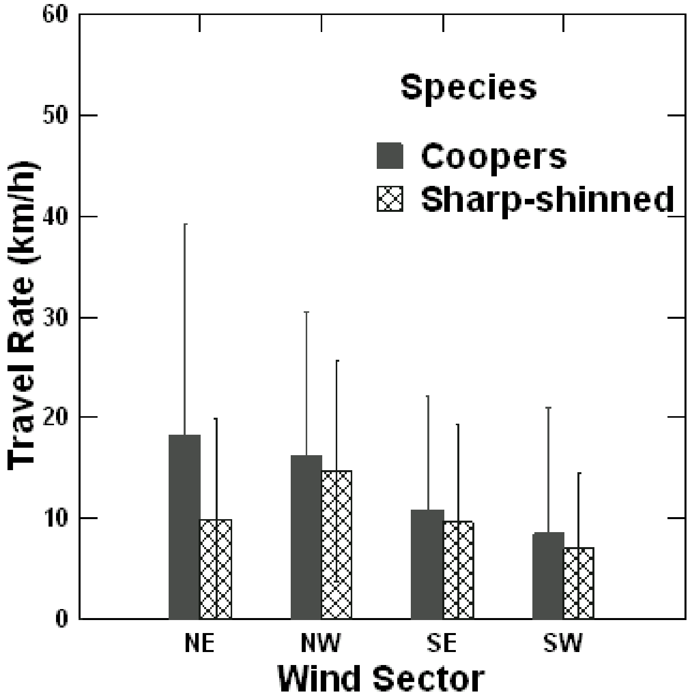

Figure 3.4b. Mean (SD) daily travel rate (km/h) under differing winds for migrating Cooper's and Sharp-shinned hawks in Central Appalachians during autumn 2003 and 2004 (n=59 days).

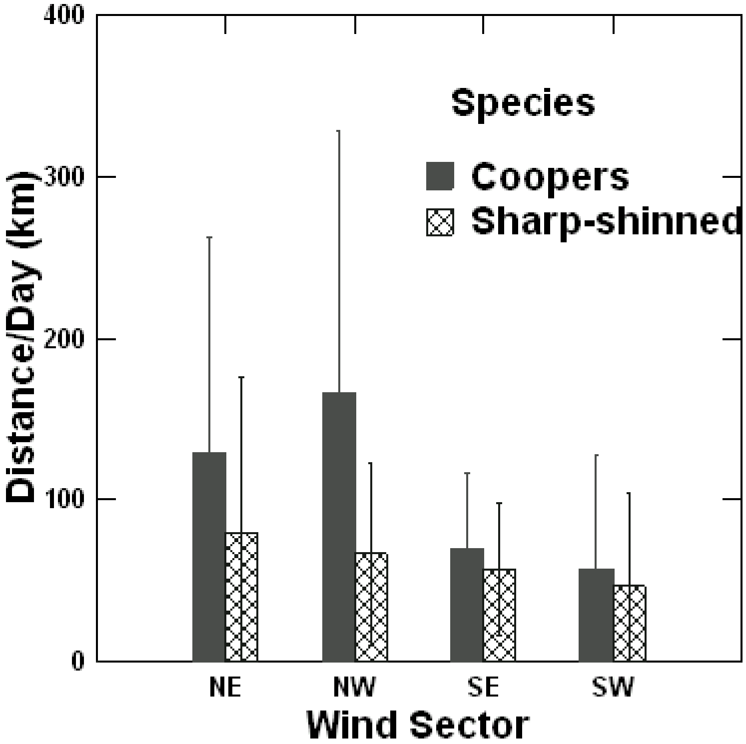

Figure 3.5. Mean (SD) distance traveled per day (km) under differing winds by migrating Cooper's and Sharp-shinned hawks in Central Appalachians during autumn 2003 and 2004 (n=59 days).

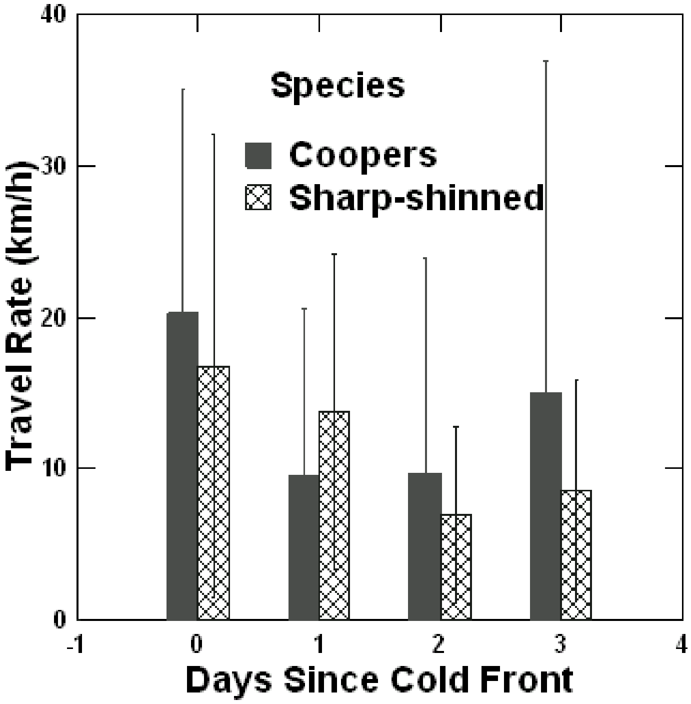

Figure 3.6. Mean (SD) daily rate of travel (km/hr) by species in relation to cold front passage during autumn migration in the Central Appalachians in 2003 and 2004 (days 0 to 3 only, n=38 days).

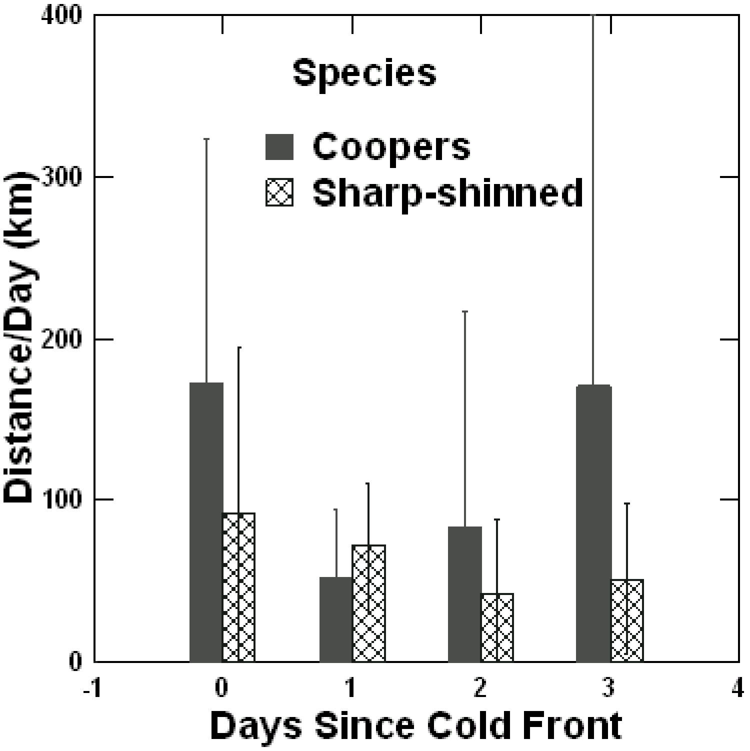

Figure 3.7. Mean daily distance (±SD, km) traveled by accipiters during autumn migration in 2003 and 2004, compared by days since cold front passage (days 0 to 3 only, n=38 days).

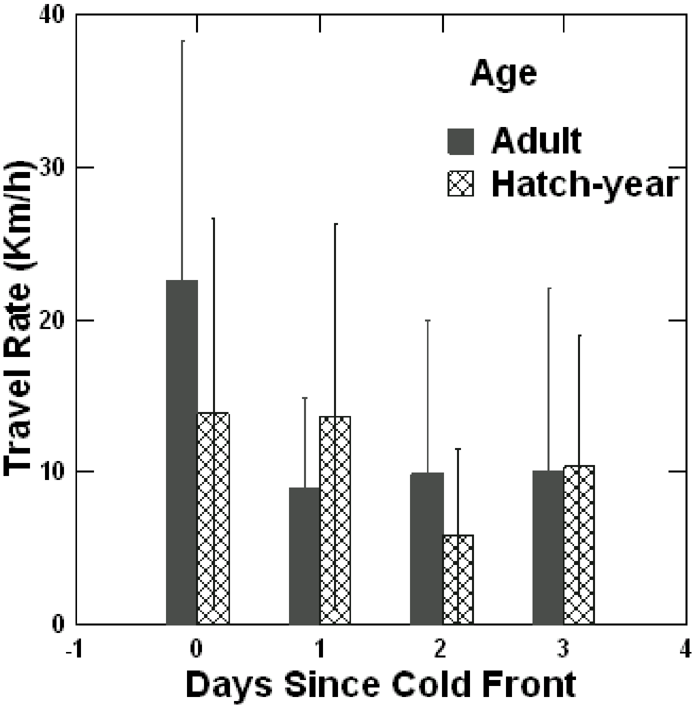

Figure 3.8. Mean (SD) daily rate of travel (km/hr) by age class of accipiters in relation to cold front passage during in autumn migration in 2003 and 2004 (days 0 to 3 only, n=38 days).

Table 3.1. Migration parameters of Sharp-shinned and Cooper's Hawks using Central Appalachians during autumn 2003 and 2004 by age and species. [a]

Species	Age	n	Mean (SD) Distance/Day (km)	p=	Mean Rate (SD) (*km/hr*)	p=	Mean Bearing (º) (SD)	, p=
Sharp-shinned Hawk	All	59	60.1 (7.4)		10.5 (1.2)		216.5 (5.8)	
	Adult	25	56.6 (12.5)	*ns*	10.8 (2.1)	*ns*	216.5 (47.6)	ns
	Hatch-year	34	62.6 (9.0)		10.3 (1.5)		216.4 (7.5)	
Cooper's Hawk	All	30	108.9 (20.9)		13.6 (2.5)		190.2 (8.3)	
	Adult	16	160.2 (32.6)	***	18.6 (3.6)	*	199.1 (12.4)	*ns*
	Hatch-year	14	50.3 (13.7)		7.8 (2.9)		181.0 (11.6)	
Sharp-shinned vs. Cooper's				*		*ns*		**

[a] n is the total days of migrating flight; "*" = t-test significant at 0.05, "**"= p<0.01, "***"=p<0.005.

Table 3.2. Mean daily migratory travel parameters of accipiters flying on the Kittatinny Ridge and within three different Central Appalachian regions during autumn 2003 and 2004.

Region	# Travel Days	Mean Daily bearing° mean° (SD)	% Total Travel time mean% (SD)	Mean Distance (km/d) (SD)	Mean Daily Rate (SD) (km/hr)
Cooper's Hawk					
Kittatinny Ridge	15	202.6 (44.3)	57.1 (46.9)	60.5 (82.9)	6.8 (8.4)
Northern Ridges	0				
Valley	8	177.2 (41.4)	31.7 (43.0)	77.6 (44.0)	10.6 (9.5)
Plain/Piedmont	7	179.5 (49.5)	5.6 (15.8)	248.5 (122.0)	31.5 (12.4)
Statistic[a]*, p=*		*ns*	*KW=21.47, 0.000*	*F=12.17, 0.000*	*F=16.08, 0.000*
Sharp-shinned Hawk					
Kittatinny Ridge	28	219.9 (51.7)	53.6 (44.5)	54.1 (54.6)	9.6 (8.8)
Northern Ridges	7	221.2 (35.3)	10.5 (23.8)	18.1 (18.1)	2.4 (2.2)
Valley	18	207.6 (39.9)	42.0 (43.0)	87.6 (62.8)	13.7 (10.1)
Plain/Piedmont	6	226.8 (46.1)	2.8 (11.7)	54.3 (39.7)	14.5 (10.6)
Statistic[a]*, p=*		*ns*	*KW=38.99, 0.000*	*F=3.17, 0.03*	*F=3.17, 0.03*

[a] Kruskal Wallis test used to compare % observed migration, ANOVA used on other measures.

Chapter 4. Stopover habitat use and selection by migrating Sharp-shinned and Cooper's hawks in the central Appalachians.

ABSTRACT

Quality and abundance of stopover habitat can influence the survival of migrating birds. To better understand the stopover ecology of migrating raptors, I radio-tracked 44 Sharp-shinned (*Accipiter striatus)* and Cooper's hawks (*A. cooperii*) along the Kittatinny Ridge in eastern Pennsylvania during autumn 2003 and 2004. I examined stopover habitat selection at three scales, (1) regionally, including an area encompassing 95% of the daily migration tracks in our study, (2) the landscape scale, an area within 10 km of stopover sites, and (3) near-scale, an area within 0.5 km of a stopover site. Covariates examined included the proportional cover of six cover types surrounding used and available sites as well as the relative size of the forest patch used for stopover. I also measured the distance migrants traveled from the flyway for stopover sites. The habitat important to stopover-site selection varied among scales and by species and age. At a regional scale, both species selected stopover sites in areas with greater cover of mixed forest and pasture. Areas with greater wetland and less suburban cover were selected by Sharp-shinned Hawks as well. At the landscape and near scale, forest patch size was the most important factor in stopover site selection, with both species using larger forest patches than were expected based on availability. Large forest patches may afford a greater diversity of habitats, attract more prey, and provide greater protection from predators or disturbance. Cooper's Hawks selected for areas with less mixed and more deciduous forest at the near-scale, perhaps reflecting a preference for more open forest structure. At a near-scale, adult and hatch-year birds differed primarily in the size of forest patches used. Hatch-year birds used smaller forest patches more often than adults, whereas adults used large or contiguous forests predominantly, avoiding smaller patches. Both age groups avoided non-forest sites. Hatch-year birds may be less likely to move within a landscape to locate better foraging or roosting opportunities or adults may be more vigilant against predation and other dangers. The conservation of a natural landscape along the Kittatinny Ridge in Pennsylvania as well as other key migration corridors appears important to the long-term conservation of eastern North American migratory raptors. For accipiters, large forested blocks amid a mix of rural landscape including forest-field edges or wetlands may be ideal. The avoidance of suburban areas by migrants indicates that large areas of suburban development within important migration corridors should be limited, and land use with a focus on rural or natural landscapes prioritized.

INTRODUCTION

Quality and abundance of stopover habitat can influence the survival of migrating birds. Ideal stopover sites provide migrants with water, food, and protection from predation (Barrow et al. 2000, Moore et al. 1995). How migrants select stopover habitat when migrating through unfamiliar terrain is unclear (Alerstam 1990, Moore et al.1995, Mehlman et al. 2005). If a stopover site is unsuitable, a migrant may depart with less fat reserves than needed, which may jeopardize survival or require additional stops and a longer migration (Berthold 1996, Moore and Yong 1991, Newton 2008).

Migrant songbirds appear to select stopover habitat based on food availability or potential food availability (Moore et al. 1995, Rodewald and Brittingham 2002, Rodewald and Brittingham 2007, Keller et al. 2009). Recent studies show that songbirds use a wider array of habitats during stopover than during breeding periods, and habitat use patterns can vary among years and regions (Moore et al.1995, Petit 2000, Rodewald and Brittingham 2004, Rodewald and Matthews 2005). Forest-interior songbirds will use early successional and edge habitats during migration regularly, possibly responding to prey availability (Petit 2000, Rodewald and Brittingham 2004, 2007).

Landscape-scale habitat characteristics also may influence the use of sites for migration stopover and the ability of migrants to replenish fat stores (Moore et al. 1995, Dunn 2002). Buler et al. (2007) found that forest cover, distance to the migration flyway, and the abundance of invertebrates and fruit at a local scale were all important in explaining songbird densities during migration along the Gulf of Mexico. Ktitorov et al. (2008) suggested that large patches of suitable habitat form the basis for the initial selection of sites by forest songbirds and may be more important than other landscape attributes.

Raptor stopover behavior and habitat has been much less studied than that of songbirds. Niles et al. (1996) found that migrating raptors flew over habitats similar to nesting habitats as they migrated south through the Cape May peninsula in New Jersey, a major eastern flyway. Open-country birds, e.g., Northern Harriers (*Circus cyaneus*), were found migrating more over open habitats and forest birds, e.g., the Sharp-shinned Hawk, were found more over wooded areas (Niles et al. 1996). A study of Sharp-shinned Hawks during migration stopover in Cape May Point, New Jersey, suggested that migrants selected woodlands for roosting (Holthuijzen et al. 1985). However, many raptors concentrate in migration in regions where habitats similar to their breeding habitat may be difficult to find (Bildstein 2006, Ruelas Inzunza et al. 2005). And, some researchers have suggested that raptor migrants rarely feed en route (Smith et al. 1986, Harmata 2002), therefore habitat type may not be particularly important.

If raptors do seek out certain habitats for stopover, when or how they might select stopover sites is unknown. Research on nocturnal migrating songbirds suggests that birds select locations for stopover during pre-dawn and may use morning flights to search for or sample potential stopover sites (Gauthreaux 1978, Kerlinger and Gauthreaux 1985, Moore et al. 1995). The similarity of a potential stopover site to a species' breeding habitat may be an important step in stopover site selection (Hutto 1985). However, time spent searching may need to be minimized when fat stores are depleted and suitable habitat is scarce.

Migrants may select stopover sites in a hierarchical manner with different cues operating at different scales (Johnson 1980, Hutto 1985, Moore et al. 1995, Buler et al. 2007). Diurnal, short-distance migrants, such as accipiters, often fly at lower altitude than nocturnal songbird migrants using lift from air currents such as thermals and updrafts (Kerlinger and Gauthreaux 1984, Kerlinger 1984). They may minimize search time by selecting a flight path near suitable stopover habitats when possible, exhibiting a regional or broad spatial scale selection (Buler et al. 2007). More specific selection for certain habitat features may occur as a bird begins to seek a specific stopover site, selecting an area, or landscape, equivalent to a third-order, home range scale selection (Johnson 1980). Further refinement of site selection may occur at a 'near-scale', where an individual might choose the patch or site within a patch for its roost. As in Johnson (1980), each level of selection is conditional upon choices made by the migrant at the higher level with the habitat available at one scale possibly contingent upon choices made at a wider scale.

Migrant age can influence stopover choices as well. First-year raptors suffer high rates of mortality (up to 70%) presumably because learning to capture live prey is difficult (Newton 1979, Roth et al. 2005). Learning which habitats provide suitable stopover sites could be equally challenging for inexperienced, hatch-year hawks. Young birds may settle in less suitable habitat more readily. Immature songbirds often harbor lower levels of fat than adults and exhibit longer stopover periods, possibly indicating they are choosing less productive stopover sites (Woodrey 2000). Because raptors often migrate singly (Kerlinger 1989) they have less opportunity to learn from con-specifics and may make inopportune choices more often than songbirds.

To learn more about raptor stopover habitat use, I examined habitat selection by two species, the Sharp-shinned and Cooper's hawk *(A. cooperii*), as they migrated along the Kittatinny, a critical inland migration corridor for North American raptors (Bildstein 2006, Goodrich and Smith 2008). Our objective was to compare habitat use and availability at three scales to explore if migrants are exhibiting selection for habitat, and if they are selective, which habitat features may influence selection at differing scales (Johnson 1980, Hutto 1985, Moore et al. 1995, Buler et al. 2007). Because Cooper's Hawks use a wide array of habitats during breeding, from lone urban trees to contiguous forests (Curtis et al. 2006), and Sharp-shinned Hawks select primarily contiguous forest for nesting (Bildstein and Meyer 2000), I hypothesized the two species would differ in their pattern of stopover habitat use. I also compared habitat selection by age, predicting that the hatch-year birds would use a wider array of habitats than adults.

METHODS

Study Area

Birds were trapped on the Kittatinny Ridge, or Blue Mountain, located in the Ridge and Valley Province (www.dcnr.pa.us/topogeo) of eastern Pennsylvania. For further description see Section 2.3.

Trapping

Between 2 September and 22 November in 2003 and 2004, 48 accipiters (34 Sharp-shinned and 14 Cooper's Hawks) were banded and radio-tagged. The birds were caught by a volunteer team between 0830 and 1630 under federal banding permit 21371 (Pennsylvania State permit 00032, Penn State University IACUC permit # 19240). For details on trapping methods see Section 2.3.

Radio-tracking

Birds were radio-tracked by four wheel drive vehicles with roof-mounted, foru-element yagi antennae. For further details on radio-tracking methods see Section 2.3.

Roost Identification

I considered a bird to be roosting if it spent more than 30 minutes in one location. If the bird remained on the roost after dusk or selected the roost after dark, it was considered a 'night roost'. I defined 'day roosts' as places a bird perched during daylight hours for greater than 30 minutes.

The first roost after each bird's release was excluded from analysis and the first night roost was excluded if a bird was released in the afternoon and did not migrate that day to avoid possible bias from trapping. I attempted to track each bird to at least three separate night roosts, including at least one migration day. Some birds were lost before three roosts were identified and others were tracked for longer periods. To exclude resident birds, six birds that exhibited no migration travel during tracking were excluded from the study, including three Cooper's and three Sharp-shinned Hawks. As a result, I included roost sites from 42 migrant accipiters, 31 Sharp-shinned and 11 Cooper's Hawks.

Locating Roosts and Available Habitat Points

The field team estimated the UTM coordinates of each roost location using three or more bearings taken in the field entered into LOCATE II software (ver. 1.82, Pacer 2000). The LOCATE II program estimated the point location and calculated an error polygon around the predicted location. I then entered the coordinates of roost sites into ArcGIS 8.3 (ESRI, Redlands, California, www.esri.com) to measure site attributes. Estimated roost sites with an error polygon larger than 500 square meters were eliminated from consideration.

To compare roost site habitat to the surrounding landscape available to each migrant, I selected five potential roost locations randomly within GIS ArcMap 8.3 for each roost site. Sharp-shinned and Cooper's hawks traveled at an average rate of 8 to 25 km/h, (Chapter 3) and I assumed they might travel up to a half-hour or hour in search of a stopover site. Thus, I arbitrarily set a radius of 10 km from the known roost site for the samples of available habitat.

Some researchers have suggested that migrants choose to travel over habitats consistent with their stopover needs (Niles et al. 1996, Buler et al. 2007), representing a regional-scale habitat selection. To assess how habitat near migration routes compared to habitat available across the wider region being traversed by migrants, I sampled regional habitat availability by drawing a polygon around all migration pathways of accipiters followed during the study, excepting outlier tracks that lay greater than 40 km from any other track. The resulting polygon included all of southeastern Pennsylvania and excluded areas east of Pennsylvania and south of northern Virginia, Maryland, and Delaware (included area=503,954 km^2) (Fig. 1). I also excluded any grid intersection points that fell completely in large water bodies (i.e., Chesapeake Bay) as raptors are not known to stop on water (Newton 2008). Water was mapped as a surrounding cover type, however. The regional grid intersection points (n=79) were used to sample habitat available throughout the area used by migrants at a 10 km radius to compare to habitat surrounding roosts within a 10 km radius (Fig. 1). A 10 km radius sample of habitat was selected to represent a landscape-scale view of roost habitat and random points.

Patch Size Analysis

Both accipiters breed primarily in forests, and Sharp-shinned Hawks primarily nest in large forests (Bildstein and Meyer 2000, Curtis et al. 2006). I categorized the forest patch size of each roost, random and regional point, into one of seven categories to examine whether forest patch size influences stopover site selection. The size of each forest was assessed by creating a sequence of seven circular 'buffers' of known area and comparing the buffer size to the forest patch area in ArcMap to classify the forest patch size. The seven categories included: Contiguous Forest = forest > 400 ha, Very Large forest included forest area from 200-400 ha, Large forest=100-199 ha, Medium forest= 40-99 ha, Small forest= 10-39 ha, Tiny forest = wooded area <10 ha, or Non-forest habitat, e.g., hedgerows or forest strips <1 ha. The forest sizes were selected to represent the array of forest types available in southeastern Pennsylvania (Goodrich et al. 2002). I did not consider patch shape in this study. I estimated the size of odd or narrow-shaped forests by placing smaller buffers within the forest and summing their area to estimate approximate patch size. To define a patch, any forest connector thinner than 100 meters and longer than 100 meters was considered a forest break.

Distance to the Flyway

I examined the fidelity of migrants to the Kittatinny Ridge migration flyway by measuring the shortest straight-line distance of each roost from the roost point to the base of the Ridge in ArcMap, as defined by the forest edge at the bottom of the slope. Roosts in either the Piedmont or Coastal Plain topographic regions or roosts south of Pennsylvania were not included as birds located in these regions may have been too far south or east for birds to roost on the ridge. Because many roosts were located on the Ridge, I transformed each roost distance using a log transformation I then compared age and species groups using a two-way ANOVA. Distances are presented as means with standard deviation (SD).

Habitat Sampling

I quantified the habitat cover around each roost and the five random-associated points using the ArcGIS 8.3 Spatial Analyst program. I measured cover at a near scale, within a 500 meter circle around each roost and random point (0.5 km), and at a landscape scale, within a 10 km circle around each point. For a regional scale analysis, I quantified the habitat surrounding each of the regional grid sample points at a 10 km radius for comparison to the 10 km habitat circles around roosts.

I calculated the percent cover of 12 land cover types using the National Land Cover dataset computed from LandSat Satellite Thematic mapper ™ imagery (circa

2001) at a spatial resolution of 30 meters (Homer et al. 2004). The national land cover types were reduced from the standard 21 habitat types into 12 by collapsing similar categories where appropriate or not using types of extremely low abundance in the landscape (i.e., <1%). I retained cover types known to be used by both species, such as all forest types (Bildstein and Meyer 2000, Curtis et al. 2006). For example, I pooled row crops with vineyards and orchards and eliminated shrubland which occurred rarely. Low-intensity residential was renamed suburban and merged with recreational grasses (e.g., golf courses, ball fields). High-intensity residential and commercial/industrial were pooled into an urban habitat type. Other land cover types quantified included: emergent wetlands, woody wetlands, pasture (hay, old fields, pasture), bare rock and quarries habitat, transitional (e.g., clearcut forest, sparse vegetation), deciduous forest (>75% deciduous trees), evergreen forest (>75% conifers), mixed forest (neither deciduous or conifer trees represent >75% cover) and open water (Homer et al. 2004).

Habitat Analysis

I identified a different number of roosts per bird depending on the extent the field team was able to follow each bird tracked. Roosts were classified by time of day (day and night), species, age (adult and hatch-year), and topographic region, for roost selection and habitat cover analyses. Because the Coastal Plain and Piedmont topographic regions are characterized by more open areas, more development, less hills and less forest than the Ridge and Valley topographic region I examined roost selection within Ridge and Valley separately from the Coastal Plain and Piedmont areas. Because there were less roost sites found outside the Ridge and Valley topographic region and differences between the areas was small, I pooled roosts for most of the above-mentioned comparisons. Topographic regions are compared in Appendix B.

Habitat selection of roost site were evaluated by species and age groups at a near scale (0.5 km) and by species at a landscape scale (10 km) by using a matched case-control design with the roost location defined as the case (Sadoti 2008, Witte et al. 2008). Each case was matched with the five random points selected within 10 km radius of the roost. I conducted a case-control logistic regression using % habitat cover and forest patch size as the possible contributing factors to the model. In case-control regression the analysis is conducted on the difference between the case and controls. I used a standard logistic regression analysis to evaluate selection at a regional scale comparing the 10 km habitat samples around roost sites with the 79 regional samples.

Covariates were screened for correlations for each of the three scales of analysis. When a pair of habitat covariates exhibited a significant correlation of $r \geq 0.5$ ($p< 0.05$), one habitat type was dropped, prioritizing the cover type with a greater significance to study species, a greater representation in the landscape, and least correlation to other remaining habitat variables (Sadoti 2008). Final covariates considered in model selection at near and landscape scale consisted of mean proportional covers of six vegetation types as well as forest patch size. Final covariates used in regional habitat selection models included five vegetation types and forest patch size. Habitat covariates not considered in near and landscape scale model selection included pasture (correlated to row crops and deciduous), woody wetlands (correlated to emergent wetlands), urban (correlated to suburban) water (correlated to emergent wetland and deciduous forest), rock (correlated to deciduous forest), and transitional (correlated to all forest types). Final covariates considered in near and landscape-scale model selection included % cover of deciduous forest, evergreen forest, mixed forest, row crops, suburban, emergent wetlands, and forest patch size. In the regional scale analysis, final covariates included deciduous forest, mixed forest, pasture, suburban, emergent wetlands, and forest patch size.

Near and landscape scale analyses were carried out via multivariate case-control logistic regression using the proportional hazards survival regression (PROC PHREG) algorithm in SAS statistical program (Witte et al. 2008). Selection of regression models occurred in two steps. First, for each scale of analysis, a screening regression using the best subsets method was used to identify the best five candidate models of each size (number of covariates) based on the differences in global score chi-square statistics (Hosmer and Lemeshow 2000). An information-theoretic approach was then used to identify the most likely models among these 31 candidate models (Hosmer and Lemeshow 2000, Burnham and Anderson 2002). The Akaike's Information Criterion for small sample sizes (AICc) was used to identify the best model for near and landscape scale habitat selection (Burnham and Anderson 2002).

Due to the smaller sample size for available habitat used in regional-scale habitat selection coupled with the wider diversity of landscapes sampled, the variance in the available habitat samples was fairly high. As a result, I calculated a variance inflation factor from the global model and derived a corrected AICc for overdispersion, QAICc, for habitat models at a regional scale (Burnham and Anderson 2002). Parameter estimates were then derived for each of the three habitat scales using model-averaged estimates (Burnham and Anderson 2002) that incorporated all models having ΔAICc (ΔQAICc) ≤ 2 units from the best model. The relative effect size of habitat parameters was evaluated using the model-averaged odds ratio. For example, at a regional scale an odds of 2.0 for a habitat cover covariate indicates a 1% increase in that variable within 10 km radius will double the probability that a site be selected as a stopover site. For forest patch size, a categorical variable, an odds of 2.0 represents that as the patch size category increases by one scale unit (out of seven categories, Table 1), the probability of it being used as a stopover site doubles. For landscape and near scale case-control habitat selection models, the models are evaluating the relative difference between case and control values. Thus, a covariate's odds ratio represents the relative increase in probability of use as a stopover site as the relative difference in forest size class of a site increases compared to available sites, or as the difference in percent habitat cover between case and control increases by 1%.

RESULTS

I tracked 42 migrant accipiters to 307 roost sites during migration in autumn 2003 and 2004, including 194 Sharp-shinned and 113 Cooper's hawk roosts. Of these, 28 roosts (9.1%) were in the Piedmont and Coastal Plain topographic regions and 279 (91%) were in the Ridge and Valley geographic region; 153 were day roosts and 154 were night roosts. Roosts were compared to 79 regional-scale habitat sample points and 1,530 randomly-selected available habitat points. I used an average of seven roosts per bird in the analysis (± 6.19, range 1-26), or 0.3% to 8.4% of roosts per bird.

I failed to detect a difference in the forest patch size distribution between day and night roosts for either species (Sharp-shinned Hawk, Pearson χ^2 =2.2, df=6, p=0.89; Cooper's Hawk, χ^2 =9.273, df=6, p=0.16). Distance from the Kittatinny Ridge did not vary by day or night either (Sharp-shinned t =-1.085, df=179, p=0.28; Cooper's Hawk t =1.125, df=94, p=0.266). Proportional habitat cover surrounding roosts did not vary by roost time for any of the habitat cover variables measured for the Sharp-shinned Hawk (Mann-Whitney U test, p>0.05). Cooper's Hawk roosts exhibited greater deciduous cover and less pasture around day roosts than around night roosts (deciduous forest day roosts =56.6% (SE=3.9) versus deciduous night roost=46.8% (SE=4.1); pasture day roosts=22.9% (SE=2.6) versus night roosts=32.3% (SE=3.3) (deciduous U=1940.5, p df =1, p=0.05; pasture U=1222.5, df=1, p=0.033). Because habitat cover varied only for two out of nine habitat parameters in one species I pooled day and night roosts for all subsequent analyses for both species, to improve sample sizes.

Characteristics of Stopover Sites

Distance to the Kittatinny Ridge

Migrant accipiters of both species roosted an average of 6.91 km from the Kittatinny Ridge (SD=11.40 km; median = 0.93 km). Both species and age influenced the distance of migrant roosts from the Ridge (ANOVA on log (distance): species F=6.712, p=0.01; age F=6.437, p=0.012). Sharp-shinned Hawks roosted farther from the ridge, 7.65 km (±11.21 SD) than Cooper's Hawks, 5.50 km (±11.68). Adults of both species roosted closer to the Ridge than hatch-year birds (mean distance Sharp-shinned adult=4.57 km (±5.52), hatch-year =9.69 km (±13.37); mean distance Cooper's adult=0.41 (±1.07), hatch-year=8.58 km (±2.21).

Habitat Cover

Although all forest sizes were used for stopover during the study, both accipiters roosted predominantly in contiguous forest and very large (>200 ha) forest patches (>50% of roosts) and used non-forest habitat much less than it was available at random (Table 4.1). Hatch-year birds also used tiny forests (1-9 ha) more than adults and more than they were available at random (Table 4.1).

The habitat cover surrounding stopover sites and random points was comprised predominantly of deciduous forest and pasture (Table 4.2). Regional points showed less deciduous and mixed forest and greater cover of row crops and suburban habitat types than roost or random points (Table 4.2).

Habitat Selection – Sharp-shinned Hawk

Regional Scale The best model for predicting Sharp-shinned Hawk stopover sites at a regional scale included mixed forest, pasture, suburban, and emergent wetland (Table 4.3). Only one other model was ranked highly, and included deciduous forest along with the four habitat cover types from the first model (Table 4.3). Sharp-shinned Hawks showed strong selection at a regional-scale for stopover sites with greater availability of mixed forest cover (OR (odds ratio)=16.84, 95% c.i.=5.56-51.0) and with greater emergent wetland and pasture cover (OR =1.40, c.i=1.11-1.76 ; OR=1.33, 1.17-1.52 respectively), but with less suburban cover within a 10 km radius (OR=0.66, 95% c.i.=0.50-0.86) (Table 4.4).

Landscape Scale

The model that best predicted Sharp-shinned Hawk stopover habitat selection at a landscape scale (within 10 km of roost) included emergent wetland, row crop, and forest patch size. Eleven other models also were highly ranked (Table 4.5). Forest patch size (OR=1.25, 95% c.i.=1.12-1.27) and cover of emergent wetland (OR=1.21, 95% c.i.=1.07-1.28), had a strong positive effect on stopover site selection by Sharp-shinned Hawk, and were present in all highly ranked models. Although other habitat covariates were included in highly ranked models, none of the other effect size estimates differed from 1.0 (Table 4.6).

Near Scale

The best model for predicting Sharp-shinned Hawk roosts at a near scale (0.5 km radius) included evergreen forest, emergent wetland, mixed forest, and patch size. Four other models also were ranked highly (Table 4.7). The variable with the strongest influence on Sharp-shinned Hawk stopover-site selection at near-scale was forest patch size (odds ratio=1.25, 95% c.i.=1.16-1.36) (Table 4.8).

Selection by Age

Habitat cover surrounding adult and hatch-year roosts were similar for most cover types, although the cover of evergreen forest was lower, and row crop and suburban cover higher for hatch-year stopover sites (Table 4.9). Adult Sharp-shinned Hawk roosts were best predicted by a model containing suburban cover, evergreen forest, emergent wetland and patch size. Ten other models were also ranked highly (Table 4.10). Adult Sharp-shinned Hawks selected roosts within a larger forest patch (odds=1.217) and with greater cover of evergreen forest (OR=1.03) (Table 4.11).

Hatch-year Sharp-shinned Hawks were best predicted by a model containing mixed forest and forest patch size (AICc=355.48, *w*i=0.158). Six other models were ranked highly in model selection (Table 4.10). Hatch-year birds roosted within larger forest patches than were available (OR=1.28) and selected sites with less mixed forest cover at near-scale (OR=0.924) (Table 4.11).

Habitat Selection – Cooper's Hawk

Regional Scale

The best model to predict Cooper's Hawks stopover sites at a regional scale included mixed forest and pasture (AICc= 42.945, wi=0.232). Four other models were highly ranked (Table 4.3). Cooper's Hawks selected roost sites at a regional scale with greater cover of mixed forest (OR=61.9) and more pasture (OR=1.58) (Table 4.4). None of the other covariates showed an effect size that differed from 1.0 (Table 4.4).

Landscape Scale

The model that best predicted Cooper's Hawk stopover sites at a landscape scale included evergreen forest, emergent wetland, mixed forest, and forest patch size. Four other models were also highly ranked (Table 4.5). Cooper's Hawks selected sites within larger forest patches than were available at random in the landscape (OR=1.40). None of the other model covariates effect sizes differed from 1.0 (Table 4.6).

Near Scale

The best model predicting Cooper's Hawk roosts at a near scale (0.5 km radius) included deciduous forest, evergreen forest, emergent wetland, mixed forest, and forest patch size. Five other models were also ranked highly (Table 4.7). Cooper's Hawks selected stopover sites in larger forest patches than were available (OR=1.45). They also selected stopover sites with less mixed forest at near-scale than nearby random points (OR=0.89) (Table 4.8). The influence of other habitat covariates on stopover selection did not differ from 1.0 (Table 4.8).

Selection by Age

Both adult and hatch-year Cooper's Hawks exhibited similar near-scale habitat cover surrounding stopover roosts, although evergreen forest and suburban cover were higher around hatch-year sites (Table 4.9). Adult Cooper's Hawk roosts were best predicted by a model containing deciduous forest, emergent wetland, mixed forest and patch size (Table 4.10). Four other models were also ranked highly. Adult Cooper's Hawks selected roosts within larger forest patches (OR=1.898), with greater deciduous cover than random points (OR=1.016), and with less mixed forest cover (OR=0.833) (Table 4.11).

Hatch-year Cooper's Hawks roosts were best predicted by a model containing deciduous forest, evergreen forest, mixed forest and forest patch size. Three other models were also ranked highly (Table 4.10). Hatch-year Cooper's Hawks roost sites were found in larger forest patches (OR=1.205), with a greater proportion of evergreen forest (OR=1.102) and greater deciduous forest (OR=1.017) than random sites (Table 4.11).

Stopover Habitat and Scale

At a regional scale, migrant Sharp-shinned Hawks used stopover sites within a more rural landscape, exhibiting greater cover of mixed forest, emergent wetland, and pasture and less suburban habitat cover near stopover sites than found at points across the surrounding region (Table 4.12). Once located in a rural landscape, Sharp-shinned

Hawks selected the larger forest patches available and selected sites with more emergent wetland cover nearby. At a near scale, selecting a larger forest patch for stopover roosts appeared most important. No other habitat cover values had influence on near-scale selection.

Cooper’s Hawks selected to stop in areas with greater mixed forest and pasture cover surrounding them than found available across the region, but did not specifically avoid suburban cover (Table 4.12). At the landscape and near scale, Cooper’s selected larger forest patches for stopover similar to the Sharp-shinned Hawk (Table 4.12). At a near-scale, Cooper’s Hawks appeared also to select sites with greater deciduous forest and less mixed forest cover, possibly indicating a preference for more open upland forests.

At near-scale, both age classes of Sharp-shinned Hawk were strongly influenced by forest patch size (Table 4.12). However, adult Sharp-shinned Hawks also selected stopover sites with greater evergreen cover. In contrast, hatch-year birds avoided sites with mixed forest cover. Both age classes of Cooper’s Hawks selected stopover sites in deciduous forest and within larger forest patches (Table 4.12). Although adult Cooper’s Hawks used areas with less mixed forest and hatch-year birds selected sites with greater evergreen forest than found at random, both age classes showed similar patterns of less mixed and greater evergreen cover around stopover sites suggesting the difference may be small (Table 4.12).

Forest Patch Size

Forest size was one of the most consistent influences on accipiter stopover site selection models in this study. Both accipiters showed strong preference for roosting in larger forests particularly contiguous forest (Fig. 4.2). Only 9.2% of stopover sites occurred non-forest habitat, although 44.1% regional samples and 36.3% of random points were represented by non-forest habitat (Fig. 4.2). Hatch-year birds of both species used small forests more often than adults. Hatch-year Cooper's Hawks used contiguous forest similar to its availability in the landscape, in contrast to adults (Table 4.1).

DISCUSSION

Both Sharp-shinned and Cooper's Hawks sought out specific habitat features during their autumn migration stopover periods in the Central Appalachians. Large forests within a rural landscape were important to both species. Birds migrating within the Ridge and Valley region roosted within seven kilometers of the flyway, suggesting habitat near the flyway is particularly important. Although Cooper's Hawks are considered a generalist-nesting species and regularly nest in suburban or urban areas (Curtis et al 2006), they displayed more conservative habitat selection during migration, seeking out forests larger than 200 hectares for most of their roosts. Mixed evergreen-deciduous forest was important at a landscape scale; however, at near-scale evergreen forest was important for adult Sharp-shinned Hawks only whereas Cooper's Hawks selected deciduous forest predominantly. Evergreen or mixed forest is used for roosting and nesting by both species in the breeding season (Fischer 1986, Murphy et al 1988, Bildstein and Meyer 2000, Curtis et al 2006). The availability of mixed and evergreen cover is low within the study landscape and may be less available in the larger forests they appeared to prefer.

The Sharp-shinned Hawk also avoided suburban areas, despite a habit of hunting bird feeders in winter (Bildstein and Meyer 2000). Cooper's Hawks in this study selected areas with less suburban areas nearby but the pattern was not strong (Table 4.2). Although Cooper's Hawks will nest in suburban landscapes, they have been found to avoid suburban areas in some studies (Murphy et al. 1988, Boal and Mannan 1999, Roth et al. 2008). How raptors respond to human-use areas may vary with region or experience and deserves further investigation.

The preference for wetlands displayed by Sharp-shinned Hawks may reflect an attraction for thicker cover as protection from predators or a preference for areas that might attract songbird prey (Sapir et al. 2004). Sharp-shinned Hawks feed primarily on small birds (Bildstein and Meyer 2000), and wetlands or riparian areas can attract migrating birds (Finch and Yong 2000). Wetlands also may be attractive as migrating hawks may need to replenish water reserves en route (Sapir et al. 2004, Yosef 1996). Stress from water imbalance has been suggested to be a factor affecting long-distance migrants (Klaassen 2004, Sapir et al. 2004).

A comparison of habitat selection across scales suggests that both species may begin to make stopover choices during travel through a region. Both landscape and near-scale selection models compared stopover sites to random points located less than 10 km away and found forest patch size was the main influence on site selection at this scale. At a regional scale, both species selected to stopover in areas represented by a mix of habitat types associated with a rural and less developed landscape (Bishop 2008). Suburban or urban areas were not used as much as they were available. Other researchers have suggested that migrants may begin their stopover-site search in the latter part of their daily journey (Buler et al. 2007). Niles et al (1996) suggested that raptors may choose to fly over habitat similar to their breeding areas during their daily migration. In this study, I observed both species to cross over small urban areas occasionally, and Cooper's Hawks would cross over inlets along the Chesapeake Bay as well (Fig. 4.1). Other studies have showed that raptors will cross water bodies during migratory flights, despite these areas being inhospitable to raptor stopover (Bildstein 2006). I suspect that raptor migrants may often begin to move towards areas with suitable stopover sites during the latter part of their daily flight. In this study, migrants sometimes changed their flight behavior slightly during the latter part of a day or travel period (Chapter 3). The field team regularly observed birds flying lower in the mid-afternoon, appearing to head for a particular forest, or stopping briefly and then moving on again as if assessing the foraging and roosting habitat conditions.

Songbirds are suggested to select stopover sites in a hierarchical manner by selecting a landscape first and specific habitat types within that landscape secondarily (Hutto 1985, Moore and Aborn 2000). I suggest that migrating accipiters also use a hierarchical approach to stopover site selection, selecting a general landscape first and then a stopover habitat within the landscape. Further research on daily migration behavior across an array of landscape types may clarify this further, and research on the habitat structure of the roost may be insightful.

The reliance on contiguous and larger forest patches during migration by both species was surprising, particularly for the Cooper's Hawks. Raptors traversing an unfamiliar landscape during migration may be more conservative in their choices than birds inhabiting a known home range or wintering area. Prior research suggests that

Sharp-shinned Hawks prefer to hunt in forest during non-breeding periods (Roth et al. 2008, Woltmann 2001, Holthuijzen and Oosterhuis 1985), but this is the first study to identify that larger forest patches as especially critical. Cooper's Hawks may prefer to stopover in a more open forest structure, as found in deciduous forest. They prey upon a wider variety of species, including small mammals, which may be more abundant in larger deciduous forest areas (Yahner 2000). Edges of large forests may provide access to songbird prey as well whereas the forest itself provides cover from predators (Petit 2000, Rodewald and Brittingham 2004, Rodewald and Matthews 2005). Large forest patches also were selected by songbird migrants on stopover along the Gulf of Mexico (Buler et al. 2007).

Although age has been suggested to affect stopover choices in songbirds (Yong et al. 1998, Jones et al. 2002), I did not find large differences in this study. Hatch-year accipiters selected a wider array of forest sizes than adults and roosted farther from the Ridge than adults but showed few other differences. Adults may be more likely to develop preferences or have learned the value of larger forest. Large forests appear to provide more cover from potential predators or inclement weather and disturbance. Roth et al. (2005) found 52% of radio-tagged wintering Sharp-shinned Hawks were killed by avian predators, so selecting protective cover during migration could be an important survival strategy. I suggest that adults may have learned that larger forests can be useful for predator protection during stopover. Because movement across a landscape to find a better stopover site may require both time and energy, young birds may be less prone to make fine scale adjustments to stopover site, especially after a recent migratory flight (Moore and Aborn 2000, Woodrey 2000). Both accipiters examined in this study are short-distance migrants and rarely build up appreciable fat prior to migration (Kerlinger 1989, Delong and Hoffman 2004), suggesting they may not have reserves of energy after a long migration.

Adults also may locate appropriate roosting habitat more quickly and make such selections during flight (Weber and Houston 1997). The closer roost distance of adults may reflect a greater propensity for adults to fly along the Kittatinny Ridge corridor due to the air currents available on ridge slopes. Hatch-year accipiters may exhibit less ridge affinity in the eastern flyway due to the earlier timing of their migration, when off-ridge thermals are more abundant (Kerlinger 1989, Mueller et al.2000). However, although radio-tagged hatch-year Sharp-shinned Hawks flew more often over the valley than adults in this study (Chapter 3), Cooper's Hawks showed no difference by age.

That migrant raptors may seek out certain habitats during travel has important implications for our understanding of raptor migration patterns, stopover ecology and raptor conservation. The strong selection for larger forest patches in this study emphasizes the importance of conserving the large forest patches near the Kittatinny Ridge and other key migration corridors. Large patches of suitable habitat have been found to be important for migrant songbirds as well, another migrant group using the Kittatinny Ridge (Moore and Aborn 2000, Buler et al. 2007, Ktitorov et al. 2008). In this study, even where contiguous forest was limited (e.g., Coastal Plain region, Appendix D), larger forest patches were preferred and non-forest areas avoided by accipiters. These results reinforce the suggestion that protection of patches of natural habitat within suburban areas provides an important conservation benefit to migrants (Mehlman et al. 2005). Further research is needed on non-forest raptors to see if parallel patterns exist.

These results have important implications for the theoretical understanding of migration patterns as well. The strong selection shown for certain habitat types indicates that stopover habitat choices may be as important as weather and orientation decisions in determining the success of a migrant's journey and ultimately its long-term fitness (Hutto 2000). Further research on habitat use and the interplay of migration corridors and habitat within an array of landscapes will better inform conservation planning within critical migration corridors.

Table 4.1. Forest patch size associated with stopover roost sites of migrating accipiters in the central Appalachians during autumn 2003 and 2004 (% of total roosts).

Species Group	Point Type	n	Contiguous >400 ha	Very Large 400-200 ha	Large 199-100 ha	Medium 99-40 ha	Small 39-10 ha	Tiny 9-1 ha	Non-forest <1 ha
Sharp-shinned Hawk									
Total	Roosts	194	36.08	14.43	6.19	11.34	5.67	18.56	7.73
	Random	970	25.91	7.77	5.29	7.25	8.60	12.85	32.33
Hatch-year	Roosts	115	33.91	19.13	6.09	6.09	2.61	21.74	10.44
	Random	575	23.30	9.57	4.87	8.70	8.90	12.87	32.35
Adult	Roosts	79	39.24	7.60	6.33	18.99	10.13	13.92	3.80
	Random	395	29.74	5.13	5.90	5.13	8.97	12.82	32.31
Cooper's Hawk									
Total	Roosts	113	46.02	15.04	1.77	14.16	0.89	13.27	8.85
	Random	565	23.19	7.08	6.90	6.73	5.49	7.61	43.01
Hatch-year	Roosts	49	18.37	24.49	2.04	16.33	2.04	26.53	10.20
	Random	245	21.22	5.71	8.16	5.71	4.08	7.35	47.76
Adult	Roosts	64	67.19	7.81	1.56	12.50	0.00	3.13	7.81
	Random	320	24.69	8.13	5.94	7.50	6.56	7.81	39.38

Table 4.2. Mean % habitat cover surrounding migrant accipiter roost sites, random and regional points in the Central Appalachians during autumn 2003 and 2004[1].

		Near Scale (0.5km)		Landscape Scale (10 km)		Regional Scale (10 km)
Group	Variable	Roost Sites mean (SD)	Random mean (SD)	Roost Sites mean (SD)	Random mean (SD)	mean (SD)
Sharp-shinned Hawk	Deciduous Forest	46.08 (27.92)	41.05 (29.52)	42.59 (14.76)	41.66 (16.31)	28.06 (15.50)
	Evergreen Forest	6.30 (8.08)	5.44 (8. 14)	5.51 (2.41)	5.24 (3.60)	1.76 (1.75)
	Mixed Forest	4.15 (3.88)	4.53 (5.13)	4.92 (3.20)	4.61 (2.94)	0.84 (1.47)
	Row Crops	7.49 (12.66)	8.45 (12.31)	7.84 (7.02)	8.90 (7.52)	21.29 (12.56)
	Pasture	28.15 (22.15)	29.25 (24.03)	26.59 (10.72)	28.39 (13.06)	22.79 (14.06)
	Suburban	2.68 (6.58)	3.00 (9.20)	2.91 (4.39)	3.43 (4.68)	11.57 (10.29)
	Emergent Wetlands	1.00 (3.73)	0.48 (1.90)	1.24 (3.60)	0.58 (1.38)	1.43 (3.68)
Cooper's Hawk	Deciduous Forest	51.97 (30.28)	35.13 (29.81)	37.86 (11.77)	36.00 (16.59)	28.06 (15.50)
	Evergreen Forest	4.13 (6.09)	4.36 (6.94)	5.14 (4.01)	4.25 (3.10)	1.76 (1.75)
	Mixed Forest	2.74 (3.17)	4.11 (6.41)	3.80 (2.22)	4.17 (3.89)	0.84 (1.47)
	Row Crops	8.52 (11.42)	11.20 (15.73)	10.88 (6.11)	11.17 (9.25)	21.29 (12.56)
	Pasture	27.39 (22.56)	33.73 (25.82)	32.44 (10.00)	31.89 (14.53)	22.79 (14.06)
	Suburban	2.01 (6.50)	2.72 (8.43)	2.72 (2.69)	3.11 (4.48)	11.57 (10.29)
	Emergent Wetlands	0.32 (0.63)	1.34 (7.94)	0.42 (0.35)	1.13 (3.52)	1.43 (3.68)

[1] Sample sizes: Sharp-shinned Hawk roosts=194, random=965, regional points=79; Cooper’s Hawk roosts=113, random=565, regional=79.

Table 4.3. Top-ranked logistic regression models distinguishing migrant accipiter roosts and regional sample points in the Central Appalachians in autumn 2003 and 2004 (10 km radius sample). †

Roost Type	Model Rank	Variables in Model	K	QAICc	ΔQAICc	w_i
Sharp-shinned Hawk	1	EW,MF,SB,PS	6	55.509	0.00	0.537
N=190 roosts	2	EW, MF, DF, SB, PS	7	56.961	1.45	0.260
Cooper's Hawk	1	PS, MF	4	42.945	0.00	0.232
N=104 roosts	2	MF, SB. PS	5	43.838	0.89	0.148
	3	PT, MF, PS	5	44.448	1.50	0.109
	4	MF,DF, PS	5	44.522	1.58	0.105
	5	EW, MF, PS	5	44.987	2.04	0.084

†DF=deciduous forest, EW=emergent wetland, MF=mixed forest, PS=pasture, SB=suburban; K=number of model parameters; QAICc= Akaike’s Information Criterion adjusted for small sample size and overdispersion, ΔQAICc= the difference between QAICc of given model and top-ranked model, and w_i = Akaike model weight.

Table 4.4. Model-averaged parameter estimates for migrant accipiter habitat selection at a regional scale in the Central Appalachians during autumn 2003 and 2004 (including models with $\Delta QAIC_C \leq 2$).

Species	Variable	β Estimate	SE	Odds Ratio (*95% CI*)	$\sum w_i$
Sharp-shinned Hawk	Emergent Wetland	0.335	0.117	1.40 (*1.11 - 1.76*)	0.796
N=190, 79[1]	Mixed Forest	2.824	0.566	16.84 (*5.56 - 51.0*)	0.796
	Deciduous Forest	0.041	0.051	1.04 (*0.94 - 1.15*)	0.260
	Suburban	-0.423	0.141	0.66 (*0.50 - 0.86*)	0.796
	Pasture	0.285	0.067	1.33 (*1.17 - 1.52*)	0.796
Cooper's Hawk	Patch Size	0.194	0.234	1.21 (*0.77-1.92*)	0.148
N=104, 79	Emergent Wetland	0.259	0.374	1.30 (*0.62 - 2.70*)	0.084
	Mixed Forest	4.121	0.947	61.9 (*9.64 - 394.26*)	0.678
	Deciduous Forest	0.031	0.041	1.03 (*0.95 - 1.17*)	0.109
	Suburban	-0.124	0.110	0.88 (*0.71 -1.09*)	0.105
	Pasture	0.456	0.111	1.58 (*1.27 - 1.96*)	0.678

[1] n=# roosts, # regional points.

Table 4.5. Case-control logistic regression models distinguishing migrant accipiter roosts and random sites at landscape scale in the Central Appalachians during autumn 2003 and 2004 (10 km radius sample). †

Roost Type	Model Rank	Variables in Model	K	AICc	ΔAICc	w_i
Sharp-shinned Hawk	1	EW,RC,PT	4	607.91	0	0.113
n=194 roosts	2	EW,RC,MF,PT	5	608.32	0.41	0.092
	3	EW,PT	3	608.55	0.64	0.082
	4	SB,EW,RC,PT	5	608.69	0.78	0.077
	5	SB,EW,PT	4	608.92	1.01	0.068
	6	SB,EW,RC,MF,PT	6	609.26	1.35	0.058
	7	DF,EW,PT	4	609.51	1.6	0.051
	8	EF,EW,PT	4	609.62	1.71	0.048
	9	SB,DF,EW,RC,PT	6	609.79	1.88	0.044
	10	DF,EW,RC,PT	5	609.83	1.92	0.043
	11	EF,MF,EW,RC,PT	6	609.88	1.97	0.042
	12	EF,EW,RC,PT	5	609.9	1.99	0.042
Cooper's Hawk	1	EF,EW,MF,PT	5	291.84	0	0.182
n=113 roosts	2	EF,EW,PT	4	292.56	0.72	0.127
	3	DF,EF,EW,MF,PT	6	292.57	0.73	0.126
	4	EF,EW,RC,MF,PT	6	293.57	1.73	0.077
	5	SB,EF,EW,MF,PT	6	293.69	1.85	0.072

†DF=deciduous forest, EF=evergreen forest, EW=emergent wetland, MF=mixed forest, PT=patch size, SB=suburban; K=number of model parameters including unexplained variance; AICc= Akaike's Information Criterion values, ΔAICc= the difference between AICc of given model and top-ranked model, and w_i = Akaike model weight.

Table 4.6. Model-averaged parameter estimates distinguishing migrant accipiter roosts and random points at landscape scale in the Central Appalachians during autumn 2003 and 2004 (cover at 10 km radius).

	Variable	β Estimate	SE	Odds Ratio (*95% CI*)	$\sum w_i$
Sharp-shinned Hawk n=194 roosts	Patch Size	0.179	0.032	1.25 (*1.12-1.27*)	0.761
	Evergreen Forest	0.023	0.041	1.02 *(0.94-1.11)*	0.132
	Emergent Wetland	0.158	0.044	1.21 (*1.07-1.28*)	0.761
	Mixed Forest	-0.053	0.042	0.95 (*0.87-1.03*)	0.192
	Deciduous Forest	-0.002	0.010	1.00 (*0.98-1.02)*	0.138
	Suburban	-0.012	0.010	0.97 (*0.97-1.01*)	0.247
	Row Crop	-0.025	0.015	0.97 *(0.95-1.00)*	0.511
Cooper's Hawk N=113 roosts	Patch Size	0.338	0.055	1.40 *(1.26-1.56)*	0.584
	Evergreen Forest	0.168	0.182	1.18 *(0.83-1.69)*	0.584
	Emergent Wetland	-0.464	0.391	0.63 *(0.29-1.35)*	0.584
	Mixed Forest	-0.162	0.097	0.85 *(0.70-1.03)*	0.457
	Deciduous Forest	0.013	0.012	1.01 *(0.99-1.03)*	0.126
	Suburban	-0.016	0.042	0.98 *(0.91-1.07)*	0.072
	Row Crop	-0.012	0.022	0.99 *(0.95-1.03)*	0.077

Table 4.7. Competing models from case-control logistic regression distinguishing land cover surrounding migrant accipiter roost sites from random points at near scale (0.5 km radius, only models where ΔAICc ≤2) in central Appalachians during autumn 2003 and 2004 .†

Roost Type	Model Rank	Variables in Model	K	AICc	ΔAICc	*Wi*
Sharp-shinned Hawk n=194 roosts	1	EF,EW,MF,PT	5	621.18	0	0.205
	2	EW,MF,PT	4	622.54	1.36	0.104
	3	DF,EF,EW,MF,PT	6	622.82	1.64	0.090
	4	SB,EF,EW,MF,PT	6	623.01	1.83	0.082
	5	EF,EW,RC,MF,PT	6	623.18	2.00	0.076
Cooper's Hawk n=113 roosts	1	DF,EF,EW,MF,PT	6	283.36	0	0.174
	2	DF,EW,MF,PT	5	283.57	0.21	0.157
	3	DF,MF,PT	4	284.47	1.11	0.100
	4	DF,EF,MF,PT	5	284.66	1.30	0.091
	5	SB,DF,EF,EW,MF,PT	7	285.26	1.90	0.067
	6	DF,EF,EW,RC,MF,PT	7	285.36	2.00	0.064

†PT=patch size; DF=deciduous forest; EF=evergreen forest; MF=mixed forest; EW=emergent wetland; SB=suburban; RC=row crop; K=number of model parameters including unexplained variance; AICc= Akaike's Information Criterion values; ΔAICc= difference between AICc of given model and best model; and w_i = Akaike weight of given model.

Table 4.8. Model-averaged parameter estimates distinguishing habitat surrounding migrant accipiter roosts and random points at near-scale (0.5 km radius) in central Appalachians in autumn 2003 and 2004.

Group	Variable	β Estimate	SE	Odds Ratio	$\sum w_i$
Sharp-shinned Hawk n=194 roosts	Patch Size	0.226	0.040	1.25 *(1.16-1.36)*	0.557
	Evergreen Forest	0.021	0.012	1.02 *(0.99-1.05)*	0.453
	Emergent Wetland	0.068	0.040	1.07 *(0.99-1.16)*	0.557
	Mixed Forest	-0.049	0.024	0.95 *(0.91-1.00)*	0.557
	Deciduous Forest	0.002	0.003	1.00 *(1.00-1.01)*	0.090
	Suburban	-0.004	0.011	0.99 *(0.98-1.02)*	0.082
	Row Crop	0.001	0.008	1.00 *(0.99-1.02)*	0.076
Cooper's Hawk n=113 roosts	Patch Size	0.369	0.057	1.45 *(1.29-1.61)*	0.653
	Evergreen Forest	0.031	0.020	1.03 *(0.99-1.07)*	0.396
	Emergent Wetland	-0.111	0.105	0.90 *(0.73-1.10)*	0.462
	Mixed Forest	-0.101	0.044	0.89 *(0.83-0.99)*	0.653
	Deciduous Forest	0.017	0.004	1.02 *(1.01-1.03)*	0.585
	Suburban	0.005	0.016	1.01*(0.97-1.04)*	0.067
	Row Crop	-0.001	0.010	0.99 *(0.98-1.02)*	0.064

Table 4.9. Mean % habitat cover at near scale (0.5 km radius) for stopover sites of adult and hatch-year accipiters during autumn migration in the Central Appalachians, 2003 and 2004.

Mean % Habitat Cover At Near-scale	Sharp-shinned Hawk		Cooper's Hawk	
	Adult mean (SD) (n=79)	Hatch-year mean (SD) (n=115)	Adult mean (SD) (n=64)	Hatch-year mean (SD) (n=49)
Deciduous Forest	49.94 (25.89)	43.43 (29.34)	53.59 (30.93)	49.86 (29.59)
Evergreen Forest	9.54 (25.39)	4.08 (4.69)	3.39 (5.21)	5.10 (7.01)
Mixed Forest	4.95 (4.42)	3.60 (3.37)	2.79 (3.73)	2.67 (2.28)
Row Crops	4.25 (8.01)	9.71 (14.67)	8.60 (9.63)	8.41 (13.52)
Pasture	26.31 (22.82)	29.41 (21.69)	28.06 (24.07)	26.51 (20.63)
Suburban	0.87 (3.36)	3.93 (7.86)	1.68 (5.46)	2.43 (7.68)
Emergent Wetlands	1.53 (5.39)	0.64 (1.84)	0.22 (0.34)	0.46 (0.86)

Table 4.10. Competing models from case-control logistic regression distinguishing migrant accipiter stopover sites from random points by age at near scale (0.5 km radius) in central Appalachians in autumn 2003 and 2004.

Roost Type	Model Rank	Variables in Model	K	AICc	ΔAICc	w_i
Sharp-shinned Hawk	1	SB,EF,EW,PT	5	263.21	0	0.107
Adult	2	EF,EW,PT	4	263.67	0.46	0.085
n=79 roosts	3	SB,EF,EW,RC,PT	6	263.72	0.51	0.083
	4	SB,EF,EW,MF,PT	6	264.02	0.81	0.072
	5	SB,EF,EW,RC,MF,PT	7	264.36	1.15	0.061
	6	EF,EW,MF,PT	5	264.53	1.32	0.056
	7	EF,EW,RC,PT	5	264.53	1.32	0.056
	8	SB,EF,PT	4	264.8	1.59	0.049
	9	SB,DF,EF,EW,PT	6	265.03	1.82	0.043
	10	DF,EF,EW,PT	5	265.11	1.9	0.042
	11	EF,PT	4	265.17	1.96	0.040
Sharp-shinned Hawk	1	MF,PT	3	355.48	0	0.158
Hatch-year	2	EW,MF,PT	4	355.94	0.46	0.126
n=115 roosts	3	RC,MF,PT	3	356.98	1.5	0.075
	4	EW,RC,MF,PT	5	357.21	1.73	0.067
	5	SB,MF,PT	4	357.33	1.85	0.063
	6	DF,MF,PT	4	357.44	1.96	0.059
	7	EF,MF,PT	4	357.47	1.99	0.058
Cooper's Hawk	1	DF,EW,MF,PT	5	121.57	0	0.187
Adult	2	DF,MF,PT	4	121.94	0.37	0.156
n=64 roosts	3	DF,EW,RC,MF,PT	6	122.91	1.34	0.096
	4	SB,DF,EW,MF,PT	6	123.24	1.67	0.081
	5	DF,EF,EW,MF,PT	6	123.52	1.95	0.071
Cooper's Hawk	1	DF,EF,MF,PT	5	148.32	0	0.179
Hatch-year	2	DF,EF,EW,MF,PT	6	148.89	0.57	0.134
n=49 roosts	3	DF,EF,RC,MF,PT	6	149.62	1.3	0.093
	4	SB,DF,EF,MF,PT	6	149.96	1.64	0.079

*†*PT=patch size; DF=deciduous forest; EF=evergreen forest; MF=mixed forest; EW=emergent wetland; SB=suburban; RC=row crop***;*** K=number of model parameters; AICc=Akaike's Information Criterion, ΔAICc= difference between AICc of given model and best model; w_i= Akaike's weight of given model.

Table 4.11. Model-averaged parameter estimates from case-control logistic regression comparing habitat surrounding migrant accipiter stopover sites and random points by age class at near-scale (0.5 km radius) in central Appalachians in autumn 2003, 2004.

	Variable	β Estimate	SE	Odds Ratio (95% CI)	$\sum w_i$
Sharp-shinned Hawk	Patch Size	0.246	0.055	1.279 *(1.15-1.42)*	0.605
Hatch-year	Evergreen Forest	0.002	0.020	1.002 *(0.96-1.04)*	0.058
n=115 roosts	Emergent Wetland	0.111	0.082	1.117 *(0.95-1.31)*	0.192
	Mixed Forest	-0.079	0.037	0.924 *(0.86-0.99)*	0.605
	Deciduous Forest	0.001	0.004	1.001 *(0.99-1.01)*	0.059
	Suburban	0.004	0.011	1.004 *(0.98-1.03)*	0.063
	Row Crop	0.007	0.009	1.007 *(0.99-1.03)*	0.141
Sharp-shinned Hawk	Patch Size	0.196	0.059	1.217 *(1.08-1.37)*	0.693
Adults	Evergreen Forest	0.030	0.013	1.030 *(1.00-1.06)*	0.693
n=79 roosts	Emergent Wetland	0.059	0.033	1.061 *(0.99-1.13)*	0.604
	Mixed Forest	-0.034	0.032	0.967 *(0.91-1.03)*	0.188
	Deciduous Forest	0.003	0.005	1.003 *(0.99-1.01)*	0.085
	Suburban	-0.046	0.034	0.955*(0.89-1.02)*	0.415
	Row Crop	-0.017	0.015	0.983 *(0.96-1.01)*	0.199
Cooper's Hawk	Patch Size	0.187	0.075	1.205 *(1.04-1.40)*	0.484
Hatch-year	Evergreen Forest	0.097	0.039	1.102 *(1.02-1.19)*	0.484
n=49 roosts	Emergent Wetland	-0.124	0.157	0.884 *(0.65-1.20)*	0.134
	Mixed Forest	-0.104	0.064	0.901 *(0.80-1.02)*	0.484
	Deciduous Forest	0.017	0.006	1.017 *(1.01-1.03)*	0.484
	Suburban	0.015	0.024	1.015 *(0.97-1.06)*	0.079
	Row Crop	0.013	0.015	0.908 *(0.98-1.04)*	0.093
Cooper's Hawk	Patch Size	0.641	0.423	1.898 *(1.50-2.40)*	0.590
Adults	Evergreen Forest	0.008	0.034	1.008 *(0.94-1.08)*	0.071
n=64 roosts	Emergent Wetland	-0.199	0.232	0.819 *(0.52-1.29)*	0.434
	Mixed Forest	-0.182	0.072	0.833*(0.72-0.96)*	0.590
	Deciduous Forest	0.015	0.006	1.016 *(1.00-1.03)*	0.590
	Suburban	-0.013	0.024	0.987*(0.94-1.04)*	0.081
	Row Crop	-0.012	0.015	0.988*(0.96-1.02)*	0.096

Table 4.12. Habitat parameters influencing stopover site selection in migrating Sharp-shinned and Cooper's hawks in central Appalachians during autumn 2003, 2004 ('+' = odds ratio >1.0; '-'= odds ratio < 0.99, blank= odds ratio=1.0.) †

Group	Deciduous Forest	Evergreen Forest	Mixed Forest	Emergent Wetland	Pasture	Row Crop	Suburban	Patch Size
Sharp-shinned Hawk								
Regional		na	+	+	+	na	-	
Landscape Scale				+	na			+
Near Scale					na			+
Cooper's Hawk								
Regional		na	+		+	na		
Landscape Scale					na			+
Near Scale	+		-		na			+
Sharp-shinned Hawk								
Adult*		+			na			+
Hatch-year			-		na			+
Cooper's Hawk								
Adult*	+		-		na			+
Hatch-year	+	+			na			+

†Due to covariate correlations, pasture was included in model selection only at a regional scale; row crop was included in models at landscape and near scale and not at regional scale, and evergreen forest was excluded from regional scale model selection; *Age class case-control regression conducted on near-scale habitat cover only.

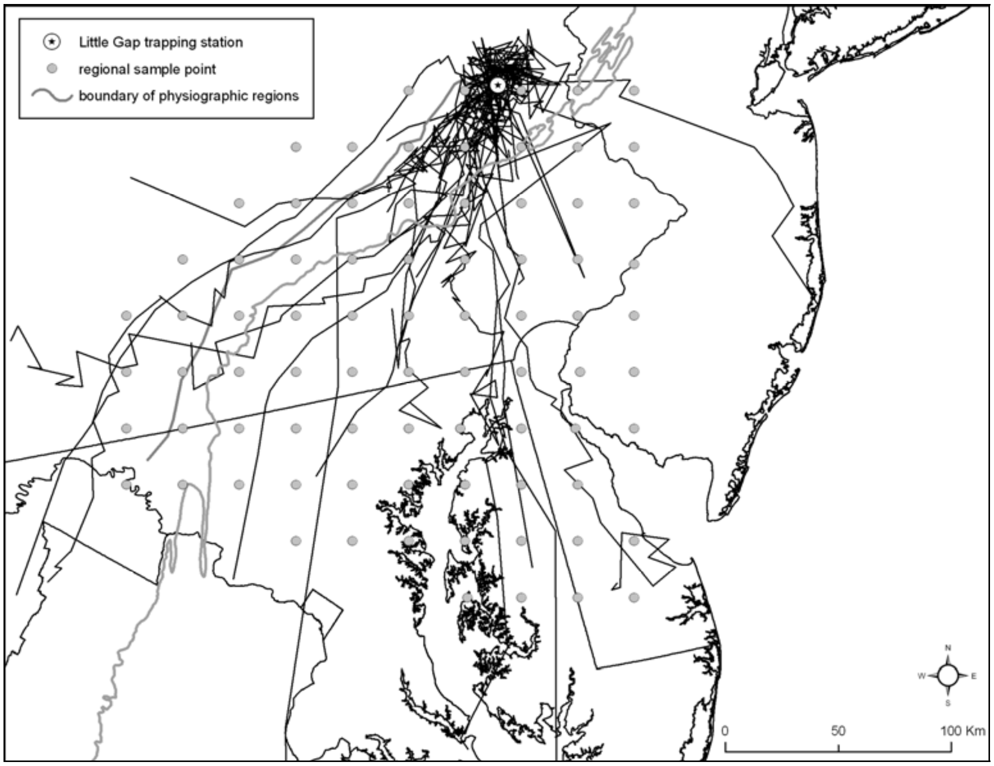

Figure 4.1. Flight paths of migrant accipiters (black lines, n= 42) from release point (white circle) compared to regional habitat sample points (grey dots, n=79) and the physiographic boundaries (grey wavy line separates the Ridge and Valley north of line and Piedmont and Coastal Plain, south of line).

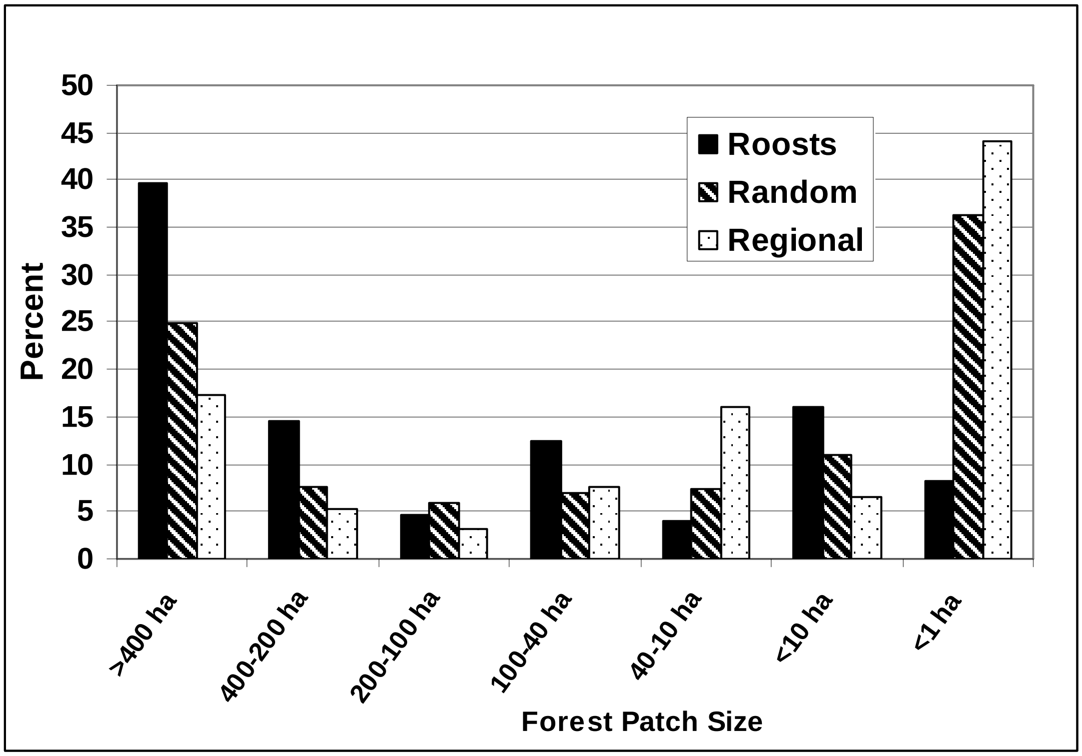

Figure 4.2. Proportion of accipiter roosts, random points, and regional habitat samples located in forest patches of differing sizes during autumn migration, 2003-2004 (Cooper's and Sharp-shinned hawk pooled).

Chapter 5. The Behavior, Abundance, and Distribution of Autumn-migrating Raptors along a Key Migration Corridor, the Kittatinny Ridge, Pennsylvania.

ABSTRACT

I studied the behavior and distribution of raptors on stopover during autumn along an important migration corridor for eastern North American raptor populations, the Kittatinny Ridge, during autumn 2002 and 2003. I set up seven transects in five clusters or 'routes', with each route containing a transect crossing the Ridge, and six positioned parallel to the ridge. Within each route, I surveyed transects on the north and south side of the Kittatinny Ridge at three distances from the ridge: 1 km, 6 km, and 16 km. I and the field team conducted morning roadside surveys weekly on each 8 to 10 km long transects from September 1 to November 20 over the two years (n=15 to 30 surveys/transect/year). For each raptor the field team recorded the location, the perpendicular distance from the road, and recorded the habitat and behavior. Abundance (birds/km) and density (birds/ha) of diurnal raptors were estimated for all diurnal raptors and sub-groups (i.e., forest habitat raptors and open habitat raptors). I estimated abundance for any raptor species with greater than 30 detections. I estimated abundance of large and small avian prey using fixed radius 30 m point counts in forest along each transect and compared prey abundance to raptor abundance patterns. I observed raptors during autumn stopover perching, 47.4%, flying below tree height, 39.5%, and hunting from flight or a perch, 13.1% (n=1134). Raptor abundance varied by distance from the ridge and prey abundance but less so by habitat type. Raptors concentrated primarily from 1 to 6 km from the Kittatinny Ridge. Forest raptors and American Kestrels (*Falco* *sparverius*) were more abundant on the north side whereas soaring birds, e.g., the Red-tailed Hawk (*Buteo jamaicensis*) and vultures, were more abundant on the south side where thermal activity was presumably greater. Raptor abundance on transects was correlated with prey abundance. Forest raptor abundance was highest within 6 km of the Ridge, overlapping areas with higher small prey abundance. Raptor and avian prey distribution suggest that the Kittatinny Ridge flyway represents a corridor with habitats near the Ridge being more heavily used for stopover by migrants than areas farther away. Although habitat cover did not strongly influence patterns of migrant abundance, open habitat raptors were found at higher densities in areas with less forest. Behavior did not vary by distance or forest cover suggesting that stopover foraging and roosting are not limited by landscape factors. Raptors spent less time roosting in suburban habitats than other habitats perhaps due to a higher disturbance. Conservation of rural habitats along the Kittatinny Ridge may be important for migrant raptor and songbird conservation. Further research on migrant raptor behaviors in different habitats along this and other migration flyways could be useful to understanding stopover patterns and differences among habitats.

INTRODUCTION

The quality and abundance of stopover habitat can influence the survival of migrating birds (Barrow et al. 2000, Petit 2000, Mehlman et al. 2005). Landscape attributes and habitat composition both may influence the use of sites during migration stopover and the ability of birds to replenish fat stores (Moore et al. 1995). Buler et al. (2007) found that forest cover, distance to the migration flyway, and the abundance of food at a local scale were all important in explaining songbird densities during migration along the Gulf of Mexico. Large patches of suitable habitat appear to form the basis for initial selection by forest songbirds on stopover (Ktitorov et al. 2008).

In northeastern North America, the Kittatinny Ridge of the Central Appalachians is one of the primary corridors for southbound raptors leaving Canada and New England during autumn migration (Zalles and Bildstein 2000, Goodrich and Smith 2008). The Kittatinny Ridge was designated a global, national, and state Important Bird Area due to the concentration of raptors and other birds that occur along the ridge during autumn migration (Crossley 1999, Commission for Environmental Cooperation 1999, Bildstein 2006). The volume of migrants using this corridor has been well-documented (Broun 1939, Bednarz et al. 1990, Van Fleet 2001). Some species concentrate on the ridge in greater numbers than any other place in eastern North America (Goodrich and Smith 2008). Migrants may follow the Ridge for long distances as they traverse Pennsylvania and others may use the Ridge only for short periods (Maransky et al. 1997, Kunkle et al. 2009, Chapter 3). Although the Ridge is used by thousands of raptors each autumn, little is known about how migrating raptors use the habitats along the Ridge and within the nearby landscapes and whether migrants concentrate near the migration flyway during stopover or disperse widely.

Some scientists suggest that raptor migrants may fast during several weeks of their migration or spend very little time foraging during their migration (Hofslund 1973, Smith 1985, Smith et al. 1986, Harmata 2002). Raptors regularly cross large areas of inhospitable terrain during migration (e.g., water, deserts) where foraging opportunities are rare and may be capable of fasting for long periods (Martell et al. 2001, Fuller et al.

1998, Bildstein 2006, Strandberg et al. 2009). In contrast, raptors are observed hunting during migration at northern latitude watch-sites and migrating past watch-sites with full crops regularly (Holthuijzen et al. 1985, Shelley and Benz 1985, Chapter 2). The frequency of foraging by migrating raptors and among all species is little studied. Moreover, the behavior of migrating raptors can vary with latitude, migration progress and length (Kerlinger 1989, Bildstein 2006, Newton 2008).

The importance of stopover habitat to migrating raptors also is unclear. Niles et al. (1996) found that migrating raptors in the Cape May peninsula of New Jersey, a major migration corridor, flew over habitats similar to nesting habitats as they migrated south, perhaps indicating that stopover habitat availability may influence a raptor's travel path. If raptors do seek out certain habitats during stopover, the distance they travel away from a migration pathway in search of appropriate habitat is unknown (Chapter 4). Conserving natural habitats near migration flyways, such as the Kittatinny Ridge, may be important if migrants do need to rest and feed as searching for suitable stopover habitat can stress energy reserves of migrants (Mehlman et al. 2005).

The energy-minimization hypothesis of migration predicts that migrant raptors would feed regularly during non-travel periods but avoid carrying additional fat that may affect flight dynamics (Newton 2008) . If suitable habitat is abundant, raptors might concentrate closer to the migration flyway to save energy. Alternatively, if birds do not need to feed or they are too weak to disperse, they may roost near the flyway as well. The energy-minimization hypothesis also suggests they would minimize travel away from the flyway on stopover to lessen energy consumption. If foraging regularly is a priority for migrating raptors, migration patterns could be influenced by the abundance of prey populations as well as habitat. Kerlinger (1989) suggested that concentrations of migrating accipiters along the Atlantic coast during late September may be a response to the large numbers of prey, e.g., migrating songbirds, concentrating in coastal habitats. Recently, Alerstam proposed a ’fly and forage strategy’ of migration where aerial insectivores or other birds migrate during the daylight to take advantage of foraging opportunities during migration travel (Alerstam 2009). Diurnal raptors travel primarily during daylight to take advantage of energy savings from thermals and other air currents (Kerlinger 1989, Bildstein 2006). It is possible they also migrate during the day to forage opportunistically en route. This theory also would support the observed orientation of migrating raptors to certain habitats observed by Niles et al. (1996), and would predict an association of habitat type on migratory travel and stopover patterns.

Age may affect stopover distribution and behavior. Immature songbirds have less fat than adults when trapped during migration (Woodrey 2000) and can spend more time foraging during stopover (Woodrey 2000, Petit 2000, Deutshchlander and Muheim 2009). First-year raptors suffer high rates of mortality (up to 70%) presumably because learning to capture live prey is difficult (Newton 1979, Roth et al. 2005). Learning which habitats provide suitable stopover sites could be challenging for inexperienced, hatch-year hawks. Young birds may settle in less suitable habitat more readily and show a different distribution along flyways and among habitats than adults. Young birds may use a wider range of stopover sites or be less likely to travel away from a migration corridor in search of appropriate sites.

Critical stopover areas for songbirds have been defined and designated for protection along migration corridors in other regions (e.g., Moore et al. 1995, Petit 2000).

Although habitats for migrating birds inland are not as restricted as those found along coastlines, the availability of critical habitats along inland migratory pathways still may influence long-term population health. As the landscape near and upon the Kittatinny Ridge is being increasingly altered (Goodrich et al. 2002, Bishop 2008), it is important to better understand how migrant raptors use the landscape along this migratory corridor and how that might inform conservation planning.

In this study, I examined stopover distribution and behavior of migrant raptors observed along a major inland autumn migration corridor, the Kittatinny Ridge of the Central Appalachians. I quantified the behavior of raptors and their distribution in relation to the flyway and available habitat. Because food resources have been suggested to be an important cue that songbirds use in selecting stopover sites (Moore et al. 1995, Rodewald and Brittingham 2004), I also examined avian prey abundance along the Kittatinny Ridge, to compare to patterns of raptor abundance.

METHODS

Study Area

The Kittatinny Ridge or Blue Mountain, is the eastern-most ridge of the central Appalachians, and has been recognized as a major migration corridor for southbound migrating raptors and songbirds since the 1930's (Broun 1939, Heintzelman 1986, Bildstein 2006). Data collected on other Appalachian ridges indicate that more raptors migrate along the Kittatinny in autumn than other ridges in the region (VanFleet 2001, Goodrich and Smith 2008). The Kittatinny Ridge extends more than 300 kilometers from western New Jersey south and west through Pennsylvania, crossing 11 counties before ending just north of the Maryland border. Most of the ridge is forested with second-growth deciduous forest although some residential development occurs along its slope. Five rivers break the mountain corridor during its extent, and only a few highways cut through the prominent mountain corridor.

Road Survey Methods

Five road survey routes were mapped along the Kittatinny Ridge from eastern through west-central sections of Pennsylvania (from 75º 20' to 77 º 10' latitude). Routes were placed in the vicinity of the following locations, listed in east to west as follows, Little Gap, Bake Oven Knob, Leaser Lake, Lamb's Gap, and Waggoner's Gap. Each route was composed of seven 8 to 10 km transects placed on rural roads parallel to the Ridge, with three transects on the north side, three transects on the south side, and one crossing over the Mountain connecting the two sides (Fig. 5.1). Transects were placed at approximately 1 km, 6 km and 16 km perpendicular distance from the Kittatinny Ridge-top to examine migrant raptor abundance and ridge affinity at different distances from the migration corridor. These distances were selected to examine if birds concentrate more near the Ridge than farther away, and to keep from transects spaced far enough apart to avoid overlap in detections.

I and the field team surveyed each of the five routes once every 5 to 7 days from September 1 through November 21st. One or two observers surveyed each transect between 0700 and 1030 on non-rainy days by driving 10 to 25 km per hour and stopping when a raptor was observed or when a songbird point count was conducted (see below). All transects per route were surveyed on the same day. Based on previous research on stopover duration in birds, I assumed that the five to seven day spacing of surveys allowed most migrants to move out of the area between surveys (Newton 2008).

The starting point of the survey alternated each week from the north to the south side of the ridge to minimize time of day bias. The field team varied the beginning point among transects to ensure both outer and inner transects were sampled during early and mid morning hours regularly. The mountain transect was usually sampled in between north and south slope surveys. The 16 km transects were only surveyed in 2003, thus I and the field team conducted 15 to 21 surveys per transect at 16 km and 30 to 41 at all other distance categories.

Observers recorded the species, age, habitat type, and the general behavior for each raptor detected. Behaviors were classified into flying high (flying above tree-top height and possibly migrating), flying low (flying below tree-top height), perched, fly-hunting (e.g., actively hovering or pursuing prey, and perch-hunting (actively hunting or eating prey on a perch or the ground). The GPS location of each raptor was recorded (in UTM), a compass bearing from the observer to the bird, and the distance of the observer to the bird using a Rangematic 1000 meter range finder. If a bird was sighted near the road during the survey, the observer halted the survey vehicle before flushing the bird to collect the data.

The GPS location of the observer, the distance and bearing to each bird were input into ArcGIS 8.3 ArcMap program to calculate the estimated UTM coordinates of each bird. Each estimated raptor location was mapped and then used to calculate the perpendicular distance of the bird to the survey route for estimation of raptor abundance and densities.

I recorded data on 16 species of diurnal raptors from the Order *Falconiformes*, including buteos, accipiters, falcons, eagles and vultures. I used the 98% migration interval for each species determined from Hawk Mountain Sanctuary long-term counts (Bednarz et al. 1990) to trim the data seasonally to consider only sightings during the migratory period. For example, no vultures of either species were considered prior to September 20th and no American Kestrels (*Falco sparverius*) were included in the analyses if detected after October 30. Timing of the 98% migration interval of most other species spanned the entire sample period (Bednarz et al. 1990).

Habitat Cover

The percent habitat coverage along each segment, within one km distance of the road was quantified in GIS ArcGIS 8.3 Spatial Analyst. The percent cover of 21 vegetation types (see Appendix D) was calculated using the National Land Cover dataset computed from LandSat Satellite Thematic mapper ™ imagery (circa 1992). The land cover classification contains 21 different land cover categories with spatial resolution of 30 m. Forest types were combined into one variable ‘forest’ and all field or agricultural uses collapsed into ‘open’ habitat cover. All residential and urban or commercial land uses were collapsed into a ‘suburban’ category, representing all human disturbed lands. The five final habitat types considered in the study included forest, open habitats (row crops, fields, etc.), edge (on the edge of forest and fields), suburban, and mixed (a mix of all habitat types). Because routes were pre-selected to allow slow uninterrupted surveys by vehicle, suburban land cover was pre-selected to be minimal where possible. For analyses I also created a forest cover index variable ranking each transect as having abundant forest cover (70% or more), moderate forest cover (40 to 69%), or low forest cover (<40%). Most non-forest habitat was pasture, row-crop, or old field habitat (Table 5.1).

Raptor Density

The perpendicular distance, habitat type, and location for each raptor was input into Distance 4.1 for calculation of densities of raptors along each of the seven segments of each of five routes and by segment type (mountain, 1, 6, and 16 km) (Thomas et al. 2003). Because samples per species were inadequate to compare individual species (Buckland et al. 2001), I grouped raptors into three groups for density estimation based on their usual nesting preferences. Groups included all raptors, all open-habitat species (Northern Harrier (*Circus cyaneus*), Cooper's Hawk (*Accipiter cooperii)*, American Kestrel (*Falco* s*parverius*), Red-tailed Hawk (*Buteo jamaicensis*), and all forest habitat raptors (Sharp-shinned Hawk, Northern Goshawk (*Accipiter gentilis*), Red-shouldered Hawk (*Buteo lineatus*), Broad-winged Hawk (*Buteo platypterus*)). A global detection function or probability of detection was calculated for each raptor group and a density estimate by group calculated for each transect (Buckland et al. 2001). I treated flocks of birds (primarily vultures) as single individuals for these analyses because of detectability difference in groups of birds. I was unable to stratify by habitat because of the small number of birds detected within some areas (Buckland et al. 2001), however the habitat on each transect was fairly similar (forested, open, or mixed). I assumed the detection probability for birds on the road equaled one for all Distance calculations and I used a half-normal model based on examination of detection distributions by raptor group (Appendix D). For each raptor group I compared densities across distance and slope categories using non-parametric statistics.

Raptor Abundance

I also examined raptor distribution among species and groups by calculating an index to raptor abundance by transect. I estimated a detection radius for all small raptors (American Kestrel, Sharp-shinned Hawk, Merlin), and all large raptors (Cooper's Hawk, Northern Harrier, Broad-winged Hawk, and larger birds) by plotting the frequency of sightings of each size class within three habitat groupings, forest, open, and mixed habitats (Appendix E). 'Mixed' habitats included detections of birds in suburban, edge, and mixed habitat types combined. Sightings were plotted by 10 m increments from the road for all surveys. Data were truncated at the distance increment which included 90% of each group (Appendix E) (Buckland et al. 2001). Sightings beyond the truncation distance were considered outliers and eliminated from consideration. The truncation distance for small raptors was 50 m for forest, 80 m for mixed habitats, and 120 m radius in open habitat. The truncation distances for large raptors were 150 m in forest, 200 m in mixed habitat, and 250 m in open habitat. These truncation distances are similar to that calculated in a controlled experiment using raptor silhouettes along roads, i.e., 100 m for small raptors (Milsap and LeFranc 1988).

Raptor abundance was derived for the truncated dataset by dividing raptor numbers by the transect length to derive an estimated abundance for each transect (raptors/km) for each day. Mean abundance on transects was compared by habitat composition, distance from ridge, ridge side, prey abundance, and route using Kruskal-Wallis non-parametric tests and Spearman rank correlation. Abundance was analyzed by species for groups with adequate sample size and by groups including 'all raptors', 'forest habitat raptors', and 'open habitat raptors'. Individuals in flocks (both vultures and

Broad-winged Hawks) were tallied as one entity and analyzed separately from lone individuals for that species to avoid detection bias of flocks. I did not calculate abundance for any species with less than 40 detections over the two year study.

Avian Prey Abundance

To measure songbird abundance along the Ridge (i.e., potential prey), two or three point count stations were conducted within forest habitats during each transect (Verner 1985). Where forest was limited only two point counts were used. Each point count was surveyed eight to nineteen times over the two years with an average of 11 surveys per point in 2002 and 16 per point in 2003. Forest patches surveyed reflected the forest available along the route and varied from continuous forest to small forest patches (<5 ha). Point counts were placed at least 2 km apart along the road transects and were conducted during transect surveys. The counts were conducted for three-minutes by a single observer standing outside the vehicle along the transect survey (Verner 1985). The order varied as described for transect road surveys above (i.e., beginning point varied across transects within a route). If wind exceeded 10 km per hour or rain began falling, the point count was not conducted.

All birds detected by sight or sound within 30 m were tallied at each count station. Because surveys were conducted once a week, I assumed that that any migrant birds from the prior week had continued on their migration between surveys (Morris et al. 1996, Newton 2008). To examine potential prey of bird-eating raptors, I classified the data into birds small enough to be taken by small raptors e.g., Sharp-shinned Hawks as ‘small prey’, e.g., passerine birds smaller than the American Robin (*Turdus migratorius*) (Bildstein and Meyer 2000), and those that were at least as large as a robin but small enough to be prey of larger raptors, as large prey, e.g., robins, grackles, blackbirds, doves (Curtis et al. 2006). Larger birds that were unlikely prey of most raptors, i.e., waterfowl, turkey, were not counted. I derived a mean number of individuals by size category per station for each of the 35 transects. These indices to avian songbird abundance were compared to raptor abundance, habitat cover, and distance to the Ridge.

RESULTS

I and the field team conducted 200 transect surveys between September 1 and November 21 in 2002 and 2003 with 15 to 30 surveys per transect per year. Some routes were sampled at 7-day intervals and others at 5-day intervals. A total of 1168 raptors or flocks were sighted on all routes pooled, with 706 raptors detected in 2002 and 462 in 2003. More raptors were observed on the two routes west of the Susquehanna River, Lamb's Gap (333, 28.5% of total observed) and Waggoner's Gap (343, 29.4%) as compared to the three routes east of the river, Leaser Lake (211, 18.1%), Bake Oven Knob (175,15.0%), Little Gap, (106, 9.1%) (Pearson χ^2=180.116, df=4, $p<0.001$).

Fifteen species were detected during stopover along the routes with the Turkey Vulture (*Cathartes aura*), Red-tailed Hawks, and American Kestrels, the most abundant species detected (Table 5.3). Rarities observed included Bald Eagles (*Haliaetus leucocephalus*), Golden Eagles (*Aquila chrysaetos*), Peregrine Falcon (*Falco peregrinus*), Osprey (*Pandion haliaetus*), and Merlin (*Falco columbarius*) (Table 5.3).

Habitat Cover

On all transects combined, forest and open habitats were of similar proportion (Table 5.1). Forest habitat was more abundant on the Ridge and at 16 km distance on north side where transects often intersected other ridges (Table 5.1, Fig. 5.1). The most forested transects were on the Ridge and on the north side at 1 or 16 km distance. Open habitat was more extensive on the south side at 6 and 16 km distance from the Ridge (Table 5.1). Suburban development was in low abundance on most routes however areas of development were avoided in our study design to allow a slow driving pace.

Raptor Behavior

Of the 1168 individuals or flocks sighted, I classified behavior of 1134 raptors (97.1%) (Table 5.1). Of these, 30 (2.26%) were flying high or soaring, and the remainder 1104 (97.4%) were perching or displaying other stopover behaviors. Excluding birds flying high as they might be migrating, the field team observed 47.2% of the raptors perched, 38.7% flying below tree height, 7.7% hunting from flight (includes hovering, pursuing prey, eating, etc.), and 5.6% were actively hunting from a perch (i.e., observed actively looking for prey or eating prey while on a perch). Thus, a total of 13.3% of raptors on stopover were observed to be actively hunting during surveys (Table 5.2).

The proportion of all raptors displaying the four different stopover behaviors did not vary with distance from the Ridge (Pearson χ^2=22.0, df=15, p=0.102). The behavior of open-habitat raptors also did not vary significantly by distance from Ridge although perching ranged from a low of 53.8% on Ridge to 80% at 16 km (Pearson χ^2=13.246, df=9, p=0.152). Forest habitat raptors also showed no difference in behavior by distance from Ridge (Pearson χ^2=9.23, df=9. p=0.416)

When examined by species, Red-tailed Hawks perched more at 16 km radius than at closer distances to Ridge and showed no fly-hunting or perch-hunting on the Ridge (Pearson χ^2=44.229, df=12, p=0.000). Broad-winged Hawks perched more near the Ridge (91.7% at 1 km and 46% at 6 km) and they showed less low flight, 8.3% at 1 km, compared to 53.8% at 6 km. (Pearson chi-square=6.53, df=2, p=0.038). Detections on Ridge were too few to consider in this analysis. Other species showed no differences by transect distance or the data were too few to analyze (Table 5.2).

Behavior did not vary between the north and south slope for all raptors or forest habitat raptors. Open habitat raptors displayed fly hunting behavior more on south side (9.3%) and perch hunting less (6.9%) compared to north side (4.2% and 13.2% respectively) (Pearson chi-square =11.926, df=1, p=0.008). Red-tailed Hawks were observed more often in low flight on the north side (36.2% of birds) than the south side (17.6%) (Pearson chi-square =12.949, df=1, p=0.005). In contrast, flocks of Turkey Vultures were observed flying low more on the south side than on north side (75% versus 50%) (Pearson Chi-square =4.032, df=1, p=0.045). Single Turkey Vultures showed no difference in behavior by side of ridge. Flocks may have been locating thermals in the more open habitat found on the south side.

Behavior varied significantly among the five habitat types for all raptors although in all habitats low flight or perching were the most commonly observed behaviors (Pearson χ^2=35.913, df=12, p=0.000). Perching was reduced in suburban habitats (31.2% compared to 47% overall) whereas flying low was elevated (54.5% versus 38% overall) (Table 5.3). Fly-hunting was observed more in suburban habitats (13.0% versus 8%

overall) and perch-hunting was rarely observed in suburban and mixed habitat types (1.3% and 0.9% respectively versus 5.7% overall).

The species using different habitats varied as some species, e.g., American Kestrel and Northern Harrier, were found mostly in open habitats (Table 5.4). However, I found differences in behavior for the Red-tailed Hawk which was observed in all habitats. Red-tailed Hawks perched less and flew more in suburban habitat compared to other habitats (36.8% perched in suburban versus 66.0% perched in other habitats ; 47.4% flying low in suburban versus 21.3% in other habitats, n=356; Pearson χ^2= 25.138, df=12, p=0.014) (Table 5.2).

Raptor Density

Mean densities of all raptors on transects ranged from 0.040 to 0.096 raptors/ha (n=35). Densities of all raptors and forest habitat raptors did not vary significantly among distance categories or between sides of the ridge (Table 5.1; Kruskal Wallis, p>0.05). However, density of all raptors and forest habitat raptors on transects was positively correlated to percent forest cover on transects (Spearman rank correlation: r=0.391, p<0.05, forest r=0.340, p<0.01).

Density of open habitat raptors (birds/ha) was higher on the south side of the Ridge where open habitats were most common (Table 5.1) (Mann-Whitney U=62.500, p=0.038). The density of open habitat raptors was higher at 6 km from the Ridge than at other distance categories (e.g., 0, 1, 16 km) (H=8.303, df=3, p=0.04) (Table 1). The density of open raptors and American Kestrels was higher on transects with low and moderate forest cover compared to areas of high forest cover (open: H=7.721, df= 2, p=0.02; American Kestrel: H=6.025, p=0.049, df=2) (Fig. 5.2).

Raptor Abundance

Mean abundance of raptors observed on surveys averaged 0.122 hawks/km (SD=0.24) and 0.04 vultures/km (SD=0.15) over all surveys (Table 5.4). Raptor abundance differed among the five routes with lower overall abundance on the eastern route, Little Gap (mean=0.074 ±0.184) and highest at Waggoner's Gap, the western route (Waggoner's Gap mean raptors/km =0.169 ±0.316 SD, H =18.762, df=4, p=0.001).

All raptors, vultures, open-habitat raptors, and Red-tailed Hawks were more abundant on the south side of the Ridge than on the north side whereas forest raptors were more abundant on the north side (Table 5.4). All raptors combined showed significant differences in abundance on transects (birds/km) by distance from the Kittatinny Ridge (Table 5.4). All raptors and open-habitat raptors were most abundant from 1 to 6 km distance with the highest abundance at 6 km (Table 5.4). Vultures were more abundant at 6 km distance. Forest raptors were most abundant from the 0 to 6 km radius, with few observed at 16 km distance (Table 3). The American Kestrel and Cooper's Hawk were equally abundant at 1 to 6 km with lower detections at 0 and 16 km. Red-tailed and Sharp-shinned hawks were most abundant at 6 km radius from the Ridge (Table 5.4).

When transects were classified by forest cover (high, moderate, low) I found that all raptor groups were more abundant (birds/km) from 1 to 6 km radial distance from the Ridge and lower at the 16 km distance within the three forest cover categories (Table 5.4, Fig. 5.1). Raptor abundance did not vary among the three forest cover categories when ridge distance was held constant (e.g., comparing raptor abundance within high, moderate and low forest cover at 0, 1, 6, or 16 km from ridge) except for the American Kestrel.

Kestrels were more abundant in moderate forest cover (mean=0.047 kestrels/km, SD=0.086), compared to 0.028 and 0.035 kestrels/km along high and low forest cover transects respectively along 6 km radius transects (H=6.456, df=2, p=0.02). Kestrel abundance did not vary by forest cover type for other distance categories.

Age Distribution

I aged a total of 502 raptors as adult or hatch-year birds during the surveys (buteos and accipiters primarily). Aged raptors were predominantly adult, 78.6%, with 20.8% aged as hatch-year birds. Proportion of hatch-year birds detected on surveys decreased from a high of 46.7% on the Ridge to the 12.5% on the most distant transects (16 km) (Pearson χ^2=15.192,df=6, p=0.019). Adult and hatch-year proportions did not differ between north and south slopes (north=75% adult, south=81.2% adult).

Of the total aged raptors, 68.3% were recorded in open habitats, 9.1% in forest, 9.7% in mixed open and forest types, 5.9% on forest edge, 6.9% in suburban habitat, similar to the proportions of all birds (Table 5.1). For all species pooled, open-habitat raptors and forest-habitat raptors, distribution by age among habitat types did not differ (χ^2, p>0.05). However, adult Red-tailed Hawks were seen more in open habitats than immatures (70% versus 52%) whereas immature birds used more forest-field edge and forest than adults (13 and 15% versus 5% and 8%) (Pearson χ^2=11.671, df=4, p=0.02).

Avian Prey Abundance

A total of 4,001 birds of 90 species was recorded on the point counts during both field seasons, for a mean of 15.15 songbirds/transect (range 0-327). Abundance of avian prey was not correlated to forest cover on transects (Spearman rank correlation r <0.07, p>0.05). Mean abundance of small and large prey was highest on the 6 km distance transects (large: mean= 35.94, SD=84.85, H=50.281 df=3, p=0.000; small: mean 17.01, SD=7.66, H=60.946, df=3, p<0.001) (Table 4). Abundance of large prey was higher on the south side and farther from the Ridge, on the 6 to 16 km transects (H=205.05, df=2, p<0.001,) (Table 5.4).

Avian Prey and Raptor Abundance

Abundance of large songbird prey (mean birds per point) was correlated to abundance of Red-tailed Hawks on transects (Spearman rank r=0.079, p<0.05) and inversely correlated to abundance of American Kestrels (Spearman r=0.066, p<0.05). Small songbird prey abundance was correlated with total hawk abundance on transects (Spearman rank r=0.093, p<0.05), forest habitat raptor abundance (Spearman rank r=0.079, p<0.05), Red-tailed Hawk abundance (Spearman rank r=0.078, p<0.05), and American Kestrel abundance (Spearman rank r=0.064, p<0.05) (Table 5.4).

When transects with high forest cover are examined alone, only large prey were correlated with Red-tailed Hawk abundance (Spearman rank correlation r=0.152, p<0.05). On transects with low forest cover, small prey were significantly correlated with total raptors (Spearman rank r=0.131, p<0.05), forest-habitat raptors (Spearman rank r=0.136, p<0.05), and American Kestrels (Spearman rank r=0.107, p<0.05). Prey abundance and raptor abundance was not correlated on transects with moderate cover (Spearman rank correlation, p>0.05).

DISCUSSION

Raptors on stopover along the Kittatinny Ridge were observed foraging at lower proportions than observed in studies using radio-telemetry techniques (Chapter 2, Holthuijzen et al. 1985, Shelley and Benz 1985, Roth et al. 2008). However, many observed in low flight could have been hunting for prey as well, and the roadside survey method provides only a brief snapshot of bird behavior during morning hours whereas telemetry studies reveal more detail on behavior and may be more representative (Chapter 2). A variety of species were observed foraging (7 out of 15), suggesting that feeding occurs during migration for many species. Nearly half of all raptors were seen roosting during morning surveys suggesting that diurnal roosting is common across all species (Chapter 2, Holthuijzen et al. 1985). Broad-winged Hawks and American Kestrels have been documented to actively forage on invertebrates during migratory flight (Shelley and Benz 1985, Nicoletti 1997) supporting the 'flight and forage hypothesis' and perhaps obviating the need to forage as often during stopover as other species (Alerstam 2009).

Some differences in migrant behavior occurred by distance, slope, and habitat for total raptors, and Red-tailed and Broad-winged Hawks. Broad-winged Hawks roosted within the large forest of the Ridge more than areas away from the Ridge. Similar to forest songbird migrants that sought out protective cover of forest for roosting (Petit 2000), Broad-winged Hawks may seek large forests when needing to rest on migration as it offers protection from potential predators. Moore and Aborn (2000) showed that songbirds may select different habitats whether they seek roosting or foraging opportunities as well. Alternatively, Broad-winged Hawks may roost near the flyway when foraging is a low priority.

Low flight by Broad-winged Hawks was more common at 6 km radius perhaps because as a soaring migrant it was seeking thermals in the more open habitat of the south side (Goodrich et al. 1996) or moving in search of prey. Similarly, the Red-tailed Hawks showed more low flight on the north side of the ridge consistent with individuals beginning to migrate using ridge updrafts along the north slope. Updrafts may be more available during the Red-tailed Hawk late autumn peak migration than earlier in autumn (Maransky et al. 1997). Ridge updrafts are more likely along the north side of the ridge during autumn (Broun 1939) and thermals diminish in late autumn (Chapter 2).

Suburban habitat appeared less conducive for roosting by migrants, because Red-tailed Hawks spent less time perching within suburban habitats, similar to that observed for roosting accipiters (Chapter 4). Because the Red-tailed Hawk often nests in suburban and urban habitats, these results were surprising (Preston and Beane 2009). However, the lower proportion of birds observed roosting within suburban habitats suggests these areas may involve more disturbances for birds. Further research on migrant bird behavior amid different habitats could be helpful to fully understand these patterns and their significance to evaluating habitat quality along migration flyways.

The distribution of raptors during autumn stopover along the Kittatinny Ridge indicated that flyway proximity, habitat type, and prey abundance all influenced migrant raptor distribution during stopover along a migratory corridor. Flyway proximity appeared to have greater influence on distributions, however with both higher densities and abundance of autumn raptors from 1 to 6 km radius from the migration flyway. Habitat may have affected forest raptors as they were as abundant on the heavily forested Ridge as in habitats out to the 6 km radius. Other studies have shown large forested blocks similar to that found on the Ridge, attract greater stopover by forest birds during migration (Buler et al. 2007, Ktitirov et al. 2008, Chapter 4). Prey abundance and availability, particularly of migrant songbirds, could also be influencing the patterns of raptor stopover observed in this study and warrants further investigation.

These findings also coincide with the 'energy-minimization' hypothesis of migration which suggests that migrant raptors would minimize travel away from the flyway and concentrate near the flyway to feed or rest when possible (Alerstam and Lindstrom 1990, Newton 2008). Although forest was abundant along the 16 km northern transects, forest raptors were in higher numbers closer to the Ridge and on the Ridge.

Habitat cover also influenced the distribution of open habitat raptors with greater numbers in areas with low forest cover. Adult Red-tailed Hawks, an open habitat species, were more likely away from the Ridge in open fields than immature birds. Immatures may have less internal resources after travel periods to seek out better stopover sites en route and may be less apt to move to find better sites. Accipiters in the same flyway showed an opposite pattern where hatch-year birds roosted farther from the Ridge (Chapter 4), however hatch-year accipiters may be more likely to migrate off-ridge as they move earlier in the autumn than Red-tailed Hawks (Broun 1939, Chapter 3). Hatch-year songbirds have been suggested to minimize movement after travel periods as predicted by the energy-minimization hypothesis (Alerstam 1990, Woodrey 2000, Newton 2008). Despite the open habitat raptors preference for open fields, they were most abundant at 1 to 6 km distance and were less abundant at 16 km on the south side, where open habitats were prevalent, again suggesting a distinct affinity to the flyway. Non-breeding raptors show affinity to habitats similar to their nesting areas (MacWhirter and Bildstein 1996, Smallwood and Bird 2002, Preston and Beane 2009, Chapter 4). Even when the data were stratified by forest cover, migrant raptors were more concentrated near the Ridge (within 6 km). Small songbirds were more abundant along the base of the Ridge as well. Distance to the flyway appeared more important than habitat in autumn migrant raptor distribution.

Similar to raptors, large and small songbird prey abundance were highest at the 6 km radius from the Ridge. However, habitat appeared less important to numbers of prey, although large prey were found in higher numbers on the south side which contained more open habitats. Buler et al (2002) found both habitat and migration flyway were important for songbirds along the Gulf of Mexico. In this study, distance had more consistent influence on abundance of songbird prey, however songbirds were only sampled in forest habitat which may have concentrated birds during stopover compared to open or mixed habitats. The correlation of hawk numbers with prey abundance suggests that both migrant groups may be responding to similar landscape attributes (flyway nearness, habitat, etc.) or that the raptors could be responding to concentrations of prey en route. Because songbird prey were in higher numbers from the base of the Ridge out to 6 km, I suspect the edge of the large forested block and the mix of habitats along the base of the ridge may attract a variety of migrants (Rodewald and Brittingham 2002, 2004, Keller et al. 2009). Further research is needed to examine how migrants respond in more urbanized, disturbed landscape, where habitat may become a more important predictor of avian abundance (Rodewald and Matthews 2005).

In contrast, larger avian prey, which included robins, grackles, doves, were also more numerous from 6 to 16 km radius where habitat was most open. These data support previous findings by this author (Chapter 4) that suggest Kittatinny migrants may prefer to roost on or near the migration corridor but are also influenced by habitat availability.

Both Cooper's and Sharp-shinned Hawks sought out forested habitats on migration, often using larger forest patches (Goodrich, Chapter 4) and forest raptors in this study were most abundant from the base of the Ridge out to six km distance from the Ridge. That small prey abundance followed similar patterns of concentration near the Ridge suggests that accipiters migrating during peak songbird flight periods (September) may not need to travel away from the Ridge to find their prey.

Weather both on the day of migration and on subsequent days as well as individual condition may influence an individual's motivation and ability to travel in search of stopover sites (Chapter 2, Kerlinger 1989). I did not examine patterns with weather or seasonal timing due to limitations of data, however I suspect birds may concentrate at different sides or at different distances according to these factors.

In this study, the importance of finding stopover sites for raptors near the migration flyway and within appropriate habitat suitable for roosting and foraging is demonstrated. Similar to songbirds on stopover (Buler et al. 2007), raptors appear to concentrate in areas near the flyway. Goodrich et al. (Chapter 4) found that migrant accipiters appear to avoid suburban areas during migration suggesting such landscapes may be less used by raptors than during breeding seasons (Curtis et al. 2006).

Our research supports conservation planning efforts to conserve rural habitats in a corridor along the Kittatinny Ridge across Pennsylvania and New York states (Audubon Pennsylvania 2006, Heintzelman 2008) as well as other corridors (Hutto 2000, Mehlman et. al. 2005, Ruelas Inzunza et al. 2005). Habitats within a swath from the Ridge to six or more km radial distance to the Ridge appear to be a priority. Habitats along the base of the ridge were used by small songbird migrants to greater degree that areas more distant suggesting that a focal areas of habitat protection near the Ridge would benefit songbirds as well as raptors. In addition, our results suggest that many species of migrant raptors rest and feed regularly along migration routes and habitat conservation along other major corridors in North America should also be considered a priority in migratory bird conservation initiatives.

Table 5.1. Mean density (birds/ha, SD) of raptors on stopover and % habitat cover[a] along road transects across and adjacent to the Kittatinny Ridge, in central Appalachians of Pennsylvania during autumn 2002 and 2003.

Transect	No. Transects	No. Raptors	Mean % Forest [a]	Mean % Open[a]	Mean % Suburban[a]	All Raptors	Forest Raptors[b]	Open Raptors[c]
On Ridge	5	35	62.3 (31.1)	36.4 (30.3)	0.5 (0.9)	0.073 (0.073)	0.062 (0.116)	0.021 (0.026)
North Side	15	317	52.4 (24.6)	43.5 (24.2)	1.3 (1.9)	0.075 (0.054)	0.109 (0.252)	0.032 (0.058)
1 km	5	151	71.9 (17.6)	23.0 (15.2)	2.4 (3.0)	0.096 (0.073)	0.087 (0.132)	0.010 (0.007)
6 km	5	229	48.3 (11.5)	49.3 (10.8)	0.4 (0.5)	0.067 (0.033)	0.200 (0.430)	0.071 (0.094)
16 km	5	27	66.1 (16.5)	25.7 (21.9)	2.3 (4.0)	0.064 (0.053)	0.039 (0.048)	0.014 (0.009)
South Side	15	536	51.5 (24.6)	44.4 (24.1)	1.3 (1.9)	0.051 (0.021)	0.018 (0.022)	0.037 (0.036)
1 km	5	253	41.1 (16.0)	55.3 (15.5)	1.3 (2.4)	0.040 (0.010)	0.018 (0.016)	0.015 (0.009)
6 km	5	382	20.0 (11.0)	75.4 (8.4)	2.6 (2.3)	0.053 (0.019)	0.013 (0.010)	0.050 (0.026)
16 km	5	77	24.6 (15.9)	72.1 (17.0)	2.4 (1.9)	0.060 (0.029)	0.023 (0.035)	0.047 (0.032)
Total	35	1154	47.8 (25.2)	48.1 (25.8)	1.7 (2.4)	0.065 (0.046)	0.063 (0.172)	0.033 (0.043)

[a] Habitat cover measured within one km of road using GIS ArcMap; density estimated using Distance 4.1 (Buckland et al. 2001);

[b] Broad-winged Hawk, Sharp-shinned Hawk, Red-shouldered Hawk; Northern Goshawk.

[c] American Kestrel, Red-tailed Hawk, Northern Harrier, Cooper's Hawk.

Table 5.2. Proportion of raptors exhibiting different behaviors on roadside surveys along the Kittatinny Ridge during autumn 2002 and 2003.

		% Total Observations					
Species	N	Flying High	Flying Low	Fly-Hunting	Perch-Hunting	Perched	Other
All Raptors	1134	2.65	37.65	7.50	5.47	45.94	0.79
Turkey Vulture	148	3.38	83.78	0.68	1.35	10.81	0
Turkey Vulture flocks	71	2.81	66.2	0	0	30.99	0
Black Vulture	9	0	100	0	0	0	0
Black Vulture flocks	12	16.67	50	0	0	33.33	0
Osprey	9	55.56	22.22	0	0	22.22	0
Bald Eagle	3	0	66.67	0	0	33.33	0
Northern Harrier	18	0	33.33	66.67	0	0	0
Sharp-shinned Hawk	69	1.45	57.97	17.39	0	21.74	1.45
Cooper's Hawk	69	4.38	42.03	11.59	0	42.03	0
Northern Goshawk	2	0	100	0	0	0	0
Broad-winged Hawk	35	22.86	22.86	0	0	54.29	0
Broad-winged Hawk flocks	6	16.67	83.33	0	0	0	0
Red-shouldered Hawk	4	0	0	0	25.0	75.0	0
Red-tailed Hawk	367	0.55	21.53	7.63	4.63	65.12	0
Golden Eagle	1	0	100	0	0	0	0
American Kestrel	280	0	17.14	6.79	15.0	58.93	2.14
Merlin	7	0	57.14	14.29	0	28.57	0
Peregrine Falcon	2	50	50	0	0	0	0
Unidentified Raptor	23	0	66.67	16.67	0	16.67	0

Table 5.3. Percent of raptor sightings within different habitat types during roadside surveys in autumn 2002 and 2003.[1]

Species	N	Forest	Open	Edge	Mixed	Suburban
N		*105*	*765*	*69*	*79*	*80*
Turkey Vulture	145	9.0	64.8	2.1	10.3	13.9
Turkey Vulture flocks	71	4.4	50.0	11.8	14.7	19.1
Black Vulture	8	0	75.0	00	25.0	0
Black Vulture flocks	11	18.2	54.5	9.1	0	18.2
Osprey	9	4	3	1	0	1
Bald Eagle	3	0	100	0	0	0
Northern Harrier	18	0	88.9	0	0	2.0
Sharp-shinned Hawk	69	17.6	48.5	13.2	10.3	10.3
Cooper's Hawk	69	16.2	58.8	7.4	10.3	7.4
Northern Goshawk	2	50	0	50	0	0
Broad-winged Hawk	35	37.9	20.7	3.4	34.5	3.4
Broad-winged Hawk flocks	6	100	0	0	0	0
Red-shouldered Hawk	4	0	50.0	25.0	25.0	0
Red-tailed Hawk	367	9.3	65.5	7.7	12.1	5.5
Golden Eagle	1	0	100	0	0	0
American Kestrel	280	0.7	91.3	2.9	3.6	1.4
Merlin	7	0	100	0	0	0
Peregrine Falcon	2	50.0	50.0	0	0	0
Unidentified Raptor	23	22.2	44.4	0	16.7	16.7
All Raptors	1134	9.2	67.5	6.1	10.0	7.1

[1] Available habitat along transects (within 1 km radius) included: 44.1% open, 51.9% forest, and 1.3% suburban cover, And mixed and edge occurred at the interface of these habitat types.

Table 5.4. Mean abundance of raptors on roadside surveys (birds/km) and their songbird prey on point counts (mean birds/point) (±SD) during autumn stopover along the Kittatinny Ridge in Pennsylvania compared distance from ridge in autumn 2002 and 2003.

Species Group	Overall	North Side	South Side	Kruskal Wallis *p=*	On Ridge	1 km	6 km	16 km	Kruskal Wallis *p=*
		441	439		177	354	355	171	
All Raptors	0.122	0.125	0.151		0.045	0.132	0.200	0.024	
	(0.241)	(0.251)	(0.244)	0.000	(0.188)	(0.234)	(0.291)	(0.077)	0.000
Hawks[a]	0.092	0.085	0.124		0.031	0.097	0.138	0.052	
	(0.164)	(0.151)	(0.171)	0.001	(0.161)	(0.147)	(0.188)	(0.114)	0.000
Vultures	0.04	0.041	0.049		0.014	0.035	0.075	0.005	
	(0.148)	(0.171)	(0.141)	0.008	(0.09)	(0.158)	(0.184)	(0.025)	0.000
Open Habitat	0.06	0.058	0.081		0.011	0.073	0.094	0.015	
Raptors	(0.116)	(0.109)	(0.135)	0.005	(0.049)	(0.117)	(0.143)	(0.056)	0.000
	0.021	0.023	0.019		0.019	0.022	0.029	0.003	
Forest Habitat Raptors	(0.083)	(0.079)	(0.054)	0.001	(0.138)	(0.054)	(0.089)	(0.019)	0.000
Red-tailed Hawk	0.030	0.019	0.052		0.007	0.032	0.052	0.008	
	(0.077)	(0.061)	(0.102)	0.000	(0.033)	(0.079)	(0.097)	(0.034)	0.000
Broad-winged Hawk	0.006	0.008	0.005		0.002	0.007	0.004	0.009	
	(0.064)	(0.084)	(0.053)	*ns*	(0.016)	(0.092)	(0.028)	(0.081)	*ns*
American Kestrel	0.026	0.036	0.025		0.004	0.036	0.037	0.005	
	(0.065)	(0.079)	(0.058)	*ns*	(0.027)	(0.07)	(0.08)	(0.025)	0.000
Sharp-shinned Hawk	0.007	0.009	0.006		0.004	0.007	0.012	0.001	
	(0.032)	(0.036)	(0.028)	*ns*	(0.031)	(0.028)	(0.040)	(0.014)	0.050
Cooper's Hawk	0.007	0.006	0.008		0.004	0.008	0.009	0.001	0.050
	(0.028)	(0.028)	(0.028)	*ns*	(0.026)	(0.028)	(0.032)	(0.014)	
Large 'Prey'[b]	17.74	7.71	31.95		7.47	9.22	35.94	8.21	
(mean birds/pt.)	(50.95)	(4.81)	(76.73)	0.000	(2.04)	(5.22)	(84.85)	(2.473)	0.000
Small'Prey'[b]	14.96	16.37	13.95		13.97	14.39	17.01	13.28	
(mean birds/pt.)	(7.55)	(9.66)	(4.91)	ns	(6.38)	(7.31)	(7.66)	(5.21)	0.000

[a] Hawks include all raptors excluding vultures; [b] Large 'prey' are songbirds larger than an American Robin (*Turdus migratorius*), small prey are songbirds smaller than an American Robin.

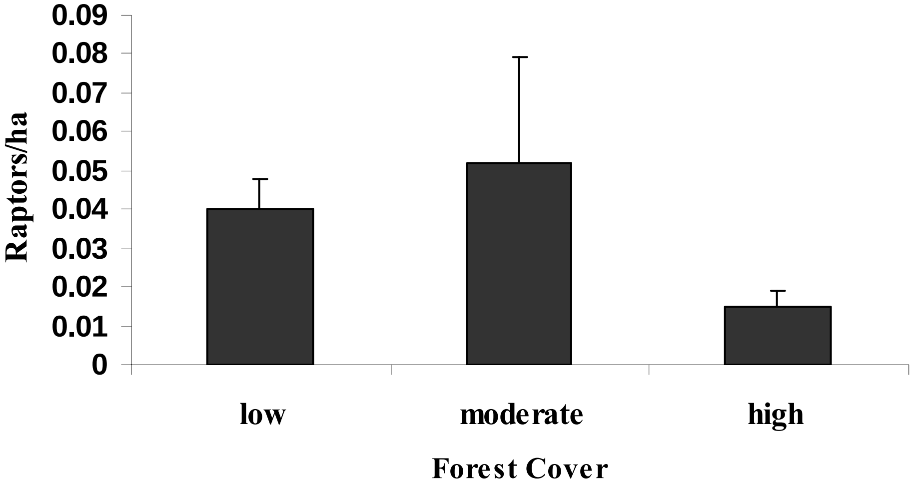

Figure 5.1. Density of open habitat raptors (mean ± SE) on roadside transects with low, moderate, and high forest cover on and near the Kittatinny Ridge in Central Pennsylvania during autumn 2002 and 2003 (density estimated using Distance 4.1; high cover>70%, low<40%, moderate=40% to 70%).

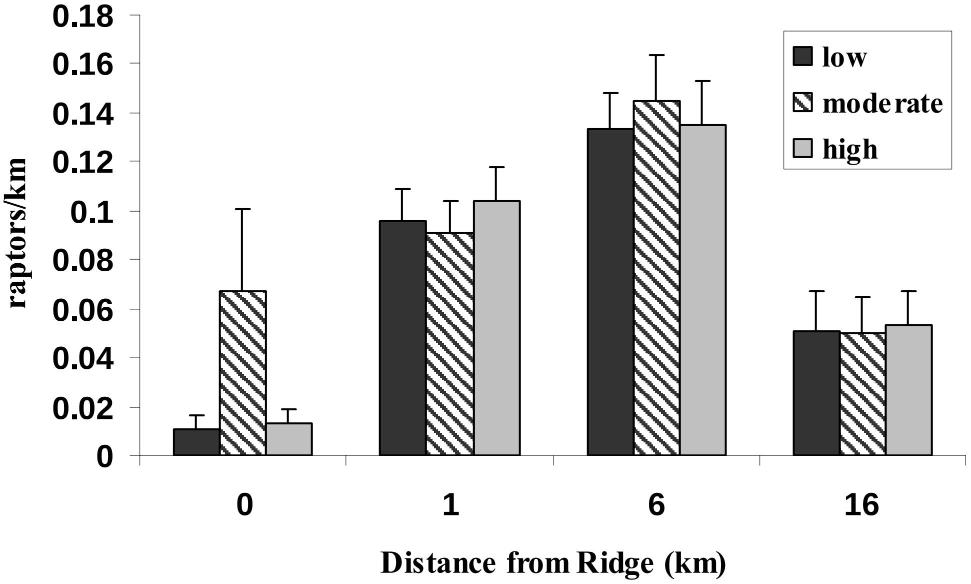

Figure 5.2. Mean abundance of raptors on stopover (± SE, birds/km) on transects in areas of low, moderate, and high forest cover within four distance categories from the Kittatinny Ridge in autumn 2003 and 2004 b (>70% cover=high forest cover, <40%=low' and moderate cover=40 to 70%).

Chapter 6. Stopover Ecology of Migrating Raptors and Conservation.

The Kittatinny Ridge of the Central Appalachians has been recognized as a major migration corridor for northeastern raptors for more than 75 years (Broun 1939, Bildstein 2006). Some birds migrating along the Ridge concentrate in larger numbers here than elsewhere in eastern North America (Goodrich and Smith 2008). Yet, despite the extensive database of migration counts from across the Appalachians little has been discovered about the ecology of migrating raptors within this region until recent years. The importance of stopover periods and habitat to raptor migration strategies was revealed in these studies. And, migrant raptors displayed more adaptable migration behavior and more specific habitat use patterns than I had predicted.

In this study, Sharp-shinned and Cooper's Hawks integrated foraging and resting as a regular part of their daily routine even on travel days.. The preponderance of diurnal time spent foraging and resting suggested that stopover periods are important to the seasonal migration movements and perhaps the survival of migrant raptors. The consistency of both foraging and resting among days during the migration revealed that both activities are important aspects of energy-management during migration. Weather appeared less important in determining migrant behavior as the need for adequate rest and refueling. During roadside surveys, the field observers recorded a wide variety of species foraging during mornings suggesting that many species may integrate regular foraging as part of their migration journey.

Data from migration watch sites support the hypothesis that raptors migrate more when tail winds prevail as that is when they observe the migrants (Broun 1939, Allen et al. 1996). However, in this study, accipiters commonly traveled using thermals, and did not migrate regularly when tail winds occur. I also found that migrants may use tail winds and thermals together to make extraordinary flights over some landscapes..

Despite their adaptable migration strategy, both accipiters used the Kittatinny Ridge extensively during migration both for stopover sites and migration lift. Cooper's Hawks appeared to prioritize stopover when migrating along the Ridge, making short leisurely flights with long foraging periods when flying along the Ridge. Longer more intense flights were observed over less forested and more suburban habitats of southern Pennsylvania, New Jersey, and eastern Maryland where presumably prey may be less predictable. These patterns suggest that Cooper's Hawks maybe using an energy minimization strategy by feeding regularly and interspersing flight and feeding (Alerstam 1990). However, Cooper's Hawks may us a different strategy, i.e., time-minimization, during flights across the Piedmont and Coastal Plain regions where foraging and roosting opportunities were less likely. Sharp-shinned Hawks appeared to use an energy-minimization strategy exclusively, perhaps having less ability to make long powered flights. Further radio-tracking data and use of satellite-tracking of larger birds may clarify raptor migration strategies and whether they shift across the journey's path and between landscapes. Regardless, both species used the Kittatinny Ridge for extensive resting and foraging prior to heading further south, reinforcing the importance of this Pennsylvania landscape to migrating birds.

Moore et al. (1995) defined the ideal stopover habitat as "providing food, water, and protection from predators." For raptors, food and protection both appear highly valued. Large forests were sought by both species for migration stopover Safe roosting sites may have been the highest priority for migrants as they sought out contiguous forests and Sharp-shinned Hawks selected areas with mixed or evergreen forest. Sharp-shinned Hawks also showed an affinity for wetlands, however it was unclear if it was the thick cover or its potential prey it sought.

The roadside surveys showed that more raptors were found in area zone from 1 to 6 km from the Kittatinny Ridge than on the Ridge or farther away from the Ridge. This distance coincides with the average roosting distance found for the two radio-tracked accipiters as well. I suspect that the intersection of a diversity of habitats, with large forest blocks, and the abundance of prey found in this zone (Chapter 5) attracted raptor migrants seeking foraging opportunities. Based on these data, I suggest that a corridor of migrant use can be defined at a distance of 6 km from the Ridge. This region should be slated for conservation planning efforts to maintain a rural mix of habitats.

Despite observations of accipiters foraging at feeders and the urban nesting pattern of Cooper's Hawks, both accipiters occurred less in areas with greater suburban development. This finding has important implications for raptor conservation along the Kittatinny Ridge and elsewhere. Migrants appear more selective in habitat use in migration than during nesting and non-breeding periods. If this is true, greater conservation attention to habitat conservation focused on the migratory period is needed.

These results have important implications for theoretical understanding of migration choices and patterns as well. Stopover habitat availability may be as important as weather and orientation decisions in determining the success of a migrant's journey and ultimately its long-term fitness (Hutto 2000). Stopover priorities may also influence migration routes, as suggested for Sharp-shinned Hawks in this study. Some migrants may avoid crossing large areas that appear inhospitable or where suitable roosting habitat is not within view.

The roadside surveys across Pennsylvania highlighted the presence of a migration corridor along the Kittatinny Ridge. Because birds on stopover appear to settle close to the Ridge (within 1 to 6 km), habitat conservation within 6 or more km of key flyways may be a priority for migrant raptor conservation. The results from the surveys also suggested that habitat type was important in determining stopover patterns. Open habitat raptors were most abundant at six km radius as field habitats were most available than closer to the Ridge.

The use of conifers and wetlands by Sharp-shinned Hawks during migration highlights the significance of conserving special habitats for migrants as well. Such habitat was found along the Lehigh River and in small streams running off the mountain or into the valley forest patches. Riparian habitats may be especially important for migrants as they may have a diversity of cover and prey and allow rehydration (Carmi et al 1992).

In summary, finding suitable stopover sites along migration routes appears important to raptors. Foraging and resting are integral aspects of the migration strategy of many species. Further, the migration direction and pattern shown by accipiters in response to weather and landscape suggest that minimizing energy use and maintaining access to refueling and roost sites may be a dynamic and adaptive process for migrating raptors. Although migrants had flexibility in travel patterns, their habitat selection patterns remained relatively consistent. Migrants appear to exhibit affinity to the migration flyway and settle in greater numbers near the migration route, reinforcing the importance of conserving a mix of native habitats near the mountain. Our research emphasizes the importance of landscape-scale conservation planning efforts along the Kittatinny Ridge and other key raptor migration corridors. Migrant raptors showed highly selective habitat choices during stopover in this landscape. And, as development continues to accelerate across southern Pennsylvania, the current conservation planning efforts to conserve a corridor along the Kittatinny Ridge across Pennsylvania and New York states becomes more vital (Audubon Pennsylvania 2006, Heintzelman 2008).

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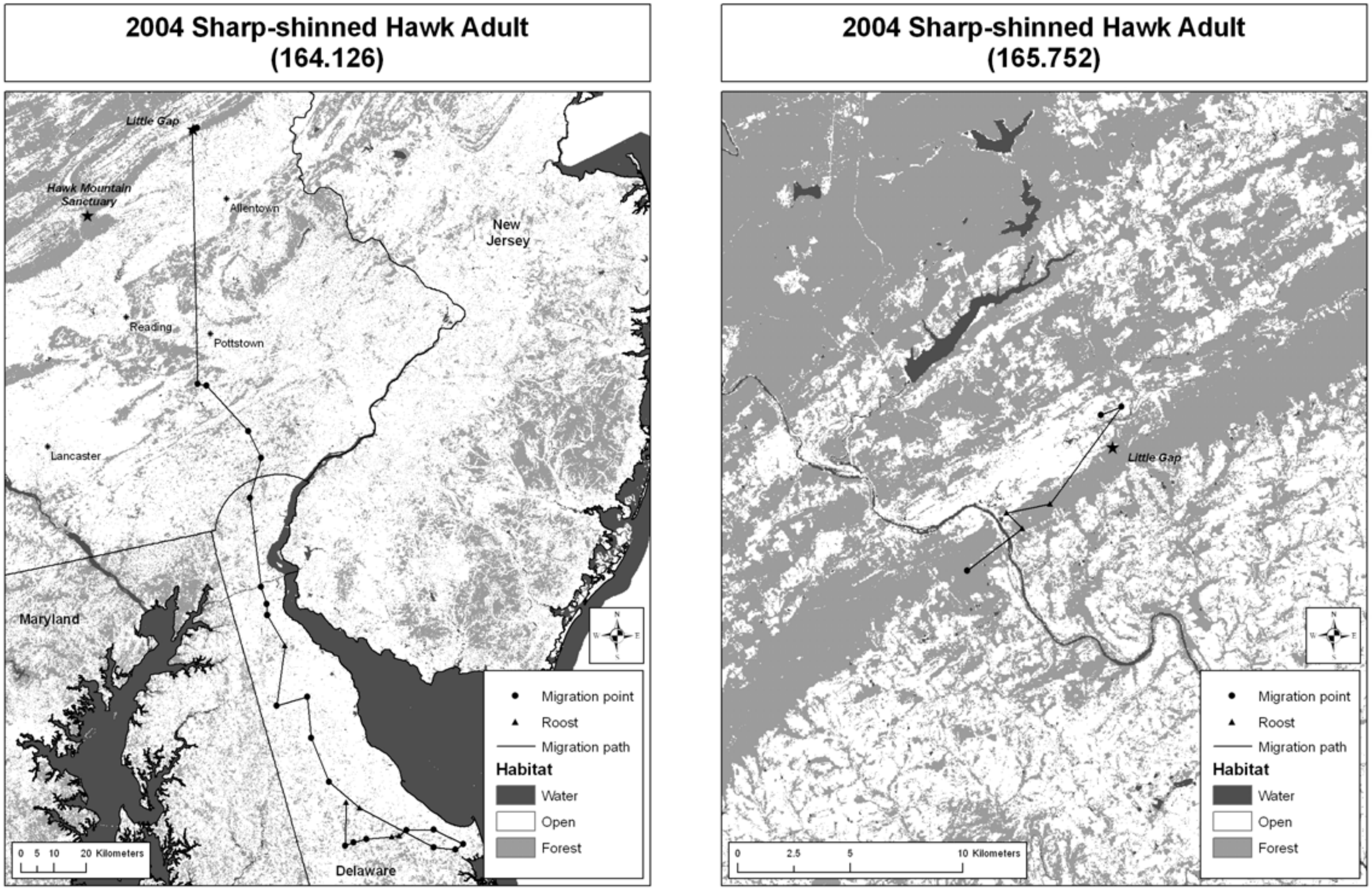
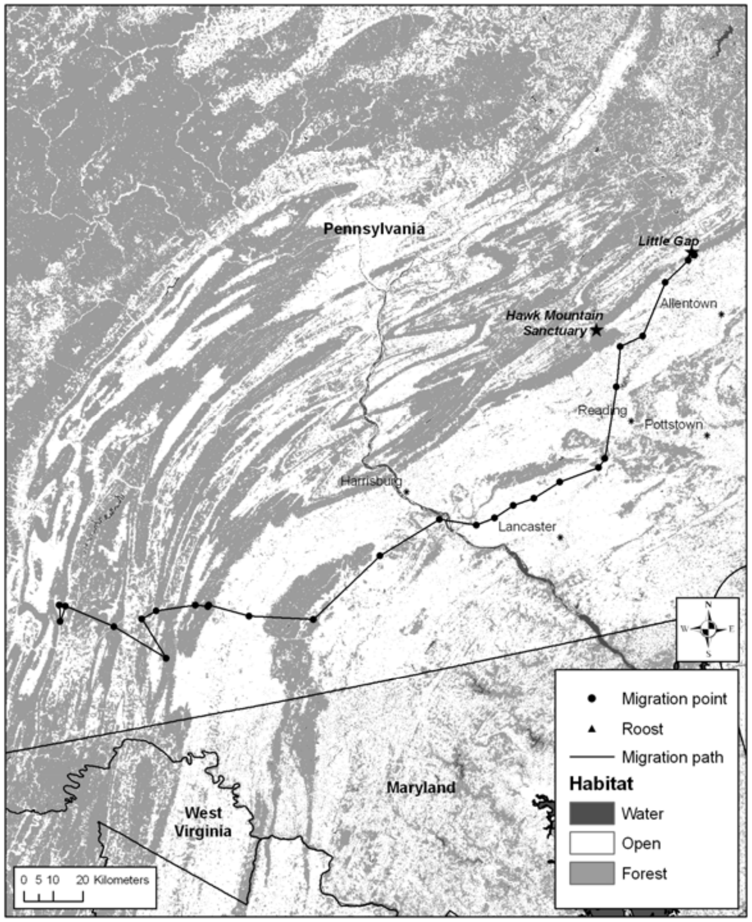
APPENDICES

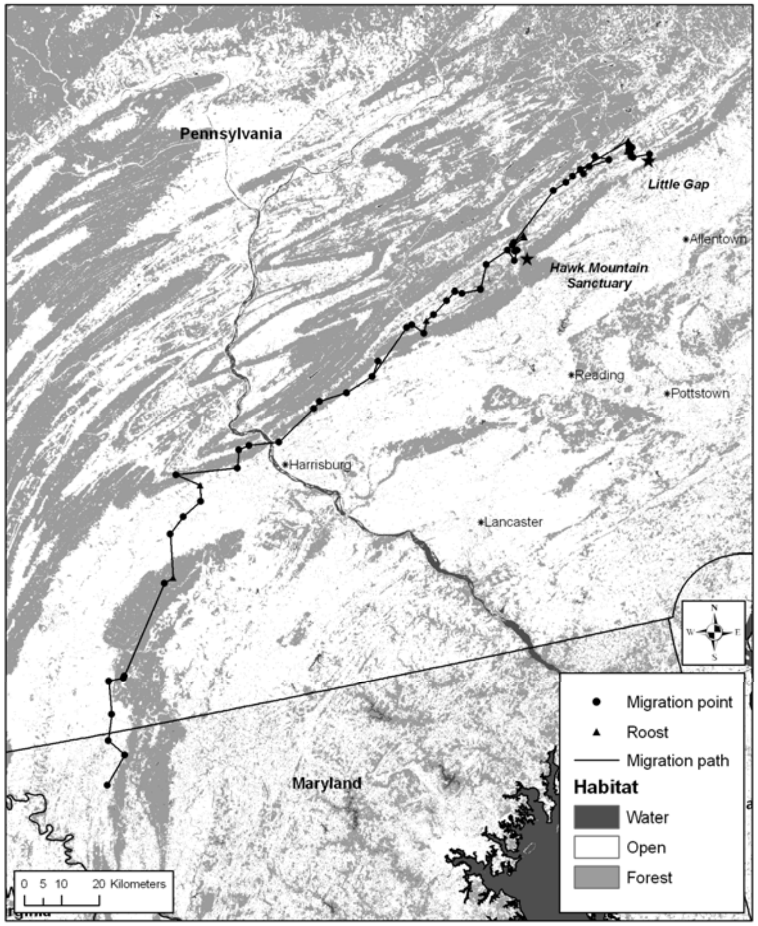
Appendix A.1. Migration paths taken by individual Sharp-shinned Hawks during autumn 2003 and 2004

(from Little Gap Raptor Research in Danielsville, Pennsylvania for any bird traveling more than 40 km.)

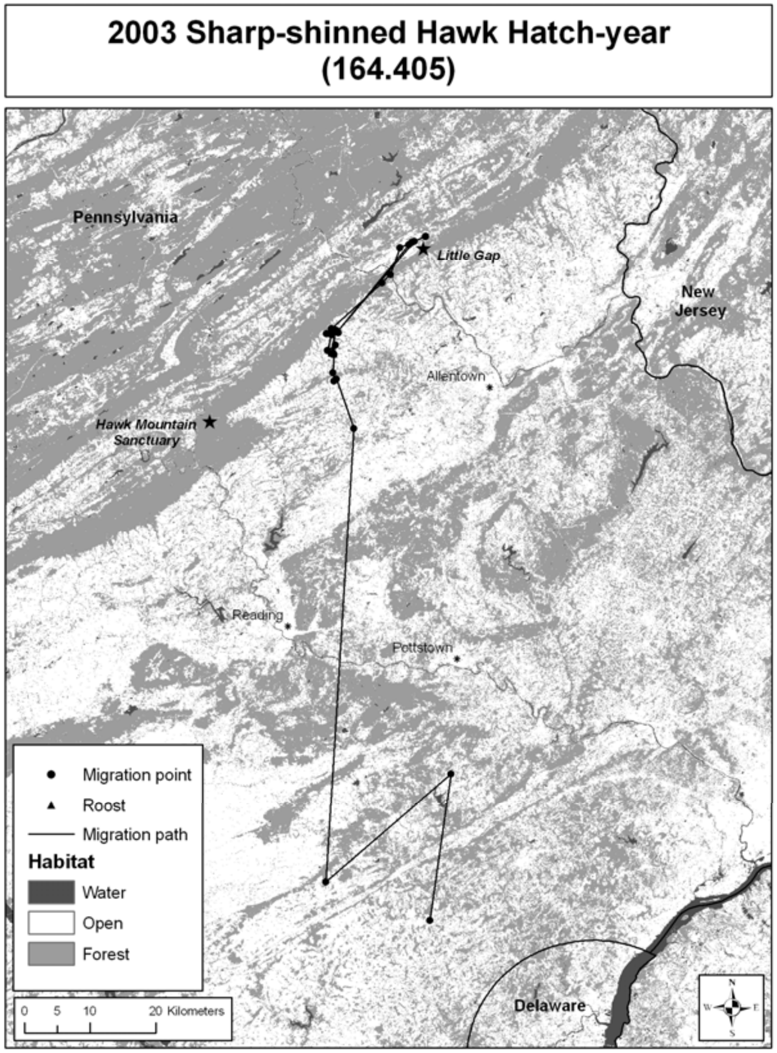




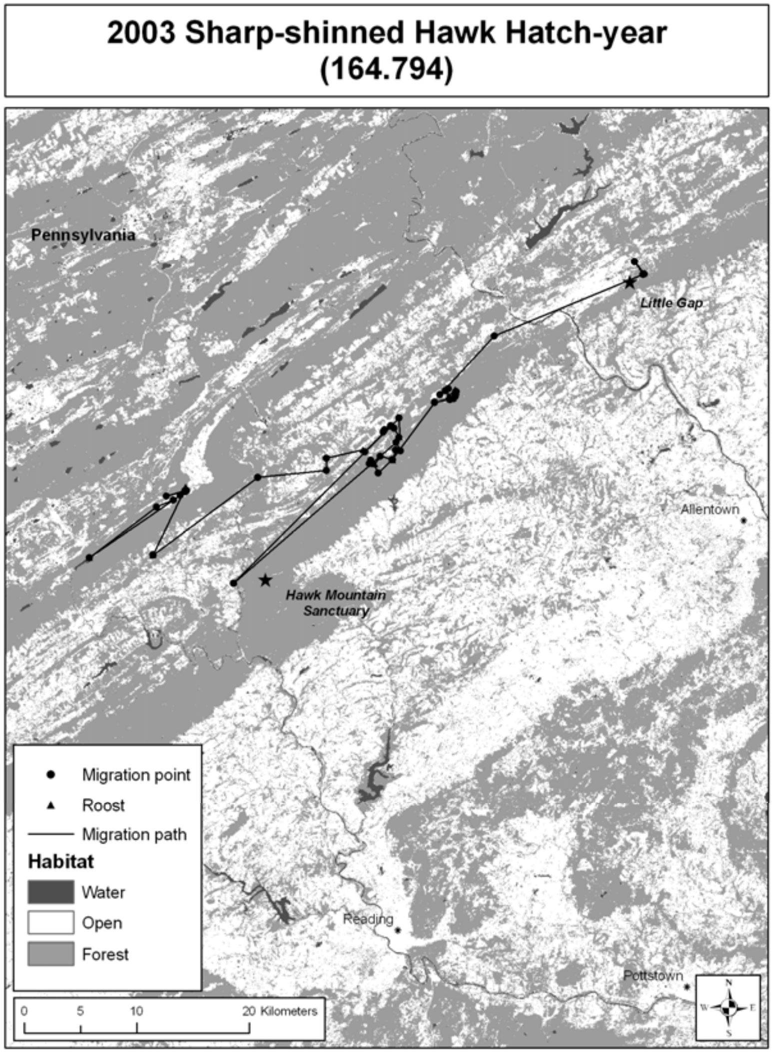
2004 Sharp-shinned Hawk Hatch-year (164.219)



2003 Sharp-shinned Hawk Adult (164.387)

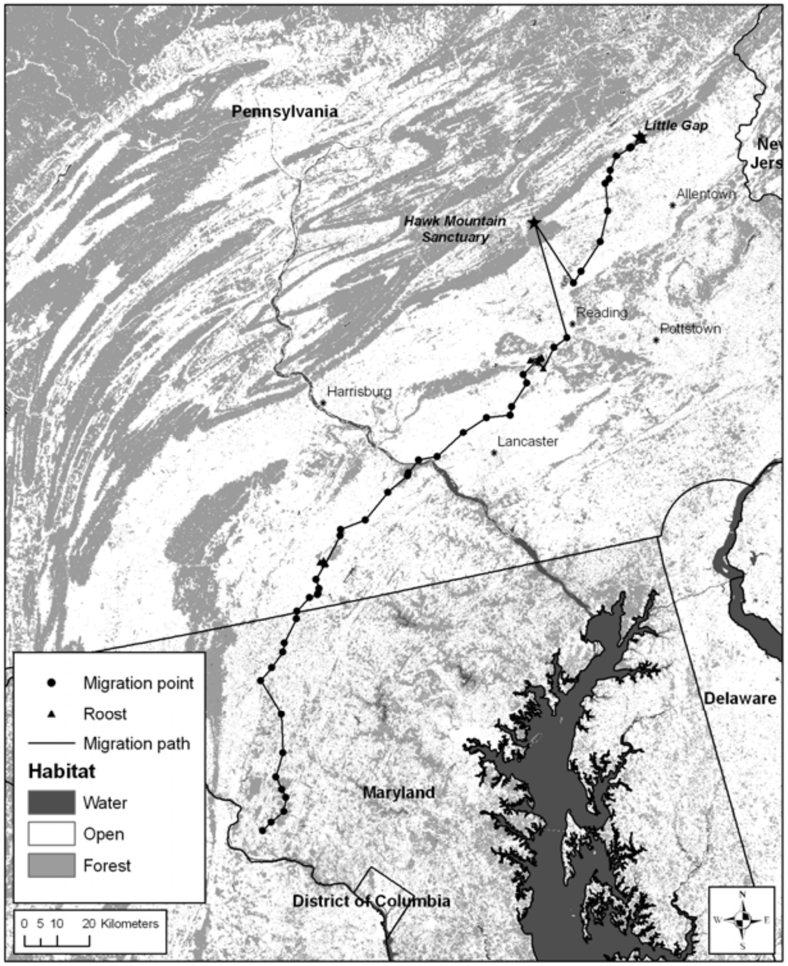


2003 Sharp-shinned Hawk Hatch-year
(164.405)

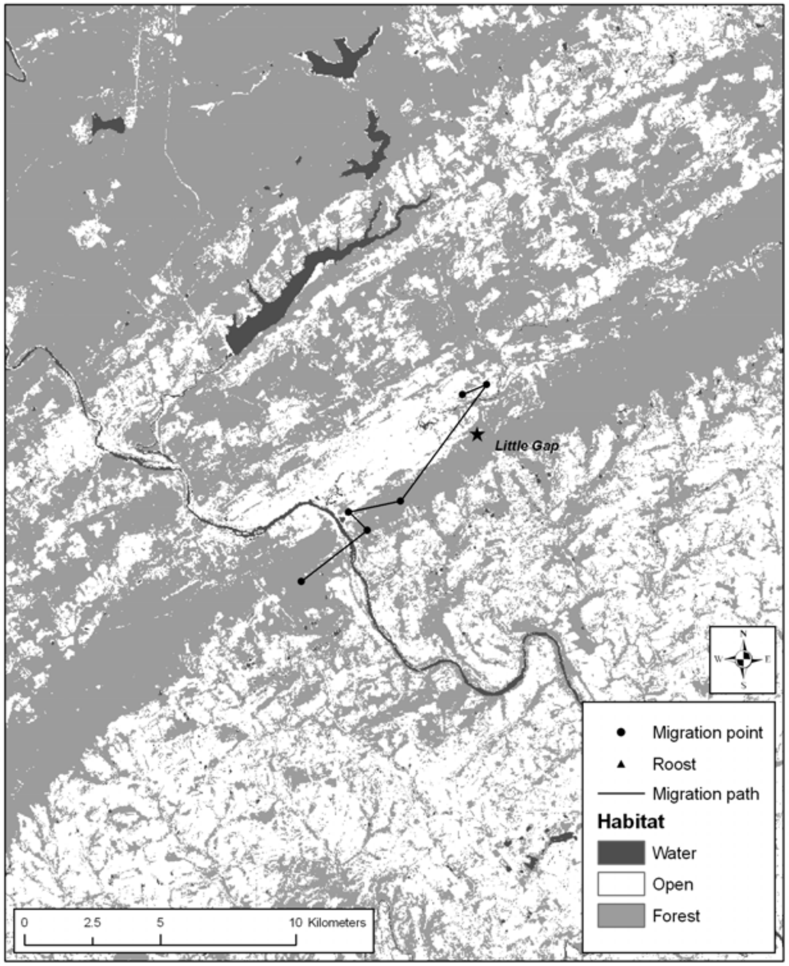


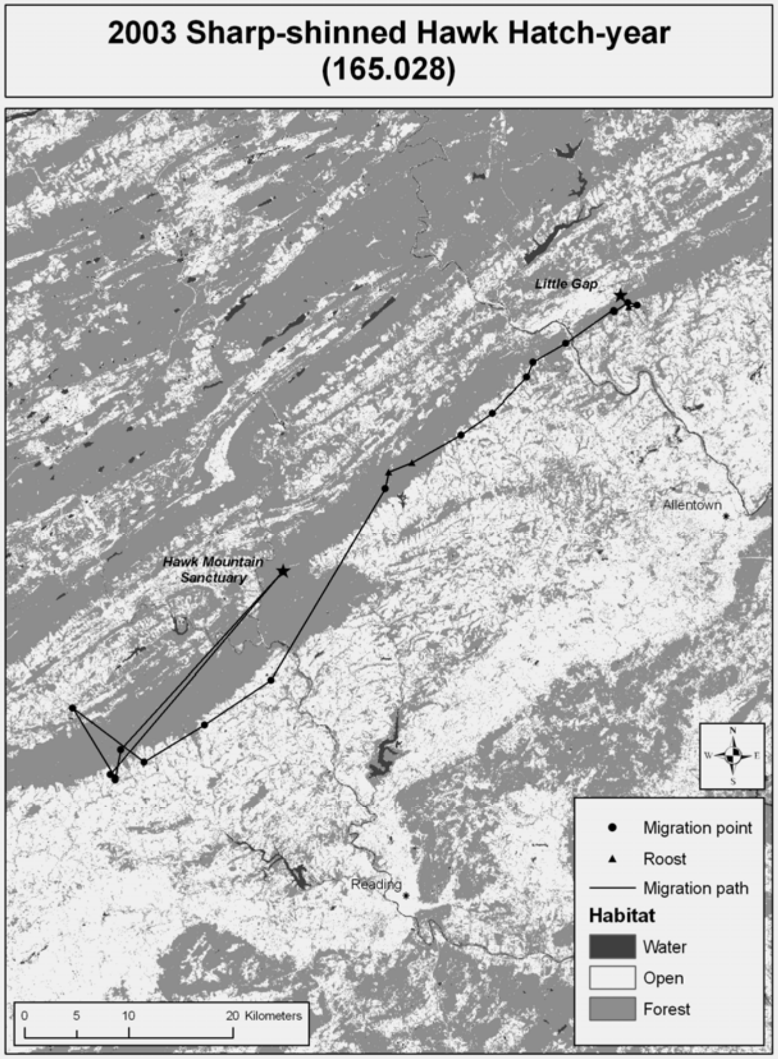
2003 Sharp-shinned Hawk Hatch-year
(164.794)

2003 Sharp-shinned Hawk Hatch-year (164.961)

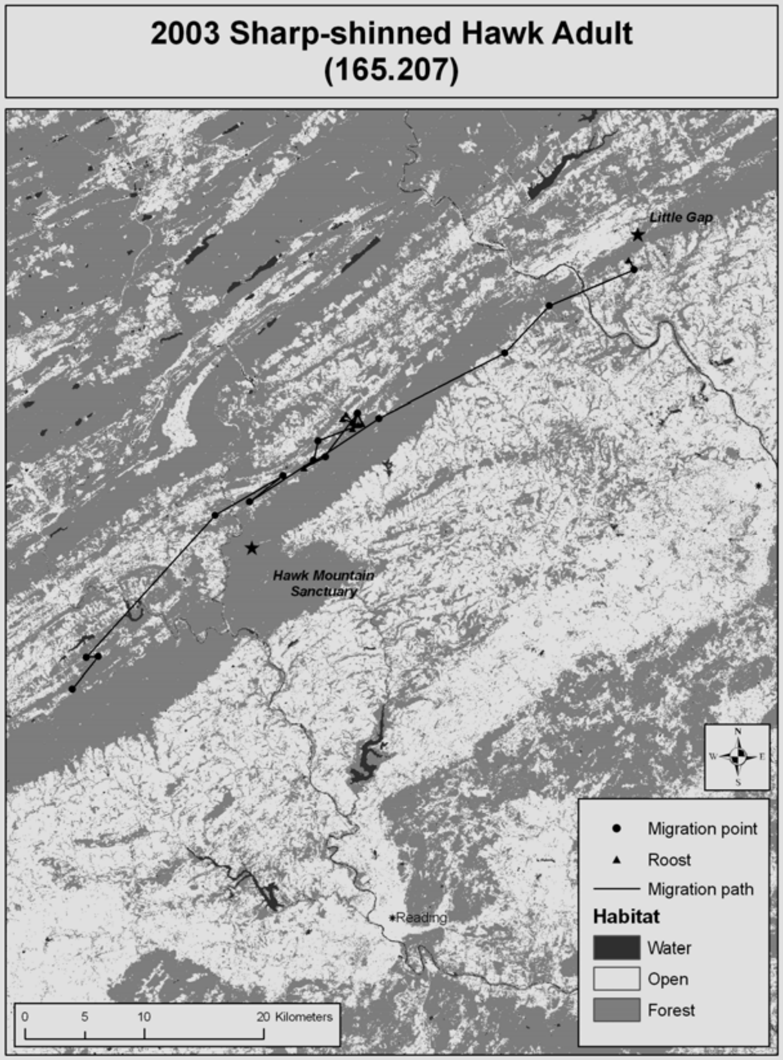


2004 Sharp-shinned Hawk Adult (165.752)



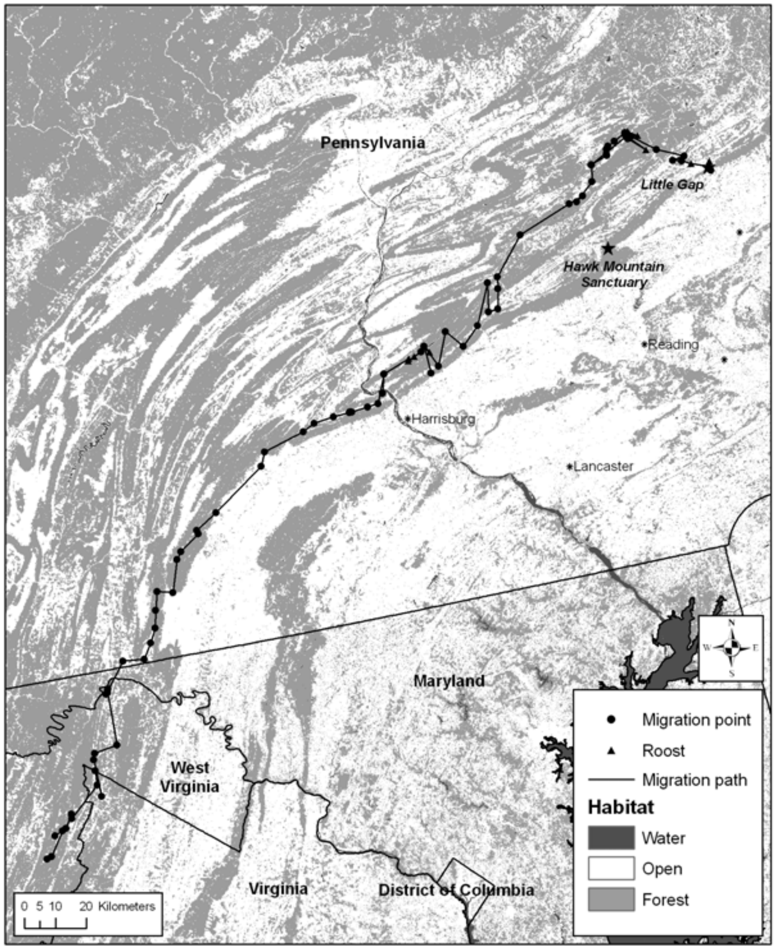


2003 Sharp-shinned Hawk Hatch-year
(165.028)

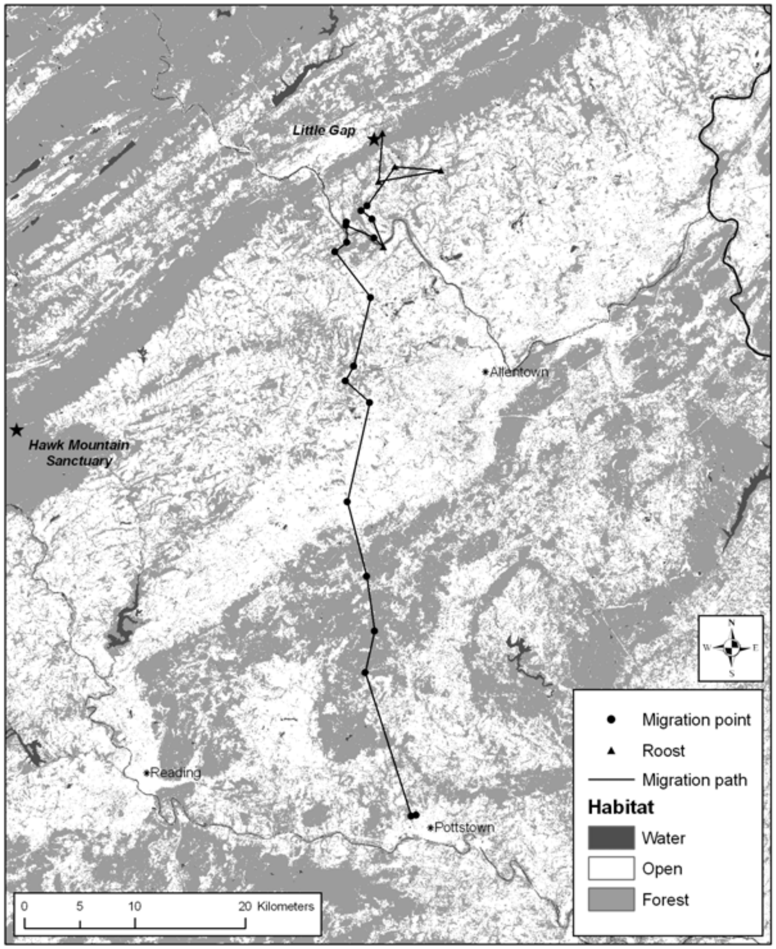


2003 Sharp-shinned Hawk Adult
(165.207)

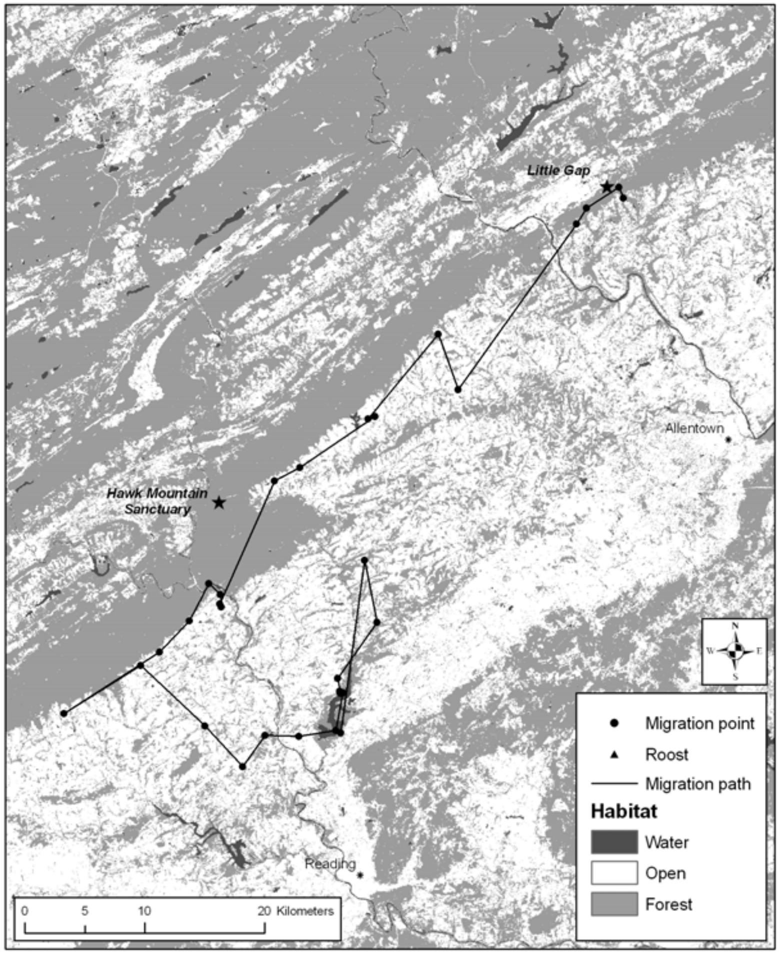
**2003 Sharp-shinned Hawk Adult
(165.740)**



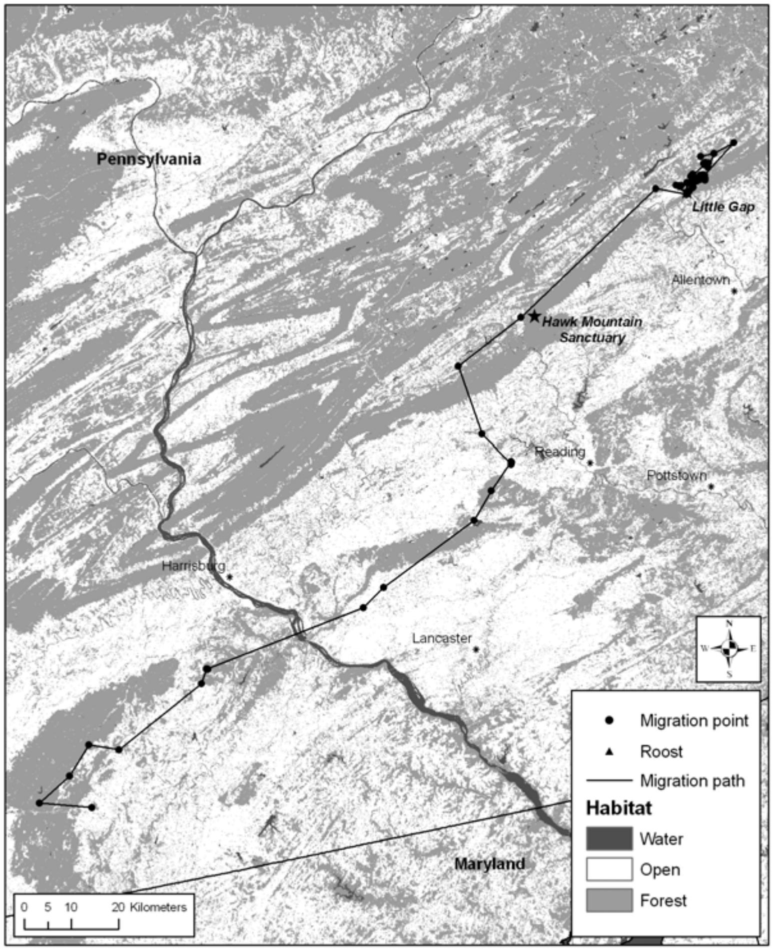
**2003 Sharp-shinned Hawk Adult
(165.720)**

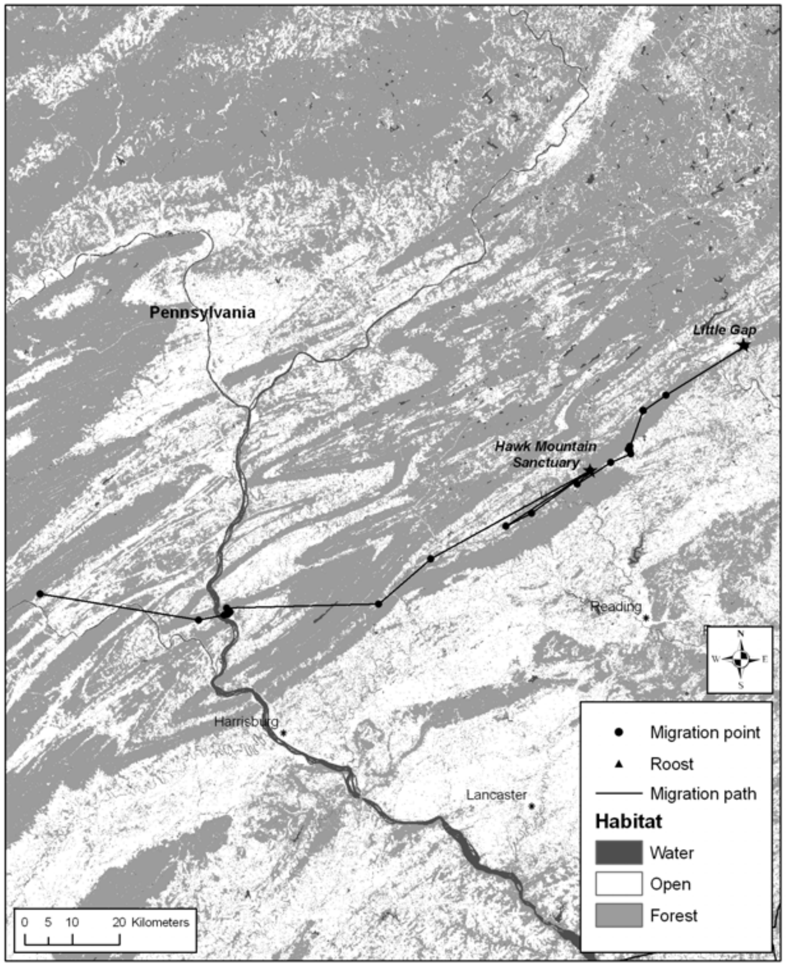


2004 Sharp-shinned Hawk Adult
(165.805)



2004 Sharp-shinned Hawk Hatch-year
(165.856)





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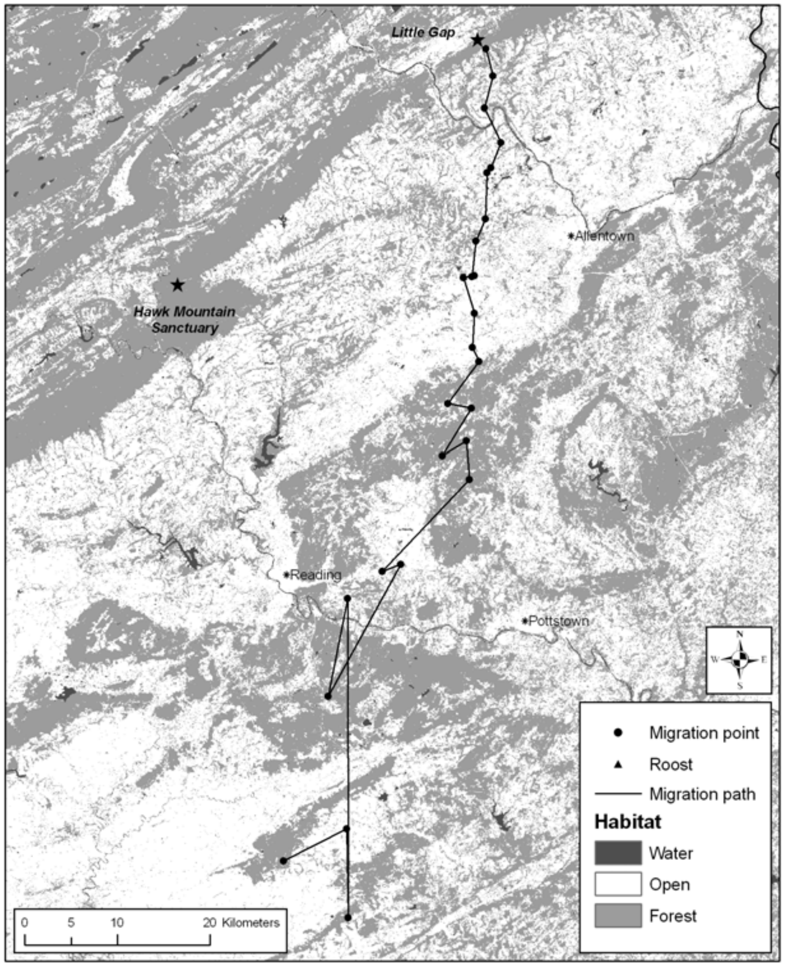
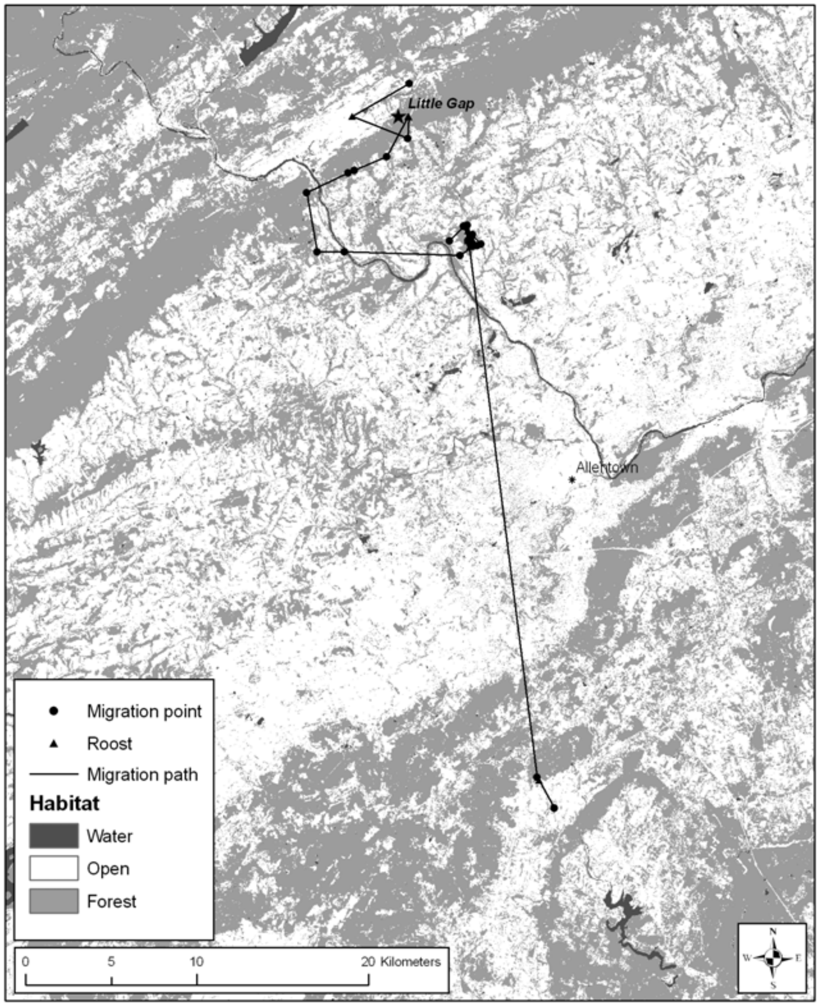


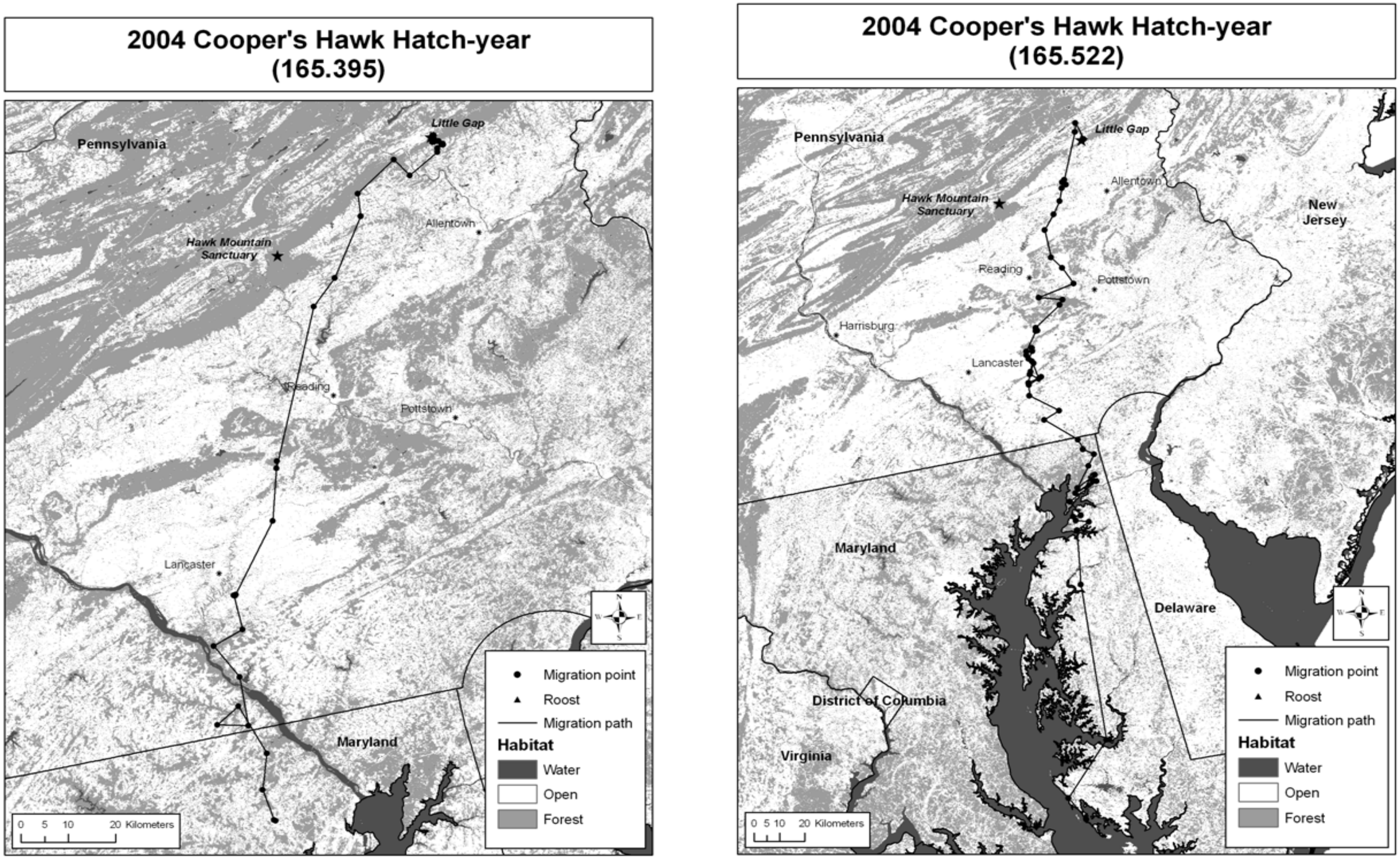
2004 Sharp-shinned Hawk Hatch-year
(165.987)

2003 Sharp-shinned Hawk Hatch-year
(165.611)



Appendix A.2. Migration paths taken by individual Cooper's Hawks during autumn 2004

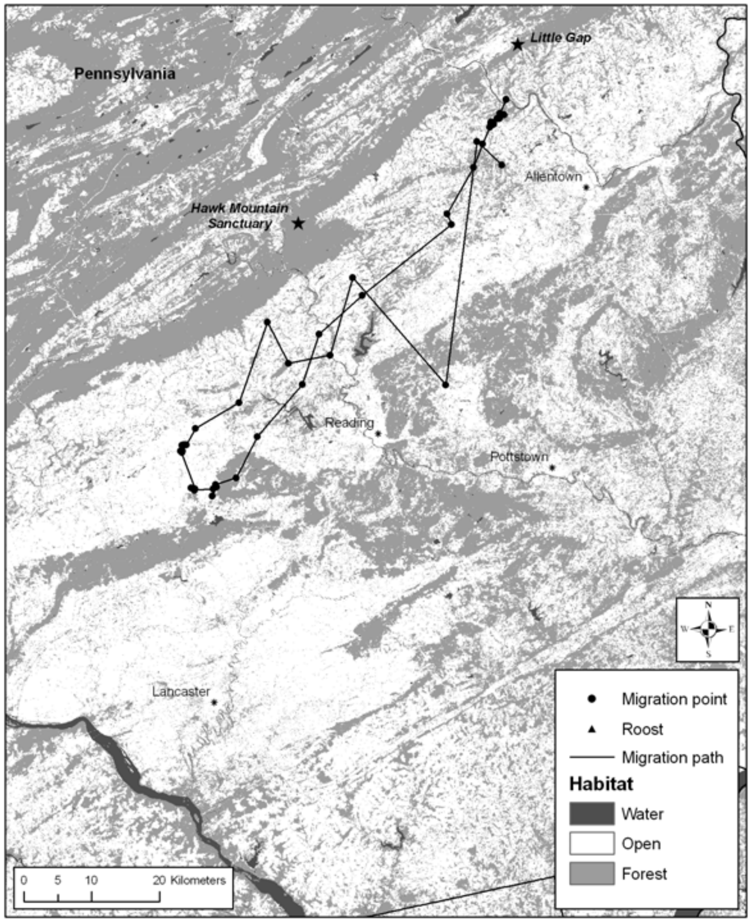
(from Little Gap raptor trapping station and including only birds traveling 40 km or more).



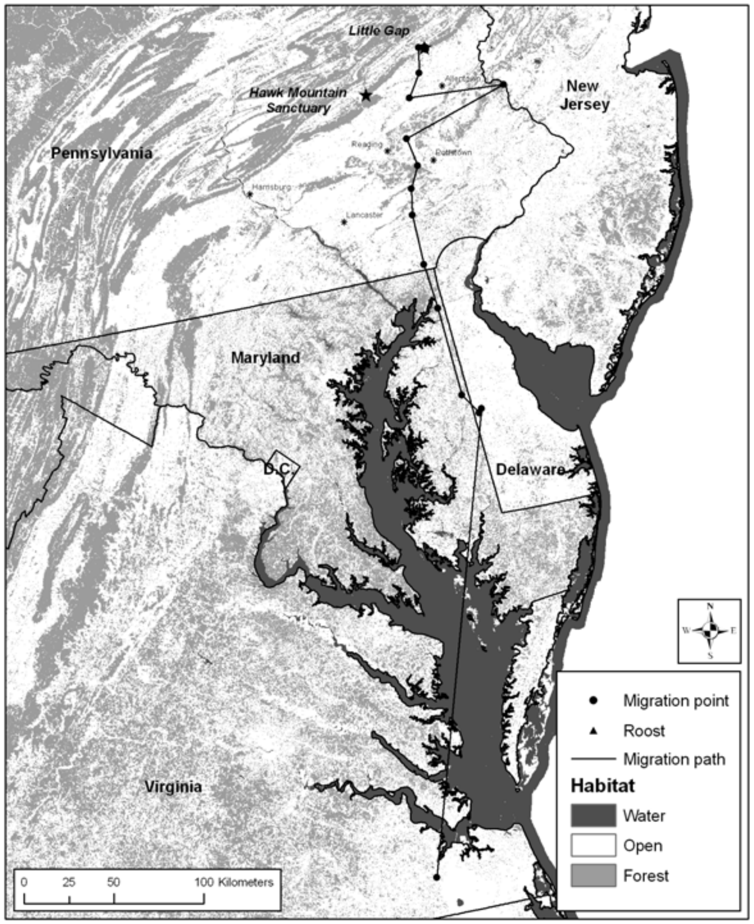
2004 Cooper's Hawk Hatch-year (165.395)

2004 Cooper's Hawk Hatch-year (165.522)

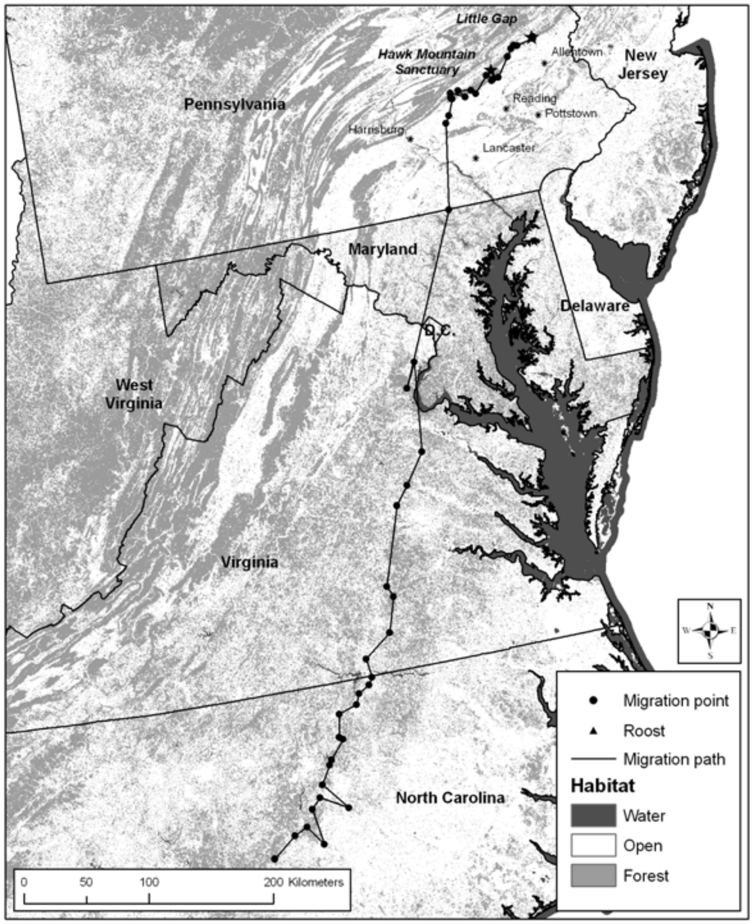
2004 Cooper's Hawk Hatch-year (165.547)



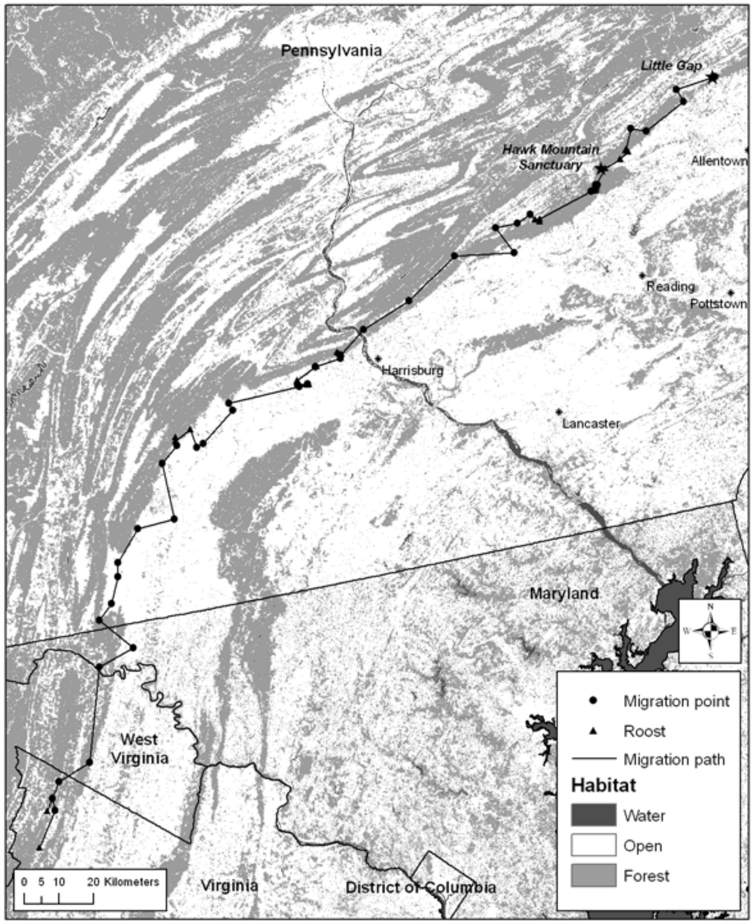
2004 Cooper's Hawk Adult (165.001)



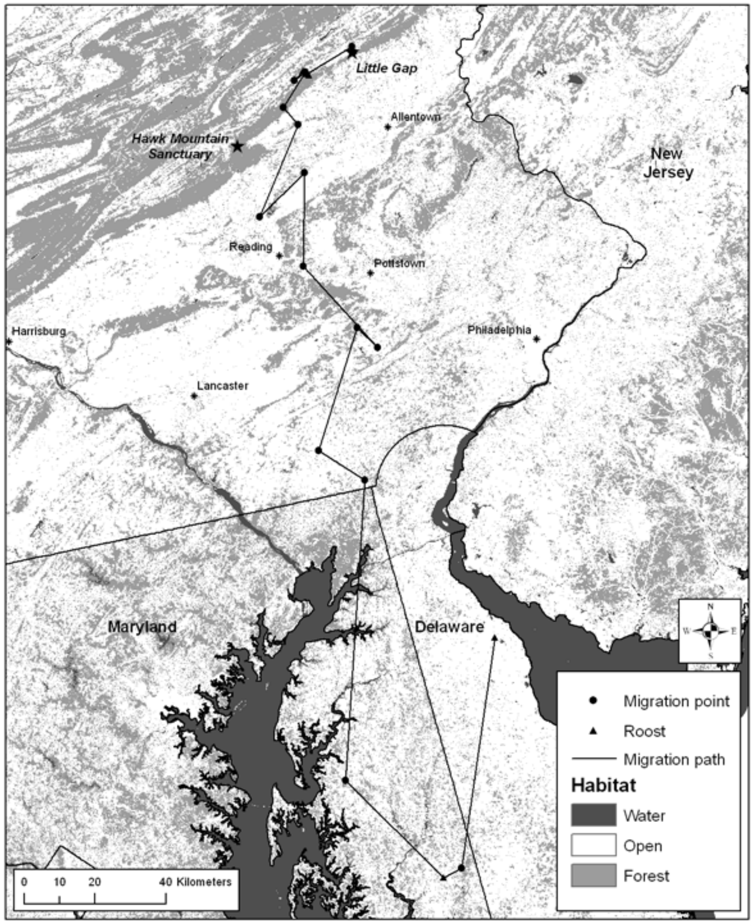
2004 Cooper's Hawk Hatch-year
(165.606)



2004 Cooper's Hawk Adult
(165.418)

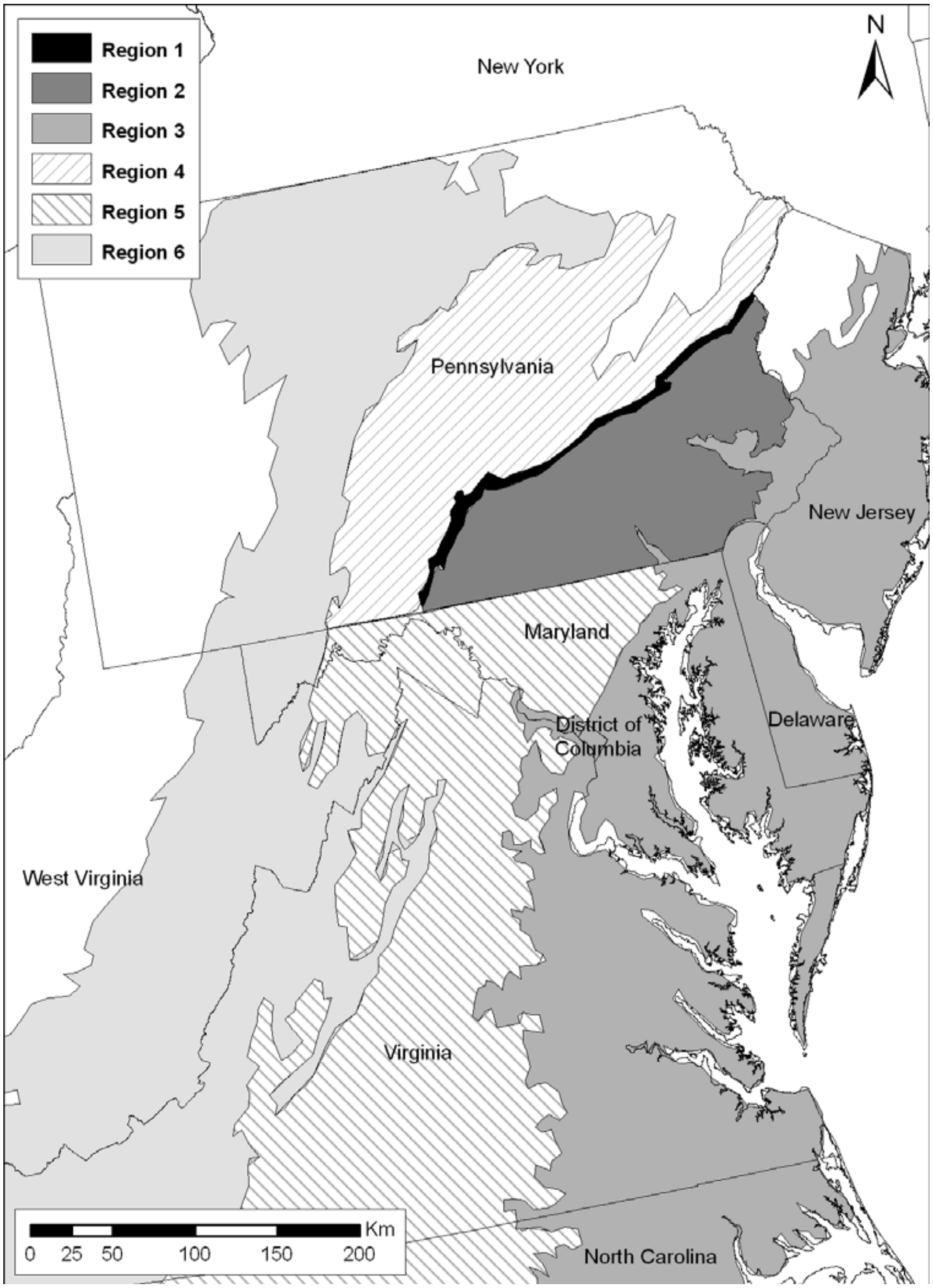


2004 Cooper's Hawk Adult
(165.697)



Appendix B. Stopover behavior of autumn-migrating accipiters in Central Appalachians during 2003 and 2004.

Figure B. 1. Regions defined for estimating thermal updraft velocity across the landscape encountered by migrating accipiters during autumn 2003 and 2004 (see Chapter 2). ***(Note: Regions: 1=Kittatinny Ridge, 2=Piedmont, 3=Coastal Plain, 4=Northern Ridges, 5=Southern Ridges, 6=Allegheny)***



Appendix B (continued). Stopover Behavior of Migrating Accipiters

Results—comparing behavior by age

Adult and immature accipiters varied in the time spent roosting and foraging however the direction of the difference differed between the species. Sharp-shinned Hawk adults foraged more than hatch-year birds on average, whereas Cooper's Hawk adults foraged less than hatch-year birds. The later timing of migration for the adults may reduce the quantity of prey available for the smaller Sharp-shinned Hawk more than the Cooper's Hawk which can take small mammals and larger, less migratory birds.

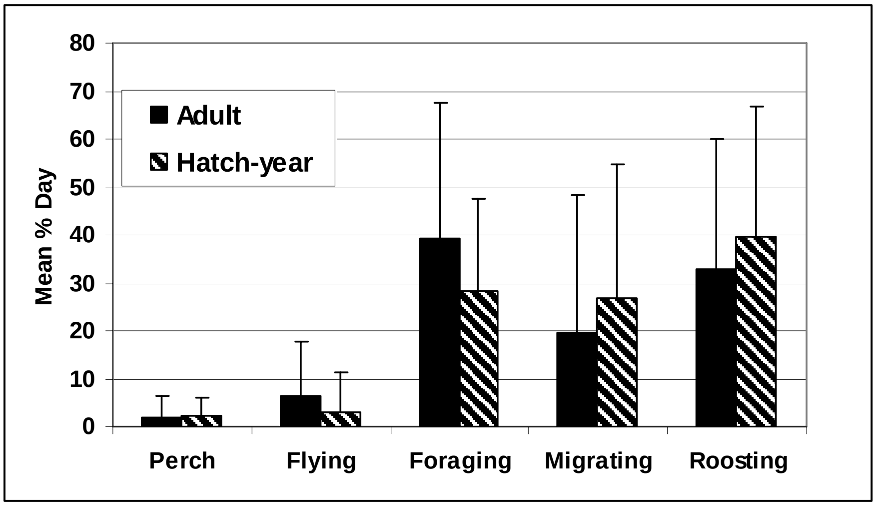


Figure B2a. Mean proportion of day (±SD) adult and hatch-year Sharp-shinned Hawks spent in different behaviors during autumn migration 2003-2004, (n=29 birds)

.

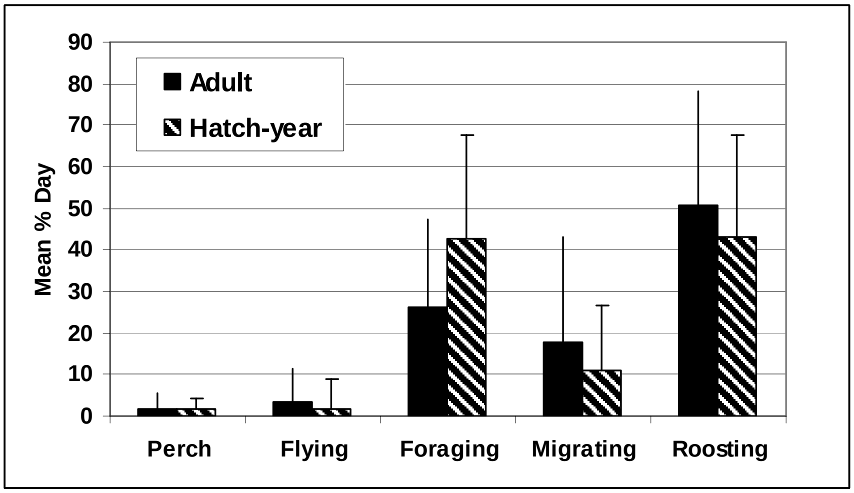


Figure B2b. Mean proportion of day adult and hatch-year Cooper's Hawks (±SD) spent in different behaviors during autumn migration in 2004 (n=11 birds).

Appendix C. Migration behavior of autumn-migrating accipiters in the Central Appalachians in 2003 and 2004.

Travel Direction

When Sharp-shinned and Cooper's hawks are pooled, the combined average direction of travel during autumn migration through the Central Appalachians was to the south-southwest (210º), similar to October migrating Red-tailed Hawks (Kunkle et al. 2009). Some individuals moved more westerly and others more southerly with a small number of flights scattered in other compass directions.

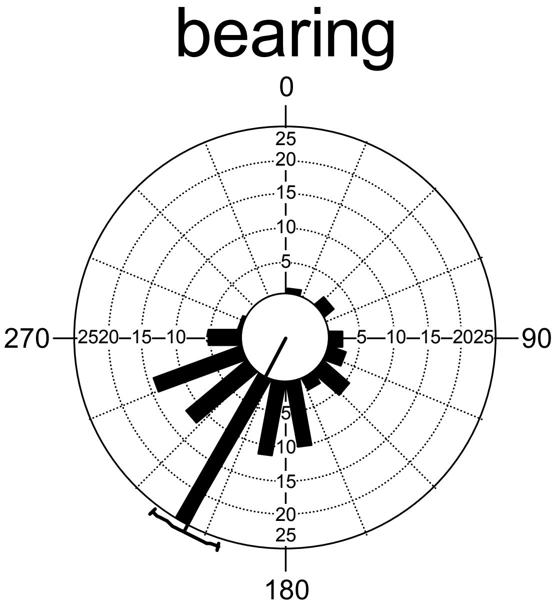


Figure C1. The direction of travel for all accipiters autumn 2003-2004, line shows mean vector and 95% confidence interval around mean.

Appendix D. Stopover habitat use by migrating accipiters in Central Appalachians.

Forest Patch Size by Region

Because forest habitat is more abundant within the Ridge and Valley Province compared to the Piedmont and Coastal Plain regions (here on "Plain" region), I compared patch size selection by region across the study area pooling across species. The most notable landscape difference between regions was the availability of contiguous forest. Contiguous forest patches were scarce in the Plain region, representing only 5% of the random points compared to 26.9% of random sites in the Ridge and Valley (Table D1, Fig. D1, D2). The pattern of patch size use differed significantly between regions (Pearson chi-square 46.06, df=6, p=0.0001).

Within the Ridge and Valley region, accipiter roosts were found more often in contiguous forest, 43.7%, and less often in non-forest when compared to available Ridge and Valley sites (Table 3) (Pearson chi-square=100.88, df=6. p<0.0001). Other patch sizes were used at similar levels to their occurrence (Table D1, Fig. D2).

Significantly more accipiter roosts in the Plain region were found in medium to very large categories of forest patches (e.g., >75% in 40 to 400 ha patches), although these patch sizes only represented 32% of patches available for roosting (Pearson chi-square= 34.686, df=6, p<0.0001). As found in Ridge and Valley and in throughout the study area, accipiters used non-forest habitat for roosting less than expected based on availability within the Plain region (Fig. D1, D2).

Roost selection by Topographic Region

Because available habitat cover varied between the two topographic regions used by migrating hawks in this study, the Ridge and Valley (highly forested) and the 'Plain' (including Piedmont and Coastal Plain topographic regions, more open and more developed), I compared cover available and habitat use by region at a near-scale (0.5 km).

Random sites associated with Ridge and Valley Sharp-shinned roosts (n=905) compared to random sites around Plain region roosts (n=60) had less evergreen cover (mean=5.21%, 7.73 (SD) vs. 8.97%,12.4 (SD); U=31,704, p<0.03), less mixed forest (mean=4.40%,4.97 vs. 6.57%,6.78; U=32,786, p<0.007), more pasture (mean=29.67%,24.12 vs. 22.89%,21.86; U=23,336, p=0.07), and less woody wetland (mean=1.09%,5.90 vs. 3.16%,6.93; U=33,555., p<0.001) (Fig. D3, D4).

Sharp-shinned Hawk roosts in the Ridge and Valley (n=182) had less suburban cover at near scale than roosts in the Plain region (n=12) (mean=2.33% ±6.01 versus. 8.04% ±11.51; U=12.957, p<0.0001) and more evergreen cover (mean=6.59% ±8.24 vs.2.00% ±2.44; U=596.0, p=0.008).

Sharp-shinned Hawks in the Ridge and Valley region were best predicted by a model containing evergreen forest, mixed forest, and patch size (AICc=582.98). Four other models were also highly ranked in model selection (Table 14). The most important parameters predicting roosts in this region were forest patch size (*wi*=0.87), emergent wetland (*wi*=0.87), and row crop (*wi*=0.57). Lower ranked parameters in roost selection models were suburban cover, mixed forest, evergreen forest, and deciduous forest (Table D2, D3). Ridge and Valley Sharp-shinned Hawk roosts were found at sites within a larger forest patch, with a greater cover of emergent wetland, row crop, evergreen forest, and deciduous forest. Roosts were more likely in areas with less suburban cover and less mixed forest as well, although these attributes were less important (Table D2).

Sharp-shinned Hawk roost site selection in the Coastal Plain and Piedmont region was best predicted by a model containing evergreen forest, emergent wetland and patch size (AICc=28.38; Table D2). Two other models were also highly ranked (Table D2, D3). Sharp-shinned Hawk roost in the Plain region were found at sites within a larger forest patch (*wi*=0.67), and at sites with less evergreen forest (*wi*=0.45), more emergent wetland (*wi*=0.45) and less mixed forest (0.11) (Table D3).

Habitat Selection by Region

Random sites around Cooper's Hawk roosts in Ridge and Valley (n=565) compared to Plain region random points (n=80) had more deciduous cover (mean=36.7% ¸30.13 vs. 25.65% ¸26.01; MW U= 15,160.0, p=0.002), less mixed forest (mean=3.48% ¸4.50 vs. 7.92%¸6.34; MW U=22,377.0, p=0.028), and less woody wetlands and (mean=0.57%¸1.97 VS. 4.23% ¸10.07; MW U=23,482.5, p=0.000)(Table D1, Fig. D1). Coopers Hawk roosts in the Ridge and Valley (n=97) had less evergreen cover than in the Plain region (n=16) (3.95%¸6.35 vs. 5.21%¸4.14.; MW U=1,059.0, p=0.02).Cooper's Hawk roosts in the Ridge and Valley region were best predicted by a model of deciduous forest, mixed forest and patch size (AICc=246.94; Table D1, D2). Model-averaged parameter estimates suggest Ridge and Valley roosts are found within larger forest patches (*wi*=0.67), and at sites with less mixed forest cover (*wi*=0.63), greater deciduous forest cover (*wi*=0.67) and greater row crop cover (*wi*=0.34) (Table D2, D3).

In the Plain region, Cooper's Hawk roosts were best predicted by a model of deciduous forest, row crops, mixed forest and forest patch size (AICc=36.24). Roosts were located in larger forest patches (*wi*=0.64) and in areas with greater cover of deciduous forest (wi=0.64), and less row crop cover (*wi*=0.64) and less mixed forest (wi= 0.63). Other habitat types had less weight in the selection models (Table D3). The primary difference in Cooper's Hawk roost selection between regions was the avoidance of row crop cover in the Plain-Piedmont region and the positive association of row crop cover for the roosts located in the Ridge and Valley region.

Table D1. Patch size distribution of migrant accipiter roosts compared by topographic region (% total) during autumn 2003 and 2004.

Roosts	Point Type	N	Contiguous >400 ha	Very Large 400-200 ha	Large 199-100 ha	Medium 99-40 ha	Small 39-10 ha	Tiny 9-1 ha	Non-forest <1 ha	Pearson X^2
All Accipiters	All Roosts	307	39.74	14.66	4.56	12.38	3.91	16.10	8.14	
Plain	Roosts	28	0	25	7.14	46.43	7.14	10.71	3.57	p<0.001
	Random	140	5.00	12.14	9.29	10.71	7.86	5.71	49.29	
Ridge/Valley	Roosts	279	43.73	13.62	4.3	8.96	3.58	17.2	8.6	p<0.001
	Random	1390	26.91	7.05	5.54	6.69	7.41	11.44	34.96	

Table D2. Top-ranked models from case-control logistic regression distinguishing accipiter stopover roosts from random points by topographic region.[a]

	Model Rank	Variables in Model	K	AICc	ΔAICc	*Wi*
Sharp-shinned Hawk Ridge &Valley (n=182 roosts)	1	EF,MF,P	5	582.98	0	0.1949
	2	EF,EW,MF,P	6	584.48	1.5	0.0920
	3	SB,EF,MF,P	6	584.57	1.59	0.0880
	4	DF,EF,MF,P	6	584.83	1.85	0.0773
	5	EF,RC,MF,P	6	584.95	1.97	0.0728
Cooper's Hawk Ridge & Valley (n=97 roosts)	1	DF,MF,P	5	246.94	0	0.1197
	2	DF,RC,MF,P	6	247.75	0.81	0.0799
	3	DF,EW,MF,P	6	247.78	0.84	0.0787
	4	DF,EF,MF,P	6	248.07	1.13	0.0681
	5	SB,DF,MF,P	6	248.14	1.2	0.0657
	6	SB,DF,RC,MF,P	7	248.28	1.34	0.0613
	7	DF,EF,RC,MF,P	7	248.47	1.53	0.0557
	8	SB,DF,EF,RC,MF,P	8	248.61	1.67	0.0519
	9	DF,EW,RC,MF,P	7	248.82	1.88	0.0468
	10	DF,RC,P	5	248.91	1.97	0.0447
Sharp-shinned Hawk Plain (n=12)	1	EF,EW,P	5	28.38	0	0.2485
	2	EF,EW,MF,P	6	30.11	1.73	0.1046
	3	DF,EF,EW,P	6	30.34	1.96	0.0932
Cooper's Hawk Plain (n=16)	1	DF,RC,MF,P	6	36.24	0	0.1092
	2	DF,RC,P	5	36.25	0.01	0.1086
	3	DF,EW,RC,MF,P	7	36.57	0.33	0.0926
	4	DF,EW,RC,P	6	36.94	0.7	0.0769
	5	SB,DF,EW,RC,MF,P	8	37.46	1.22	0.0593
	6	DF,EF,RC,MF,P	7	37.68	1.44	0.0531
	7	SB,DF,RC,MF,P	7	37.69	1.45	0.0529
	8	DF,EF,RC,P	6	37.96	1.72	0.0462
	9	DF,EF,EW,RC,MF,P	8	38.12	1.88	0.0426

[a] DF=deciduous forest, EF=evergreen forest, EW=emergent wetland, MF=mixed forest, PA=pasture, P=patch size, SB=suburban; K=number of model parameters including unexplained variance; AICc= Akaike's Information Criterion values, ΔAICc= the difference between AICc of given model and top-ranked model, and *wi* = Akaike model w

Table D3. Model-averaged parameter estimates from case-control logistic regression distinguishing stopover roosts from random points by species and topographic region (at 0.5 km radius; n=# models averaged).

	Variable	β Estimate	SE	Odds Ratio	$\sum Wi$[1]
Sharp-shinned Hawk	Patch Size	0.217	0.041	1.239	0.869
Ridge and Valley	Evergreen Forest	0.031	0.012	1.032	0.229
n=5	Emergent Wetland	0.031	0.041	1.032	0.869
	Mixed Forest	-0.049	0.026	0.952	0.278
	Deciduous Forest	0.001	0.003	1.001	0.150
	Suburban	-0.008	0.013	0.992	0.295
	Row Crop	0.001	0.008	1.001	0.568
Sharp-shinned Hawk	Patch Size	0.488	0.260	1.629	0.446
Coastal Plain	Evergreen Forest	-0.300	0.173	0.741	0.446
n=3	Emergent Wetland	0.226	0.162	1.253	0.446
	Mixed Forest	-0.059	0.144	0.943	0.105
	Deciduous Forest	0.004	0.018	1.004	0.093
Cooper's Hawk	Patch Size	0.298	0.049	1.183	0.672
Ridge and Valley	Evergreen Forest	0.026	0.022	1.027	0.108
n=10	Emergent Wetland	-0.065	0.091	0.937	0.115
	Mixed Forest	-0.077	0.041	0.729	0.628
	Deciduous Forest	-0.014	0.004	0.831	0.672
	Suburban	-0.008	0.006	0.322	0.179
	Row Crop	-0.013	0.010	0.833	0.339
Cooper's Hawk	Patch Size	0.413	0.187	1.372	0.641
Coastal Plain	Evergreen Forest	-0.026	0.042	0.652	0.142
n=9	Emergent Wetland	-0.210	0.326	0.597	0.271
	Mixed Forest	-0.068	0.059	0.667	0.410
	Deciduous Forest	-0.029	0.013	0.859	0.641
	Suburban	-0.016	0.027	0.456	0.112
	Row Crop	-0.067	0.026	0.764	0.641

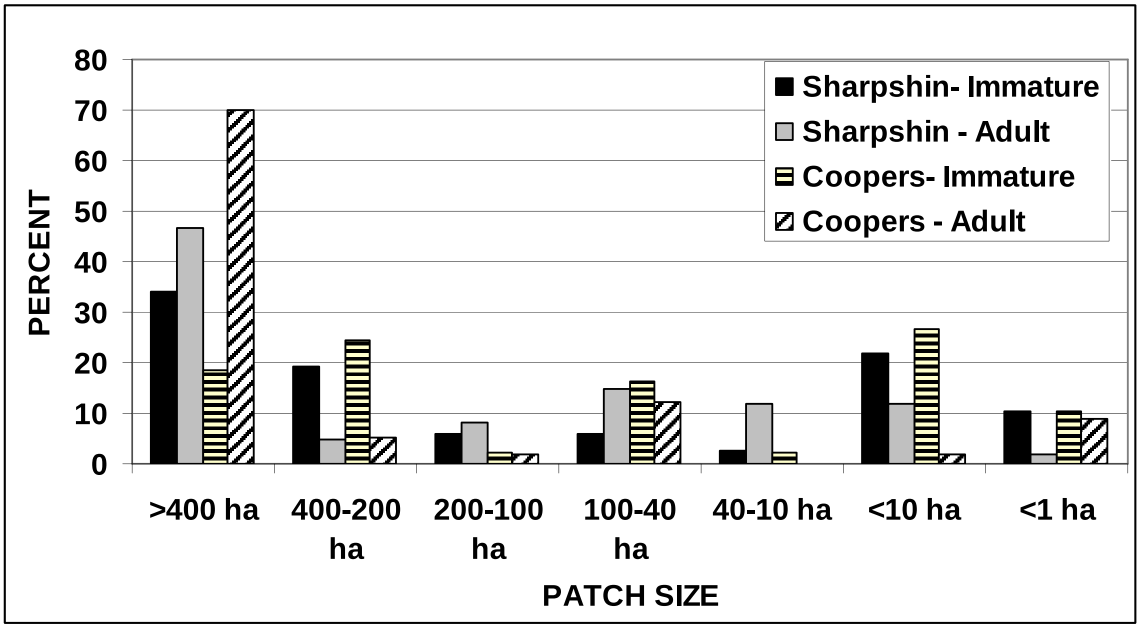


Figure D1. Comparison of forest patch size of stopover roosts selected by adult and immature migrating Sharp-shinned and Cooper's hawks during autumn 2003-2004.

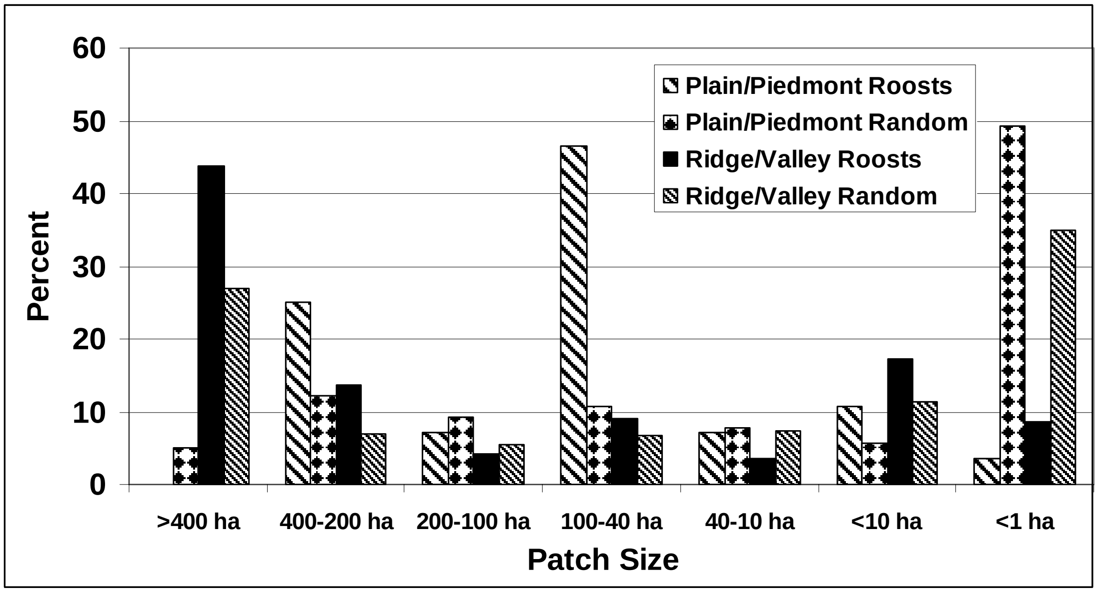


Figure D2. Comparison of forest patch size of stopover roosts selected by migrating accipiters (Sharp-shinned and Cooper's hawks pooled) in two topographic regions during autumn 2003-2004.

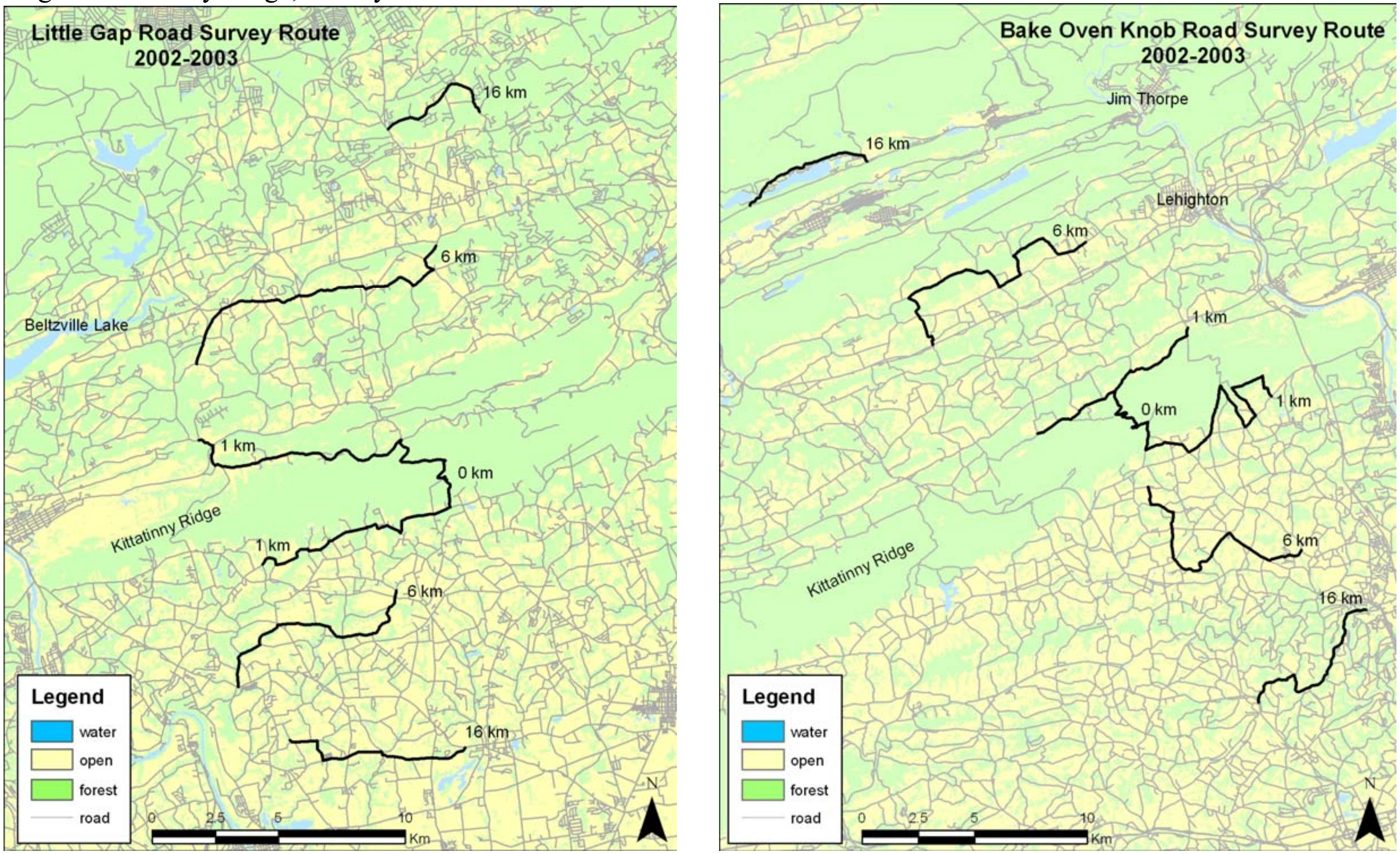
Appendix E. Stopover behavior and distribution of raptors along the Kittatinny Ridge in Central Appalachians during autumn 2002 and 2003.

Road Survey Study Area and Additional Methods

Five study road survey routes were established along the Kittatinny Ridge in Pennsylvania and surveyed for raptors in autumn 2002 and 2003. Each road survey route contained seven 8-10 km. transects including three parallel transects on the north and three on the south side of the ridge placed at approximately 1, 6 and 16 km distance from the Ridge. The seventh transect, i.e., the mountain transect, was placed across the ridge connecting the north and south slopes (Fig. E1a, 1b, 1c, 1d, 1e).

To compare the distribution of raptors I plotted the distance of birds from the road within open, forest, and mixed habitats (E2, E3, E4) and by size categories, e.g., large (Cooper's Hawk and larger) and small raptors (smaller than a Cooper's Hawk). Data were truncated according to habitat and body size by eliminating 5 to 10% of the detected raptors in the outer tail of the distributions.

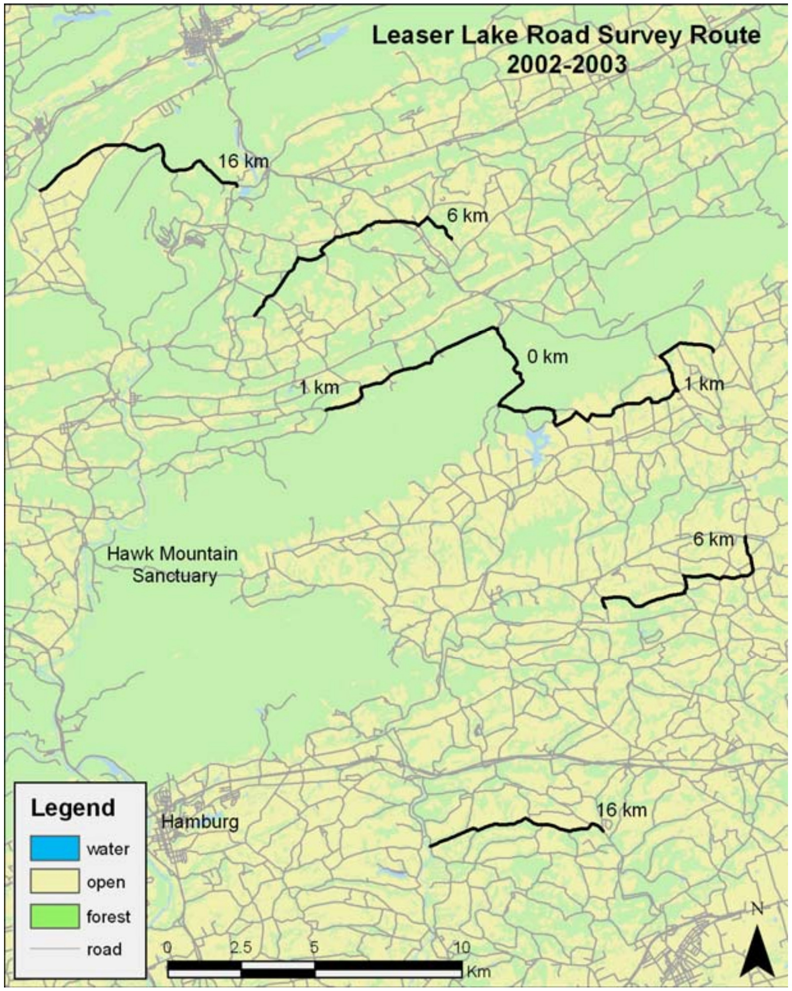
Figure E1. Road survey routes used to assess migratory raptor abundance and behavior during autumn stopover in 2002 and 2003 along the Kittatinny Ridge, Pennsylvania.



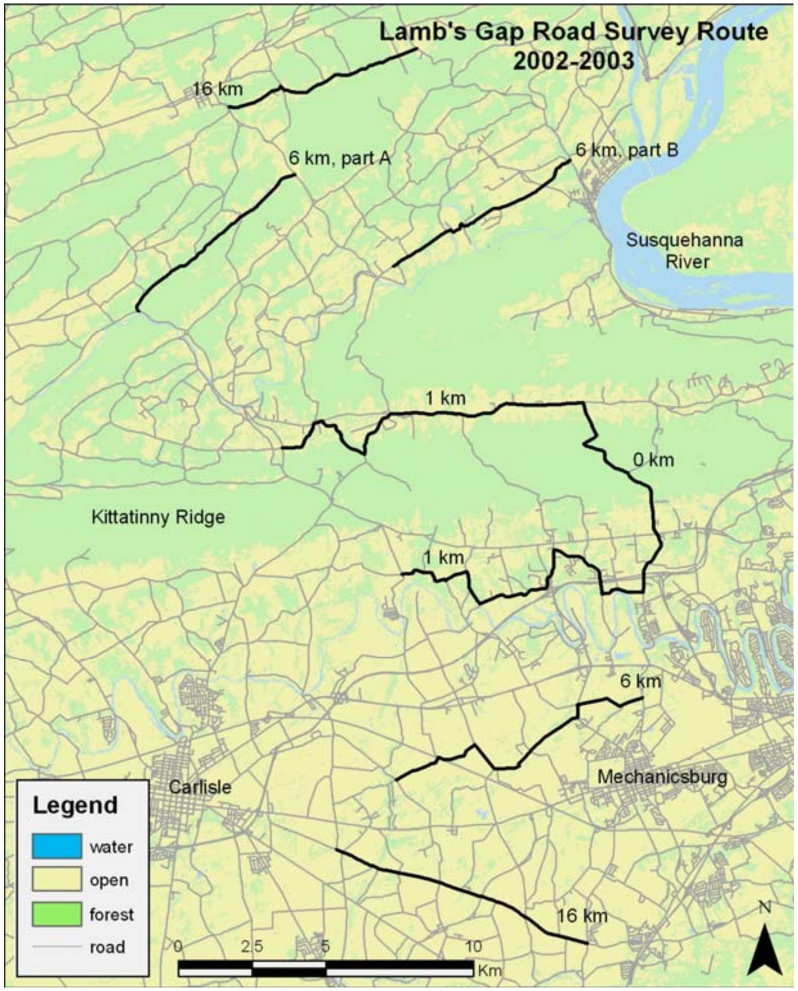
a.

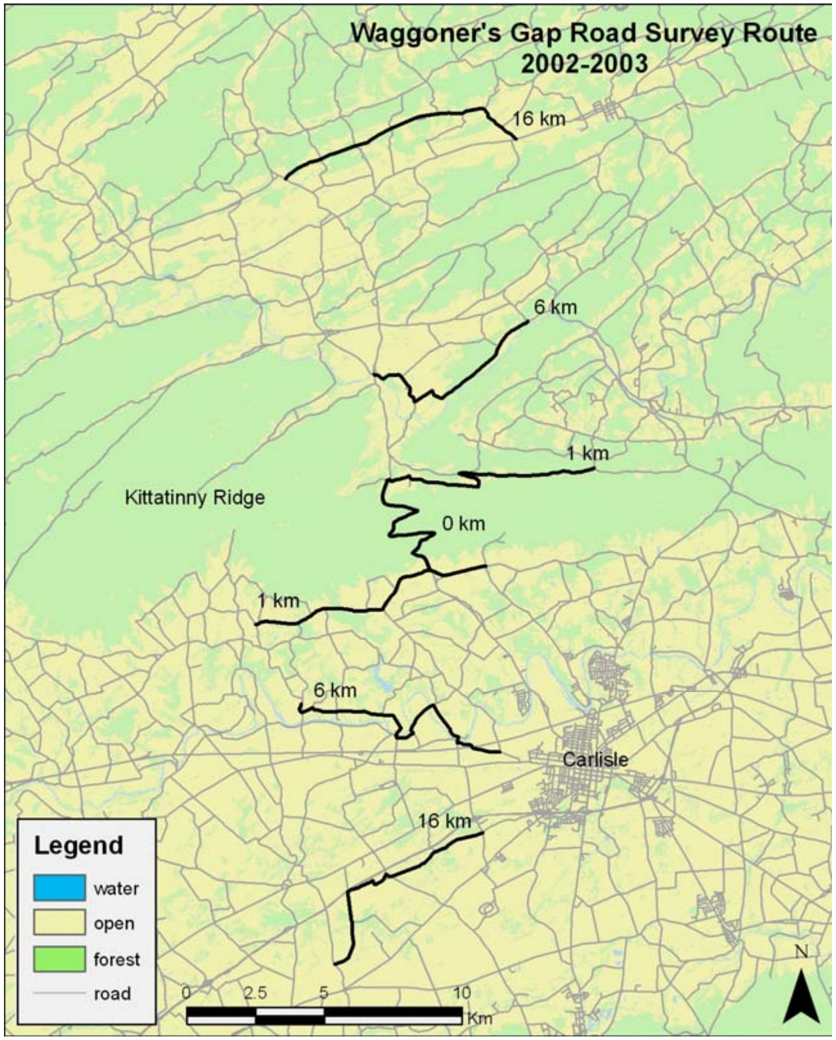
b.

c.


Leaser Lake Road Survey Route
2002-2003
16 km
6 km
0 km
1 km
1 km
6 km
16 km
Hawk Mountain
Sanctuary
Hamburg
Legend
water
open
forest
road
0
2.5
5
10
Km
N

d.


Lamb's Gap Road Survey Route
2002-2003
16 km
6 km, part A
6 km, part B
Susquehanna
River
1 km
0 km
Kittatinny Ridge
1 km
6 km
Carlisle
Mechanicsburg
16 km
Legend
water
open
forest
road
0
2.5
5
10
Km
N

e. 
Waggoner's Gap Road Survey Route
2002-2003
16 km
6 km
1 km
Kittatinny Ridge
0 km
1 km
6 km
Carlisle
16 km
Legend
water
open
forest
road
0
2.5
5
10
Km
N

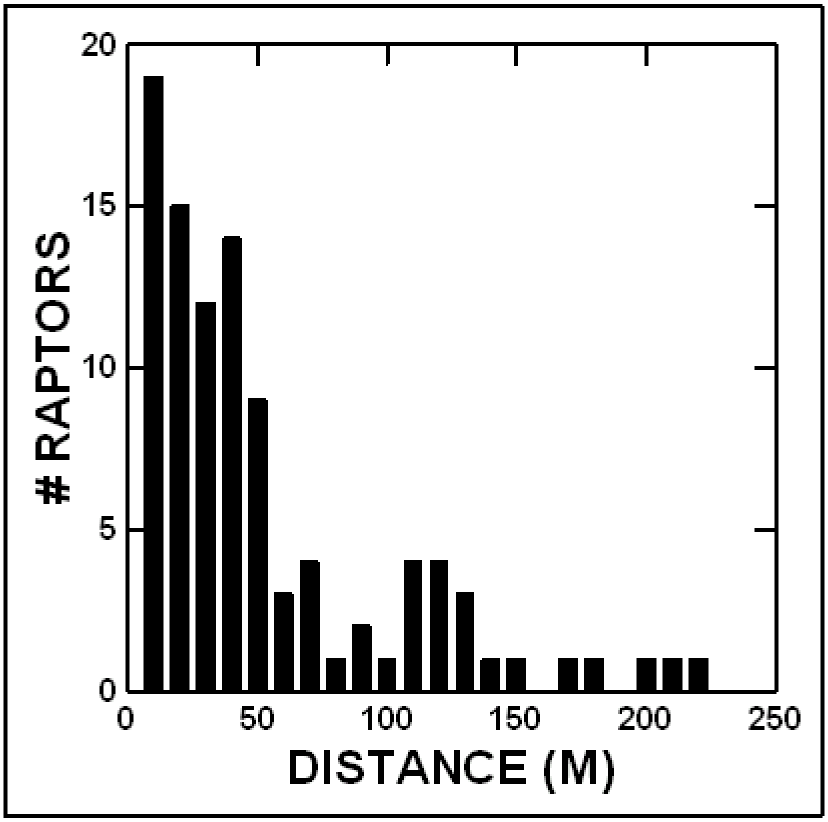


Figure E2. Number of total raptors observed in forest habitat on road surveys compared to perpendicular distance from the road in autumn 2002 and 2003 (n=98).

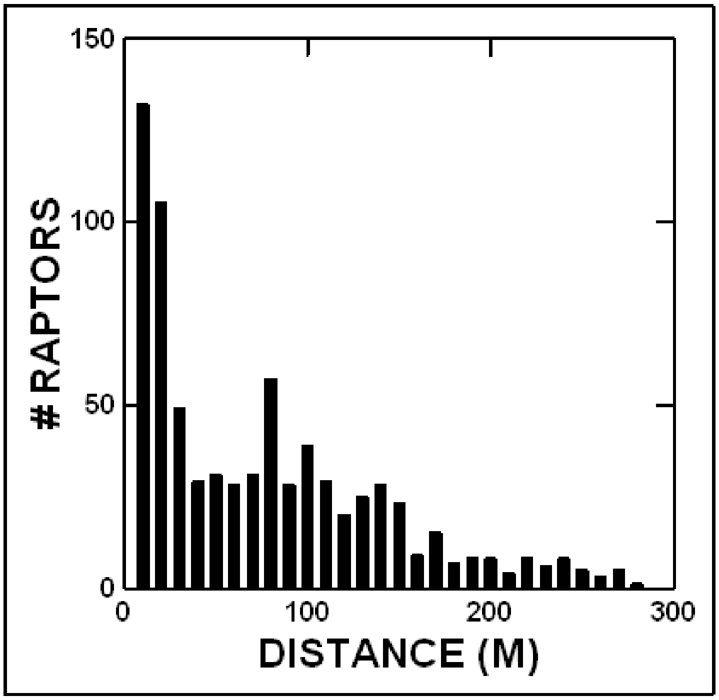


Figure E3. Number of total raptors observed in open habitats on road surveys compared to perpendicular distance from the road in autumn 2002 and 2003 (n= 841).

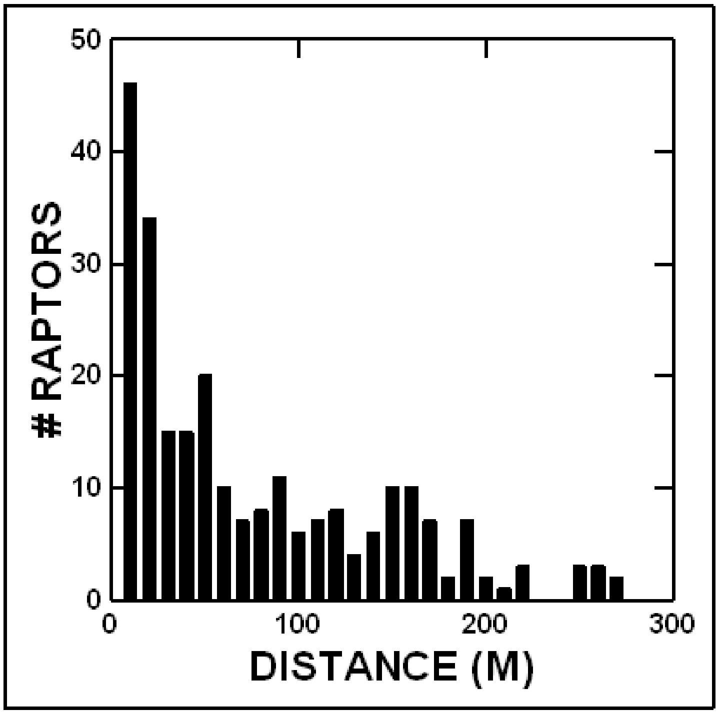


Figure E4. Number of total raptors observed in mixed habitats on road surveys compared to perpendicular distance from the road in 2002 and 2003 (mixed includes suburban, edge, mixed forest-open categories, (n=240).

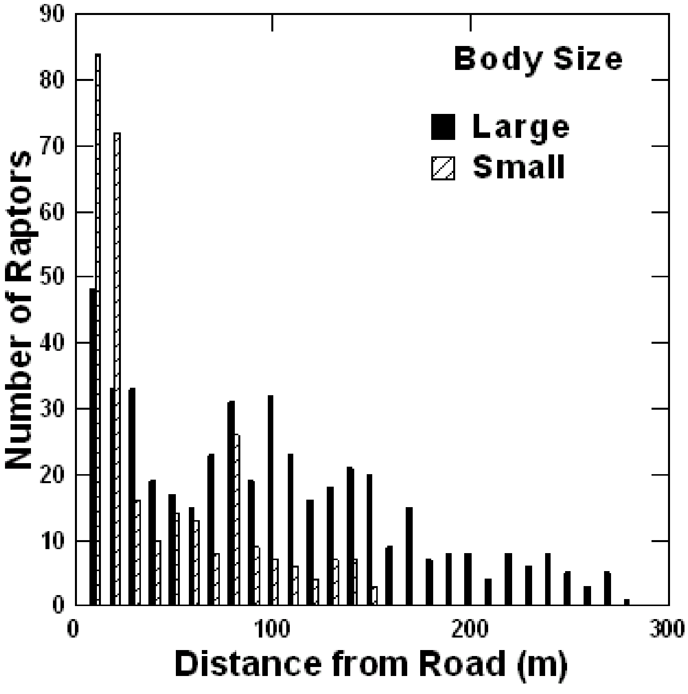


Figure E5. Number of large and small raptors observed in open habitats on road surveys compared by perpendicular distance from the road in 2002 and 2003 (n=841).

Curriculum Vitae

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