Linking Hawk Watch Sites to Breeding and Wintering Catchment Areas of Red-tailed Hawks

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Introduction

Red-tailed hawks are a widespread, partial migrant raptor throughout North America. Year-round ranges extend coast to coast in North America and from Panama to the U.S.-Canadian border (Preston and Beane 2009). Breeding ranges additionally extend as far north as Alaska on the west coast and to central Quebec and Nova Scotia on the east coast (Preston and Beane 2009).

Red-tailed Hawks exhibit differential migration where populations from more northern latitudes tend to migrate longer distances than those in the mid- and lower-latitude regions of North America, e.g. leap-frog migration (Cristol et al. 1999, Preston and Beane 2009). Their migration patterns are affected by topography, notably mountain ridges and water bodies, which mold migration routes and create concentrations along leading lines (Mueller and Berger 1967, Kerlinger 1985).

Previous studies have provided valuable insight into raptor population connectivity by using band recovery data to link migration routes to source populations (Mazerolle et al. 2005). For example, Goodrich and Smith (2008) illustrated longitudinal differentiation and overlap in the breeding and wintering grounds of migratory Sharp-shinned Hawks sampled by hawk watch sites throughout the continent. Juvenile Red-tailed Hawks from western parts of North America displayed discrete differential migration, where migrants that used the Pacific coast corridor originated from central California and the Intermountain West, while migrants along the Intermountain West corridor originated from more northern breeding populations (Hull et al. 2009). Patterns of northward summer migratory movement in southern California have also been documented for Red-tailed Hawk juveniles and Cooper's Hawks (Bloom et al. 2015, Bloom et al. 2017). In Idaho, 19 migratory Red-tailed Hawks banded during nesting were recovered wintering throughout areas of the Intermountain West and the western coast of Central America (Steenhof et al. 1984).

Additionally, Morrison and Baird (2016) analyzed banding and recovery data for Red-tailed Hawks in the northeastern U.S. and found that band recoveries of northeastern birds occurred from the Atlantic Coast to Mississippi flyway and from Canada to the Gulf Coast of Florida. They also observed hawks banded at higher latitudes wintered below hawks banded at lower latitudes, showing a leapfrog type of migration pattern.

Understanding migration patterns among populations is especially useful when using migration count data to comprehend overall population trends. Previous studies have shown that migration counts reflect trends in the populations of raptors being counted (Bednarz et al. 1990, Farmer et al. 2008). As such, hawk watch sites play an important role in the collection of population trend data across the continent. However, wildlife managers have questioned how migration data connects to the breeding populations they manage.

The Raptor Population Index project was launched in 2004 to derive trends in raptor migration data from across North America (www.rpi-project.org). Based on these analyses, migratory Red-tailed Hawk population numbers appear to have shown declines over the past ten years in northeastern regions of the U.S. (Brandes et al. 2013). However, detections of Red-tailed Hawks in winter bird counts suggest migration declines may be due to changes in migration patterns, as residential individuals and migratory short-stopping are increasing within the eastern flyways (Bolgiano 2013, Paprocki et al. 2017). Linking Red-tailed Hawk breeding and wintering regions to data collected at hawk watch sites can increase recognition of changes in migration and population trends for all raptor species.

The purpose of this project was to determine which Red-tailed Hawk breeding and wintering catchment areas are sampled by various hawk watch sites across North America and the degree of overlap among them. A "catchment area" is defined as the breeding and wintering area sampled by groups of hawk watch sites. Here we used band recovery data to assess if migratory Red-tailed Hawks showed latitudinal or longitudinal differentiation in their breeding and wintering regions among the migration corridors and to define catchment areas for each flyway or migration corridor in North America. We examined Red-tailed Hawk banding data because the dataset is large, and we predict their catchment areas can be used as a proxy to estimate catchment regions for other partial migrant raptors throughout North America.

Methods:

Banding and recovery data for Red-tailed Hawks throughout North America were obtained from the U.S. Geological Survey Bird Banding Laboratory. Records occurred from 1914 to 2019, and information was extracted based on banding season, banding location coordinates, recovery season, and recovery location coordinates.

Only individuals that were banded during migration seasons and then recovered during either wintering or breeding season were included in analysis. Migration seasons were defined as March–May 30 and September 1–November 30, breeding season as June 1–August 31 and wintering season as December 1–February 28 (Preston and Beane, 2009).

The banding coordinates of Red-tailed Hawks that met the set criteria were projected as points in ArcGIS 7.0 (using

the WGS 84 projection coordinate system). Additionally, the coordinates of North American hawk count sites, obtained from HMANA, were projected. Banding coordinates and hawk count site points were then grouped based on the flyway in which they were banded.

Seven flyways were defined based on major topographic features in the United States, following the same model as the one used for mapping Sharp-shinned Hawk catchment areas in Goodrich and Smith (2008) "Raptor Migration of North America," The State of North America's Birds of Prey. The Atlantic Coast flyway extended from the Atlantic Coast to the eastern edge of the Appalachian Mountain ridge. The Appalachian flyway extended from the eastern ridge of the mountain range to the western edge inclusive of the plateau region. The Eastern Great Lakes Flyway incorporated regions between Lake Ontario running down the western side of the Appalachians to Lake Huron running southeast of the Mississippi River. The Western Great Lakes Flyway included territory west of Lake Huron and west of the Mississippi river but east of the Great Plains. The eastern Rockies flyway extended west across the Great Plains regions to the Rocky Mountain ridge. The western Rockies flyway range encompassed the Great Basin and Intermountain West. Lastly, the Pacific Coast flyway included everything west of Sierra Nevada and Cascade Range.

Within each flyway, a map was produced based on the recovery season and recovery location of the Red-tailed Hawks banded within the flyways' boundary. To do this, the projected banding locations were selected within each flyway, exported, then re-projected on a new map based on the Red-tailed Hawks' recovery coordinates. Recovery points were then categorized based on breeding or wintering season recovery, and a 95% minimum convex polygon (MCP) was created for both seasons in each flyway to compare breeding and wintering catchment areas.

The 95% MCP was used as it outlined the area where 95% of Red-tailed Hawk recoveries were detected, while leaving out areas where ≤5% of recoveries occurred. Additionally, the catchment areas and hawk watch sites for each flyway were overlaid on a map of North American Bird Conservation Regions (BCR) (Fig. 1). The BCRs were used to determine which hawk watch sites sample populations that breed and winter within the BCRs and where sampling overlap occurs. We used BCRs to subset populations as they are often used for setting conservation priorities.

Results:

A total of 4972 Red-tailed Hawks were banded during fall and spring migration and then recovered during breeding (n=3529) or wintering (n=1443) seasons in each of the lower 48 states, in most provinces of southern Canada, and in western Mexico. The number of banded Red-tailed Hawks and band recoveries varied greatly between seasons and flyways across the continent. Less than half the number of individuals were recovered during the breeding season compared to the wintering season. Additionally, the available dataset contained double the number of individuals banded during fall compared to spring migration. The distribution of Red-tailed Hawk recoveries exhibited a longitudinal division of breeding and wintering catchment areas with some overlap among flyways. Additionally, 324 migration monitoring sites throughout North America were mapped and linked to Red-tailed Hawk breeding and wintering catchment areas.

Atlantic Coast and Appalachian Mountain Catchment Areas

Red-tailed Hawks banded along the Atlantic Coast maintained a longitudinal wintering and breeding range near the coast, with a few breeding individuals extending as far west as Michigan (Fig. 2). 95% of Red-tailed Hawks were recovered between southern Quebec and South Carolina. Overall, recoveries were recorded in 14 states and Quebec with broad overlap between wintering and breeding regions (Table 3).

Additionally, a latitudinal gradient was observed in the Atlantic Coast flyway for the catchment areas of Red-tailed Hawks. Hawk watch sites located along northern regions of the Atlantic Coast count migratory birds breeding between New Brunswick and southern Quebec and monitor birds wintering south to Massachusetts and New York, while hawk watch sites along the southeast coast of the United States mostly observe Red-tailed Hawks breeding only as far north as North Carolina and wintering into Florida.

In the Appalachian flyway, breeding and wintering ranges almost entirely encapsulated Atlantic Coast ranges, but additionally extended further inland, northeast, and southwest (Fig. 2). Most recoveries (95%) occurred between the Atlantic Coastline and Ohio, extended into Quebec during breeding season, and south into northern Florida during the wintering season (Table 3). Wintering and breeding ranges for Appalachian migrants covered 21 states and two Canadian provinces (Table 3). Unlike the Atlantic Coast birds, no distinct latitudinal gradient was found. Hawk watch sites throughout the Appalachian range encounter Red-tailed Hawks migrating from as far north as Quebec or from as far south as northern Florida. However, Red-tailed Hawks banded further inland dispersed further during wintering and breeding seasons than coastal migrants (Fig. 2). Additionally, it appears that hawk watch sites in the western ridges of the Appalachians are more likely to detect birds that breed and winter further inland, such as birds nesting in western Pennsylvania and New York.

Eastern and Western Great Lakes Catchment Areas

Migratory Red-tailed Hawks banded in the eastern and western Great Lakes flyways showed a longitudinal gradient, with broadly overlapping breeding and wintering areas (Fig. 3). Within the eastern Great Lakes flyway, wintering Red-tailed Hawk recoveries occurred from the Atlantic Coast to the Mississippi River and from southern Ontario to Alabama

covering 18 states and Ontario, Canada (Table 3). The breeding range catchment area did not extend as far south or west as the wintering area but did extend further northeast into southern Ontario (Fig. 3). It was comprised of 14 states and Ontario, Canada. Similar to the Appalachian flyway, no latitudinal gradient was detected for Red-tailed Hawks migrating through the eastern Great Lakes flyway. Hawk watch sites around the eastern Great Lakes count migratory individuals breeding in Ontario and wintering as far south as Alabama. However, hawk watch sites along the eastern shore of Lake Ontario and up the St. Lawrence River in Quebec also monitor outlier migratory Red-tailed Hawks (≤5%) that breed in more northeasterly regions of Canada, such as New Brunswick.

The western Great Lakes flyway had the highest number of Red-tailed Hawk recoveries during both breeding and wintering periods (n=437, n=988). Breeding recoveries occurred in 18 states and two Canadian provinces extending from the western edge of the Appalachians to the eastern edge of the Great Plains (Table 3, Fig. 3), while wintering recoveries covered similar territory but extended further south into eastern Texas and western Florida, covering 22 states (Table 3). The longitudinal gradient showed hawk watch sites detecting Red-tailed Hawks in western Michigan are recovering birds that bred mostly in Ontario and wintered southeast into Florida. Hawk watch sites west of the Great Lakes detect Red-tailed Hawks breeding in Ontario and Manitoba and wintering from Texas to Louisiana. Additionally, hawk watch sites in Texas and Arkansas recover short-distance migrant Red-tailed Hawks from northern Texas, Oklahoma and Kansas.

Overlap among Atlantic Coast, Appalachian, Eastern and Western Great Lakes Flyways

Overlap between flyway catchment areas was also evident. Red-tailed Hawks breeding and wintering in New England and along the U.S. Atlantic Coast in BCR 14 and 30 are monitored by hawk watch sites throughout both the Appalachian Mountain and Atlantic Coast flyways (See Table 3 for the states and provinces included in each flyway, Table 2 for the BCRs in each flyway, and Figures 1-5 showing the location within each state and province of these BCRs).

Along the border region between eastern Canada and the U.S. in BCR 13, and the Appalachian Mountains region, BCRs 28 and 29, breeding and wintering Red-tailed Hawk populations are monitored by the Atlantic Coast, the Appalachian, and the Eastern Great Lakes flyways (Table 2). Additionally, wintering birds in BCR 13 and 28 are sampled by the Western Great Lakes flyway. In the southeastern United States in BCR 27, Red-tailed Hawk breeding populations are monitored by the Atlantic Coast and the Appalachian flyways, while wintering populations are detected by the Atlantic Coast, Appalachian, Eastern and Western Great Lakes flyways. Additionally, there are outlier Red-tailed Hawks wintering in southern Florida's BCR 31 that are sampled by Atlantic, Appalachian, Eastern and Western Great Lakes flyways (Table 2).

In BCR 12, around the Great Lakes, breeding Red-tailed Hawks are counted by the Atlantic Coast, Appalachian, Eastern and Western Great Lakes flyways. Wintering birds are monitored by the Appalachian, Eastern and Western Great Lakes flyways (Table 2).

Eastern and Western Rocky Mountains and Pacific Coast Catchment Areas

The eastern Rocky Mountain flyway had the fewest breeding and wintering recoveries of any flyway (n=17, n=31). However, migratory individuals covered the longest longitudinal range and were found breeding and wintering across Canada, the United States and Mexico (Fig 4.). One Red-tailed Hawk banded in Alaska was recovered wintering in Montana almost 10 years later. Wintering individuals extended as far east as Arkansas and west into southern California (Fig. 4). The breeding range was narrower than the wintering range but extended further north into Canada and south into the northwestern regions of Mexico. No recoveries in the dataset were recorded near hawk watch sites along the eastern coast of Mexico, though.

Patterns in western North American flyways mirrored patterns in eastern North America. Red-tailed Hawks banded along the western Rocky Mountains bred and wintered further inland into Colorado and New Mexico than migrants along the Pacific Coast (Fig. 5). They also originated from further north into British Columbia during breeding season and wintered further south into western Mexico, with ranges covering 10 states, a Canadian province, and northwest Mexico (Table 3). Pacific Coast migrants were recovered breeding and wintering in six states and British Columbia. Additionally, outlier winter migrants extended into western Mexico (Fig. 5).

Finally, a slight latitudinal gradient was detected in the Western Rockies and Pacific Coast flyways (Fig. 5). Hawk watch sites in states bordering Canada are more likely to detect northern Red-tailed Hawks from Alaska and British Columbia but occasionally monitor migrants wintering as far south as Mexico. Conversely, hawk watch sites in more southern states may detect breeding individuals from Canada, but a majority of their migratory Red-tailed Hawks breed from regions south of Oregon.

Overlap among Western Great Lakes, Eastern Rockies, Western Rockies, and Pacific Coast Flyway

In the Midwest and southeast in BCRs 22, 23 and 24, breeding and wintering Red-tailed Hawks are detected by the Eastern and Western Great Lakes Flyways (Table 2). Additionally, wintering populations in BCR 22 and 24 are sampled by the Eastern Rockies flyway. The central southern United States regions include BCRs 21, 25 and 26. For BCR 21 only, wintering Red-tailed Hawks were recovered and are monitored by the Western Great Lakes flyway. BCRs 25 and 26 have breeding and wintering Red-tailed Hawk populations that are monitored by hawk watch sites in the Western Great

Lakes flyway. Outliers are also monitored by the Eastern Great Lakes flyway (Table 2).

Breeding Red-tailed Hawks from higher latitudes in BCR 8 are only monitored by the Western Great Lakes flyway (Table 2). BCR 11 is sampled during breeding and wintering season by the Western Great Lakes and Eastern Rockies flyways. Red-tailed Hawks breeding and wintering in the Intermountain West and Midwest states in BCR 17, 18 and 19 are monitored by the Eastern Rockies flyway but also contain outliers monitored by the Western Great Lakes and Western Rockies flyway.

In BCRs 9 and 10, breeding and wintering Red-tailed Hawks are detected by the Eastern Rockies, Western Rockies, and Pacific Coast flyways, with outliers detected in the Western Great Lakes (Table 2). In the southern Intermountain West range of BCR 16, breeding Red-tailed Hawks are sampled by the Eastern Rockies, Western Rockies, and Pacific Coast flyways, while wintering birds are sampled just by the Eastern and Western Rockies flyways.

Along the southern border of the U.S. and into northern Mexico in BCR 35, breeding Red-tailed Hawks are monitored by the Eastern Rockies flyway, and wintering birds are detected by the Eastern and Western Rockies flyways (Table 2). Slightly further west in BCR 34, breeding and wintering birds are sampled by the Eastern and Western Rockies, with a few outliers detected in the Pacific Coast flyway. In BCR 33, breeding Red-tailed Hawks are monitored by Western Rockies and Pacific Coast flyways, and wintering birds by Eastern Rockies, Western Rockies, and Pacific Coast flyways.

Red-tailed Hawks breeding along of the western coast in BCR 5, are monitored by the Western Rockies and Pacific Coast flyways. Wintering birds are sampled by just the Pacific Coast flyway. On the Pacific Coast of California, BCR 32, breeding Red-tailed Hawks are monitored by the Pacific Coast flyway, while wintering Red-tailed Hawks are monitored by the Western Rockies and Pacific Coast flyways (Table 2). For BCR 15, in northeastern California, both breeding and wintering birds are monitored by the Western Rockies and Pacific Coast flyways.

Lastly, in the northern regions that include BCR 4, breeding Red-tailed Hawks are monitored primarily by the Western Rockies flyway with outliers detected by the Eastern Rockies flyway (Table 2).

Discussion

Red-tailed Hawks banded during migration exhibited widely dispersed breeding and wintering catchment areas throughout North America. Longitudinal and sometimes latitudinal overlap was apparent among flyways and between the breeding and wintering grounds within each flyway. The overlap is expected for a short-distance migrant, such as the Red-tailed Hawk that has a proportion of non-migrant individuals across latitudes (Preston and Beane 2009).

Migration patterns also varied among flyways. Within the Atlantic Coast flyway, Red-tailed Hawks showed a latitudinal gradient, suggestive of a "chain migration" pattern (Goodrich and Smith 2008, Bildstein 2006). Within the Appalachian Mountains flyway, Red-tailed Hawks from high latitude regions were seen wintering as far south as Florida. This type of leap-frog migration in the northeastern United States is consistent with findings described by Morrison and Baird (2016). Within the Eastern and Western Great Lakes flyways, a latitudinal gradient wasn't well-defined, and leap-frog migration patterns were mostly observed for northern birds. However, detections of outlier Red-tailed Hawks in Canada and short-distant migrants in Texas, Oklahoma, and Kansas might indicate that chain migration patterns are also utilized in these two flyways. Migration patterns were difficult to discern in the eastern Rocky Mountain flyway due to the limited amount of recovery data. In the western Rocky Mountains and Pacific Coast flyway, the distribution of Red-tailed Hawk recoveries suggested both leap-frog and chain migration patterns. Chain migration was apparent as Red-tailed Hawks that bred in northern Canada and Alaska wintered in the northern United States. Individuals breeding in the northern United States in Montana, Wyoming, and Idaho exhibited leap-frog migration, passing over Red-tailed Hawks in the southern United States to winter in Mexico, a pattern previously demonstrated in Red-tailed Hawks breeding in Wyoming (Craighead 2016).

Frequent overlap was observed between flyways as well. Red-tailed Hawks within the Atlantic Coast, Appalachian Mountains, and Eastern and Western Great Lakes flyways shared a large proportion of their breeding and wintering grounds, suggesting sampling overlap is high for hawk watch sites in these regions. Similar patterns were observed in the west between the Eastern and Western Rocky Mountains and Pacific Coast flyways; hawk watch sites along these corridors can probably expect high sampling overlap and mixing of populations.

The Eastern Rocky Mountains and Western Great Lakes flyway also displayed a small overlap in the southern United States, and, hawk watch sites may sample a proportion of the same wintering birds. However, their breeding and wintering ground overlap was relatively small compared to other flyway overlap, highlighting a longitudinal division between Red-tailed Hawks migrating through eastern flyways and western flyways. This division could be caused by a lack of monitoring stations in the Great Plains region or by the Great Plains region acting as a geographic barrier separating eastern and western Red-tailed Hawks. The latter explanation is supported by findings from Pearlstine (2004), who showed western and eastern Red-tailed Hawks exhibited small genetic differences in their mitochondrial DNA haplotypes.

Additionally, no eastern Red-tailed Hawks from the Atlantic, Appalachian, and Eastern Great Lakes flyways, except for outliers (<5%), maintained wintering or breeding grounds west of the Mississippi River, suggesting the river also acts as a distinct geographic barrier. In the west, the Rocky Mountains seems to be the biggest geographic barrier for the species as few Red-tailed Hawks from the Western Rockies or Pacific Coast flyways were found breeding or wintering east of the

Rockies. These geographic barriers provide a useful overview of broad regions where sampling overlap does and does not occur between the hawk watch sites within the different flyways across North America.

It is important to note that hawk watch sites and banding sites are not randomly nor uniformly distributed throughout the United States, which may affect sampling overlap. Red-tailed Hawk banding data showed a cluster sampling bias around hawk watch sites. Current Red-tailed Hawk count trends reported by the Raptor Population Index show widespread declines in Red-tailed Hawks in the eastern flyways; however, this may be due in part to short-stopping (Brandes et al. 2016, Bolgiano 2013). Clear gaps in the available data were apparent in the Great Plains and southern United States. As such, these regions could likely benefit from more migration monitoring and banding to better understand trends in Red-tailed Hawk populations.

Additionally, Red-tailed Hawk movements are non-linear between banding and recovery locations, so additional breeding or wintering territory may be utilized that was not captured. Incorporating telemetry or genetic analysis data may be a useful next step to explore migration patterns and catchment areas throughout North America, as has been done with discrete populations of Red-tailed Hawks in California and Sharp-shinned Hawks in New Mexico (Smith et al. 2003, Hull et al. 2009).

The amount of overlap between flyways in this study may be influenced by early and late migrants as well. Red-tailed Hawks on fall migration can be detected as early as August and into January (Broun 1995, Mueller et al. 2000, Preston and Beane 2009). Since this is outside of the mean migration dates we used, a few migratory individuals may have been unknowingly classified as breeding or wintering. Additionally, non-migrant Red-tailed Hawks could have been included in the data if they were banded during a migration month and recovered during breeding or wintering months. Some residential individuals were filtered out through the 95% MCP analysis, including individuals in the southwest United States and the southern Florida subspecies B.j. umbrinus, but there was most likely a percentage of residents still included in higher latitude regions where migratory and residential populations show overlap.

Nevertheless, similar catchment areas and sampling overlap patterns have been shown in other partial migrant raptors. Based on band recovery data, Sharp-shinned Hawks showed very similar flyway overlap patterns to Red-tailed Hawks (Goodrich and Smith 2008). Sharp-shinned Hawks also showed similar breeding and wintering recovery patterns as Red-tailed Hawks, where migrants along the coasts of North America are more restricted while inland migrants disperse further (Goodrich and Smith 2008). Our analysis and that for Sharp-shinned Hawks suggest that these flyway maps could represent catchment areas and patterns for other short-distance migrants in North America as well (e.g., Cooper's Hawk). A similar methodology could also be used to create a potential model for long distance migrants such as Broad-winged Hawks.

By linking migratory Red-tailed Hawks to their breeding and wintering areas we can better understand which Red-tailed Hawk populations are represented in watch site count trends and detect potential changes in migration and population patterns. As a short-distance migrant with a large non-migratory population (Preston and Beane 2009), we expected and found a large overlap of breeding and wintering regions with some longitudinal and latitudinal distinctions across North America. The catchment areas and sampling overlap demonstrated by Red-tailed and Sharp-shinned hawks provide a useful model for estimating the catchment regions and overlap of other partial migrant raptors throughout North America. In this study, we underscored the degree of overlap, and how it may influence the trends observed at different watch sites. By better understanding population trends. we hope to improve monitoring practices and conservation for North American raptors.

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Literature Cited

Bednarz, J. C., D. Klem, Jr., L. J. Goodrich, and S. E. Senner. 1990. Migration counts of raptors at Hawk Mountain, Pennsylvania, as indicators of population trends, 1934–1986. *Auk* 107:96–109.

Bildstein, K. L. 2006. *Migrating Raptors of The World: Their Ecology And Conservation* Cornell University Press, Ithaca, New York, USA.

Bloom, P. H., M. D. Mccrary, J. M. Papp, and S. E. Thomas. 2017. Banding Reveals Potential Northward Migration of Cooper's Hawks from Southern California. *Journal of Raptor Research* 51:409-416.

Bloom, P. H., M. D. McCrary, J. M. Scott, J. M. Papp, K. J. Sernka, S. E. Thomas, J. W. Kidd, E. H. Henckel, J. L. Henckel, and M. J. Gibson. 2015. Northward Summer Migration of Red-tailed Hawks Fledged from Southern Latitudes. *Journal of Raptor Research* 49:1–17.

Bolgiano, N. 2013. Evidence for Changed Migration of Red-tailed Hawks in Eastern North America. *Hawk Migration Studies* 38:16-24.

Brandes, D., D. Oleyar, S. Hoffman, and L. Goodrich. *The Raptor Population Index, 2013 Regional Trend Summaries and Conservation Assessments.* Available at http://rpi-project.org/2013/assessments2013.php.

Broun, M. 1935. The Hawk Migration during the Fall of 1934, along the Kittatinny Ridge in Pennsylvania. *Auk* 52:233-248.

Craighead, D., R. H. Crandall, R. N. Smith, and S. L. Cain. 2016. Migration of Red-tailed Hawks (Buteo jamaicensis) from Northwest Wyoming. *The Wilson Journal of Ornithology* 128:150–158.

Cristol, D. A., M. B. Baker, and C. Carbone. 1999. Differential Migration Revisited. In: Nolan V., Ketterson E.D., Thompson C.F. (eds) *Current Ornithology* 15:33-88.

Farmer, C. J., R. J. Bell, B. Drolet, L. J. Goodrich, E. Greenstone, D. Grove, D. J. T. Hussell, D. Mizrahi, F. J. Nicoletti, and J. Sodergren. 2008. Trends in Autumn Counts of Migratory Raptors in Northeastern North America, 1974–2004. In *State of North America's Birds of Prey* (K. L. Bildstein, J. P. Smith, E. Ruelas I., and Veit, R. R. Editors). Nuttall Ornithological Club, Cambridge, MA, and American Ornithologists' Union, Washington, DC, USA.

Goodrich, L. J., and J. P. Smith. 2008. Raptor migration in North America. In *State of North America's Birds of Prey* (K. L. Bildstein, J. P. Smith, E. Ruelas I., and Veit, R. R. Editors). Nuttall Ornithological Club, Cambridge, MA, and American Ornithologists' Union, Washington, DC, USA.

Hull, J. M., H. B. Ernest, J. A. Harley, A. M. Fish, and A. C. Hull. 2009. Differential Migration between Discrete Populations of Juvenile Red-tailed Hawks (Buteo jamaicensis). *Auk* 126:389–396.

Kerlinger, P. 1985a. Water-crossing Behavior of Raptors During Migration. *Wilson Bulletin* 97:109–113.

Mazerolle, D. F., K. A. Hobson, and L. I. Wassenaar. 2005. Stable Isotope and Band-Encounter Analyses Delineate Migratory Patterns and Catchment Areas of White-Throated Sparrows at A Migration Monitoring Station. *Oecologia* 144:541–549.

Morrison, J. L. and J. M. Baird. 2016. Using Banding and Encounter Data to Investigate Movements of Red-tailed Hawks in the Northeastern United States. *Journal of Raptor Research* 50:161–175.

Mueller, H. and D. Berger. 1967. Wind Drift, Leading Lines, and Diurnal Migration. *The Wilson Bulletin* 79:50-63.

Mueller, H. C., D. D. Berger, and N. S. Mueller. 2003. Age and Sex Differences in the Timing of Spring Migration of Hawks and Falcons. *The Wilson Bulletin* 115:321-324.

Paprocki, N., D. Oleyar, D. Brandes, L. Goodrich, T. Crewe, and S. W. Hoffman. 2017. Combining Migration and Wintering Counts to Enhance Understanding of Population Change in A Generalist Raptor Species, The North American Red-Tailed Hawk. *Condor* 119:98–107.

Pearlstine, E. V. 2004. Variation in Mitochondrial DNA of Four Species of Migratory Raptors. *The Raptor Research Foundation* 38:250-255.

Preston, C. R. and R. D. Beane. 2009. Red-tailed Hawk (Buteo jamaicensis). *The Birds of North America. Number 52.*

Smith, R., T. Meehan, and B. Wolf. 2003. Assessing Migration Patterns of Sharp-Shinned Hawks (Accipiter striatus) Using Stable-Isotope and Band Encounter Analysis. *Journal of Avian Biology* 34:387-392.

Steenhof K., M. Kocher, M. Moritsc. 1984. Dispersal and Migration of Southwestern Idaho Raptors. *Journal of Field Ornithology* 55:57–368.

Figure 1: Bird Conservation Regions (BCR) throughout North America.

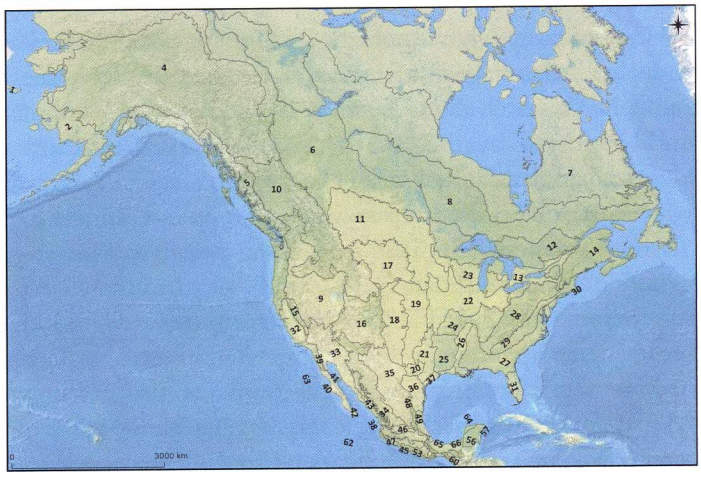

Figure 2: 95% MCP Catchment Areas based on Red-tailed Hawk Band Recoveries for the Atlantic Coast and Appalachian flyways.

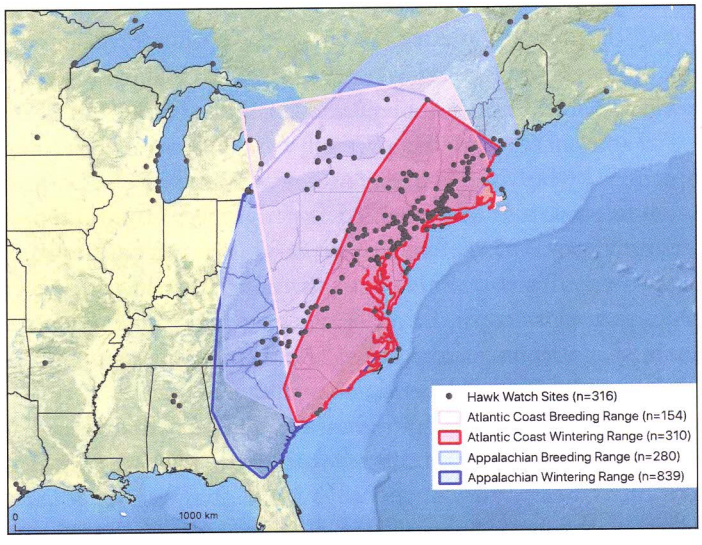

Figure 3: 95% MCP Catchment Areas based on Red-tailed Hawk Band Recoveries for the Eastern and Western Great Lakes flyways.

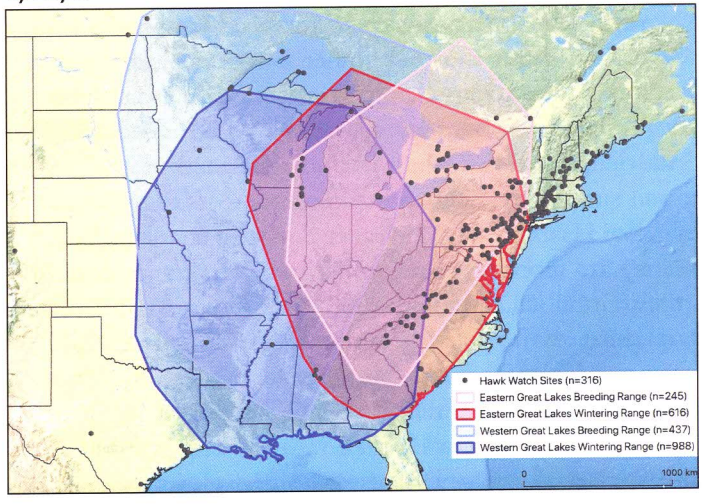

Figure 4: 95% MCP Catchment Areas based on Red-tailed Hawk Band Recoveries for the Eastern Rocky Mountain Flyway.

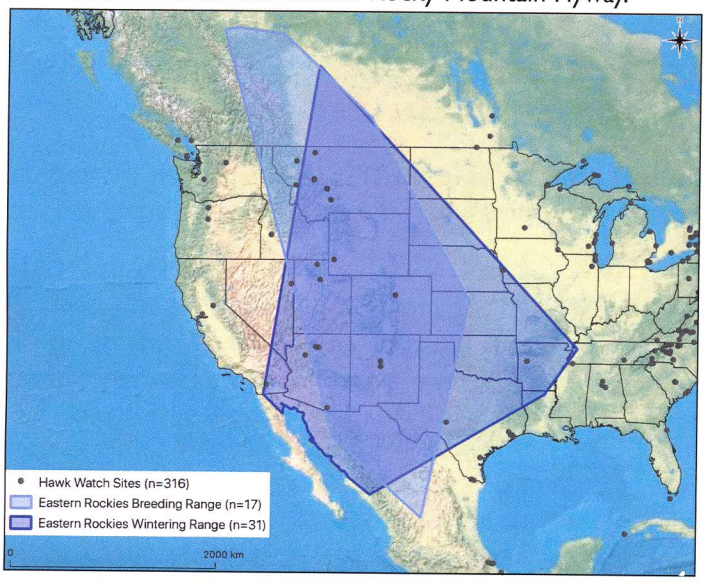

Figure 5: 95% MCP Catchment Areas based on Red-tailed Hawk Band Recoveries for the Pacific Coast and Western Rocky Mountain flyways.

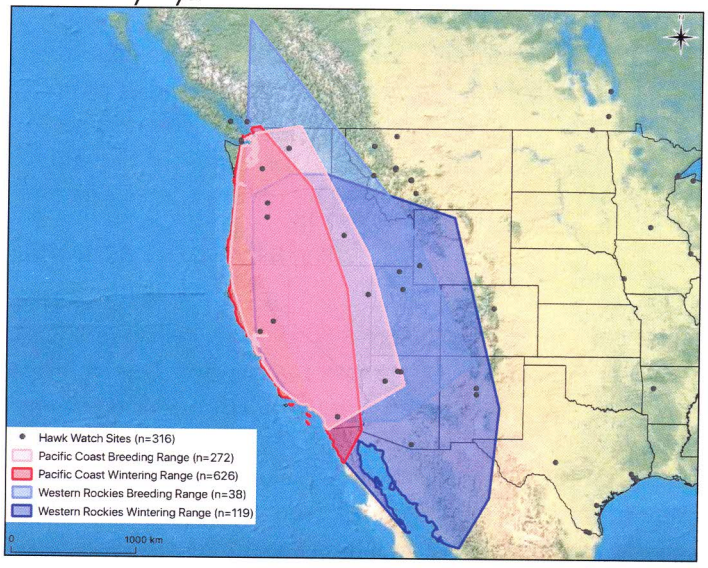

Table 1: The Fish and Wildlife Service Region (FWS) Monitoring by each Migration Flyway.

Fish & Widlife Service Region	Wintering RTHA Flyways	Breeding RTHA Flyways
1. Pacific Region	Pacific Coast Western Rockies	Pacific Coast Western Rockies
2. Southwest Region	Western Great Lakes Eastern Rockies Western Rockies	Western Great Lakes Eastern Rockies Western Rockies Pacific Coast
3. Midwest Region	Appalachians Eastern Great Lakes Western Great Lakes	Appalachians Eastern Great Lakes Western Great Lakes Atlantic Coast
4. Southeast Region	Atlantic Coast Appalachians Eastern Great Lakes Western Great Lakes	Atlantic Coast Appalachians Eastern Great Lakes Western Great Lakes
5. Northeast Region	Atlantic Coast Appalachians Eastern Great Lakes	Atlantic Coast Appalachians Eastern Great Lakes
6. Mountain-Praire Region	Western Great Lakes Eastern Rockies Western Rockies	Western Great Lakes Eastern Rockies Western Rockies
8. Pacific Southwest Region	Pacific Coast Western Rockies	Pacific Coast Western Rockies

Table 2: The Bird Conservation Regions (BCRs) Monitored by each Migration Flyway

Red-tailed Hawks Migration Flyway	Primary BCRs used for Breeding	Primary BCRs used for Wintering	BCR Regions for Outliers
Atlantic Coast	12, 13, 14, 27, 28, 29, 30	14, 27, 28, 29, 30	31
Appalachian Mountains	12, 13, 14, 27, 28, 29, 30	12, 13, 14, 27, 28, 29, 30	22, 24, 25, 31
Eastern Great Lakes	12, 13, 22, 23, 24 28, 29	12, 13, 22, 23, 24, 27, 28, 29	25, 26, 31
Western Great Lakes	8, 11, 12, 22, 23, 24, 25, 26,	11, 12, 13, 21, 22, 23, 24, 25, 26, 27, 28, 37	10, 13, 18, 19, 20, 31
Eastern Rockies	6, 9, 10, 11, 16, 17, 18, 19, 34, 35	9, 10, 11, 16, 17, 18, 19, 20, 21, 22, 24, 25, 33, 34, 35, 36	4
Western Rockies	4, 5, 9, 10, 15, 16, 33, 34	9, 10, 15, 16, 32, 33, 34, 35	18
Pacific Coast	5, 9, 10, 15, 16, 32, 33	5, 9, 10, 15, 32, 33	34

Table 3: Wintering and Recovery Catchment Areas of Red-tailed Hawks for each Flyway

Flyway	Wintering Recovery Areas		Breeding Recovery Areas		Outliers/Other occurances* *W= Wintering, B= breeding
Atlantic Coast	Southern Maine	Pennsylvania	Michigan	Pennsylvania	New Brunswick (W,B)
Winter Recoveries (n=310)	Southern Quebec	New Jersey	Southern Quebec	New Jersey	Georgia (W)
Breeding Recoveries (n=154)	New Hampshire	Maryland	New Hampshire	Maryland	Florida (W,B)
	Vermont	Delaware	Vermont	Delaware	
	Massachusetts	Virginia	Massachusetts	Virginia	
	Connecticut	North Carolina	Connecticut	North Carolina	
	Rhode Island	South Carolina	Rhode Island	South Carolina	
	New York		New York		
Appalachians	Southern Quebec	Maryland	Southern Quebec	Maryland	New Brunswick (W,B)
Winter Recoveries (n=839)	Southern Ontario	Delaware	Southern Ontario	Delaware	Southern Illinois (W,B)
Breeding Recoveries (n=280)	Maine	Ohio	Maine	Ohio	Alabama (W,B)
	New Hampshire	Virginia	New Hampshire	Virginia	Mississippi (W)
	Vermont	West Virginia	Vermont	West Virginia	Louisiana (W)
	Massachusetts	Kentucky	Massachusetts	Kentucky	Southern Florida (W)
	Connecticut	Eastern Tennesse	Connecticut	Eastern Tennesse	
	Rhode Island	North Carolina	Rhode Island	North Carolina	
	New York	South Carolina	New York	South Carolina	
	Pennsylvania	Georgia	Pennsylvania	Georgia	
	New Jersey	Northern Florida	New Jersey		
Eastern Great Lakes	Southern Ontario	Kentucky	Southern Ontario	Virginia	Southern Quebec (W,B)
Winter Recoveries (n=616)	Wisconsin	Tennessee	Wisconsin	West Virginia	Western Vermont (W)
Breeding Recoveries (n=245)	Michigan	North Carolina	Michigan	Kentucky	Missouri (W)
	Indiana	South Carolina	Indiana	Tennessee	Arkansas (W)
	Illinois	Georgia	Illinois	North Carolina	Louisiana (W)
	Ohio	New Jersey	Ohio	South Carolina	Mississippi (W,B)
	New York	Maryland	New York	Georgia	Florida (W)
	Pennsylvania	Eastern Iowa	Pennsylvania		Alabama (B)
	Virginia	Alabama			
	West Virginia				
Western Great Lakes	Minnesota	Mississippi	Minnesota	Kentucky	Southern Manatoba (B)
Winter Recoveries (n=988)	Iowa	Arkansas	Iowa	Tennesse	Southern Saskatchewan (B)
Breeding Recoveries (n=437)	Wisconsin	Oklahoma	Wisconsin	Alabama	Southern Ontario (W)
	Michigan	Texas	Michigan	Mississippi	Utah (W)
	Ohio	Louisiana	Ohio	Arkansas	Idaho (W)
	Indiana	West Virginia	Indiana	Oklahoma	Eastern Pennsylvania (W)
	Illinois	Virginia	Illinois	North Dakota	Texas (B)
	Nebraska	Western Pennsylvania	Nebraska	South Dakota	Florida (B)
	Missouri	Western North Carolina	Missouri	Southern Alberta	
	Kansas	South Carolina	Kansas	Southern Ontario	
	Kentucky	Georgia			
	Tennesse	Northern Florida			
	Alabama				
***Eastern Rockies**	Southern Alberta	Arizona	Southern Alberta	Kansas	Louisiana (W)
Winter Recoveries (n=31)	Montana	New Mexico	Southern British Columbia	Missouri	Tennesse (W)
Breeding Recoveries (n=17)	Idaho	Mexico	Montana	Arkansas	California (W)
	Wyoming	Texas	Idaho	Oklahoma	
	Western South Dakota	Oklahoma	Wyoming	Texas	
	Nebraska	Missouri	South Dakota	Arizona	
	Utah	Arkansas	Nebraska	New Mexico	
	Colorado	Eastern Nevada	Utah	Western Mexico	
	Kansas	Southern California	Colorado		
Western Rockies	Western Wyoming	California	Western Wyoming	California	
Winter Recoveries (n=119)	Western Colorado	Nevada	Western Colorado	Nevada	
Breeding Recoveries (n=38)	Washington	Arizona	Washington	Arizona	
	Oregon	New Mexico	Oregon	New Mexico	
	Idaho	Mexico	Idaho	Southern British Columbia	
	Utah		Utah		
Pacific Coast	Southern British Columbia	Oregon	Southern British Columbia	Idaho	Montana (B)
Winter Recoveries (n=626)	Washington	California	Washington	Nevada	Mexico (W)
Breeding Recoveries (n=272)			Oregon	Arizona	
			California		