Movements of Red-tailed Hawks Color-marked on the Kittatinny Ridge in Eastern Pennsylvania

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We color marked 356 Red-tailed Hawks on the Kittatinny Ridge in the central Appalachians of eastern Pennsylvania during the autumns of 2000 through 2003. None of the color-marked birds remained near our trap site during the study. Seventy resightings were reported to us during the four-year study, with 52 seen during autumn (September to December). Most autumn sightings (90%) were south or southwest (mean = 230°) of the trapping site.

We conclude that the Red-tailed Hawks we trapped along the ridge were migrating at the time of their capture, and were en route to destinations at least as far to the southwest as central Tennessee. Birds marked in early autumn (August 29 to October 13) showed a greater tendency to disperse than those marked later (October 14 through November) and had a more southerly mean flight direction (204° versus 243°, $P < 0.005$) than late-season birds. Even so, most early season birds appeared to be migrating (73%), and none were observed lingering at the trapping site. Our results suggest that northeastern migration watchsites that dismiss early season Red-tailed Hawks as "residents" are undercounting early migrants, and also confirm that migrants show greater ridge fidelity in late autumn than in early autumn.

During autumn migration, Red-tailed Hawks frequently soar on updrafts along ridges (slope soaring) that provide lift for the raptors and minimizes energy expenditure (Maransky et al. 1997, Swartzentruber and Beck 2001). The Kittatinny Ridge in the central Appalachians (Fig. 1) extends continuously through parts of New York, New Jersey, most of Pennsylvania nearly to Maryland and acts as a major leading line that concentrates the movements of thousands of migrating birds of prey during autumn migration (Broun 1948; Heintzelman 1975, 1986). Red-tailed Hawks are seen at migration watchsites in the northeast as early as August, although peak migration tends occur in late October-early November, with immatures migrating earlier than adults (Kerlinger 1989). Little is known about the early season migratory movements of Red-tailed Hawks when strong thermals provide energy-saving opportunities for migration (Broun 1948, Heintzelman 1975).

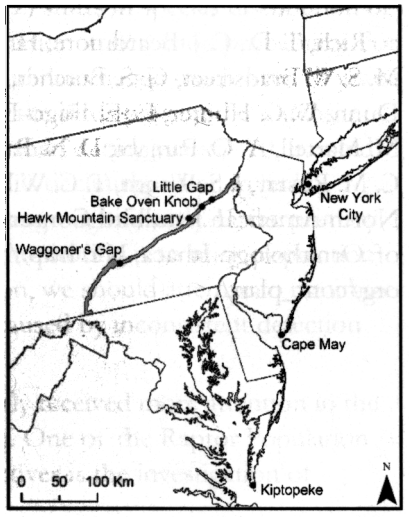

Figure 1. Location in eastern United States of hawk migration watchsites referenced.

Many individuals observed along the ridge early in the season are dismissed by hawkwatchers as "resident" or "local" birds (e.g. Heintzelman 1975, Brett 1991, Barber et al. 2001, Chartier and Stimac 2002). Existing protocols for identifying migrants tend to be based on behavior (Barber et al. 2001, Kunkle 2002a), and many watchsites lack written protocols entirely. Continued calls for standardization of practices for recording "local" or "resident" birds (Dunn, et al 2008) show that hawk count protocols remain deficient in dealing with this problem.

Brinker and Erdman (1985) found that in Wisconsin, early-autumn Red-tailed Hawks often moved to the northeast from their banding site, most likely in post-breeding dispersal. A northern movement has been observed in the eastern Great Lakes as well with Red-tailed Hawks banded in August recovered from areas north of the banding site (J. Dodge, pers. comm.). Late-summer and early-autumn Red-tailed Hawks flying along ridges in the central Appalachians may be dispersing in post-breeding movements, migrating or are residents moving up and down ridge to forage but not making directed flights as appears to occur later in the autumn. Here, we report the movements of Red-tailed Hawks trapped and color marked on the Kittatinny Ridge during autumn to better understand seasonal patterns of migration, dispersal and local use of the central Appalachians by Red-tailed Hawks, especially in early autumn, and provide insight into where migrants over-winter and breed.

Methods

During the autumns of 2000–2003, we captured and color-marked Red-tailed Hawks at the Little Gap Raptor Research Group's banding station on the Kittatinny Ridge, near Danielsville, Pennsylvania. Birds were captured using bow traps, mist nets and dho-gazas, and were released after being color-marked, banded and measured using standard U.S. Geological Survey's Bird Banding Lab protocols (Bloom et al 1987, Gustafson et al. 1997).

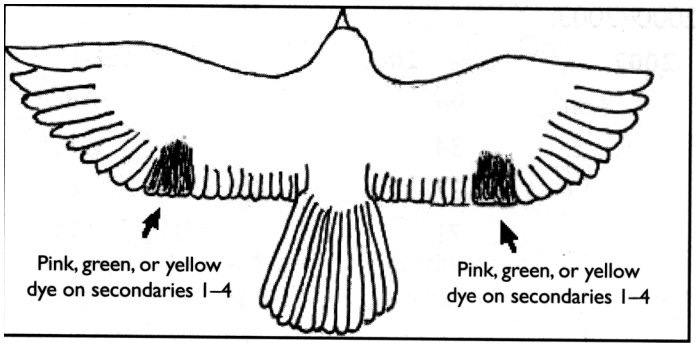

Figure 2. Location of color-marking on a Red-tailed Hawk. (Marking was visible to observers both from above and below.)

We dyed the four outermost secondaries on both wings with the same color. The entire area dyed was approximately 120 cm^2 when the feathers were overlapping during normal soaring flight (Fig. 2). Three dyes (Aldrich Chemical Company, Milwaukee) were used following Young and Kochert (1987): Rhodomine B (hereafter called pink), Malachite Green (green), and Picric Acid (yellow). Crystal dyes were dissolved in a solution of 33% isopropyl alcohol (95% pure) and 67% distilled water (Wadkins 1948, Belant and Seamans 1993). Feathers were sponged with vinegar before dying (Leopold 1938, Belant and Seamans 1993).

We used different dyes at different times with pink used from August 29–October 13 (early season), green from October 14–November 8 (mid-season); and yellow from November 9–December 1 (late season). Because yellow proved difficult to see on migrants and there were only four sightings of yellow-marked Red-tailed Hawks in the first three years, we discontinued use of yellow in 2003 and used green for mid-season and late-season captures.

We publicized the marking project widely among bird watchers, at migration watchsites and in the media of the region (New York, New Jersey, Pennsylvania, Delaware, Maryland and Virginia). Of the watchsites notified to look for the birds, four full-time sites were west of the trapping site on the Kittatinny Ridge, four were off-ridge in Pennsylvania north and south of the site, and others were located in northern and southern New Jersey, Virginia, Maryland and New York. Episodic watchsites included several east and south of the marking site on the ridge.

Because lighting, weather and flight profiles can influence which field marks are seen on passing raptors, we asked observers at the watchsites to record additional data to learn how many Red-tailed Hawks that passed their sites were seen well enough to detect whether the wings were marked. Three watchsites complied with the request. These sites recorded how many of the passing Red-tailed Hawks had secondaries one through four visible enough for observers to see the color markings.

We asked individuals who observed color-marked birds to report the date, time of day (EST), location of sighting (state, county, exact locality), color of markings, age of bird (adult or immature) and the behavior of the bird when sighted. Locations of sightings were entered into a geographic information system (GIS) (Arcview 9.0). Sightings were projected using a Mercator projection (Gudmundsson and Alerstam 1998) and the direction and compass bearing from Little Gap to each sighting was calculated using Hawth's tools (Beyer 2004). We compiled sighting angles and directions in circular graphs and analyzed them using the non-parametric Hodges-Ajne test for uniformity and the Watson's U2 statistic for data with ties (Zar 1996).

Because secondaries three and four can be retained from the time of color marking into the next autumn (Wheeler 2003), color-marked birds could possibly be resighted in the subsequent year. Three birds were reported in years two and three with colors that had not yet been used that autumn. We presumed that these birds were marked the previous year and did not include them in the analysis.

We considered each bird sighted as an independent sighting. Because our marking system did not allow identification of individuals, we do not know the proportion of individuals that were seen at more than one location.

Results

We color marked 356 Red-tailed Hawks in the autumns of 2000–2003, about 4% of the visible migrants (Kunkle 2000, 2001, 2002b, 2003). Of the marked birds, 78% immatures (hatch-year birds) and 22% were adults (after hatch year birds). Of those marked, 135 (38%) were marked with pink dye, and 221 (62%) with green or yellow dye (148 and 73, respectively) (Table 1).

Seventy sightings of color-marked birds were reported within one year after marking date (Tables 2 and 3). Fifty-two (74%) were in autumn (September-December). Eighteen (26%) were from January through August (Fig. 1). Early season (pink) marked birds were resighted 35 times (50%; 77% of aged birds were hatch year). Late season (green or yellow) marked birds were resighted 31 times (45%; 61% of aged birds were hatch year). Four birds were reported as having "dark" markings at the correct place but color could not be determined. Three "dark-marked" birds were seen during the pink marking period (before October 14) and one early in the green marking period. Resighting rates varied among the four years from a low of 8% in 2002 to 33% in 2003.

Table Red-tailed Hawks color-marked at Little Gap, PA, 2000–2003.

	2000		2001		2002		2003		Total	
	Im.	Adult	Im.	Adult	Im.	Adult	Im.	Adult	Im.	Adult
Pink	26	2	28	7	31	2	34	5	119	16
Green/Yellow	34	28	44	9	43	13	37	13	158	63
Total	60	30	72	16	74	15	71	18	277	79

a Im. = Hatch year, Adult = any bird after hatch year

About half of the sightings occurred on the Kittatinny Ridge west-southwest of where the birds were marked (N = 36, 51%). Most autumn resightings occurred on the ridge (69%). However, 27% of autumn sightings and 49% of all sightings occurred away from the ridge (Fig. 3).

To quantify observer effort and resightings at autumn raptor-migration watchsites, we compiled statistics on observer effort at all watchsites within 400 km of the trapping site that averaged more than 250 hours per season throughout the marking period (Table 4).

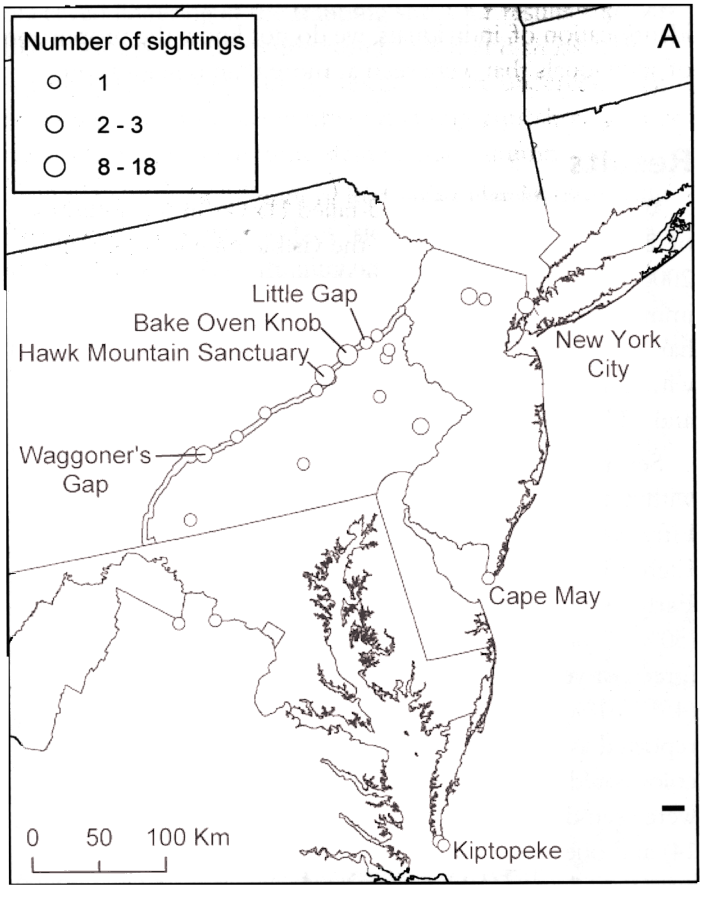

Figure 3. Location and magnitude of color-marked Red-tailed Hawk resightings.

Only one bird was resighted near the trapping site. This was an early-morning sighting 1km east of the trapping site before color marking had begun for the day. No marked birds were seen lingering in an area either at the trap site or at any resighting location. Three times during the study, there was a repeat sighting on the same day of a marked bird of the same age and color at a watchsite (e.g. two adult green marked birds at Hawk Mountain on November 1, 2000). In each case, both birds were observed moving down ridge to the southwest and the second sighting was presumed to be of a different bird.

Observers at three migration watchsites recorded data on how many birds were seen well enough to determine if they were color-marked during autumn migration. Of 9,650 Red-tailed Hawks recorded, 3,293 (34%) were seen well enough to observe color markings, and only five of those birds were marked (<0.2% of total observed on those days).

Autumn resightings (N= 52) had a mean angle of 230° (standard deviation (s) = 47.37°, r (measure of concentration) = 0.71) and were significantly different from random [Hodges-Ajne test for uniformity (Zar 1996), $P < 0.01$]. January to August sightings, (N = 18) had a mean angle of 178° (s = 97.86°, r = 0.23), and were not significantly different from random (bearing range = 30° to 254°; Hodges-Ajne test, $P > 0.05$) (Fig. 4).

The mean bearings of travel of early-season (N = 24) and late-season (N = 24) birds compared using the non-parametric Watson's U2 test for two samples with ties (Zar 1996), showed a significantly stronger bearing to the west in late season birds (243°, s = 20°) than in early season birds (204°, s = 65°) (Watson's U2 = 0.322, n1 = 24, n2 = 24, $P < 0.01$). To test if autumn adults differed from autumn hatch-year birds in their bearing of travel, we again used a Watson's U2 test. We found no significant difference in the mean track of adult (223°, s = 53°, N = 12) and hatch-year individuals (235°, s = 47°, N = 27) birds with a combined mean angle of travel of 231° (s = 49°; $P > 0.05$). Similarly, we found no difference by age class in late season birds only, although our sample size was small (N = 21; $P > 0.05$).

Table 2. Color-marked Red-tailed Hawk sightings by color.

Year	Pink	Green	Yellow	Unknown	Total
2000	7	7	2	0	16
2001	11	1	2	4	18
2002	2	5	0	0	7
2003	15	14	Xa	0	29

a The use of yellow dye was discontinued in 2003; therefore there were no sightings possible. Green dye was used throughout the season formerly designated with yellow dye.

Three resightings were reported from the Atlantic coast. A pair of them at Cape May, New Jersey (October 27, 2000), and Kiptopeke, Virginia (November 3, 2000), could have been the same bird as both were hatch-year, pink-marked birds. Another pink-marked bird of undetermined age was sighted at Eastern Shore National Wildlife Refuge, Virginia, on October 19, 2001. Two other pink-marked, hatch-year birds were seen in Central Park in New York City on September 21 and October 5, 2003.

Winter resightings occurred in New Jersey, Virginia, Maryland and Pennsylvania, and an autumn resighting of a pink-marked bird was reported from Soddy Mountain, Tennessee (977 km), on October 29, 2001. We obtained few breeding season records, but a sighting from San Fabian, Quebec, (939 km) on April 28, 2001 suggests that migrants derive from at least as far north as the Rimouski area of Quebec on the St. Lawrence River.

Discussion

The Kittatinny Ridge is an important leading line for both early-season and late-season autumn-migrating Red-tailed Hawks (Broun 1948, Heintzelman 1975, 1986). The ridge traverses eastern Pennsylvania in a general east-northeast to west-southwest direction (general orientation is 249° in our study area). Our results indicate that Red-tailed Hawks move primarily in a southwest direction (230°) throughout autumn migration.

Early-season migrants showed a significantly greater tendency to move off-ridge and migrate in a more southerly direction (mean angle 204°) than late-season migrants (243°). Dispersion rates also appeared to be higher, with several early-season birds seen in New York City and along the Atlantic coast. Late-autumn birds were more strongly oriented west-southwest in parallel to the Kittatinny Ridge with only one late season bird discovered south or east of the marking site. This finding is consistent with earlier studies that indicated stronger ridge affinity by migrants during late autumn when updrafts are prevalent compared to early autumn when thermals are stronger and more prevalent (Maransky et al. 2001, Swartzentruber and Beck 2001). It also is consistent with band-recovery analyses that suggest the principle axis of migration for Appalachian ridge-trapped Red-tailed Hawks to wintering areas is 215° (Holt and Frock 1980). Despite the greater dispersion found in early season migrants, some Red-tailed Hawks marked in both early and late season were found to follow the Kittatinny Ridge as far southwest as the Second Mountain and Waggoner's Gap watchsites in Pennsylvania, more than 75 and 140 km from the marking site. This indicates that some raptor migrants follow the Kittatinny Ridge for long distances as they traverse Pennsylvania during both early-season and late-season migration periods.

Table 3. Autumn migration (September–December) and post-migration (January–August) sightings.

Year	Migration	Post-migration	Total
2000–2001	11	5	16
2001–2002	13	5	18
2002–2003	7	0	7
2003–2004	21	8	29

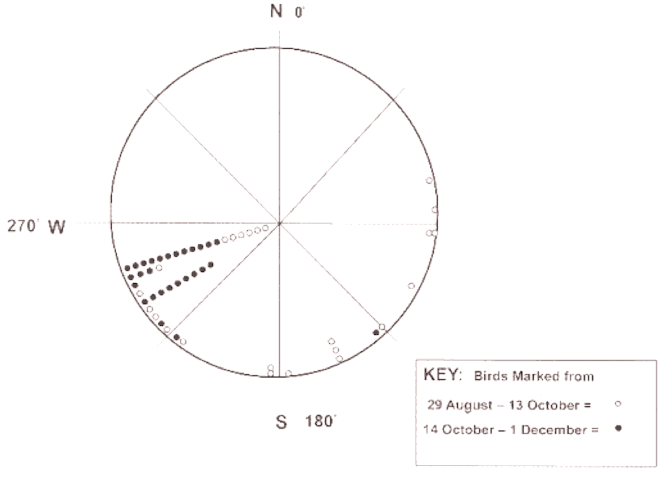

Figure 4. Comparison of movement direction of Red-tailed Hawks marked in early autumn (prior to 14 October) compared to birds marked in late autumn (14 October to 1 December), 2000–2003.

Table 4. Autumn raptor watchsites† and effort within 400 km of Red-tailed Hawk trapping site.

State	Site	Sighted Birds	Total Hours 2000–2003	Bearing (°)	Distance (km)
NJ	*Kittatinny Mountain	0	1818	57	92
PA	*Little Gap	1	2808	0	1
PA	*Bake Oven Knob	17	3104	249	23
PA	*Hawk Mountain	8	4300	244	56
PA	*Second Mountain	1	4197	248	130
PA	*Waggoner's Gap	3	4527	248	208
NY	Franklin Mountain	0	3116	9	337
NY	Mt. Peter	0	2161	65	154
NY	Hook Mountain	0	1157	75	187
NJ	Wildcat Ridge	1	2378	80	120
NJ	Scott's Mountain	0	1134	101	49
PA	Militia Hill	2	1332	160	106
NJ	Cape May	1	3358	167	278
PA	Rose Tree Park	0	2534	173	127
PA	Allegheny Front	0	2995	250	370
PA	Jack's Mountain	0	1502	261	250
PA	Stone Mountain	0	1618	262	257

†Watchsites averaging >250 hours per season, 2000–2003 *Watchsites on or adjacent to Kittatinny Ridge.

Overall, age did not appear to significantly affect the flight direction of migrants. That said, the five birds found east of the marking location all were early-season, hatch-year birds and our sample size of aged marked birds was small (N = 39). Most early-season marked birds moved predominantly south-southwest, a typical migratory direction through the region. Some of the early-season easterly movements may represent dispersal rather than migration as noted by Brinker and Erdman (1985).

The lack of resightings of marked birds at the trapping site or during days after first sighted at any of the ridge-top watchsites suggests that Red-tailed Hawks sighted at watchsites are predominantly non-resident birds migrating through the region.

We relied on sightings by volunteer observers, and their geography may have affected our results. Because most full-time watchsites and observers on the Kittatinny Ridge are west of the trapping site there is a possible bias for observations along the Kittatinny west of the trap site. That said, there are migration watchsites to the north and east of the trapping site that never detected marked birds, and Pennsylvania watchsites south of the trapping site reported far fewer birds than the Kittatinny sites west of the trapping site (Table 4). In addition, if there was any bias, it existed in both early and late autumn; therefore comparisons between these two groups are valid.

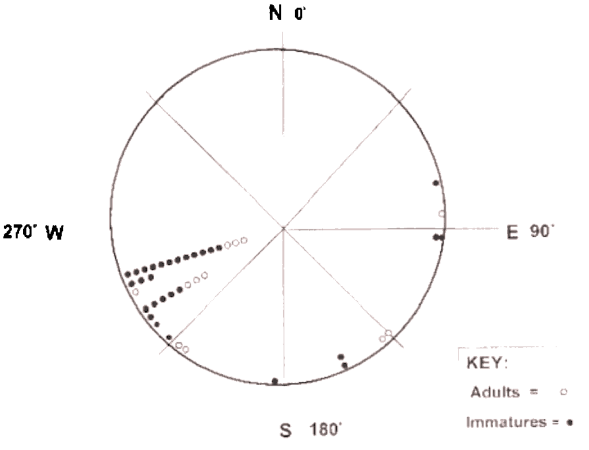

Figure 5. Comparison of movement direction of adult and immature Red-tailed Hawks marked in autumns 2000-2003.

The movement of all marked birds away from the marking site and the surrounding area (regardless of direction of movement) contradicts the assumption that most early autumn Kittatinny Ridge Red-tailed Hawks are "local" or "resident" birds (Heintzelman 1975, Brett 1991, Barber et al. 2001, Chartier and Stimac 2002). In addition, the mean direction of flight of marked birds was similar to the principle axis of migration derived from band-recovery data for ridge migrants (Holt and Frock 1980). Our findings were similar to a study in Idaho that showed early autumn Red-tailed Hawks moved away from their natal areas but dispersed more widely than late autumn birds, when their movements became longer and more directed (Steenhoff et al. 1984).

Our study showed that most Red-tailed Hawks sighted at migration watchsites during early and late autumn along the central Appalachians are migrants. The migrants appear to move in a south-southwest to west-southwest trajectory to wintering areas at least as far south as Tennessee, and they originate from at least as far north as Quebec. Early-season birds show greater variation in direction of movements than late-season birds, but still showed a predominantly southwesterly migration track. Watchsite protocols should take these findings into account and specify methods for counting migrating early-autumn Red-tailed Hawks.

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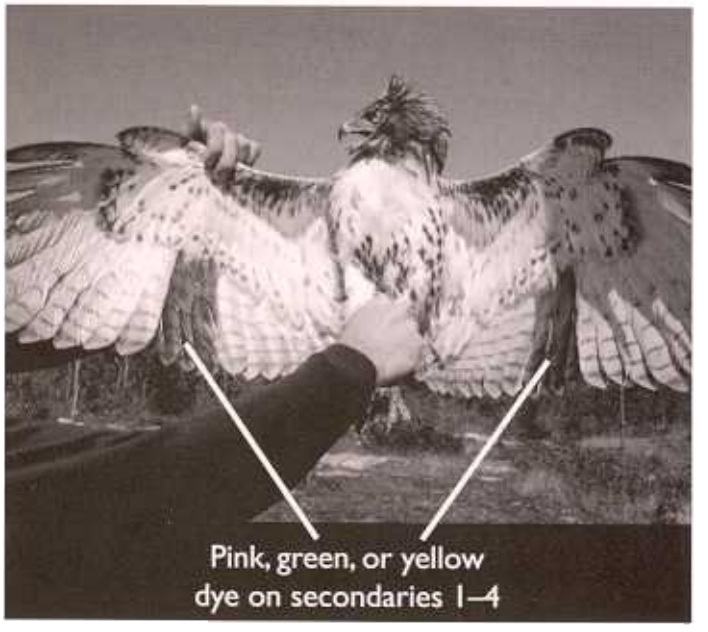

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Red-tailed Hawk. Photo by Steve Byland