CHANGES IN THE WINTER DISTRIBUTION OF THE ROUGH-LEGGED HAWK IN NORTH AMERICA

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ABSTRACT: We used Christmas Bird Count (CBC) data to demonstrate a shift in the winter distribution of the Rough-legged Hawk (*Buteo lagopus*) in North America from the late 1970s to the early 2000s. Data from nearly 300 CBC circles reveal decreases in the Rough-legged Hawk's abundance on the east and west coasts and throughout the southern portion of this species' winter range. Its abundance increased in the northern portions of the Great Plains. This distributional shift was associated with a decrease in the number of December days with substantial snow cover in the northern Great Plains and an increase in the winter abundance of the Red-tailed Hawk (*Buteo jamaicensis*) throughout most of the range of the Rough-legged Hawk. In addition, increasing human populations and associated loss of open country may have contributed to this shift.

The Rough-legged Hawk (*Buteo lagopus*) is a holarctic breeder that, in North America, winters from southern Canada through all but the most southerly parts of the continental United States (Johnsgard 1990, Bechard and Swem 2002). On the basis of Christmas Bird Count (CBC) data from 1962 to 1972, Root (1988) showed that its main areas of winter abundance were the northern Great Basin and the Great Plains from western Kansas to eastern Montana. The northern limit of the winter range seems determined by climate (Bock and Lepthien 1976, Root 1988, Olson and Arsenault 2000), while it is unclear what factors determine the southern limit.

Although there are no obvious continent-wide trends in breeding or winter populations of the Rough-legged Hawk in North America (McCay et al. 2001, Bechard and Swem 2002), from the late 1980s into the late 1990s local declines were reported from New Jersey (Walsh et al. 1999), Delaware (Hess et al. 2000), Colorado (Schmidt and Bock 2005), and California (Pandolfino 2006). To determine if these local changes represent a widespread phenomenon, we examined CBC data from throughout the Rough-legged Hawk's North American winter range over roughly the past three decades. We examined climate data, changes in Red-tailed Hawk abundance, and trends in the human population (possibly an indicator of habitat loss) to assess possible effects of these factors on the Rough-legged Hawk's winter distribution. Winter temperature and/or snow cover can affect the Rough-legged Hawk's distribution (Root 1988), movements (Theil 1985, Watson 1986a), and behavior (Schnell 1968, Klein and Mason 1981, Temeles and Wellicome 1992, Watson 1986b, Lingle 1989), and the Red-tailed Hawk is a documented interspecific competitor (Schnell 1968, Bildstein 1987).

METHODS

CBC Data

We obtained CBC data from the National Audubon Society's database (www.audubon.org/bird/cbc/hr/index.html). For all analyses we used the

CBC count year to identify time. For example, count year 79 = winter of 1978–1979, count year 80 = winter of 1979–1980, etc. We chose a 28-year period from 1978 to 2006 because we found that the number of CBC circles (CBCs) within the range of the Rough-legged Hawk decreased rapidly prior to count year 79, resulting in large geographical gaps in the data set. We used data from CBC circles (CBCs) that met the following two criteria:

- Conducted during at least 8 of the 14 years between count year 79 and count year 92 and at least 8 of the 14 years between count year 93 and count year 106.
- Averaged more than three Rough-legged Hawks per year for at least one of the two 14-year periods so defined.

We chose the first criterion to ensure that the CBCs used were conducted on a fairly regular basis over the entire 28-year period used for this analysis. A more stringent criterion (e.g., >8 of 14 years), would reduce the number and the geographic coverage of the CBCs substantially. We used the average of at least three Rough-legged Hawks per year to ensure that each CBC was within the normal winter range of the Rough-legged Hawk and to exclude CBCs where this species occurs rarely. A higher threshold for inclusion would have required dropping many CBCs that record the Rough-legged Hawk nearly every year. Of approximately 2000 CBCs in North America, 293 met these criteria. We normalized CBC data for the Rough-legged and Red-tailed Hawks by party hour.

Regional Analyses

We divided the Rough-legged Hawk's winter range into ten geographic regions (Figure 1). The line separating the two Pacific regions from the two Intermountain West regions is the axis of the Cascade Range–Sierra Nevada, the line separating the two Intermountain West regions from the two Plains regions is the axis of the Rocky Mountains, and the line separating the Atlantic Coast region is the axis of the Appalachian Mountains. For the line dividing these regions into northern and southern segments, we used latitude 41° N from the Pacific Ocean to Illinois in the west and the border between Pennsylvania and New York in the east. For the area between Illinois and Pennsylvania we defined a border placing CBCs within 50 km of one of the Great Lakes into one of the Great Lakes regions. The border between the North Plains and West Great Lakes regions is the western border of Wisconsin, deviating from that border in the north to place any CBC within 50 km of a Great Lake into the West Great Lakes region. The border between the two Great Lakes regions was chosen to divide the number of CBCs between those two regions roughly in half.

We analyzed data by region by comparing results for two consecutive periods of 14 years each (count years 79–92 vs. count years 93–106). We also performed linear regression analyses to compare the Rough-legged Hawk's trends in each region versus various predictor variables. In addition, we analyzed data by comparing four consecutive intervals of 7 years each in order to display trends for each region graphically.

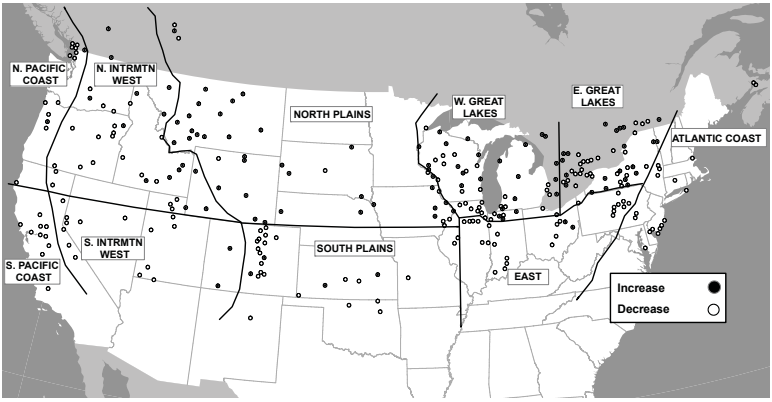

Figure 1. Ten regions and sites of Christmas Bird Counts used to evaluate changes in the numbers and distribution of the Rough-legged Hawk in North America. Black circles represent counts on which the number of Rough-legged Hawks per party hour increased from count years 79–92 to count years 93–106; white circles represent counts on which the number decreased. Circles are approximately to scale.

Potential Predictor Variables

To assess variables that might influence the Rough-legged Hawk's winter range, we attempted to link climate factors, human-population changes, and Red-tailed Hawk abundance to each CBC circle. Because of lack of data we did not analyze other variables such as prey density or composition or specific land-use changes that likely also have an effect.

We obtained climate data from the U.S. Historical Climatology Network web site (http://cdiac.ornl.gov/epubs/ndp/ushcn/usa_monthly.html). We assigned climate data to a CBC circle on the basis of the weather station closest to that CBC circle, provided that station was within 100 km of the center of the CBC circle. In 11 cases the closest weather station was at an elevation more than 400 m different from the CBC circle. In those cases, because of concern that the elevation difference would create too large a discrepancy in climate conditions between the CBC circle and the weather station, we used the next nearest weather station within 100 km of the CBC circle and similar in elevation. For our analyses, we used two climate variables: average December temperature (°F as reported by weather stations) and the number of December days with snow cover >5 cm (2 inches as reported by weather stations). Although temperature data were complete, in some cases there were gaps in the snow-cover data. In cases where snow cover measured >5 cm on a given day and subsequent days had no data, we used daily high temperatures to determine whether snow cover remained. If the daily high temperatures remained at 0 °C or less through the gap, we assumed that the snow cover remained >5 cm during those days.

Since historical land-use data for each CBC circle are either unavailable or impractical to obtain, we used population change between the 1980 and 2000 U.S. censuses for the county constituting the largest fraction of a given CBC circle as a crude proxy for land-use change.

We chose Red-tailed Hawk abundance to test the potential effect of interspecific competition on the Rough-legged Hawk. The Red-tailed Hawk is a documented interspecific competitor (Schnell 1968, Bildstein 1987) and is, by far, the most abundant raptor across nearly all the winter range of the Rough-legged Hawk (Root 1988). We determined Red-tailed Hawk abundance by using data from the same CBC circles used for the Rough-legged Hawk's abundance.

Statistical Analysis

We screened the data to check assumptions related to normality and heterogeneity by using probability plots in Systat Version 9 (SPSS, Chicago). We also screened the continuous covariates (average December temperature, December days with snow cover >5 cm, and numbers of Red-tailed Hawks per party hour) for multicollinearity by using PROC REG in SAS 9.1 (SAS Institute 2005) and removed any variables with tolerance values <0.40 (Cody and Smith 2006).

We used a paired *t* test to determine the statistical significance of changes in Rough-legged Hawk abundance between the two periods (first 14 years versus second 14 years) for each of the ten regions. We applied the Bonferroni method to yield a threshold of significance of <0.005 for these analyses.

We used logistic regression to analyze the effects of single predictor variables on Rough-legged Hawk numbers. We used the change in Rough-legged Hawks per party hour from the first 14 years to the second 14 years as the binary response variable. That is, if the average number of Rough-legged Hawks per party hour over the second 14 years was greater than the average over the first 14 years, that CBC circle was assigned a value of one. If the average over the second 14 years was less than over the first 14 years, that CBC circle was assigned a value of zero. We performed logistic regression versus the following four predictor variables:

- The change in December average temperature between the two periods,
- The change in the average number of December days with snow cover >5 cm,
- County population increase (percent) from 1980 to 2000, and
- The number of Red-tailed Hawks per party hour over the entire 28-year period (count years 79–106).

Because climate or population data were not available for some CBC circles, not every circle was analyzed for each variable. Also, in evaluating the effects of snow cover, we used only CBCs that averaged at least five December days with snow cover >5 cm during one of the two periods. As a result, we used 259 CBC circles for analysis of the change in December temperature, 199 for analysis of December snow cover, 245 for analysis of change in human population, and 293 for analysis of Red-tailed Hawks per party hour.

RESULTS

Figure 1 shows all 293 CBCs used. Numbers of the Rough-legged Hawk on nearly all (101/112, 91%) of the CBCs on the coasts and in the three southern regions decreased. In all but seven of the 43 CBCs in the North

Plains region they increased (36/43, 84%). Similarly, when counts are pooled by region, Rough-legged Hawk numbers decreased in the westernmost, easternmost, and southern regions but increased in the North Plains (Table 1). The North Intermountain West and the two Great Lakes regions showed decreases that were not statistically significant. The results of linear regression by region (Figure 2) were qualitatively identical, with negative trends for the southern and coastal regions and a strong positive trend for the North Plains.

Logistic regression of the change in the Rough-legged Hawk versus single predictor variables indicated there were statistically significant negative effects on the abundance of the Rough-legged of the abundance of the Red-tailed (coefficient = −1.90 ± 0.38, $P < 0.001$; odds ratio = 0.15, 95% confidence interval 0.07–0.32; $n = 293$) and of an increase in the number of December days with snow cover >5 cm (coefficient = −0.19 ± 0.05, $P < 0.001$; odds ratio = 0.83, 95% confidence interval 0.75–0.92; $n = 199$). Increase in human population had a significant negative effect on Rough-legged Hawk abundance (coefficient = −1.12 ± 0.54, $P = 0.04$; odds ratio = 0.33, 95% confidence interval 0.11–0.94; $n = 245$). Changes in average December temperature had no significant effect (coefficient = 0.14 ± 0.11, $P = 0.21$; odds ratio = 1.15, 95% confidence interval 0.92–1.44; $n = 262$).

Pacific Coast Regions

In the Pacific Coast regions Rough-legged Hawk abundance was relatively low while Red-tailed Hawk abundance was relatively high (Figure 3). The South Pacific Coast had the highest Red-tailed Hawk abundance of any region with numbers consistently over 130 birds/100 party hours. Red-tailed Hawk numbers in both Pacific Coast regions were relatively stable, in contrast to the increases seen in nearly every other region. As snowfall was generally light to none in these regions, snow cover was not a factor

Table 1 Changes in Numbers of the Rough-legged Hawk (per 100 Party Hours) on Christmas Bird Counts in Ten Regions of North America.

Region	Count years 79–92	Count years 93–106	Change	P[a]	CBCs (n)
N. Pacific Coast	8	4	–50%	<0.001	15
S. Pacific Coast	6	2	–59%	0.003	10
N. Intermountain West	43	34	–22%	NS[b]	35
S. Intermountain West	24	11	–54%	0.002	16
N. Plains	13	21	60%	<0.001	43
S. Plains	13	9	–32%	0.002	27
W. Great Lakes	10	9	–12%	NS[b]	53
E. Great Lakes	8	7	–12%	NS[b]	50
East	12	6	–49%	<0.001	27
Atlantic Coast	8	3	–64%	<0.001	17
All	13	10	–20%	NS[b]	293

[a]Paired t test.

[b]Not significant, $P > 0.005$.

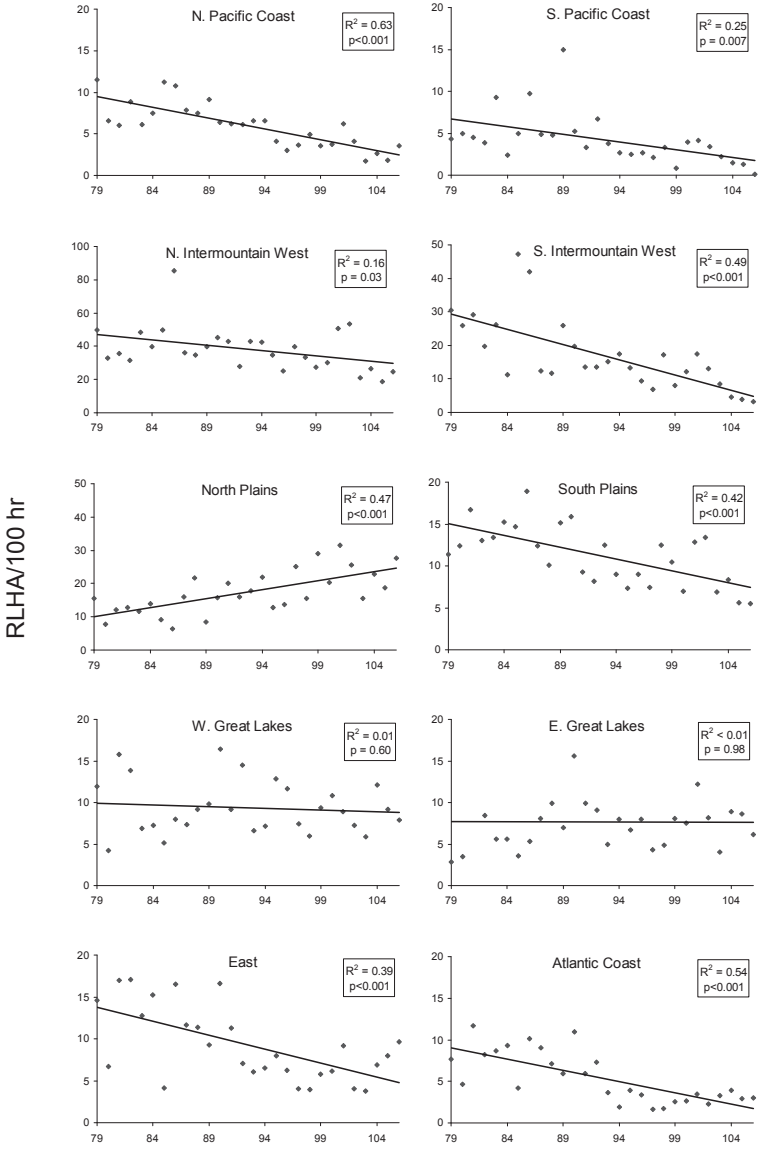

Figure 2. Linear-regression analyses of trends in Rough-legged Hawk numbers on Christmas Bird Counts by ten regions of North America, 1979–2006.

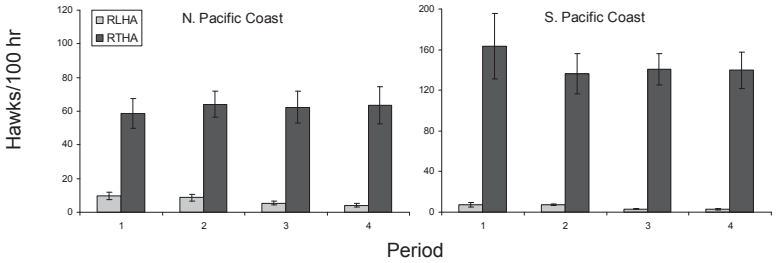

Figure 3. Average numbers of the Rough-legged Hawk (RLHA) and Red-tailed Hawk (RTHA) per 100 party hours in four successive 7-year periods (1, count years 79–85; 2, count years 86–92; 3, count years 93–99; 4, count years 100–106) for the North and South Pacific Coast regions.

there. Within both Pacific Coast regions the human population of counties associated with the CBC circles increased substantially (26% for the North Pacific Coast; 59% for the South Pacific Coast).

Intermountain West Regions

The North Intermountain West had the highest Rough-legged Hawk abundance of any region and the second-highest Red-tailed Hawk abundance

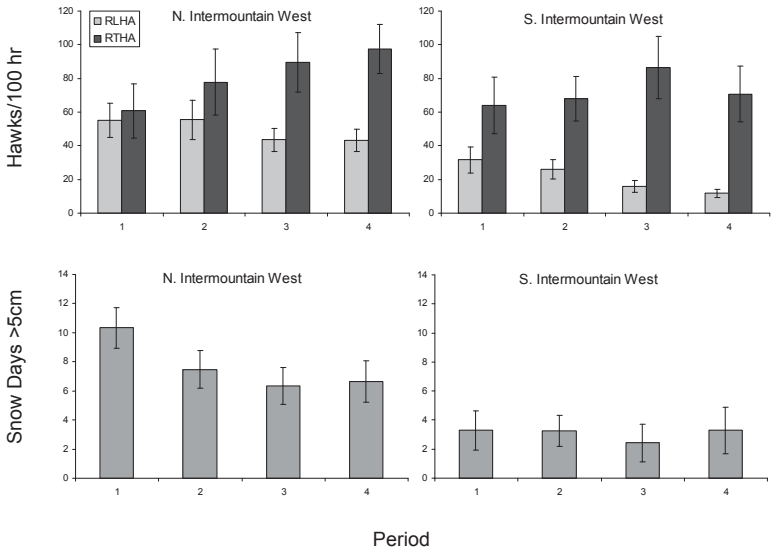

Figure 4. Average numbers of the Rough-legged Hawk (RLHA) and Red-tailed Hawk (RTHA) per 100 party hours and number of December days with snow cover in excess of 5 cm in four successive 7-year periods (1, count years 79–85; 2, count years 86–92; 3, count years 93–99; 4, count years 100–106) for the North and South Intermountain West regions.

(Figure 4). Red-tailed Hawk numbers increased in each successive period. Red-tailed Hawk abundance in the South Intermountain West was also relatively high and increased slightly. The number of days with significant snow cover decreased substantially in the North Intermountain West but remained fairly stable in the South Intermountain West. Both Intermountain West regions had large increases in human population in the counties associated with the CBC circles (30% for the North Intermountain West; 62% for the South Intermountain West).

Plains Regions

The increase in Rough-legged Hawk abundance in the North Plains was paralleled by a similar increase in the Red-tailed Hawk (Figure 5). In both 14-year periods, however, the abundance of the Red-tailed in this region was consistently lower than in any other region. Rough-legged Hawk abundance in the North Plains increased in each successive 7-year period with abundance in the last period (45 birds/100 party hours) exceeding that of the North Intermountain West (43 birds/100 party hrs). The number of days with significant snow cover in the North Plains decreased in each 7-year period. In the South Plains the abundance of the Red-tailed Hawk increased dramatically, doubling from less than 50 birds/100 party hours in the first 7-year period to nearly 100 in the last 7-year period, while Rough-legged

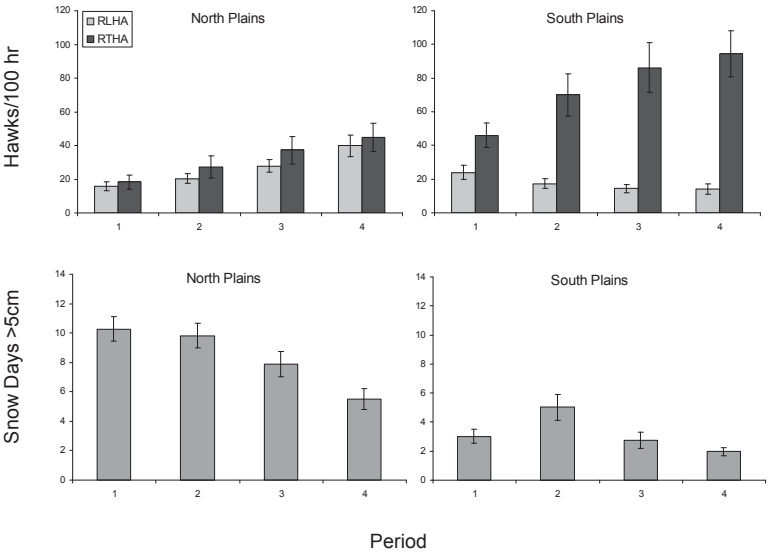

Figure 5. Average numbers of the Rough-legged Hawk (RLHA) and Red-tailed Hawk (RTHA) per 100 party hours and number of December days with snow cover in excess of 5 cm in four successive 7-year periods (1, count years 79–85; 2, count years 86–92; 3, count years 93–99; 4, count years 100–106) for the North and South Plains regions.

Hawk abundance declined from 24 to 14 birds/100 party hours. In the South Plains snow cover decreased less sharply than in the North Plains. Human population growth in the counties associated with the CBC circles in the North Plains was low (9%), in the South Plains much higher (43%).

Great Lakes Regions

Although Red-tailed Hawk abundance increased in both Great Lakes regions (Figure 6), the abundance of this species in these regions was lower than in any other except the North Plains. Rough-legged Hawk abundance did not vary significantly from period to period in either region. The number of days with significant snow cover was relatively stable in the East Great Lakes but decreased slightly in the West Great Lakes in the second 14-year period. Human population in the counties associated with the CBC circles grew slowly (10%) in the East Great Lakes and declined (–1%) in the West Great Lakes.

East and Atlantic Coast Regions

The Red-tailed Hawk's abundance in the East region increased markedly; numbers in the last 14-year period were more than double those of the first period (Figure 7). In the Atlantic Coast region, it was relatively low (51 birds/100 party hours) and increased much less dramatically. In both

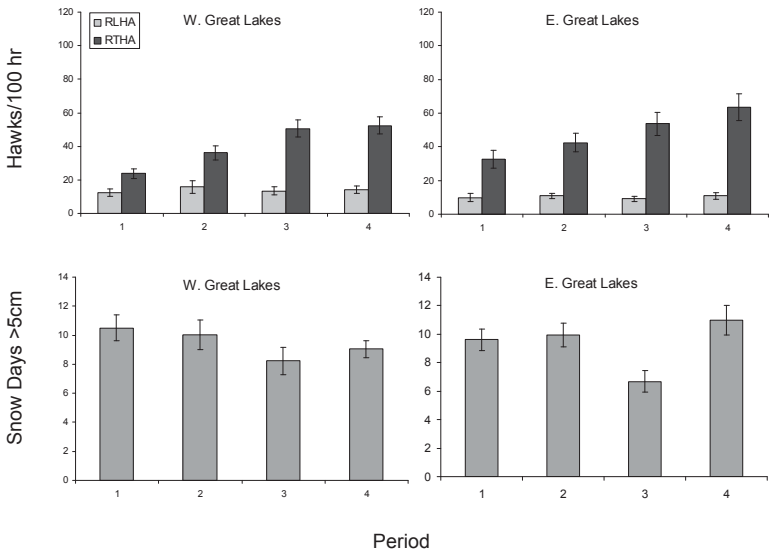

Figure 6. Average numbers of the Rough-legged Hawk (RLHA) and Red-tailed Hawk (RTHA) per 100 party hours and number of December days with snow cover in excess of 5 cm in four successive 7-year periods (1, count years 79–85; 2, count years 86–92; 3, count years 93–99; 4, count years 100–106) for the North and South Plains regions.

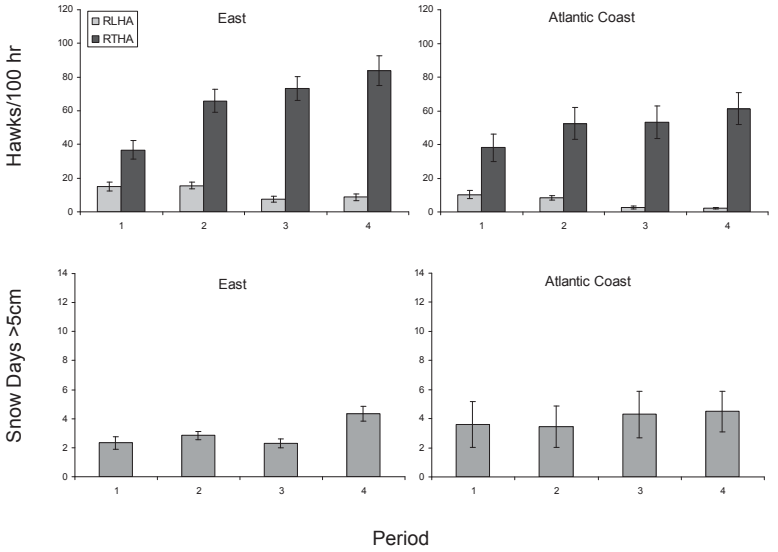

Figure 7. Average numbers of the Rough-legged Hawk (RLHA) and Red-tailed Hawk (RTHA) per 100 party hours and number of December days with snow cover in excess of 5 cm in four successive 7-year periods (1, count years 79–85; 2, count years 86–92; 3, count years 93–99; 4, count years 100–106) for the North and South Plains regions.

regions the Rough-legged Hawk declined, and in the Atlantic Coast region its abundance in the later 14-year period (2 birds/100 party hours) was the lowest of any region. In both regions days with significant snow cover remained relatively stable, with only a slight increase in snow cover for the last two 7-year periods for the Atlantic Coast. Human population growth in the counties associated with the CBC circles in both regions was low (8% for the East; 15% for the Atlantic Coast).

DISCUSSION

Christmas Bird Counts reveal changes in the winter distribution of the Rough-legged Hawk throughout its North American range. Ranges and migration dates of many species are changing in response to climate change (Møller et al. 2004, Schneider and Root 2002, Niven et al. 2009, Kim et al. 2009), and this northward shift in the Rough-legged Hawk's distribution is consistent with many other bird species in North America (Niven et al. 2009).

Logistic regression showed no significant effect of average December temperature on Rough-legged Hawk abundance. For snow cover (December days with cover >5 cm), however, the effect was negative and significant ($P < 0.001$). It is not surprising that Rough-legged Hawks might remain farther north or shift their wintering range to the north in response to less snow

cover. Thiel (1985) showed a negative correlation between snow depth and Rough-legged Hawk numbers in Wisconsin. Watson (1986a) documented movements just after a major snowfall, and numerous authors observed changes in foraging behavior in apparent response to increased snow cover (Schnell 1968, Klein and Mason 1981, Temeles and Wellicome 1992, Watson 1986b, Lingle 1989). We found no evidence in our data for short-term (within a year) shifts in response to snow cover. For example, winters when the entire North Plains region experienced heavy snowfalls and many days with significant snow cover were not associated with any obvious decrease in Rough-legged Hawks. The shift was more gradual, apparently in response to the decrease in snow cover and improved opportunities for foraging over a longer term. Perhaps birds wintering in areas with reduced snow cover had higher survival rates or were more likely to return to a given area in subsequent years if the foraging conditions were good. This possibility is more consistent with the species' winter site fidelity as described by Watson (1986a), Gatz and Hegdal (1986), and Garrison and Bloom (1993).

Some regional trends suggest that factors other than climate may also be involved in this range shift. For example, snow cover decreased in the North Intermountain West (Figure 4) and, to a lesser degree, in the South Plains (Figure 5), but Rough-legged Hawk abundance in both these regions decreased. Other factors that might influence the winter distribution of the Rough-legged Hawk include loss of habitat, changes in the density or mix of prey, and competition with other open-country raptors.

We had no access to data on prey density or mix and no practical means of examining specific land-cover changes over the 28 years of the study for all CBC circles. Because increases in human population may reflect conversion of open country to cities, suburbs, or more intense forms of agriculture, we used human population increase from 1980 to 2000 in the county associated with each CBC circle as a very crude proxy for local habitat loss. Logistic regression showed a negative effect ($P = 0.04$) of human population growth on Rough-legged Hawk abundance.

To examine the potential influence of competition with other raptors, we analyzed trends in Red-tailed Hawk abundance in these same CBC circles. The Red-tailed Hawk is the most abundant raptor with which the Rough-legged Hawk shares most of its winter range. There is nearly complete overlap in the Red-tailed Hawk's habitat use (Weller 1964, Fischer et al. 1984, Bildstein 1987) and prey base (Craighead and Craighead 1956, Bildstein 1987) with those of the Rough-legged Hawk. Although Craighead and Craighead (1956) noted little direct competition between these species in Michigan, others have noted evidence of competition. Hogan (1983) reported a Rough-legged Hawk kleptoparasitizing a Red-tailed Hawk. Bildstein (1987) noted many agonistic encounters in Ohio, with Red-tailed Hawks pirating prey from Rough-legged Hawks more often than the contrary. Schnell (1968) reported that these two species avoid competing for prey and perches when possible. The Red-tailed Hawk uses a wider variety of prey and habitats than the Rough-legged Hawk (Weller 1964, Bildstein 1987), with the latter more restricted to open areas (Zarn 1975, Baker and Brooks 1981, Fischer et al. 1984, Lingle 1989).

We found that numbers of the Red-tailed Hawk increased in all regions

except the North and South Pacific coasts. This widespread increase in wintering Red-tailed Hawks has been noted by others (Preston and Beane 1993, White 1994, McCay et al. 2001). Logistic regression of Red-tailed Hawk abundance versus changes in Rough-legged Hawk numbers showed a significant negative effect of the Red-tailed on the Rough-legged ($P < 0.001$), suggesting that competition between these species may be a factor in the range shift we observed. Given the finite amount of suitable habitat, it is reasonable to infer that large increases in the Red-tailed Hawk must, at some point, apply significant competitive pressures on the Rough-legged Hawk. In addition, the Rough-legged Hawk is more sensitive to urbanization than the Red-tailed Hawk (Bosakowski and Smith 1997, Berry et al. 1998, Schmidt and Bock 2005). Therefore, the increasing numbers of Red-tailed Hawks and increased conversion of habitat to urban uses may have a combined negative effect on Rough-legged Hawk abundance.

Regional Trends

Examination of trends for the ten regions suggests that changes in Rough-legged Hawk abundance might be influenced by some combination of the following: (1) Rough-legged Hawks staying in the North Plains region because of reduced snow cover in that area, (2) Rough-legged Hawks avoiding areas where Red-tailed Hawk density is high, and/or (3) loss of habitat associated with increases in human population. Our observation that numbers of the Rough-legged Hawk in the North Intermountain West and South Plains regions decreased in spite of reduced snow cover might be explained by these regions' high average abundance of the Red-tailed Hawk (81 and 74 birds/100 party hours, respectively). Also, both regions experienced high rates of human population growth (30% and 43%, respectively). Decreases in the Rough-legged in the South Intermountain West (Figure 4) were associated with high abundance of the Red-tailed (72 birds/100 party hours) and very high rates of human population growth (62%). The North and South Pacific Coast regions (Figure 3) had high abundance of Red-tailed Hawks (62 and 145 birds/100 party hours, respectively), high rates of human population growth (26% and 59%, respectively), and large decreases in Rough-legged Hawks. The North Plains region showed almost parallel increases in Rough-legged and Red-tailed Hawks (Figure 5). However, the abundance of the Red-tailed was low throughout the period (18–45 birds/100 party hours), and rates of human population growth were also low (9%). Both Great Lakes regions showed no significant change in Rough-legged Hawk abundance even though Red-tailed Hawk abundance increased (Figure 6). Average Red-tailed Hawk abundance was generally low for both Great Lakes regions (41 birds/100 party hours for the West Great Lakes; 48 birds/100 party hours for the East Great Lakes), however, and the human population grew slowly in the East Great Lakes (10%) and decreased in the West Great Lakes (–1%). The East region had low abundance of the Red-tailed (Figure 7) in the first 7 years (37 birds/100 party hours) but high abundance during the last three 7-year periods (66–84 birds/100 party hours) and a significant decline in the Rough-legged. Human population growth was low (8%). The Atlantic Coast was the one region where a decrease in Rough-legged Hawks was not associated with high Red-tailed Hawk abundance (Figure 7) and/or large

increases in human population. In this region the Red-tailed Hawk's average abundance (51 birds/100 party hours) and human population growth (15%) were both fairly low. Snow cover on the Atlantic Coast did increase slightly in the last two 7-year periods, but this slight change seems unlikely to have been a major factor. Other factors may be responsible for trends in this region, or the decline in Rough-legged Hawks may simply be the result of more birds remaining in the North Plains region and not migrating to the coast.

One possible hypothesis to explain our results is the following. During the period we examined, increases in Red-tailed Hawks (possibly coupled with increased loss of open country) may have applied increasing competitive pressure on wintering Rough-legged Hawks. At the same time, decreasing snow cover in the North Plains made that area more productive for winter foraging, allowing Rough-legged Hawks to shift away from areas with high concentrations of Red-tailed Hawks. More broadly, this hypothesis suggests that while the northern limit of the winter range of the Rough-legged Hawk may be determined by climate factors (Bock and Lepthien 1976, Root 1988, Olson and Arsenault 2000), the southern, western, and eastern limits may be influenced by competition with the Red-tailed Hawk. More detailed data on actual historic land-use changes and interspecific interactions at the level of specific CBC circles could help test this hypothesis.

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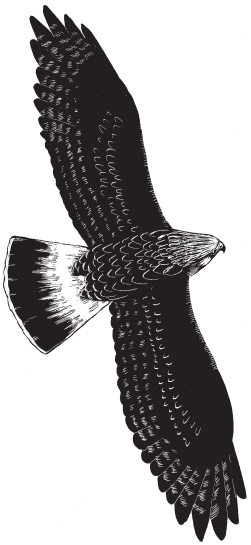

Rough-legged Hawk

Sketch by George C. West