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The Raptor Population Index in Practice

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Abstract.—This chapter describes the methods by which hawk migration count data are collected, stored, and converted into annual indexes and trends, as well as how they contribute to conservation assessments and actions. We describe the methods used to derive the results in several other chapters of this book and the methodological framework within which the Raptor Population Index (RPI) is expected to operate in the future.

Introduction

The goal of the Raptor Population Index (RPI) is to use migration counts to help monitor populations of migratory raptors in North America. Key to realizing this goal is developing a means of using migration counts to estimate temporal trends in populations by calculating trends in appropriately adjusted migration counts. Raptor migration count trends are based on daily migration counts, defined as a tally of birds during spring or autumn migration (Dunn and Hussell 1995). Consistent, standardized collection of count data and recording of counts and covariates, preferably on an hourly basis, is a prerequisite for the analysis (see Hussell and Ralph 2005, Farmer et al. 2007, Chapter 3).

The RPI program is a "citizen-science" project in the sense that many of the data are collected by a large corps of expert volunteers (as well as independent technicians and scientists) under the general direction of a

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small professional staff. In the best tradition of citizen-science projects, such as the North American Breeding Bird Survey (Robbins et al. 1986), the protocols for collecting data are set by the professional staff, and data are fed to them for analysis, interpretation, and publication.

RPI is a network composed of many individual hawk counters and independent count sites. Counts at most of the major long-term sites have institutional sponsorship, either from organizations formed solely for that purpose, or as components of the programs of organizations with wider interests. For example, the spring migration count at Grimsby, Ontario, is the principal activity of the Niagara Peninsula Hawk Watch (www.hwcn.org/link/niaghawk), which was formed to operate the count; the autumn count at Cape May Point, New Jersey, is operated by Cape May Bird Observatory, a branch of New Jersey Audubon (www.njaudubon.org/Centers/CMBO); and counts at Hawk Mountain, Pennsylvania, are operated by Hawk Mountain Sanctuary Association (www.hawkmountain.org), which originally was formed to manage the sanctuary and protect birds of prey from shooting at the site. Fourteen count sites in the western United States and along coastal areas of the Gulf of Mexico are operated by HawkWatch International, either directly or in partnership with other organizations (see Chapter 8).

Unlike most citizen-science projects, RPI is not directed by a single organization but rather is the responsibility of a partnership of three organizations: Hawk Mountain Sanctuary Association (HMS), HawkWatch International (HWI), and the Hawk Migration Association of North America (HMANA). The program is guided by a management committee, consisting of representatives of the three partners, and is advised by an external science-advisory committee. The partnership aims to build on the strengths of each of the partners to achieve its goal of contributing to the conservation of migratory raptors by using counts of migrating raptors from a continent-wide network of watchsites to provide timely and scientifically defensible assessments of population status and trends of these important biological indicators of environmental health.

HMANA is the primary contact with multiple independent hawk counts and counters. It also maintains the database and provides feedback to count sites. HMS analyzes, interprets, and summarizes the data for publication. HWI contributes data from its network of western and Gulf Coast sites, and interprets and summarizes the data for publication. All three partners are responsible for various aspects of providing input to conservation policies and actions by bringing RPI results and conservation assessments to the attention of resource-management and conservation agencies and organizations.

Below, we describe the methods by which hawk migration count data are collected, stored, and converted into annual indexes and trends, as well as how they contribute to conservation assessments and actions. We also describe, in general terms, the methods used to derive the results in several other chapters in this work and the methodological framework within which RPI is expected to operate in the future.

Data Collection

Approximately 10% of existing watchsites started regular daily counts before 1970 (see Chapter 8). Most new and existing watchsites have followed field protocols and recording procedures first recommended by HMANA in 1975, and revised in 1979 and 1986 (Harwood 1975; Hawk Migration Association of North America 2008a, 2008b). Most regularly operated sites have their own protocols that deal with site-specific concerns (e.g., Barber et al. 2001, Holiday Beach Migration Observatory 2002, Kunkle 2002, Vekasy and Smith 2002). The primary objective of the protocols is to achieve consistency in counting methods from day to day and from year to year (Robbins 1975).

The standard HMANA data-collection protocol requires reporting of separate tallies of each species for each hour of the day (local standard time), together with counts of various unidentified hawks (e.g., unidentified *Accipiter*, *Buteo*, etc.), a record of the number of contributing observers, and descriptions of predominant flight altitude and direction. Several weather variables are also recorded, including visibility, air temperature, wind speed, wind direction, cloud cover (percentage), and precipitation (Hawk Migration Association of North America 2008a).

Data Reporting and Storage

Before 2002, almost all hawk counts were reported on the standard report forms (see Chapter 3) that were sent to the regional editors of HMANA's journal, *Hawk Migration Studies*, for use in regional reports in that journal. Regional editors then forwarded the data sheets to HMANA's archive, initially at Muhlenberg College in Allentown, Pennsylvania, and thereafter at Hawk Mountain Sanctuary.

In 2002, HMANA created HawkCount.org, an online data-entry and database system (Moulton and Weber 2001). HawkCount.org allows hawkwatchers to enter their counts and other data online on an hourly or daily basis for storage in HawkCount's electronic database. By January 2007, 185 sites had registered on HawkCount and 171 of these had entered at least one daily count report. More importantly, 21 sites had entered 10 to 55 years of data, and a total of 35 sites had entered more than 5 years, either in daily or hourly format (J. Sodergren pers. comm.). Clearly, there are numerous historical data remaining to be entered, but the electronic database is rapidly becoming a valuable resource for monitoring purposes.

Data entered into HawkCount are exported for analysis. As suitable data sets become available with at least 10 years of regular counts, they are analyzed by the RPI North American Monitoring Coordinator at HMS, who calculates annual indexes and trends as described below. The data for many of the analyses described in this work, however, were not yet available in HawkCount and were obtained directly from the watchsites or otherwise, either in electronic files or on paper forms that were then entered into electronic files from the paper archives. Following compilation at HMS or HWI, counts were loaded into HawkCount for secure storage and future updating and use.

Annual Abundance Indexes

Daily migration counts are influenced by variables such as date and weather, and as a result, counts typically exhibit a strongly skewed distribution, with many low and moderate daily counts and a few large counts. An annual index based on the sum or the arithmetic mean of the daily counts will be unduly influenced by the size of the large counts in each year. However, year-to-year population change is expected to affect all daily counts in the same way (not only the large counts). Therefore, the median of the daily counts is a more useful annual index of population change than the mean or sum, because the median is more sensitive to shifts in the distribution of all of the counts and less sensitive to the sizes of the large counts.

Our analysis takes advantage of the rationale behind the use of the median while using a regression analysis to compensate for the effects of missing data and additional factors such as date and weather. A key component is that the daily counts are log transformed prior to calculation of an annual index.

Hawk counts.—We used hourly counts of visible migrating raptors during autumn migration to develop population indexes. Total hours of observation varied from day to day and among years at each watchsite, so we standardized the count day at each watchsite. For each species, we identified a daily passage window during which the middle 95% of individuals was counted. We excluded from analyses any raptors counted outside of the standard daily period at each watchsite. For days with incomplete coverage during the standard period, we estimated the daily count as $N = C \times H/h$, where C was the count during the standard hours, h was the number of hours of observation, and H was the number of hours in the standard period.

We chose a seasonal passage window for each species that included days when the middle 95% of the individuals of that species was counted across all years. Increases in the number of count days across years can increase the frequency of low counts, producing spurious trends in passage rates (Titus et al. 1989). Using a 95% seasonal passage window reduces the effect of changes in coverage. It also eliminates many days with zero counts at both ends of the season, which might otherwise contribute to unacceptable distributions of residuals in regression analyses.

Weather.—Wind speed and wind direction are believed to be the weather variables most directly affecting the concentration of raptors near watchsites (Mueller and Berger 1961, Haugh 1972, Richardson 1978, Newton 1979, Kerlinger 1989). That said recent work suggests that compensating for weather is not important for trend estimation at most watchsites over the periods considered in this volume (Allen et al. 1996, Farmer et al. 2007). Hourly surface data from observation stations near many watchsites in the United States are available from the National Climatic Data Center (www.ncdc.noaa.gov/oa/ncdc.html). Alternatively, most hawkwatchers record hourly weather observations coinciding with their raptor counts. These observations can be used as covariates in an analysis. Index calculation for RPI currently uses a date-adjusted index for all watchsites; however, wind direction and speed covariates have also been tested in indexes for all sites. We derived wind variables—E (east), SE (southeast), S (south), and SW (southwest)—from vector addition of wind speeds and directions at 0700, 1000, and 1300 hours. We calculated vectors so that positive and negative values of E represented east and west winds, respectively, positive and negative values of SE represented southeast and northwest winds, etc. (Hussell 1981). We also used second-order wind variables, enabling us to model curvilinear effects of wind speed and direction (Francis and Hussell 1998).

Migration count index.—We used multiple regression to derive geometric-mean population indexes that allowed compensation for missing days and, in some cases, weather covariates (e.g., wind speed and direction). The basic methods are described in Hussell (1981), Francis and Hussell (1998), and Farmer et al. (2007). In our description, "count" always means the daily number of hawks counted or estimated within the daily and seasonal windows. Adding wind variables in some analyses led to smaller sample sizes because we excluded days for which wind data were missing. In addition, our analysis included a regression to eliminate days at the start and end of the seasons that would result in poor distribution of residuals.

For each watchsite, the indexes we calculated were date-adjusted estimated geometric-mean daily counts ("date-adjusted" hereafter) or date-adjusted estimated geometric-mean daily counts with wind covariates ("date-wind-adjusted"). These indexes were estimates of the annual mean daily counts, derived from regression estimates of the "geometric mean" daily count, adjusted for covariates. The full regression model with all covariates was

$$\ln(N_{ij}+1) = a_0 + \sum_{j=1}^{J} a_j Y_j + \sum_{k=1}^{4} b_k i^k + \sum_{l=1}^{L} c_l W_{lij} + e_{ij} \tag{1}$$

where N_{ij} was the number of one species counted (or estimated) during the standard hours on day i in year j; Y_j was a series of J dummy variables which were set equal to one when year $= j$ and were zero in all other years (values of j vary from 0 to J representing a series of $J + 1$ years; there is no year dummy variable for year 0); i^k were first through fourth order terms in date; W_{lij} was the value of weather variable l on day i in year j; a_0 was the intercept estimated by the regression; a_j, b_k, and c_{jk} were coefficients estimated by the regression representing the effects of each independent variable on $\ln(N_{ij}+1)$; and e_{ij} represented unexplained variation. The regression model was a one-way ANCOVA, with year terms as factors and all other independent variables as covariates. Regression analyses were weighted in proportion to the number of hours of observation on each day, h_{ij}. The method of deriving geometric-mean indexes was similar to those used previously (Hussell 1981, Francis and Hussell 1998), except that each index was expressed as the estimated mean count per day (Farmer et al. 2007), instead of as the estimated mean count on a "typical" day (derived from the adjusted mean for year in the transformed scale). The latter change makes no difference to the estimated trends calculated from the indexes.

Date-adjusted and date-wind-adjusted indexes were derived from each time series of migration counts. In most cases, the date-adjusted index performed best, according to the criteria described by Farmer et al. (2007).

The date-adjusted index was estimated from the regression model including year and date terms only:

$$\ln(N_{ij}+1) = a_0 + \sum_{j=1}^{J} a_j Y_j + \sum_{k=1}^{4} b_k i^k + e_{ij} \tag{2}$$

This index was designed to eliminate bias introduced by days when data were not collected. The estimated geometric-mean count (back-transformed) for each day in each year was then calculated, summed each year over the migration period, and divided by the number of days in the season and re-transformed to obtain $(TDA)_j$. Then:

$$(index)_j = e^{[(TDA)_j + V/2]} - 1 \tag{3}$$

Three watchsites (Grand Canyon, Arizona; Tadoussac, Québec; and Veracruz, Mexico) had survey lines composed of two sites where counts were usually conducted simultaneously and generated counts that were assumed to be independent samples of the same flow of migrants. The model for these watchsites was

$$\ln(N_{hij}+1) = a_0 + \sum_{j=1}^{J} a_j Y_j + \sum_{k=1}^{4} b_k i^k + dS + e_{hij} \tag{4}$$

where N_{hij} was the number of one species counted (or estimated) during the standard hours at subsite h, on day i, in year j; S was a dummy variable whose value was set equal to 0 and 1 for observations from subsites 1 and 2, respectively; d was a coefficient estimated by the regression; e_{hij} represented unexplained variation; and all other variables and coefficients were as defined for equation (1). Therefore, for each species, this model assumed equal year effects across all sites and dates, equal date effects across all years and both sites, and equal site effects across all years and dates, all of which were additive in the transformed scale (and approximately multiplicative in the original scale). For each site, this assumption was tested by looking for year * site interactions.

The date-adjusted index was calculated in the same way as before (equation 3), except that the estimated geometric-mean count (back-transformed) for each day in each year was first adjusted to estimate the count at a hypothetical "average" site by setting S equal to its weighted-average value in the entire data set.

The date-wind-adjusted index was derived in the same manner as the date-adjusted index, with the addition of 12 variables incorporating wind speed and direction (E, SE, S, SW, $E^2 \ldots SW^3$, represented by

$$\sum_{l=1}^{L} d_l W_{lij}$$

in the regression model). However, for this index the estimated geometric-mean count (back-transformed) for each day in each year was calculated assuming that the value of each wind variable on all days in all years was equal to the mean value of that variable in the data.

Trend Analysis

Trends in annual indexes were estimated as the geometric-mean rate of change over a specified interval for each site (Link and Sauer 1997). Preliminary examination of index-by-year plots suggested that most species did not follow log-linear trajectories. We analyzed trajectories by fitting a polynomial regression to the time series of log $(\text{index})_j$ values. To reduce correlations among the polynomial terms, each regression was centered at the midpoint year in the series.

A best-fitting polynomial model was identified for each species using a three-step process. To avoid overfit, the number of possible models was limited to the set for which the number of regression coefficients was ≤ $n/5$, where n was the number of years in the regression (Tabachnick and Fidell 1989). Positive and negative autocorrelation of residuals indicate poor fit and overfit, respectively, so we identified a subset of candidate models for which autocorrelation of residuals was minimized ($-0.20 \leq a \leq 0.20$). A best-fit model was then chosen from this subset by selecting the single model that minimized Akaike's Information Criterion (AIC_c), corrected for sample size (Burnham and Anderson 2002), retaining all lower-order terms in the model. The information-theoretic approach to model selection typically identifies more than one model as approximately equally likely given the data ($\Delta AIC \leq 2.0$), so other models in each candidate set may also provide reasonable estimates of trend.

Trend estimates and their significance were derived by reparameterizing the year terms (Francis and Hussell 1998). This method takes into account the trend within the set of years being compared and uses the variance around the entire trajectory. It provides greater statistical power for the detection of trends than linear regressions that do not truly fit the trajectory of the index. The reparameterization transformed year terms so that the first-order term estimated the rate of change between the two sets of years and therefore was equivalent to the slope of a log-linear regression. To reduce the potential effect of extreme trajectories at the ends of the polynomial model, we compared mean indexes for the three-year periods at either end of the period of interest (e.g., 1974–1976 and 2002–2004). These estimates of the mean were influenced by the observed index in all years, thereby accounting for any trend within the averaged years (Francis and Hussell 1998). Similarly, tests of trend significance were based on the mean-squared deviation from the regression curve of all index values, not just those in the averaged years.

Interpretation of Abundance Indexes and Trends

One objective of the RPI is to provide information relevant to assessing the conservation status of migratory raptors. Species conservation status reports in this volume (Chapter 9) and elsewhere (e.g., www.hawkmountain.org/index.php?pr=raptor_life_history) show how RPI provides input to an integrated approach to assessing the status of North American migratory raptors.

It is not possible to combine data from multiple watchsites to derive a valid composite population trend for the entire continental population of any species (Dunn and Hussell 1995); however, graphic examination of consistencies and inconsistencies in estimated trends across the continent may demonstrate an overall pattern of regional and continental change or stability. For example, our analysis showed widespread declines in

American Kestrels (*Falco sparverius*) at most watchsites between 1994 and 2004 in eastern North America, and between 1995 and 2005 in western North America (Fig. 18 in Chapter 9), whereas relatively stable trends were shown for several other species. On the other hand, several species, including Bald Eagle (*Haliaeetus leucocephalus*), Cooper's Hawk (*Accipiter cooperii*), Merlin (*F. columbarius*), and Peregrine Falcon (*F. peregrinus*), increased rapidly at most sites in eastern North America following bans on DDT in 1971–1972 (Chapter 5) and have apparently recovered from earlier declines (Bednarz et al. 1990). Overall, our results, when considered in conjunction with information from the Breeding Bird Survey, Christmas Bird Counts, and other sources of population information, provide the best available assessments of the current status of North American migratory raptors.

The conservation usefulness of population trends estimated at migration watchsites is limited by a lack of knowledge of population size, as well as or the breeding and wintering ranges of the populations monitored (Chapter 2). Analyses of band encounters, ratios of stable isotopes in feathers, and tracking of individual birds by satellite have all contributed to a better understanding of the "catchment areas" and flyways used by individual species (e.g., Clark 1985, Fuller et al. 1998, Meehan et al. 2001, Hoffman et al. 2002, Smith et al. 2003, Houston 2006). Additional research specifically aimed at delineating regional populations, identifying their flyways, and establishing connectivity between breeding and wintering ranges will greatly increase the value of migration-trend estimates.

The Partners in Flight *North American Landbird Conservation Plan* (Rich et al. 2004) uses six vulnerability criteria for assessing the status of populations: (1) population size, (2) breeding distribution, (3) nonbreeding distribution, (4) threats to breeding, (5) threats to nonbreeding, and (6) population trend. In the latter category, species declining 50% or more over a 30-year period were considered most vulnerable, whereas species with increasing trends were considered least vulnerable.

Butcher et al. (1993) suggested that 80% power to detect a 50% decline in 20 years is a reasonable target for a trend-monitoring program. This target was evaluated and extended by Bart et al. (2004), who proposed a standard for considering landbird populations to be adequately monitored: 80% power to detect a 50% decline occurring within 20 years, using a two-tailed test and a significance level of 0.10, and incorporating effects of potential bias, and coverage of at least two-thirds of the target region. Those authors also recommended that the standard should be achieved for species' entire ranges or for any area one-third the size of the temperate portions of Canada and the United States, whichever is smaller. Exactly how these standards can be applied to or adapted for migration monitoring remains to be seen. An obvious first step is to determine whether the trend standard can be met for each species at individual watchsites. For example, Farmer et al. (Chapter 5) estimate a linear, 28-year decline of 4.5% per year ($P \leq 0.01$) in the index for American Kestrels at Cape May. This translates to a 50% decline over 15.4 years, or a 59% decline from the initial population over 20 years. Farmer et al. (Chapter 5) also report a 1.6% per year ($P \leq 0.01$) decline in counts of American Kestrels at Hawk Mountain Sanctuary, during a 30-year period (27% decline in 20 years), which suggests that the power of migration monitoring to detect trends at sites with low count variance can easily exceed the Bart et al. (2004) goal. Determinations of this sort should be followed by identifying regional populations and their flyways, grouping sites within the same flyway, and determining the ability of the grouped sites to meet the standard.

As is recognized by the Partners in Flight criteria summarized above (Rich et al. 2004), population trends are not the only important criterion to consider in a conservation assessment. Viewing recent trends in the context of the historical record also adds a useful perspective. A recent sharp decline may not be a cause for concern if the population remains above historical levels or if similar declines in the past have been followed by recovery. Therefore, we suggest that it is important to consider the following questions in future RPI analyses:

- What is the estimated recent rate of change in the annual indexes, and is the change statistically significant? We define “recent” as the past 10 years.
- Are recent population levels significantly higher or lower than in the past? We suggest comparing average levels in the past 10 years with those in at least the preceding 30 years (or from the start of observations, if less than 30 years).
- Are current population levels significantly lower (or higher) than they were at any time in the historical record? We suggest comparison of the most recent five-year period with all preceding half-decade periods (e.g., 1990–1994, 1995–1999, etc).

Significant recent declines to population levels below the long-term average, and especially to five-year averages lower than ever recorded previously, would be a cause for concern and action.

Each of these questions is easily answered using the methods described in this paper for single watchsites with at least 15 years of counts. As more data accumulate at more sites, the usefulness of these data to provide answers at a broad geographical scale will increase.

In the past, questions like these were addressed less formally to describe declines in migrating raptors, usually long after the existence and nature of the threat had been identified from other information (Spofford 1969, Nagy 1977, Mueller et al. 1988, Bednarz et al. 1990). The conceptual framework and the means provided by RPI now allow us to use counts of migrating raptors to serve as a timely early-warning system of population declines, and we should do so.

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