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Long-Term Monitoring: The Raptor Population Index in Principle

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Abstract.—We present a short history of hawkwatching and the use of migration counts to monitor raptor populations in North America. We argue the need to continue monitoring hawks during their migrations as a component of a comprehensive monitoring and conservation program for North American landbirds. We also discuss some of the concepts, principles, and assumptions required for the proper analysis and interpretation of population-trend data. Since the first analyses of migration counts at the end of the 1960s, most researchers have used annual indexes of effort-adjusted counts to calculate long-term population trends using regression models. In this chapter, we advocate use of regression models designed to accommodate the non-normal distribution of counts of birds and to correct for effects of potentially confounding variables and missing data on long-term population trends. Most analyses of population trends derive from counts taken at a single site. We briefly discuss pooling of trends and interpretation of results from multiple watchsites and argue for continued improvement and standardization of methods. We also describe the development of hawkcount.org and the Raptor Population Index (RPI), and their roles in monitoring populations of North America's migratory raptors.

Counting Migrating Raptors

The modern era of hawkwatching began in 1934 when the first full-season counts were conducted at Hawk Mountain, Pennsylvania. Counts have continued there annually each autumn since, except during the war years of 1943–1945 (Bildstein 1998, Zalles and Bildstein 2000).

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Observations and trapping began at Cedar Grove, Wisconsin, in 1936, but consistent estimation of daily numbers, which were made ancillary to trapping, was only started in 1950, and records for that first year have been lost (Mueller et al. 2001). Sporadic counts were conducted at Cape May Point, New Jersey since 1931, but regular daily monitoring began there only in 1976 (Zalles and Bildstein 2000).

According to Robbins (1975), regular hawk counts occurred during the 1950s and 1960s at several sites in Massachusetts, New Jersey, New York, Pennsylvania, West Virginia, Virginia, Minnesota, and Ontario. A review of the listings for North and Central America in the Raptor Watch directory (Zalles and Bildstein 2000) shows that among sites with regular monitoring (≥20 days per year), which were still in operation in 1998, only 10% (9 of 92) began observations before 1970. A large expansion in watchsite activity occurred after 1970 (i.e., 22%, 31%, and 37% of 92 sites started regular counts in the 1970s, 1980s, and 1990s, respectively).

Increased interest in seeing, counting, and studying hawks during migration led to the formation of the Hawk Migration Association of North America (HMANA) in 1974 (Harwood 1975, Roberts 2001). HMANA designed and promoted standard protocols for counting and recording migrating hawks, published seasonal records, and undertook to store the data in a central archive for future use (Harwood 1975). This led to the founding of additional organized watchsites that fed data into the system in the following decades.

Before the 1980s, monitoring hawk migration was primarily an eastern phenomenon, but this changed with the formation of the Golden Gate Raptor Observatory, which started regular monitoring in 1982, and the establishment of several watchsites on western mountains from 1977 to 1992 (Hoffman and Smith 2003), and, thereafter, along the Gulf of Mexico. The latter developments resulted from the initiative and foresight of Stephen Hoffman and the organization that later became HawkWatch International (HWI). Hoffman and HWI have had a major impact on hawkwatching in western North America and along the coasts of the Gulf of Mexico; without their work, the continent-wide perspective of this volume would have been impossible. Currently, HWI coordinates, directly or in partnership with others, 10 watchsites in western states, 2 on the Gulf coast of Texas, 1 on the Florida Keys, and 1 at Veracruz, Mexico, the latter in partnership with Hawk Mountain Sanctuary and Pronatura Veracruz (J. Smith pers. comm.).

Hawk counting has many objectives and motivations, including recreation, conservation, and even fund-raising, as well as education and research. Nevertheless, an underlying theme throughout the literature is that hawk counts can and should be used to monitor the status and health of populations. Despite this, widespread and comprehensive use of hawk counts for monitoring has developed slowly.

A Brief History of Monitoring Population Change

Spofford (1969) and Nagy (1977) were among the first to use hawk-migration counts explicitly to track population change. Both used 5-year moving averages of counts at Hawk Mountain to plot population trajectories over 32 and 40 years, respectively. Hackman and Henny (1971) compared numbers of hawks seen per hour over three months to assess population changes between 1951–1954 and 1958–1961. Robbins (1975) presented trend graphs for Sharp-shinned Hawks (*Accipiter striatus*), Cooper's Hawks (*A. cooperii*), Red-tailed Hawks (*Buteo jamaicensis*), and Peregrine Falcons (*Falco peregrinus*) from counts at Cape May Point, New Jersey; Hawk Mountain Sanctuary, Pennsylvania; White Marsh, Maryland; and Hawk Ridge, Duluth, Minnesota. Counts were first adjusted for daily or hourly effort and then analyzed by linear regression.

Several analyses have been conducted on the long data sets from Cedar Grove Ornithological Station, Wisconsin, and Hawk Mountain Sanctuary, Pennsylvania. Mueller and Berger (1967) and Mueller et al. (1977) examined the irruptive migratory behavior of Northern Goshawks (*A. gentilis*) at Cedar Grove by comparing numbers counted in different years with an "expected" number for the dates of observation each year. Mueller et al. (1988) used counts from 1936 to 1985 to show that Peregrine Falcons migrating past Cedar Grove in fall "*declined from the 1950s to an extreme low in the early and mid-1970s and then showed a remarkable recovery in the 1980s*" (Mueller et al. 1988:504). A more recent paper graphed birds per day, 5-year moving averages, and linear regression trends for selected periods for 15 species at Cedar Grove from 1936 to 1999 (Mueller et al. 2001). Bednarz et al. (1990) presented a comprehensive analysis of Hawk Mountain counts for 1934–1986. They determined annual indexes of abundance of migrating hawks, expressed as birds per 10 hours of observation within a predetermined range of dates, for each of 14 species, and calculated linear regression trends for three periods: pre-DDT (1934–1942), DDT (1946–1972), and post-DDT (1973–1986).

There have been few multisite analyses of population trends. Titus and Fuller (1990) used linear regression to estimate trends (mean annual percent increase or decrease) of season-long total counts for 14 species at six eastern watchsites. They also estimated an overall trend using the route-regression method, weighting the site trends by the number of years of counts and the average number of hawks of each species recorded at each site. Weighting by the average size of the flight at each site assumes that the proportion of the monitored population sampled at each site is constant across sites, an assumption that is not likely to be true (Dunn and Hussell 1995). Hoffman and Smith (2003) provided the first multisite analysis from the western United States, involving 15 species migrating past six watchsites in the Intermountain and Rocky Mountain regions. They estimated linear and quadratic trajectories for annual passage rates during standardized migration periods.

The Need for Migration Monitoring

Accurate knowledge of population status and change is fundamental to species conservation if scarce resources are to be allocated wisely. Most agree that knowledge of the conservation status of most species of North American raptors is inadequate. The premier scheme for monitoring population change in North American birds is the Breeding Bird Survey (BBS; Robbins et al. 1986, Sauer et al. 2002). The BBS roadside survey method is unsatisfactory for monitoring population changes in most raptors, because of their low densities, and because the survey is conducted in June when most birds of prey are difficult to detect. For 10 raptor species monitored at Cape May, New Jersey, and Hawk Mountain, Pennsylvania, except for American Kestrels (*F. sparverius*) and Red-tailed Hawk, confidence intervals of trends derived from migration counts were much narrower than those estimated from regional BBSs, presumably because of low densities or low detection rates (or both) for the other species on the survey routes (Farmer et al. 2007). Furthermore, landscape-level nesting studies often are logistically difficult and prohibitively expensive (Bednarz and Kerlinger 1989, Dunn and Hussell 1995). Christmas Bird Counts (CBC) hold promise for monitoring raptors that winter mainly in North America (National Audubon Society 2002, Sauer et al. 2004) but are not suitable for those that winter farther south.

Migrating raptors concentrate at many watchsites throughout North and Central America and are counted in large numbers (Zalles and Bildstein 2000). Many researchers have concluded that counting migratory raptors at these concentration points is an efficient method for monitoring regional population trends of multiple species (Bednarz et al. 1990, Bildstein et al. 1995, Dunn and Hussell 1995, Dixon et al. 1998, Smith and Hoffman 2000, Zalles and Bildstein 2000, Hoffman and Smith 2003). This view was recently endorsed by The Partners in Flight North American Landbird Conservation Plan (Rich et al. 2004), whose recommendations included "*continue improvement of migration monitoring to meet information needs of many raptors…that are largely inaccessible for monitoring both in the breeding or wintering seasons*" and "*…research is needed on best analysis methods and precision estimation, and annual analysis and reporting should be instituted*" (Rich et al. 2004:29, 30).

Methodological research is ongoing (e.g., Farmer et al. 2007), and the advantages and limitations of migration monitoring are well understood, as is the research and institutional support needed to improve the conservation relevance of migration monitoring (e.g., Hussell 1981, Dunn and Hussell 1995, Dunn 2005). No monitoring method provides absolutely reliable results, and migration monitoring is no exception to this rule. But if properly analyzed, counts of migrating raptors can help to provide information relevant to determining the conservation status of migratory raptors.

A recent assessment concluded that 14 species of North American raptors are inadequately monitored, either because the precision of existing trends is unknown or low, or because more than one-third of the Canadian and United States breeding range is not covered by a breeding season survey (Dunn et al. 2005). To address these deficiencies, Rich et al. (2004) recommended an integrated approach, including expanded BBS coverage, additional breeding-season surveys, improved CBC analyses, and migration monitoring. Breeding-season surveys are always the first choice for improvement of continental monitoring, even if difficult or expensive to implement. However, most North American raptor species are partial or complete migrants, and migration monitoring can be an effective component of integrated population monitoring and was recommended for 13 of those 14 species (Table 1). Migration monitoring was recommended as a component of integrated monitoring for five other species. Two additional species were counted at many watchsites, but were judged to be well monitored by other methods.

Monitoring Migrants at a Single Site

Concepts

Many extrinsic (e.g., day length, weather) and intrinsic (e.g., observer number or experience) factors other than population levels influence numbers of migrants counted on any day. Intrinsic factors can be controlled or mitigated by adopting standardized observation procedures. Extrinsic factors can be addressed by using appropriate analysis methods (Hussell 1981).

The importance of observation consistency was recognized at the time of the formation of HMANA. The essential need was spelled out by Robbins (1975):

> *"If hawk counts are to be used for monitoring population changes, we must become interested in the standardization of observation and reporting procedures and in the consistency of the counts from year-to-year. …it is of the utmost importance that we learn how we can get the most consistent counts from year to year"* Robbins (1975:31, 37).

Table 1. Monitoring needs of migratory raptors (from Appendix 1 in Dunn et al. 2005).

Species	Monitoring-needs status[a]	Migration-monitoring recommendations[b]
Turkey Vulture (*Cathartes aura*)	–	0
Osprey (*Pandion haliaetus*)	2, 3	+ +
Swallow-tailed Kite (*Elanoides forficatus*)	2, 4	+ +
Mississippi Kite (*Ictinia mississippiensis*)	2	+ +
Bald Eagle (*Haliaeetus leucocephalus*)	3	+ +
Northern Harrier (*Circus cyaneus*)	3	+ +
Sharp-shinned Hawk (*Accipiter striatus*)	3	+ +
Cooper's Hawk (*A. cooperii*)	2	+ +
Northern Goshawk (*A. gentilis*)	2, 3	+ +
Red-shouldered Hawk (*Buteo lineatus*)	–	+
Broad-winged Hawk (*B. platypterus*)	–	+
Swainson's Hawk (*B. swainsoni*)	2	+ +
Red-tailed Hawk (*B. jamaicensis*)	–	0
Ferruginous Hawk (*B. regalis*)	–	+
Rough-legged Hawk (*B. lagopus*)	2, 3	+ +
Golden Eagle (*Aquila chrysaetos*)	3	+ +
American Kestrel (*Falco sparverius*)	–	+
Merlin (*F. columbarius*)	2, 3	+
Peregrine Falcon (*F. peregrinus*)	2, 3	+ +
Prairie Falcon (*F. mexicanus*)	2	+ +

[a] Continental monitoring need status: – = adequately monitored by other methods (usually BBS); 2 = trend information available from existing survey, but trend precision is low; 3 = one-third or more of Canadian and U.S. breeding range is not covered by a breeding season survey (i.e., much of the range north of BBS coverage); 4 = two-thirds or more of Western Hemisphere breeding range is south of the United States.

[b] Migration monitoring recommendation: 0 = not needed, adequately monitored by other surveys; + + = recommended, next to preferred option of breeding season survey; + = recommended, as third option.

HMANA took that advice to heart by providing standard protocols and reporting forms (Harwood 1975) that are essentially unchanged today. Although "consistency" is sometimes interpreted as striving to be as accurate as possible on each and every day by recruiting one or more highly skilled birders to detect and count as many hawks as possible, it really means striving for a consistent level of expertise and effort over the long term, so that *the average proportion of hawks that are missed by the counters remains relatively constant from year to year*, even if not from day to day.

Extracting the Population Signal: The Annual Abundance Index

Recognition that daily migration counts are skewed means that the median and geometric mean of the counts (or daily passage rates) are better indicators of annual abundance than the mean or sum (Dunn and Hussell 1995, Chapter 4). Compared with average or total passage rates, the geometric mean and median are less sensitive to unusually high counts and are better indicators of the shifts in the entire distribution of the counts, shifts that are expected to occur when the size of the sampled population changes. Moreover, for abundant species, we can assume a log-normal distribution of counts and safely use ordinary multiple regression methods to model the effects of other variables (e.g., date, weather, and year) on the log-transformed daily counts. Because the years are treated as categorical factors and date and weather variables are continuous independent variables, the model is best described as an analysis of covariance. This approach allows us to extract annual abundance indexes from the regression results that are "corrected" for the effects of date and extrinsic variables. Such methods have been developed and used for calculating annual indexes for songbird migrants (Hussell 1981, Hussell et al. 1992, Dunn and Hussell 1995, Dunn et al. 1997, Francis and Hussell 1998) but, prior to this work, have been little used to analyze hawk counts (for exceptions, see Hussell 1985, Hussell and Brown 1992, Farmer et al. 2007).

Trends

Once annual indexes are calculated, we need to estimate the magnitude of the trend and determine whether it is statistically significant. Several methods are available to model the pattern of change over time, or population trajectory. A trend is defined as the geometric mean rate of population change over the time period of interest (Link and Sauer 1997, 1998), which can be expressed as percentage change per year. If the trend is linear, the geometric mean rate of change can be estimated by fitting a linear regression to the logarithm of the annual index.

Most authors have analyzed trends using linear regression (e.g., Bednarz et al. 1990, Mueller et al. 2001, Hoffman and Smith 2003). Time series of animal abundance often follow a nonlinear pattern. If so, linear regression may provide a poor fit to the trajectory and misrepresent the rate and even the direction of change. Nonlinear trajectories can often be modeled better with polynomial regressions. Hussell and Brown (1992) introduced a method for estimating and testing the significance of a trend between two preselected years on a polynomial curve (see also Francis and Hussell 1998 and Farmer et al. 2007).

Combining Trends from Multiple Sites

Sites that are close together along a transect, approximately perpendicular to the principal axis of migration in the region, but not so close as to observe the same birds, probably sample the same monitored population (*sensu* Dunn and Hussell 1995), and we can calculate pooled annual indexes for the sites and use those indexes to estimate trends in the same way as for single sites, see Tadoussac, Québec (Chapter 5), the Grand Canyon, Arizona (Chapter 6), and Veracruz, Mexico (Chapter 7) for details.

Counts from a series of sites along a transect provide us with independent samples from the monitored population and their use should increase the precision of the estimates of annual indexes and the power of the method to detect trends. In the absence of a pooled trend estimate, mapping of single-site trends provides a useful qualitative picture of continental trends that can contribute valuable perspectives to conservation assessments (Chapter 9). Refinement of knowledge of migration flyways and catchment areas will increase the usefulness of these results.

Hawkcount.org and the Raptor Population Index (RPI)

The executive committee of HMANA was charged with several responsibilities. The first three of those dealt with housekeeping; the fourth outlined some immediate objectives for the new association:

> "*Prepare a standard daily reporting form, to be used by all participating hawkwatchers, spring and fall. These report forms, filled out, would be sent from the lookouts to the appropriate regional representatives/editors who would then prepare seasonal reports on the raptor migration through their respective regions… All daily report forms would ultimately be collected and filed in one place—a clearing house—as a service to researchers into the phenomena of hawk migration. An effort would be made to raise sufficient funding… to permit the association itself to sponsor a computer assisted pilot study of migration over a five-year period*" (Harwood 1975:157).

All except the last of these objectives was realized within 25 years. The initial version of the reporting form was published along with those objectives (Harwood 1975). Regions were formed and seasonal reports were published, initially in a newsletter and later in *Hawk Migration Studies*. Daily report forms were archived, initially at Muhlenberg College, Allentown, Pennsylvania, and now at Hawk Mountain Sanctuary. By January 2000, the archive contained information from 1,740 sites in the United States and 148 in Canada, but only 4% had ≥10 years of counts (McCarty et al. 2000).

Although there was some use of computers for limited studies (e.g., Titus and Fuller 1990), the original vision of HMANA itself undertaking comprehensive computer-assisted analyses never came about. By

2000, HMANA realized that "electronic" was the way to go and that a professional staff was needed (Hoffman 2000, Moulton 2000). In 2001, HMANA announced "Raptors Online" (Moulton 2001), which was further elaborated the following year with the introduction of HMANA's hawkcount.org online data entry and database system (Moulton and Weber 2002). Developing the vision and making plans to hire staff proved to be easier than raising the necessary funds. Consequently, the development of HMANA's hawkcount.org database was done entirely by a volunteer, Jason Sodergren, who adapted a system used at Holiday Beach Migration Observatory (Moulton and Weber 2002, Chapter 10).

The objectives of hawkcount.org conformed exactly to HMANA's original objectives: to collect hawk count data, store it in a secure archive, and make it available for study to qualified researchers. In 2002, HMANA began to consider a proposal for a comprehensive program to use the data for long-term population monitoring: the RPI program (Moulton and Weber 2002). During this time, Hawk Mountain Sanctuary also decided to pursue a continental strategy for monitoring North America's raptors. Discussions in 2003 led to the formation of a partnership among HMANA, Hawk Mountain Sanctuary, and HawkWatch International whose goal was to "*jointly develop a Raptor Population Index program…to determine annual population indices and trends of hawks counted during spring and fall migrations at sites throughout the United States, Canada and Central America*" and its specific objectives were "*to (1) produce scientifically defensible indices of annual abundance and trends for each species of migratory raptor, from as many count sites as possible; and (2) make those results available widely, i.e. to participating count sites, the scientific community, conservation agencies and the public*" (McLeod 2004).

In June 2004, Hawk Mountain Sanctuary was awarded a 2:1 challenge grant from the National Fish and Wildlife Foundation to support a three-year project to develop RPI, which was launched on 1 January 2005 (Goodrich 2005). Professional staff at the partner organizations and their advisors have been working diligently to bring RPI to fruition since then (Ruelas 2005, 2006a, b).

We believe that RPI ushers in a new era of focused and productive hawk watching, as well as a significant advance in monitoring to support conservation of migratory raptors in the Western Hemisphere. *State of North America's Birds of Prey* summarizes much of what has been accomplished in the past three years and points a way to the future.

Acknowledgments

We wish to thank Erica Dunn and Chandler S. Robbins for their reviews and comments on earlier drafts of this paper. David Hussell thanks Keith

Bildstein for providing office space and accommodation at the Acopian Center for Conservation Learning while writing much of the manuscript.

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