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The Future of Raptor-migration Monitoring

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Abstract.—The extent to which the Raptor Population Index (RPI) serves to monitor populations of North America's birds of prey will depend on those who choose to maintain and improve it. Much like the National Audubon Society's *Christmas Bird Counts*, and the U.S. Geological Survey's *Breeding Bird Surveys*, RPI depends on a cadre of expert volunteers to conduct the counts. Maintaining the enthusiasm of these volunteers is critical to RPI's long-term success. RPI areas in need of improvement include shortfalls in autumn coverage outside of eastern North America; shortfalls in spring coverage throughout the continent; potentially fragile analytic and interpretive protocols, particularly at mega-migration watchsites along the Mesoamerican Land Corridor in southern North America and Central America; and limited knowledge of the dynamic geography of raptor migration in North America. All areas in need of improvement can be addressed, and we believe that RPI has a bright and long-term future in conservation monitoring.

Introduction

Counting North America's migratory birds of prey for conservation dates from the early 1930s, when raptor enthusiasts at Cape May Point, New Jersey, and Hawk Mountain Sanctuary, Pennsylvania, first used migration counts in an attempt to reverse the growing threat of human persecution

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(Chapter 1, Bildstein 2006). Migration counts at Cape May Point, which were organized by the Audubon Association in 1931 (Allen and Peterson 1936), were suspended after 1937 and were not restarted on a regular basis until 1976 (Dunne and Sutton 1986). Migration counts at Hawk Mountain Sanctuary began in 1934 and have continued uninterrupted through the present, except for three years (1943–1945) during the Second World War when the watchsite's principal counter at the time, Maurice Broun, was serving in the U.S. Navy SeaBees (Bildstein and Compton 2000). Although counts at both sites were initiated principally to document the magnitude of the flight to enlist support for conservation efforts there (Broun 1935a, b; Allen and Peterson 1936), at Hawk Mountain, at least, it quickly became apparent that a series of annual counts would enable monitoring regional populations over time.

Writing in *The Auk* in 1939, Maurice Broun put it this way:

> *Since the second season (1935) uninterrupted daily censuses of hawk flights have been made, each season's observations covering an average of 575 hours. The accumulated data provide a more accurate picture of the migrations than that published prematurely for 1934* [Broun 1935b], *and also furnish a sounder basis for future statistical comparisons.*

Less than five years into the Hawk Mountain conservation effort, annual migration counts at Hawk Mountain were telling Broun something about the numbers of raptors that were out there (as well as the numbers that he was protecting on site), and Broun had the foresight to realize that long-term counts would tell conservationists something about population change over time. On top of all that, Broun found hawkwatching enjoyable, and learned that inviting others to see the migration at Hawk Mountain could provide the Sanctuary with the opportunity to spread a conservation message to thousands of visitors annually (Broun 1949).

Shortly after Hawk Mountain was established, hawkwatching—both as conservation monitoring and as recreation—began to spread across North America (Chapter 3, Bildstein 2006), in much the same way that Audubon's *Christmas Bird Counts* had earlier in the 20th century (cf. Drennan 1981).

By the late 1950s, many in the hawkwatching community were calling for the establishment of a network of migration watchsites that could do continentally what Hawk Mountain Sanctuary and other sites were doing regionally (J. Taylor pers. comm.): monitor numbers of birds of prey and offer conservation assessments for individual species. The founding of the Hawk Migration Association of North America in 1975 and of HawkWatch International in 1986 set the intercontinental stage for this dream (Chapter 3, Harwood 1975). The creation of the Raptor Population Index (RPI) in 2003 put this dream into action, and the publication of *State of North America's Birds of Prey* summarizes the history and results of this effort as of early 2007.

Below, we offer our vision of the future of counting migrating raptors for conservation.

Challenges

Bird migration, in general, and the visible daytime movements of birds of prey in particular, have fascinated humanity for millennia (Brown and Amadon 1968, Bildstein 2006). This, together with the charismatic nature of raptors themselves, has created a longstanding interest in studies of their migrations. As a result, with the possible exceptions of waterfowl and shorebirds, we now know more about the long-distance movements of raptors than we do about any group of birds (Bildstein 2006). Given the history of sustained growth in hawkwatching and raptor-migration studies (Heintzelman 1975, 1986, 2004; Kerlinger 1989; Zalles and Bildstein 2000; Bildstein 2006) there is little reason to think that this will change anytime soon. Recent advances in technology, particularly in data entry and management, data analysis, and the rapid dissemination of results, together with improvements in field guides, optics, and outdoor clothing, suggest that monitoring the movements of raptors at migration watchsites will remain a popular and largely volunteer effort for some time into the future (Bildstein 1998a). That said, much remains to be done to improve our monitoring efforts.

Aspects of our work in need of improvement include (1) the geographic coverage of both autumn and spring watchsites, (2) the number of spring watchsites and an assessment of their value for population monitoring, (3) our statistical procedures for analyzing raptor counts at "mega-watchsites" along major migration corridors, and (4) our understanding of the dynamic migration–geography of raptors, including within-species differences in migration behavior and changes in the extent of migration and migration geography over time. We address each of these needs below.

The geography of watchsites.—RPI coverage of North America is uneven geographically. Eight of the 22 watchsites whose counts were analyzed and presented in this work are east of the Mississippi River and north of the Mason-Dixon Line. And, overall, most active watchsites in North America are in the northeastern United States (Table 1, Chapter 2). This is so because the first watchsites were in the Northeast and watchsite activity spread, geographically, from them. Although some of this historical bias will self-correct as more recently established southeastern and western watchsites accumulate sufficient numbers of count years for trend analysis, it is clear that additional watchsites are needed outside of northeastern North America.

The impact of limited watchsite coverage elsewhere in North America, perhaps, is best reflected by the fact that no watchsite in Canada or the United States now counts more than one or two percent of the total known migratory flights of Swainson's Hawks (*Buteo swainsoni*) and western populations of Turkey Vultures (*Cathartes aura meridionalis*), two species of common North American migrants whose populations all but evacuate the western United States and western Canada each autumn (England et al. 1997, Kirk and Mossman 1998, Chapter 2). Although these two species are counted by the hundreds of thousands to millions at watchsites in Mexico, Costa Rica, and Panama (Ruelas et al. 2000, Porras-Peñaranda et al. 2004, G. Angehr pers. comm., Chapter 7), the lack of significant migration monitoring in Canada and the United States compromises RPI's ability to detect changes in regional populations and, thereby, its ability to assess the regional conservation status of two of North America's more abundant long-distance migrants.

Although some workers have argued that Turkey Vultures and Swainson's Hawks do not concentrate along traditional flight lines north of Mexico—thereby making counting large numbers of migrants at watchsites north of the Rio Grande difficult, if not impossible—in truth, no one has systematically searched for flight lines of these two species in the American West. Migratory routes used by satellite-tracked Turkey Vultures and Swainson's Hawks would be one place to start gathering information for such a search, as would published anecdotal reports of large movements of these two species. The movements of many other western populations of raptors including Ospreys (*Pandion haliaetus*), Northern Harriers (*Circus cyaneus*), and Peregrine Falcons (*Falco peregrinus*), also are under-sampled in the region. And, unfortunately, western North America is not the only place with too few watchsites.

Notwithstanding activities at a critical watchsite at Curry Hammock State Park in the Florida Keys (Lott 2006, Chapter 7), season-long migration counts are generally lacking along the Atlantic Coast of eastern North America south of Kiptopeke, Virginia, as well as in the interior Southeast. Watchsites also are largely absent on the Pacific Coast south of the Golden Gate Raptor Observatory in northern California (Zalles and Bildstein 2000, Chapter 6).

If the RPI is to succeed in the long term, it must activate and maintain additional long-term autumn-migration watchsites outside of northeastern North America.

The number of spring watchsites.—Most watchsites are operated by volunteers whose interest in season-long counts is often driven by the potential for seeing large flights of migrants. Because of this, most RPI watchsites are along traditional migration corridors where large numbers of migrants regularly concentrate, and autumn watchsites far outnumber spring watchsites. The latter is true mainly because autumn migration occurs shortly after the breeding season when populations are at their peaks, whereas spring migration occurs after winter when populations are at their low points. Other factors that act to favor autumn versus spring counts include *delayed return migration* in some species (Bildstein 2006) and a less geographically concentrated return migration overall (cf. McCarty et al. 1999). In addition to all of this, many species of raptors engage in *loop migration*, which means that high-volume autumn watchsites often have disproportionately low spring counts. As a result, whereas 138 of all 188 active watchsites in North America operate in autumn, only 50 watchsites operate in spring (Table 1 in Chapter 2). As is true of migration watchsites in general, most spring count sites (72%) are east of the Mississippi River and north of the Mason-Dixon Line.

The paucity of spring watchsites limits RPI's ability to assess the extent to which shifts in over-winter mortality versus changes in reproductive output affect counts at autumn watchsites, and as such limits our ability to focus conservation efforts where they are needed most.

If RPI is to succeed in the long term, it must activate and maintain additional spring watchsites throughout North America.

Statistical analysis of counts along major migration corridors.—RPI's current data analysis builds upon protocols that were developed to monitor population change in songbird migrants at Long Point Bird Observatory in southern Ontario based on spring counts there (Hussell 1981). The protocols (see Chapter 4) involve the calculation of geometric-mean daily counts, which serve to significantly reduce the influence of extremely high single-day counts. The use of this technique to monitor raptor population change is questionable at mega-watchsites along the intercontinental Mesoamerican Land Corridor, where day-to-day variation in passage rates of super-abundant, super-flocking species, including Turkey Vultures, Swainson's Hawks, and Broad-winged Hawks (*B. platypterus*) are often extreme (i.e., ranging from a few migrants on one day to hundreds of thousands of migrants on the next; Chapter 7). Although reducing the influence of occasional extreme outliers is appropriate for some species in some circumstances (Hussell 1981), it may not be so for super-flocking migrants along major migration corridors where single-day counts of as many as 800,000 birds can represent 50–60% of the total count for a season. An example of this occurred in 2001 at the Veracruz River of Raptors watchsite when 775,000 Broad-winged Hawks were counted on 28 September, and more than 360,000 were counted the next day, collectively representing 53% of the season's overall count. A similar situation occurred in 2001 at the Corpus Christi, Texas watchsite. As mentioned in Chapter

7, RPI currently is examining how best to assess population trends in such situations.

If RPI is to succeed in the long term, it must continue to develop and use the best possible statistical analyses and interpretive protocols.

Migration geography.—Until recently, most raptor-migration science has focused inwardly on the birds themselves, concentrating on descriptive natural history (e.g., Brown and Amadon 1968, Ferguson-Lees and Christie 2001) and flight mechanics (Kerlinger 1989) rather than on broader theoretical and ecological questions (Bildstein 1998b). Overall, relatively few studies in raptor-migration science have formulated hypotheses, tested predictions, and modified existing hypotheses based on findings (for notable exceptions see Kerlinger 1989). And indeed, much of the work on raptor migration is built upon *hypothesis compatibility* (*sensu* Templeton 2007), rather than upon *hypothesis testing*.

One unfortunate consequence of this approach is that many practitioners in the field still view the migration geography of birds, including raptors, as being fixed, all-but-immutably in place, despite a growing body of field and experimental evidence that suggests otherwise (Viverette et al. 1996, Berthold 1999, Bildstein 2006). The picture that is now emerging from the literature indicates that migration behavior in general, and migration geography in particular, are dynamic and flexible attributes of many species, and that both can shift quickly in response to changing ecological conditions. This, together with the fact that the overwhelming majority of North America's migratory raptors are *partial migrants* that exhibit geographic variability in migratory tendencies, leads us to conclude that changes in migration counts often can reflect changes in migratory behavior just as easily as they reflect changes in the sizes of source populations.

Thus we believe that watchsite counts alone are insufficient in assessing the conservation status of North America's birds of prey, and that additional continental survey data, including both *Breeding Bird Surveys* and Christmas Bird Counts, together with a better understanding of the current migration geography and migration behavior of North America's raptors, themselves, will be needed if RPI is to properly assess the population status of North America's birds of prey.

A case in point is global climate change. Many students of bird migration have concluded that continued global climate change is likely to hasten shifts in both migration behavior and population size in many species of migratory birds (Møller et al. 2006). A growing body of field evidence suggests that there is no reason to suppose raptors will be an exception in this regard (Bildstein 2006). With this in mind, we call for a broader and more scientific approach to the discipline of raptor-migration science (cf. Bildstein 1998b). Specifically, we recommend new studies that incorporate hypothesis testing and that use the new observational, experimental, and analytical tools now available to students in the field, so that we can better track and identify shifts in migration behavior as well as shifts in numbers.

If RPI is to succeed in the long term, it must begin to foster work that leads to a better understanding of the phenomenon of raptor migration, particularly the degree to which birds of prey shift their migratory movements and behavior in light of local, regional, and continental ecological change.

Opportunities

Important, new, and, as yet, largely underused tools in raptor-migration science include satellite tracking (Bildstein 2006, Meyburg and Fuller 2007), radar ornithology (Gauthreaux et al. 2001), stable isotopes (Hobson 2002, Lott and Smith 2006), and the use of data-loggers to monitor raptor physiology during flight (J. Mandel pers. comm., O. Bahat pers. comm.). Although these new techniques have limitations, taken together they offer complementary and potentially rich sources of information regarding the migrations of birds of prey that, together with counts of visible migrants at watchsites, can significantly improve our abilities to assess regional and continental population change. We discuss the potential benefits and limitations of each below.

Satellite tracking.—One of the most important new tools in raptor-migration science is satellite tracking (Meyburg and Fuller 2007). Developed in the early 1980s, satellite tracking employs platform transmitter terminals (PTTs) as small as 10 g that are capable of transmitting hundreds of locations annually. Although relatively expensive, tracking the migratory movements of raptors by satellite offers the holy grail of raptor migration: an ability to follow individual migrants on a daily or even hourly basis. Solar-powered PTTs, which can send signals for several years or more, allow researchers to follow the movements of individual birds on a series of outbound and return migrations. Recently developed PTTs equipped with GPS units provide location accuracy to within a few meters (Meyburg and Fuller 2007). As of early 2006, the migratory movements of at least 27 large-bodied birds of prey had been tracked by satellite (Bildstein 2006).

Initially designed to determine the geography of animal movements, satellite tracking also enables researchers to assess the flight speeds of birds during migration, the extent of nocturnal versus diurnal flight, the occurrence of stopover and night-time roosting behavior and the location of stopover and roost sites, and habitat use. One recent analysis even used satellite tracks to assess the navigational cues used by Peregrine Falcons moving between North and South America, and Western Honey Buzzards (*Pernis apivorus*) and Ospreys moving between Europe and Africa (Thorup et al. 2006). Because solar-powered satellite tracking units allow researchers to follow the movements of individuals across several years, satellite tracking allows researchers to assess the extent of inter-year flexibility in both temporal and spatial aspects of migration. Individuals tracked by satellite and outfitted with downloadable data loggers also can provide information on their physiological condition (e.g., core body temperature, heart rate, etc.) and flight mechanics (e.g., flapping rates) during their migrations (J. Mandel pers. comm, O. Bahat pers. comm.).

Population assessments of many of the RPI results reported earlier in this work have been compromised by suspected changes in migration behavior, including migration short-stopping (Sharp-shinned Hawk [*Accipiter striatus*] accounts, Chapters 5 and 9), and route shifts (Chapters 6 and 9) in response to environmental changes such as climate amelioration (Viverette et al. 1996), increased numbers of bird feeders and, consequently, bird-feeder birds (Warkentin et al. 1990, Viverette et al. 1996), and regional droughts (Chapters 6 and 9). This indicates that understanding and describing the extent of migration dynamics will be critical to population monitoring. This is likely to become increasingly so, as such changes are likely to increase rather than decrease in the face of expanding human effects on both human-dominated and natural landscapes (Jetz et al. 2007).

The use of satellite tracking, including implementation of new systems employing GPS-logging, solar-powered "mini" tags for use on small, as well as, large raptors (Wikelski et al. 2007), together with other new tracking technologies such as cellular-telephone-based tracking units, can play an important role in helping RPI conservationists better understand ongoing changes in migration behavior, and in so doing help them more accurately interpret watchsite-count data.

Radar ornithology.—Developed for the military in the 1930s, radar uses radio waves to detect the range, direction of travel, and speed of moving objects in the air column. Systematic studies of raptor migration using radar date from the 1970s, when radar was used to detect migrants crossing the Strait of Gibraltar in southern Spain and migrants following the shorelines of the Great Lakes in southern Ontario, Canada (Bildstein 2006). Doppler weather-surveillance radar recently has been installed at 150 stations across the United States. Imagery from this array enables researchers to detect groups of raptor migrants up to 110 km away (Gauthreaux et al. 2001). Used only episodically to date, Doppler radar offers considerable potential for detecting large-scale movements of soaring migrants in the American West and elsewhere. Used in conjunction with on-the-ground counts of visible migrants to enumerate the migrants and identify them to species, Doppler radar could help RPI conservationists locate outbound and return flight lines of western Turkey Vultures and Swainson's Hawks, two relatively common migrants whose movements, for the most part, have yet to be sampled in large numbers north of the Rio Grande (see above), as well the flight lines of returning Broad-winged Hawks in eastern North America.

The use of radar ornithology can play an important role in determining where to site additional autumn watchsites outside of northeastern North America, as well as additional spring watchsites throughout North America.

Stable isotopes.—One potentially powerful technique for assessing the sources of raptors seen at watchsites uses geographic variation in relative occurrences of naturally occurring rare and common stable isotopes in the feathers of captured migrants to determine where the bird has come from (Hobson 2002, Lott and Smith 2006). Investigators already have used this technique to assess birth-place latitudes of young Cooper's Hawks (*A. cooperii*) migrating south through the Florida Keys (Meehan et al. 2001), as well as the origins of Sharp-shinned Hawks captured in eastern Nevada in autumn (Lott and Smith 2006). Although the technique remains in the early stages of development, and may be of limited use in certain circumstances, it offers a critical advantage over large-scale banding and trapping in being able to determine the origins of migrants seen at watchsites contemporaneously with counts collected there, something that banding and trapping data are not able to do in that they take many years to accumulate. Contemporaneous assessments of origins are likely to become increasingly important should migration behavior continue to change as anticipated.

The use of stable isotopes can play an important role in determining the geographic sources of raptors counted at watchsites.

Conclusions

Three factors drive the rate of success in conservation biology and monitoring: serendipity, advancing technology, and the appearance and acceptance of new ideas and paradigms (cf. Bildstein 1998b). All three of these factors are thriving in RPI. First, few other charismatic diurnal migrants line up at known locales as raptors do twice a year to have their populations checked by enthusiastic volunteers, and an underlying strength of RPI is its ability to take advantage of this serendipitous situation. Second, advancing technology in the form of satellite and GPS tracking, Doppler radar, and stable isotopes offer new opportunities for studying and understanding the geography of raptor migration. Third, a new appreciation for the dynamic nature and flexibility of raptor migration itself provides us with a new and useful paradigm for understanding the movement ecology of birds of prey.

These three factors, together with our recognition of areas in need of improvement (e.g., more watchsites outside of northeastern North America, more spring watchsites overall, improved statistical analyses, and more information on the geography of raptor migration), all but ensure success.

As we move to the next stage, we need to keep all of the above in mind as we work together with volunteer hawkwatchers and the greater conservation and scientific communities in ways that will strengthen our ability to provide increasingly accurate and timely conservation assessments of North America's birds of prey.

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