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Authors: Bildstein, Keith L., and Peterjohn, Bruce G.

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THE FUTURE OF BANDING IN RAPTOR SCIENCE

KEITH L. BILDSTEIN[1]
Acopian Center for Conservation Learning, Hawk Mountain Sanctuary, 410 Summer Valley Road, Orwigsburg, PA 17961 U.S.A.

BRUCE G. PETERJOHN
Bird Banding Laboratory, USGS Patuxent Wildlife Research Center, 12100 Beech Forest Road, Laurel, MD 20708 U.S.A.

ABSTRACT.—The future of conventional banding in raptor science depends upon the types of questions asked by scientists working in the field, and the extent to which banders and researchers continue their trapping and banding efforts. Traditionally, banding data have played two important roles in raptor science: assessing demographic statistics, including age at first breeding, survival rates, and mortality factors; and tracking movements of raptors, including migration, nomadic movements, and both natal and breeding dispersal. Recent decades have seen an explosive development and use of newer techniques to document the movements of raptors, including color leg-bands, wing-tags, conventional VHF tracking units, satellite-based UHF units, GPS-GSM units, and geolocating data loggers. All of these techniques have greatly facilitated our ability to track the movements of individual birds, broadening the field of movement ecology considerably, and shifting its emphasis from traditional population studies of migration toward detailed investigations of the ecology and geography of individual birds. Although conventional banding no longer plays as large a role in the study of raptor movements as it once did, its continued use can significantly complement the newer tools in use today, and can enhance our ability to understand the demographics and movements of raptors. For example, given banding's multi-decadal history, one potential use of banding data is in the assessment of the long-term effects of environmental changes, including climate, land-use, and contaminant changes, on both raptor demographics and movements. We believe that conventional banding remains an essential tool, for both the population biologist and the ecologist studying raptor movements, and that its usefulness in the field continues. We recommend that the emphasis of banding shift from short-term independent projects aimed at documenting movement patterns toward collaborative long-term efforts designed to provide insights into the factors influencing population responses to changing environments.

KEY WORDS: *banding*; *demography*; *migration*; *raptor*; *tracking*.

EL FUTURO DEL ANILLADO EN LA CIENCIA DE LAS RAPACES

RESUMEN.—El futuro del anillado convencional en la ciencia de las aves rapaces depende del tipo de preguntas que realicen los científicos que trabajan en el campo y del grado con el que los anilladores e investigadores continúen sus esfuerzos de captura y anillado. Tradicionalmente, los datos de anillado han jugado dos roles importantes en la ciencia de las rapaces: evaluando las estadísticas demográficas, incluyendo la edad del primer evento reproductivo, las tasas de supervivencia y los factores de mortalidad; y siguiendo los movimientos de las rapaces, incluyendo la migración, los movimientos nómades y la dispersión natal y reproductiva. En las últimas décadas se ha visto un desarrollo y uso explosivo de nuevas técnicas para documentar los movimientos de las rapaces, incluyendo anillos de colores en las patas, marcas en las alas, unidades convencionales de seguimiento VHF, unidades satelitales con base UHF, unidades GPS-GSM y geo-localizadores cargadores de datos. Todas estas técnicas han facilitado enormemente nuestra habilidad para seguir los movimientos de aves individuales, ampliando considerablemente el campo de la ecología del movimiento y cambiando su énfasis desde estudios poblacionales de migración tradicionales hacia investigaciones detalladas de la ecología y geografía de aves individuales. Aunque el anillado convencional no sigue jugando un papel tan importante en el estudio de los movimientos de las rapaces, la continuidad de su uso puede complementar significativamente las nuevas herramientas que se usan actualmente y puede fortalecer nuestra habilidad para entender la

[1] Email address: bildstein@hawkmtn.org

demografía y los movimientos de las rapaces. Por ejemplo, dada la historia de varias décadas de anillado, un uso potencial de los datos de anillado es la evaluación de los efectos de largo plazo de los cambios ambientales, incluyendo clima, uso del suelo y cambios contaminantes sobre la demografía y los movimientos de las rapaces. Creemos que el anillado convencional seguirá siendo una herramienta esencial, tanto para los biólogos poblacionales como para los ecólogos que estudian los movimientos de las rapaces, y que su utilidad en el campo continúa vigente. Por lo tanto, recomendamos que el énfasis en el anillado sea re-direccionado desde proyectos independientes de corto plazo centrados en documentar los patrones de movimiento, hacia esfuerzos colaborativos de largo plazo diseñados para brindar nociones sobre los factores que influyen las respuestas poblacionales a los cambios ambientales.

[Traducción del equipo editorial]

Although people have been trapping raptors for falconry and other purposes for at least 6000 years, trapping raptors for banding dates back only about 100 years. Conventional banding (i.e., the use of uniquely numbered, return-address metal bands) owes its origins to Danish schoolteacher Hans Christian Cornelius Mortensen, who began banding large numbers of birds in 1899 with numbered metal bands (Jespersen and Tåning 1950). Word of Mortensen's successes with the European Starlings (*Sturnus vulgaris*) he banded spread rapidly. Within 20 years, hundreds of birders and ornithologists were using banding to learn more about the movements and demographics of birds (Jackson et al. 2008, Vaughan 2009).

A report detailing the migratory movements of eight Rough-legged Hawks (*Buteo lagopus*) banded in northern Scandinavia appeared in the *Journal für Ornithologie* in 1913 (Jägerskiöld 1913). By 1935 more than 4000 raptors of 17 species had been banded in North America (Lincoln 1936). By the early 1950s, Lincoln reported that banding ''great numbers of individuals . . . with numbered aluminum leg rings has come to be recognized as a most accurate means of ornithological research'' (Lincoln 1952). (As an aside, Mortensen himself banded 92 raptors of 5 species over the course of his banding career. Intriguingly, 43 of Mortensen's birds were subsequently recovered [Jespersen and Tåning 1950], most of them having been shot.)

Raptor banding has continued to grow over the years, particularly in Europe and North America. By the beginning of the 21st century, approximately 1.5 million raptors had been banded in Canada and the United States. An additional 145 000 were ringed in Britain and Ireland between 1909 and 2000. For some raptor species, banding efforts are focused primarily on nestlings; whereas for others, including many *Accipiters*, most trapped birds are fully-flighted individuals caught at banding stations along major migration corridors.

Although remarkably few changes have been made since the concept of marking birds was introduced in the early 1900s, bird banding has undergone enormous growth, and today annually engages the activities of thousands of enthusiasts, spread widely over the northern continents. Over the years, the types and sizes of bands have evolved to include lock-on and rivet bands able to withstand the prying bills of large raptors, hard-metal bands able to better withstand constant exposure to harsh environments, and tiny pieces of numbered aluminum that can be wrapped around the legs of hummingbirds. The underlying concept, however, remains unchanged: a uniquely numbered piece of metal wrapped around the leg of a bird identifies this individual if it is encountered again. Jackson et al. (2008) and Newton (2008) detail the many ways in which banding has played a role, not only in assessing the movements and demographics of species, but also in the study of avian navigation, population monitoring, the restoration of declining and extirpated species, the management of migratory-bird hunting, and the study of avian behavior and the role of birds as vectors of disease, among others.

In contrast to banding, the technology surrounding other types of markers that are used to track the movements of birds has constantly moved forward (Newton 2008, Robinson et al. 2010). Initially, numbered metal bands were supplemented with colored plastic and metal leg bands and jesses, wing tags, and other types of markers that allowed for the identification of individual birds, including raptors, at a distance (Varland et al. 2007, Newton 2008).

Conventional VHF radio transmitters that at first permitted tracking individual raptors across relatively short distances subsequently have been used in conjunction with automobiles and fixed-wing aircraft to track migrants over longer distances (e.g., Cochran 1972, 1975; Beske 1982; Harmata 2002). Growth in the use of this study technique has been phenomenal. For example, a symposium on the population biology of migratory birds organized by the U.S. Fish and Wildlife Service in October of 1969 noted that the ''use of small transmitters to monitor the movements of migratory birds was carried out in only one study in the 1960s'' (Hickey 1972). By the mid-1980s, however, hundreds, if not thousands, of studies using this technique had been undertaken (e.g., Kenward 1987).

Satellite tracking, which extends detection ranges enormously over VHF radio transmitters, has been used to track migrants on intra- and intercontinental journeys since the 1980s (e.g., Fuller et al. 1998, Mandel et al. 2008), including individuals moving over large bodies of water (Kjéllen et al. 1997, Strandberg 2008). The units, called platform transmitter terminals or PTTs, are now tiny enough (<10 g) to permit their attachment on raptors as small as <300 g Eurasian Hobbies (*Falco subbuteo*; Strandberg et al. 2009) and <200 g Amur Falcons (*F. amurensis*; B. Meyburg pers. comm.). The units, which initially were developed at the U.S. Army's Applied Physics Laboratory in Maryland, are now often solar-powered, permitting reports of hundreds or even thousands of locations annually. GPS-(global positioning system) based units have increased locational accuracy to <20 m (Bildstein 2006). New generations of GPS-based tracking units equipped with GSM (global system for mobile communications) SIM-(subscriber identity module) cards now enable tracking via mobile phone networks, reducing the expense, and permitting larger downloads of data, such that researchers can track the movements of individual birds every 15 sec (T. Katzner pers. comm.).

Although this type of satellite tracking is still in its infancy, it is fast approaching the point of offering the ''holy grail'' of raptor-migration science: the ability to follow accurately the three-dimensional path of an individual migrant in near real time, throughout its annual cycle. However, satellite tracking has its limitations. One of these is expense: traditional Doppler and GPS satellite-reporting units typically cost at least $3000 each, and GPS-GSM cellular-phone-reporting units typically cost at least $1200. A second is mass: currently, satellite-reporting units typically weigh ≥10 g, and GPS-GSM units typically weigh ≥100 g, both of which place limits on the size of raptors to which they can be attached. A third, at least for GSM-communicating units, is the necessary presence of mobile-phone networks.

Geolocating data loggers (devices that, in principle, log the time of sunrise and sunset daily) avoid these problems in being less expensive (i.e., <$200 each) and less massive (i.e., <2.0 g), and not dependent on mobile-phone networks. Unfortunately this technology too has its limitations, including decreased locational accuracy in certain places (e.g., equatorially) and at certain times of the year (e.g., equinox), the need to recapture the bird to retrieve and download the data, and the potential for physical damage to loggers that prevent downloading. Indeed, although this technique is eminently useful in principle, one of the first studies of raptor migration using this technique reported usable data from only 7 of 15 deployed units due to a combination of physical damage and difficulties with recapture (Rodríguez et al. 2009). Even with these caveats, the new technologies offer far more information than the ''Point A to Point B model'' of conventional banding, in which only two locations are known (i.e., the banding and recovery site).

The recent technological advances raise an interesting question: given the expansion of new techniques, what is the future of conventional banding? Return rates of conventional bands from nonhunted species are relatively low, falling generally in the range of 2–10% for most raptors (Bildstein 2006). Thus, tens of thousands of metal bands must be placed on birds to develop an understanding of the most general patterns of bird movements. Even then, a geographical bias in recoveries (northern-hemisphere recoveries are far more likely than southern-hemisphere recoveries, for example, as are recoveries in developed versus developing countries) makes it all but impossible to secure data from many places migrants visit. In addition, recovery rates presumably have fallen over the years as fewer raptors are shot (Newton 1979). In contrast, data from a small number of satellite transmitters can document these movements in greater detail, including passage over areas where banded birds are unlikely to be recorded, such as over open water. Although new techniques are considerably more expensive than conventional banding, these techniques provide large quantities of specific types of information, which often justifies the greater cost. Because many raptors are large enough to carry the new devices safely, they have been among the first groups of birds to be studied using these new techniques (Bildstein 2006, Newton 2008).

Below we review the challenges and opportunities for conventional banding in modern raptor science and offer our vision of how banding can continue to serve the discipline.

CHALLENGES, OPPORTUNITIES, AND RECOMMENDATIONS

Historically, raptor banding has occurred on a broad scale across most of North America. The majority

(53%) of hawk-banding records are during autumn migration. Another 26% occur during summer when large numbers of nestlings are banded. Owl banding also peaks (43%) during autumn migration reflecting recent collaborative efforts by Project Owlnet (www.projectowlnet.org) to monitor the movements of Northern Saw-whet Owls (*Aegolius acadicus*) across eastern North America. Most other owl banding is more equally divided between spring and summer seasons. Although analyses of the banding-station data have made significant contributions to the raptor literature (e.g., Clark 1985, Mueller et al. 2004, Goodrich and Smith 2008), these data largely have been underused by the raptor community, and much remains to be done to improve our use of this important resource.

Specific aspects of banding efforts in need of expansion or improvement include (1) the reporting of regional and continental summaries of banding encounters accumulating from these efforts, (2) the use of banding data in population monitoring and measurement of mortality both regionally and continentally, (3) the assessment of leapfrog and chain migration in species, (4) the use of banding data for describing natal and breeding dispersal, and (5) the standardization of protocols for collecting body-measurement and other ancillary data and samples at the time of banding. We address each of these below.

Regional and Continental Summaries of Banding Encounters. To our knowledge, the only recently published, continent-wide analysis of raptor banding data is Goodrich and Smith (2008). This report focused on assessing the extent of migratory connectivity (*sensu* Crooks and Sanjayan 2006) in Sharp-shinned Hawks (*Accipiter striatus*) across North America. Although the findings of ''distinct longitudinal differentiation of migration corridors'' and ''significant overlap of regional breeding populations on the non-breeding range'' were not particularly surprising, Goodrich and Smith (2008) provide an excellent model for further studies involving other species of raptors. We recommend that proponents of conventional banding foster thoughtful and thorough regional and continental summaries of banding encounters, including assessment of the degree of migratory connectivity in the populations involved. New analytical approaches may be required to better account for the biases inherent in banding and band-encounter data sets, and to provide a more robust analysis of movement patterns.

Population Monitoring and Assessing of Mortality. The most extensive data-gathering banding effort in these areas involves waterfowl in North America. Early assessments of the importance of banding to population monitoring in this group included Geis (1972), who stated that ''banding data are essential in order to understand population dynamics of migratory birds.'' Banding data are helpful for assessing waterfowl harvest pressure and estimating population sizes, survival, and reproductive rates, all essential to understanding the effects of harvest and survival on population dynamics and management (Blohm 2008). A series of monographs describing the population dynamics of Mallards (*Anas platyrhynchos*) illustrated how banding data influenced the evolution of harvest management for waterfowl (Pospahala et al. 1974, Anderson 1975, Anderson and Burnham 1976). Early reports of raptor banding efforts, too, often highlighted the fact that many banded raptors were subsequently shot (e.g., Lincoln 1936, Broley 1947, Henny and Wight 1972, Newton 1979). Band-encounter rates have declined now that fewer raptors are being shot, and these reduced encounter rates may pose challenges toward our understanding of the factors currently affecting raptor mortality. Unfortunately, few recent studies have looked at potential mortality factors and temporal patterns of individual factors. Notable exceptions include Clark and Gorney (1987), who reported the numbers of oil-contaminated raptors they encountered while trapping migrants in southern Israel, and Wernham et al. (2002), who provided the recovery circumstances for raptors banded in Great Britain. In at least some groups of passerines, survivorship is lowest during migratory periods (Sillett and Holmes 2002); the extent to which this is true in raptors has yet to be studied formally. Although the new marking techniques also offer an opportunity to examine this question, the historical scope of conventional banding provides the potential of tracking survivorship within and outside the migratory period across decades. We recommend that banders use current and historical data to investigate the causes of death for banded raptors (with the caveat that banding recoveries are biased toward raptors dying of human-related causes and in areas of dense human populations). We also recommend that the Bird Banding Laboratory maintain consistent useful ''how obtained'' codes that will allow appropriate inferences to be made from these data.

Year-to-year changes in survivorship of juveniles, subadults, and adults can be important factors influencing population fluctuations in many raptors (e.g., Newton et al. 1993 and Newton et al. 1997), because even relatively small changes in survival rates can result in significant changes in population trends. Site fidelity of adults during the breeding season allows apparent survival rates to be most readily estimated at that time of the year, but requires collection of recapture and resighting data over long periods of time. Unfortunately, the Bird Banding Laboratory does not currently maintain recapture and resighting data obtained from banding locations, although it is in the process of developing systems to maintain these data. We recommend that the Bird Banding Laboratory complete development of an operational recapture-resighting database that potentially could enable the estimation of survival rates and other demographic parameters. Once the recapture-resighting database becomes operational, we strongly encourage all raptor banders to routinely submit their recapture and resighting data to the Bird Banding Laboratory to facilitate population-level analyses of demographic parameters across broad geographic and temporal scales.

Recent advances in the monitoring of continental raptor populations through the Raptor Population Index (RPI) program have produced estimates of current population trends based on counts of migrant raptors (Bildstein et al. 2008). Although RPI provides estimates of population change, it does not necessarily provide insights into the causes of these changes. Information on population demographic parameters, such as survival and reproductive rates, provides insights into the factors responsible for population change and provides important complementary data for the population-trend estimates based on migration counts. Properly designed and conducted, long-term cooperative banding efforts can provide the data needed to estimate many demographic parameters. A good example of this concept is the Monitoring Avian Productivity and Survivorship (i.e., MAPS) program coordinated by the Institute for Bird Populations (www.birdpop.org). We encourage the development of cooperative long-term banding efforts that will provide specific estimates of demographic parameters over time. We also encourage the development of large-scale collaborative efforts that will help estimate these parameters over large geographic areas.

Assessment of Leapfrog and Chain Migration. Two contrasting geographic patterns of avian migration, leapfrog migration and chain migration, have been recognized for some time (Holmgren and Lundberg 1993, Smith et al. 2003, Bildstein 2006, Newton 2008). Leapfrog migration occurs when populations breeding at high latitudes migrate farther than those breeding at lower latitudes and therefore ''leap over'' their more equatorial counterparts. Chain migration occurs when populations breeding at high latitudes, migrate approximately the same distance as their more equatorial counterparts. The extent to which these two migration patterns result from competitive interactions among the populations involved remains largely unstudied. In Turkey Vultures (*Cathartes aura*), at least, subspecies differences in competitive abilities appear to play an important role in migration patterns, with equatorial populations of the species evacuating breeding areas in northern South America when the larger and more numerous North American migrants arrive in these areas in autumn (Kirk and Gosler 1994, Bildstein et al. 2007). The extent to which the arrival of one population of raptors in an area affects the movement ecology of populations that breed in that area can provide new insights into factors affecting both the distributions and abundances of raptors (Newton 2008). We encourage the study and documentation of both leapfrog and chain migration in raptors via the analysis of existing banding databases, together with complementary studies of the behavioral ecology of the populations involved.

Assessment of Dispersal in Raptors. Dispersal, the movement of individuals from one place of residence to another, generally in no fixed direction (Bullock et al. 2002), is common in raptors, especially among recently fledged individuals (Ferguson-Lees and Christie 2001, Newton 2008). Historically, one of the least understood aspects of movement in birds, dispersal (Gadgil 1971) appears to have significant consequences in raptor demographics (Newton and Marquiss 1983, Newton and Moss 1986, Newton et al. 1989, Ferrer 1993, Newton 2008) and raptor movement ecology (Cox 1985, Bildstein 2006). In at least several species of birds including raptors, juvenile dispersal (i.e., the dispersal of recently fledged young from their birthplace) appears to be linked to ''nursery areas'' from which they sometimes return to their birthplaces after one of more years of immaturity (e.g., Ferrer 1993). Knowledge of the movements and distributions of birds during this critical period of life is important for understanding the extent to which factors, including human-related threats, affect their demographics and conservation status (Weimerskirch et al. 2006). Other forms of dispersal, including natal dispersal (i.e., the movement from birthplace to the site of the first breeding attempt [Greenwood 1980]), breeding dispersal (i.e., the movements of individuals between nesting sites in successive years [Newton 2008]), may also be addressed using banding data. We encourage the continued study and documentation of natal and other forms of dispersal using both conventional banding and other more recently developed techniques, to better understand this critical aspect of the life history of raptors. The development of a database for recapture and resighting records will likely provide a valuable contribution to these studies by documenting recruitment rates of locally produced young to breeding populations.

Standardization of Protocols for Collecting Body-measurement and Other Ancillary Data. One of the most underused potential benefits of bird banding is the application of consistent protocols for obtaining measurements from birds in the hand and collecting tissue samples (e.g., feathers, blood) for isotopic, DNA, and contaminants analysis, etc., from birds during banding. To date no such standard protocols exist. A banding manual for this purpose produced by the North American Banding Council (Hull and Bloom 2001) is a good start, but needs updating. Protocols in this publication, along with information in recent cautionary papers on the subject of tissue sampling (e.g., Bortolotti 2010, Torres-Dowdall et al. 2010), and the use of new measurements in determining sex in monomorphic raptors (e.g., Muriel et al. 2010), should be incorporated into new standard protocols for use by all raptor biologists. We recommend that researchers handling birds collaborate in producing standard protocols for use in tissue sampling and the collection of ancillary data. The Bird Banding Laboratory should facilitate archiving ancillary data, and, as appropriate, alert banders to ongoing studies involving tissue sampling so that they might provide samples.

The historical and geographical scope of North American raptor banding offers researchers the data needed to conduct both long-term and large-scale studies. We believe that this may be one of its most valuable uses in the future. Although the usefulness of banding data in documenting long-term changes in raptor population dynamics was recognized almost 40 yr ago (Henny and Wight 1972), the use of banding data to study long-term trends in demographic parameters has not reached its full potential. Henny and Wight (1972) is perhaps best known for its use of band-recovery data for Cooper's Hawks (*Accipiter cooperii*) to estimate long-term declines in first-year mortality due to shooting of 28–47% in 1929–40 to 12–21% in 1946–67. The study also used information gleaned from banders to document long-term declines in the average numbers of banded nestlings in clutches of 3.53 per nest to 2.67 per nest in Cooper's Hawks across the same time frame. Unfortunately few, if any, successors to this work exist.

Another use for historical banding data is in assessing long-term changes in migration behavior due to climate change and large-scale land-use change (Lemoine and Böhning-Gaese 2003). An immediate example is documenting the extent to which migration short-stopping (*sensu* Raveling 1978) is occurring in raptors. First mentioned as a possibility in raptors in Henny and Brady (1994), migration short-stopping was more formally developed in Duncan (1996) and Viverette et al. (1996) as an explanation for declining numbers of Sharp-shinned Hawks counted at migration watchsites in the northeastern United States in the 1980s. Since then, short-stopping has been reported in a number of raptors, including Rough-legged Hawks in North America (Pandolfino and Wells 2009) and Common Buzzards (*Buteo buteo*; Strandberg 2008) in Europe. Although the exact reasons for migratory short-stopping appear to differ among species, several migration biologists have suggested the likelihood of reduced migration in response to milder winters associated with climate change (Berthold 2001, Bildstein 2006, Newton 2008). In addition, a model based on temperature and resource-availability shifts on the breeding grounds projects an overall reduction in migratory behavior in birds in the temperate zone (Lemoine and Böhning-Gaese 2003), suggesting that studies in this area will be of value.

Finally, we note that the historical nature of banding data allows for their use in tracking the timing of the irruptive movements of raptors (Newton 2008), a phenomenon that may be collapsing recently, in parallel with the cyclic nature of the prey populations on which they depend (Ims et al. 2008). The use of multi-decadal banding data can play an important and, possibly, unique role in identifying long-term trends in population dynamics, mortality factors, and the movements of raptors. To reach this potential, we recommend that banding efforts shift from those of independent banders conducting short-term projects to long-term multi-investigator collaborative efforts designed to obtain data that will provide needed information on how raptor populations are responding to their changing environments.

CONCLUSIONS

Studies of raptor demography and raptor movements fall into several categories, including the movements and demographics of local, regional, and continental populations of raptors; how movements affect the populations in question; changes in the extent and geography of migration patterns over time; and the ways in which these factors are responsible for changes in the population dynamics and conservation status of the birds involved. Other studies focus mainly on the timing, navigation and orientation, and geography of migration; variability in migration both seasonally, and within and between age and sex classes; and the orientation mechanisms and navigational cues raptors use to find their wintering and breeding grounds (i.e., the how of raptor migration). Although all such studies are linked, they use slightly different tools to answer the questions at hand. Traditionally, conventional banding has played a larger role in the raptor demography (Henny and Wight 1972, Newton et al. 1993, 1997) and the ecological and geographical aspects of migration studies (e.g., Geis 1972, Jackson et al. 2008, Vaughan 2009), whereas many of the newer techniques have provided information on more of the behavioral aspects of raptor movements (e.g., Martell et al. 2001, Bildstein 2006, McIntyre et al. 2008). We recommend that all of these tools continue to be used to foster the progress of our understanding of both raptor demographics and movements.

One of the greatest strengths of conventional banding has been the extensive application of this technique across most of the 20th and early 21st centuries. This provides researchers with potential historical records of both raptor demography and movements during this period. These historical data could be used now to address five important areas of interest: (1) the assessment of the migratory short-stopping, and the extent to which climate change, large-scale land-use change, and bird feeders may have played a role in migration shifts (Bildstein 2006); (2) the documentation of the effects of recently fading cycles of high-latitude voles and grouse (Ims et al. 2008) on cycles of high-latitude populations of Northern Goshawks (*Accipiter gentilis*); (3) the study of conditions associated with leapfrog and chain migration; (4) the assessment of causes and consequences of dispersal, and; (5) the examination of long-term shifts in mortality factors in raptors relative to their fluctuating populations throughout most of the 20th century, following the lead of Henny and Wight (1972).

As we move toward future stages in studies of the demography and movements of raptors, we recommend that amateur and professional banders, ecologists and ornithologists, and others strengthen their collaborative efforts to enhance the impact of conventional banding in improving our understanding of raptor ecology and promoting the conservation of raptor populations.

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LITERATURE CITED

ANDERSON, D.R. 1975. Population ecology of the Mallard. V. Temporal and geographic estimates of survival, recovery and harvest rates. U.S. Fish and Wildlife Service Resource Publication 125, USDI, Washington, DC U.S.A.

——— AND K.P. BURNHAM. 1976. Population ecology of the Mallard. VI. The effect of exploitation on survival. U.S. Fish and Wildlife Service Resource Publication 128, USDI, Washington, DC U.S.A.

BERTHOLD, P. 2001. Bird migration: a general survey, Second Ed. Oxford Univ. Press, Oxford, U.K.

BESKE, A.E. 1982. Local and migratory movements of radio-tagged juvenile harriers. *Raptor Research* 16:39–53.

BILDSTEIN, K.L. 2006. Migrating raptors of the world: their ecology and conservation. Cornell University Press, Ithaca, NY U.S.A.

———, M.J. BECHARD, P. PORRAS, E. CAMPOS, AND C.J. FARMER. 2007. Seasonal abundances and distributions of Black Vultures (*Coragyps atratus*) and Turkey Vultures (*Cathartes aura*) in Costa Rica and Panama: evidence for reciprocal migration in the neotropics. Pages 47–60 *in* K.L. Bildstein, D.R. Barber, and A. Zimmerman [EDS.], Neotropical raptors. Hawk Mountain Sanctuary, Orwigsburg, PA U.S.A.

———, J.P. SMITH., E. RUELAS INZUZA, AND R.R. VEIT. [EDS.]. 2008. State of North America's birds of prey. *Series in Ornithology No. 3,* Nuttall Ornithological Club, Cambridge, MA U.S.A. and the American Ornithologists' Union, Washington, DC U.S.A.

BLOHM, R.J. 2008. The role of bird banding in management of migratory bird hunting. Pages 163–179 *in* J.A. Jackson, W.E. Davis, Jr., and J. Tautin [EDS.]. Bird banding in North America: the first hundred years. *Memoirs of the Nuttall Ornithological Club No. 15.*

BORTOLOTTI, G.R. 2010. Flaws and pitfall in the chemical analysis of feathers: bad news-good news for avian chemoecology and toxicology. *Ecological Applications* 20:1766–1774.

BROLEY, C.L. 1947. Migration and nesting of Florida Bald Eagles. *Wilson Bulletin* 59:3–20.

BULLOCK, J.M., R.E. KENWARD, AND R.S. HALIS. 2002. Dispersal ecology. Blackwell Publishing, Oxford, U.K.

CLARK, W.S. 1985. The migrating Sharp-shinned Hawk at Cape May Point: banding and recovery results. Pages 137–148 *in* M. Harwood [ED.], Proceedings of Hawk Migration Conference IV. Hawk Migration Association of North America, Lynchburg, VA U.S.A.

——— AND E. GORNEY. 1987. Oil contamination of raptors migrating along the Red Sea. *Environmental Pollution* 46:307–313.

COCHRAN, W.W. 1972. A few days of migration of a Sharp-shinned Hawk. *Hawk Chalk* 11:39–44.

———. 1975. Following a migrating peregrine from Wisconsin to Mexico. *Hawk Chalk* 14:28–37.

COX, G.W. 1985. The evolution of avian migration systems between temperate and tropical regions of the New World. *American Naturalist* 126:451–474.

CROOKS, K.R. AND M. SANJAYAN. 2006. Connectivity conservation. Cambridge University Press, Cambridge, U.K.

DUNCAN, C.D. 1996. Changes in the winter abundance of Sharp-shinned Hawks in New England. *Journal of Field Ornithology* 67:254–262.

FERGUSON-LEES, J. AND D.A. CHRISTIE. 2001. Raptors of the world. Houghton Mifflin Company, Boston, MA U.S.A.

FERRER, M. 1993. Juvenile dispersal behavior and natal philopatry of a long-lived raptor, the Spanish Imperial Eagle *Aquila adalberti. Ibis* 135:132–138.

FULLER, M.R., W.S. SEEGAR, AND L.S. SCHUECK. 1998. Routes and travel rates of migrating Peregrine Falcons *Falco peregrinus* and Swainson's Hawks *Buteo swainsoni* in the Western Hemisphere. *Journal of Avian Biology* 29:433–440.

GADGIL, M. 1971. Dispersal: population consequences and evolution. *Ecology* 52:253–261.

GEIS, A.D. 1972. Role of banding data in migratory bird population studies. Pages 213–228 *in* Population ecology of migratory birds. USDI Bureau of Sport Fisheries and Wildlife, Wildlife Research Report 2. Washington, DC U.S.A.

GOODRICH, L.J. AND J.P. SMITH. 2008. Raptor migration in North America. Pages 37–150 *in* K.L. Bildstein, J.P. Smith, E. Ruelas Inzunza, and R.R. Veit [EDS.], State of North America's birds of prey. *Series in Ornithology No. 3,* Nuttall Ornithological Club, Cambridge, MA U.S.A. and the American Ornithologists' Union, Washington, DC U.S.A.

GREENWOOD, P.J. 1980. Mating systems, philopatry, and dispersal in birds and mammals. *Animal Behaviour* 28:1140–1162.

HARMATA, A.R. 2002. Vernal migration of Bald Eagles from a southern Colorado wintering area. *Journal of Raptor Research* 36:256–264.

HENNY., C.J. AND G.L. BRADY. 1994. Partial migration and wintering localities of American Kestrels nesting in the Pacific Northwest. *Northwestern Naturalist* 75: 37–43.

——— AND H.M. WIGHT. 1972. Population ecology and environmental pollution: Red-tailed Hawk and Cooper's Hawk. Pages 229–250 *in* Population ecology of migratory birds. USDI Bureau of Sport Fisheries and Wildlife, Wildlife Research Report 2. Washington, DC U.S.A.

HICKEY, J.J. 1972. Population ecology of migratory birds: symposium summary. Pages 263–271 *in* Population ecology of migratory birds. USDI Bureau of Sport Fisheries and Wildlife, Wildlife Research Report 2. Washington, DC U.S.A.

HOLMGREN, N. AND S. LUNDBERG. 1993. Despotic behaviour and the evolution of migration patterns in birds. *Ornis Scandinavica* 24:103–109.

HULL, B. AND P. BLOOM. 2001. The North American banders' manual for raptor banding techniques. North American Banding Council, Point Reyes Station, CA U.S.A.

IMS, R.A., J.-A. HENDEN, AND S.T. KILLENGREEN. 2008. Collapsing population cycles. *Trends in Ecology and Evolution* 23:79–86.

JACKSON, J.A., W.E. DAVIS, JR., AND J. TAUTIN. [EDS.]. 2008. Bird banding in North America: the first hundred years. *Memoirs of the Nuttall Ornithological Club No. 15.* Cambridge, MA U.S.A.

JÄGERSKIÖLD, L.A. 1913. Über die im Sommer 1911 in Schwedisch-Lappland vorgenommene Markierung von Rauhfufsbussarden (*Archibuteo lagopus* L.). *Journal für Ornithologie* 61:380–383.

JESPERSEN, P. AND Å.V. TÅNING. [EDS.]. 1950. Studies in bird migration: being the collected papers of H. Chr. C. Mortensen. Munksgaard, Copenhagen, Denmark.

KENWARD, R. 1987. Wildlife radio tagging. Academic Press, London, U.K.

KIRK, D.A. AND A.G. GOSLER. 1994. Body condition varies with migration and competition in migrant and resident South American vultures. *Auk* 111:933–944.

KJÉLLEN, N., M. HAKE, AND T. ALERSTAM. 1997. Strategies of two Ospreys *Pandion haliaetus* migrating between Sweden and Africa as reveled by satellite tracking. *Journal of Avian Biology* 28:15–23.

LEMOINE, N. AND K. BÖHNING-GAESE. 2003. Potential impact of global climate change on species richness of long-distance migrants. *Conservation Biology* 17:577–587.

LINCOLN, F.C. 1936. Recoveries of banded birds of prey. *Bird Banding* 7:38–45.

———. 1952. Migration of birds. Doubleday and Co., Garden City, NY U.S.A.

MANDEL, J.T., K.L. BILDSTEIN, G. BOHER, AND D.W. WINKLER. 2008. Movement ecology of migration in Turkey Vultures. *Proceedings of the National Academies of Science* 49:19102–19107.

MARTELL, M., C. HENNY, P. NYE, AND M. SOLENSKY. 2001. Fall migration routes, timing, and wintering sites of North American Ospreys as determined by satellite telemetry. *Condor* 103:715–724.

MCINTYRE, C.L., D.C. DOUGLAS, AND M.W. COLLOPY. 2008. Movements of Golden Eagles (*Aquila chrysaetos*) from interior Alaska during their first year of independence. *Auk* 125:214–224.

MUELLER, H.C., D.D. BERGER, N.S. MUELLER, W. ROBICHAUD, AND J.L. KASPAR. 2004. Temporal changes in size of Sharp-shinned Hawks during fall migration at Cedar Grove, Wisconsin. *Journal of Field Ornithology* 75:386–393.

MURIEL, R., E. CASADO, D. SCHMIDT, C.P. CALABUIG, AND M. FERRER. 2010. Morphometric sex determination of young Ospreys *Pandion haliaetus* using discriminant analysis. *Bird Study* 57:336–343.

NEWTON, I. 1979. Population ecology of raptors. Buteo Books, Vermillion, SD U.S.A.

———. 2008. The migration ecology of birds. Academic Press, London, U.K.

——— AND M. MARQUISS. 1983. Dispersal of sparrowhawks between birthplace and breeding place. *Journal of Animal Ecology* 52:463–477.

——— AND D. MOSS. 1986. Post-fledging survival of sparrowhawks *Accipiter nisus* in relation to mass, brood size and brood composition at fledging. *Ibis* 128:73–80.

———, P. ROTHERY, AND I. WYLLIE. 1997. Age-related survival in female sparrowhawks *Accipiter nisus*. *Ibis* 139:25–30.

———, I. WYLLIE, AND P. ROTHERY. 1993. Annual survival of sparrowhawks *Accipiter nisus* breeding in three areas of Britain. *Ibis* 135:49–60.

PANDOLFINO, E.R. AND K.S. WELLS. 2009. Changes in the winter distribution of Rough-legged Hawk in North America. *Western Birds* 40:210–224.

POSPAHALA, R.S., D.R. ANDERSON, AND C.J. HENNY. 1974. Population ecology of the Mallard. II. Breeding habitat conditions, size of the breeding populations, and production indices. U.S. Fish and Wildlife Service Resource Publication 115. USDI, Washington, DC U.S.A.

RAVELING, D.G. 1978. Dynamics of distribution of Canada Geese in winter. *North American Wildlife and Natural Resources Conference Transactions* 43:206–225.

ROBINSON, W.D., M.S. BOWLIN, I. BISSON, J. SHAMOUN-BARANES, K. THORUP, R.H. DIEHL, T.H. KUNZ, S. MABEY, AND D.W. WINKLER. 2010. Integrating concepts and technologies to advance the study of bird migration. *Frontiers in Ecology and the Environment* 8:354–361.

RODRÍGUEZ, A., J.J. NEGRO, J. BUSTAMANTE, J.W. FOX, AND V. AFANASYEV. 2009. Geolocators map wintering grounds of threatened Lesser Kestrels in Africa. *Diversity and Distributions* 15:1010–1016.

SILLETT, T.S. AND R.T. HOLMES. 2002. Variation in survivorship of a migratory songbird throughout its annual cycle. *Journal of Animal Ecology* 71:296–308.

SMITH, R.B., T.D. MEEHAN, AND B.O. WOLF. 2003. Assessing migration patterns of Sharp-shinned Hawks *Accipiter striatus* using stable-isotope and band encounter analysis. *Journal of Avian Biology* 34:387–394.

STRANDBERG, R. 2008. Migration strategies of raptors. Ph.D. dissertation, Univ. of Lund, Lund, Sweden.

———, R.H.G. KLAASSEN, M. HAKE, P. OLOFSSON, AND T. ALERSTAM. 2009. Converging migration routes of Eurasian Hobbies *Falco subbuteo* crossing the African equatorial rain forest. *Proceedings of the Royal Society of London B* 276:727–733.

TORRES-DOWDALL, A.H. FARMER, M. ABRIL, E.H. BUCHER, AND I. RIDLEY. 2010. Trace elements have limited utility for studying migratory connectivity in shorebirds that winter in Argentina. *Condor* 112:490–498.

VARLAND, D.E., J.A. SMALLWOOD, L.S. YOUNG, AND M.N. KOCHERT. 2007. Pages 193–220 *in* D.M. Bird and K.L. Bildstein [EDS.], Raptor research and management techniques, Hancock House Publ. Ltd., Blaine, WA U.S.A.

VAUGHAN, R. 2009. Wings and rings: a history of bird migration studies in Europe. Isabelline Books, Penryn, Cornwall, U.K.

VIVERETTE, C.B., S. STRUVE, L.J. GOODRICH, AND K.L. BILDSTEIN. 1996. Decreases in migrating Sharp-shinned Hawks (*Accipiter striatus*) at traditional raptor-migration watchsites in eastern North America. *Auk* 213:32–40.

WERNHAM, C.V., M.P. TOMS, J.H. MARCHANT, J.A. CLARK, G.M. SIRIWARDENA, AND S.R. BAILLIE. 2002. The migration atlas: movements of the birds of Britain and Ireland. T. and A.D. Poyser, London, U.K.

WEIMERSKIRCH, H., S. AKESSON, AND D. PANAUD. 2006. Postnatal dispersal of Wandering Albatrosses *Diomedea exulans*: implications for the conservation of the species. *Journal of Avian Biology* 37:23–28.

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