# Migration Counts and Monitoring

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Long-distance raptor migration has fascinated humanity for thousands of years. Palearctic accounts of the phenomenon date from the Old Testament (Job 39:26–29). Western Hemisphere accounts date from within 30 years of European settlement (Baughman 1947). Today, premiere raptor-migration watchsites, such as those in Eilat, Israel (International Birdwatching Center Eilat 1987), and at Hawk Mountain Sanctuary, U.S.A. (Allen et al. 1995, Bildstein and Compton 2000), attract tens of thousands of visitors annually (Fig. 1). In North America, the Hawk Migration Association of North America — an organization of more than 400 members — is devoted entirely to the study and conservation of migrating raptors.

Because of long-standing interest in raptor migration, specialists in the field know much about the flight mechanics and geography of the phenomenon (Kerlinger 1989, Zalles and Bildstein 2000, Bildstein 2006).

**Figure 1.** Hawk Mountain Sanctuary (top) and Eilat, Israel (below). The view at Hawk Mountain Sanctuary is to the east along the Kittatinny Ridge from the North Lookout. Populations of 16 species of North American breeders have been monitored at the site since 1934. The view at Eilat is to the south, toward the Gulf of Aqaba from near Mt. Yoash. Populations of 38 species of European and Asian breeders have been monitored at the site since 1977. *(Hawk Mountain photo by M. Linkevich; Eilat photo by K. Bildstein)*

And indeed, in many ways, the movements of the world's more than 183 species of migratory raptors are better documented than those of any other avian taxon (Zalles and Bildstein 2000, Bildstein 2006). Studies of migrating raptors have made major contributions, both to avian ecology (Newton 1979) and to conservation biology (e.g., Newton and Chancellor 1985, Senner et al. 1986, Meyburg and Chancellor 1994, Chancellor et al. 1998, Yosef et al. 2002, Thompson et al. 2003, Yosef and Fornasari 2004). The status of raptor-migration science is especially solid with regard to spatial and temporal patterns of migration, particularly along major migratory corridors in North America, the Western Palearctic, and portions of the Middle East (Shirihai et al. 2000, Zalles and Bildstein 2000, Hoffman et al. 2002, Bildstein 2006). On the other hand, much remains to be learned of raptor migration elsewhere, as well as about the principal causes and consequences of raptor migration.

Kerlinger (1989) and Bildstein (2006) provide thorough reviews of many aspects of raptor-migration science, including the principal methods of study used to date (Appendix 1). Zalles and Bildstein (2000), Bildstein and Zalles (2005), and Bildstein (2006) detail the patterns and processes of the global geography of the flight. Bildstein (1998a) reviews the status of raptor-migration science through the mid-1990s.

In this chapter we detail the rationale and methods involved in sampling the visible migration of raptors at established raptor-migration watchsites (including the means by which watchsites are identified), guidelines for data recording, information on the ways in which migration-count data can be stored for later analysis, and how resulting status and trends data can be communicated to the scientific community. We then discuss migration counts within the perspective of long-term monitoring, presenting and exploring the use of such counts as indexes of regional population trends. We offer an operational definition of environmental monitoring, and conclude by outlining a procedure for designing long-term monitoring efforts at watchsites.

## RAPTOR MIGRATION WATCHSITES

Raptors are secretive, wide-ranging, highly mobile avian predators whose populations can be both logistically difficult and financially prohibitive to survey and monitor (Fuller and Mosher 1981, 1987). One potentially cost-effective method for monitoring regional populations of raptors is sampling their numbers during migration at one or more migration watchsites along traditional migration corridors (Bildstein 1998b, Zalles and Bildstein 2000).

Counts of migrating raptors at established watchsites have been used to study raptor migration ecology since the late nineteenth century (Kerlinger 1989, Bildstein 2006). Recently, counts of visible raptor migration at watchsites (hereafter referred to as migration counts) have helped determine the conservation status of migratory populations of raptors (Carson 1962, Hickey 1969, Bednarz et al. 1990, Bildstein 1998b, Hoffman and Smith 2003, Yosef and Fornasari 2004). In addition to their value in monitoring regional populations of raptors, migration counts have helped identify principal migration routes, assess the phenology of raptor migration, and determine raptor flight dynamics and other aspects of raptor behavior (Smith 1980, 1985a,b; Kerlinger 1989, Zalles and Bildstein 2000, Bildstein and Zalles 2001, Hoffman et al. 2002).

Indeed, because they are cost-effective and relatively easy to implement, migration counts are one of the most commonly used methods in raptor migration science (Kerlinger 1989, Bildstein 1998b). Conducted over time, migration counts have been used to determine daily and seasonal timing of migration, species diversity, and the volume of migration as a function of weather (Haugh 1972, Kerlinger 1989). In addition, direct visual observations associated with migration counts have yielded valuable information on the behavior of migrating raptors, including the relative use of flight patterns (e.g., soaring versus flapping flight), flocking behavior, interspecies interactions, roosting behavior, and weather effects (Kerlinger 1989, Allen et al. 1996, Yates et al. 2001).

Although the use of migration counts to indicate raptor population trends is not without its limitations, and although statistical methods regarding their analyses continue to be modified (Hussell 1985, Fuller and Titus 1990, Titus et al. 1990, Hoffman and Smith 2003), preliminary evaluations of the usefulness of such counts for determining population trends are encouraging (Bednarz and Kerlinger 1989, Dunn and Hussell 1995). Properly collected and analyzed, such data can provide valuable information regarding population fluctuations in these species (Bednarz et al. 1990, Bildstein 1998b, Hoffman and Smith 2003, Yosef and Fornasari 2004).

## MIGRATION-COUNT TECHNIQUES

### Identifying Objectives

Both long- and short-term studies of raptor populations benefit greatly from careful planning and attention to study design (Fuller and Mosher 1987, Titus et al 1989, Fish 2001). The first step in designing a count effort is to define its objectives. Is the goal of data collection to monitor the passage of all species of raptors in the region, or only certain species? Is the focus of the effort on autumn migration, spring migration, or both? Goldsmith (1991), Spellerberg (1991), and Fish (2001) provide valuable suggestions with regard to identifying objectives of monitoring programs.

### Choosing a Site

Once objectives have been established it is necessary to identify a watchsite: the place from which migrating raptors are seen and counted. Watchsites include sites from which migratory raptors can be counted as they migrate past, as well as sites from which they can be observed entering or departing nighttime roosts. Most watchsites are along principal migration corridors, routes that raptors regularly use during their long-distance movements. Identifying these routes is the first step in determining where to locate a watchsite. Although many raptors migrate across broad fronts (cf. Bednarz and Kerlinger 1989), many concentrate during migration along "leading lines" and "diversion lines." As originally described by Geyr von Schweppenburg (1963), leading lines are narrow and relatively long geographical and topographical features that intersect with the principal axis of migration in a region, and whose properties attract migrants to them and induce them to change their direction of travel to follow the leading line. In addition to mountain ridges and their associated deflection updrafts, leading lines include rivers and associated riparian areas that often attract and concentrate large numbers of potential prey items for migrating raptors. Diversion lines, in contrast, are geographical and topographical features along which migrants concentrate not because they are attracted to them, but because they are trying to avoid what lies beyond them (i.e., large bodies of water).

Reviewing the literature on the subject of leading lines and raptor-migration corridors helps one determine the migration routes and timing of raptor migration for a given region. Kerlinger (1989) provides the most up-to-date coverage of raptor flight dynamics available. Anecdotal information and preliminary counts at several potential watchsites can play an important role in identifying points of concentration. Local or regional guides to bird fauna often imply or suggest where currently unconfirmed concentrations of migrants may be passing. Talking to local inhabitants and others who know the area surrounding possible sites also can help you determine when and where large numbers of flying raptors can be seen. Once likely sites have been identified, field reconnaissance will be needed to determine precisely where and when migrating raptors can be seen.

Once a concentration point has been found, it is necessary to establish the best vantage point for counting birds. Ideally, watchsites should have as wide a field of view of the surrounding landscape as possible. Field of view and local relief (height relative to that of the surrounding landscape) determine the amount of sky that can be seen from a counting station. Dunne et al. (1984) recommend a minimum 180° field of view. Potential visibility, however, is not the only concern in determining location. Other factors include site accessibility and safety. Good accessibility, for example, is critical to ensure the logistic feasibility for intensive and prolonged monitoring, and is particularly important if the watchsite is to be used for conservation education as well as monitoring.

In some instances, more than one count point per watchsite may be appropriate. The objectives of a particular study — for instance, determining migration volume as a function of distance from the coast — may necessitate the use of simultaneous counts at several sites, as may flight lines that shift predictably in response to local weather.

### Spotting Migrants

Much of what follows has been taken from Dunne et al. (1984) and Brett (1991). Both are useful and informative references on the subject of conducting raptor migration counts. Another useful source is the Hawk Migration Association of North America's (HMANA) *A Beginner's Guide to Hawkwatching* (1982).

Raptors are best spotted by methodically scanning the sky in the direction from which migrants are expected. Observers should scan along the horizon, or below the horizon if the watchsite is at a high-elevation point, beginning perpendicular to the direction of flight and moving upstream until facing directly into the flight line. Then, they should move their binoculars up slightly less than one field of view and repeat the procedure two or three times on the same side of the flight line, and then repeat the same systematic procedure on the opposite side of the flight line (e.g., the other side of the ridgeline). Observers should systematically scan with both binoculars and unaided eyes to ensure effective coverage of both close and distant migrants. Scanning should cover at least 180°, laterally and vertically. Between scans, counters should look to their sides as well as directly overhead to look for birds they may have missed during their scans. Multiple observers, if available, can effectively rotate responsibilities between binocular and unaided-eye scanning, and simultaneously cover different sections of the overall flight line. Observers also should watch for aggregations of resident raptors because they often indicate flight conditions that may be conducive to migration.

Migrating raptors often fly overhead or laterally at some distance from the counter. Establishing a focal point that approximates that distance will help improve detectability. Human eyes typically focus at a distance of 6–7 m if there is nothing in particular upon which to focus. Clouds, distant landmarks, and passing airplanes all provide the observer's eyes with a frame of reference for distant focusing. Particular care must be taken to ensure effective focus and scanning against clear blue skies.

Because correct identification of migrants is important, appropriate optical equipment (i.e., binoculars and telescopes) is essential for migration counts. Binoculars with 8x to 10x magnification are considered best, although 7x binoculars also can be used. Because large areas of sky must be searched, binoculars with wide-angle lens and wide fields of view are recommended. Telescopes with 15x to 20x magnification are considered sufficient magnification. And in fact, heat-wave distortion and tripod vibrations often compromise the use of telescopes with higher magnification. Unless telescopes are routinely available during all observations, they should be used sparingly and only to confirm identifications of distant birds, not for spotting migrants, as variability in their use can impart significant detectability bias. In general, observers should avoid spending too much time staring into a telescope trying to positively identify every distant migrant, as they may inadvertently miss counting far closer, more easily identified birds.

It is important to consider observer fatigue when determining the materials needed to count migrants. Factors such as binocular weight (heavy binoculars induce arm fatigue more rapidly than lighter ones) and direct sunlight (glare causes eye strain) are important considerations. Counters should dress appropriately, and a comfortable place should be provided for them to sit from time to time. A storage site for field equipment near the watchsite also is useful.

## Identifying Migrants

Many raptors are difficult to identify at the species level, especially when they are flying at great speeds and altitudes. When apparent, plumage color and pattern, overall size, general configuration, and characteristic field marks are good ways to identify a raptor. For many species, differences in plumage can be used to determine age and gender. Determining the size of flying migrants is tricky, especially when the distance to the bird is difficult to gauge. Identifying a bird to species usually involves using a combination of cues, including flight pattern, wing-to-tail ratio, head-to-body ratio, wing shape in relation to wind speed, flight profile, etc. Silhouette recognition and the overall *gestalt*, or "GISS" (general impression, size and shape), of a bird can help place individuals in groups that will aid in their identification (e.g., accipiters, buteos, falcons, vultures, eagles, etc., all of which have recognizable *gestalts*).

Field guides that describe migrating raptors in terms of their characteristic field marks are especially useful in this regard. North American field guides include *The Mountain and the Migration* (Brett 1991), *Hawk watch: A Guide for Beginners* (Dunne et al. 1984), *Hawks in Flight: The Flight Identification of North American Raptors* (Dunne et al. 1988), *A Field Guide to Hawks of North America, second ed.* (Clark and Wheeler 2001), *A Photographic Guide to North American Raptors* (Wheeler and Clark 1995), *Hawks from Every Angle* (Liguori 2005), and *Raptors of Eastern North America* and *Raptors of Western North America* (Wheeler 2003a,b). Palearctic guides include *Flight Identification of European Raptors* (Porter et al. 1976), *Collins Guide to the Birds of Prey of Britain and Europe* (Génsbøl 1984), *The Raptors of Europe and The Middle East: A Handbook of Field Identification* (Forsman 1999), and *A Field Guide to the Raptors of Europe, The Middle East, and North Africa* (Clark 1999). Although all of these guides were written for northern temperate-zone audiences, many of the species described are likely to be seen at tropical and southern hemisphere watchsites as well. For those in need of a global guide, *Raptors of the World: A Field Guide* (Ferguson-Lees and

Christie 2005), is quite useful. See Chapter 2 for additional information on ageing, sexing, and identifying raptors.

Partial migration is the most common form of raptor migration (Kerlinger 1989), and individuals migrating past a watchsite often have resident counterparts in the area. Although there is no simple way to differentiate between residents and migrants, consistency of flight direction and altitude often indicate a migrating bird. In addition, resident birds often exhibit distinct behavioral patterns, such as territorial defense or displays, and extended periods of perching and hunting behavior. For some species, the migratory status of individuals in the region is unclear. Watchsites that keep records of the movements of such species can provide important life-history information about these birds.

## Counting Migrants

In most cases, counting migrants is relatively straightforward; however, four specific complications warrant mention. First, there are times when the number of migrants is so large that counting and recording every individual becomes difficult. At such times, counters will need to estimate the number of passing migrants. Counting birds in large flocks by mentally dividing the flock into groups of 5, 10 or, if necessary, 20 or 50 migrants is a useful technique at such times, however the accuracy of estimates declines rapidly as the number of birds in a group increases. Another technique is to focus your efforts on an estimated 10 or 20 percent of the flock, and to carefully count all of the birds within that subset. Total numbers can then be estimated by extrapolation (Bibby et al. 1992). Another technique is to use a series of digital photographs to count migrants. This last approach, however, is labor-intensive and requires careful timing to avoid duplicative counts (Smith 1980, 1985a).

Flocking species (e.g., Turkey Vultures [*Cathartes aura*], European Honey Buzzards [*Pernis apivorus*], Black Kites [*Milvus migrans*], Levant Sparrowhawks [*Accipiter brevipes*], Common Buzzards [*Buteo buteo*], Broad-winged Hawks [*B. platypterus*], and Swainson's Hawks [*B. swainsoni*]), present additional complications associated with counting large numbers of migrating birds. These species often form swirling aggregations, or "kettles," of hundreds to thousands of birds while exploiting the same thermal or mountain updraft. Under these circumstances, birds are best counted as they begin "streaming" in long skeins along the principal axis of migration, rather than while they are "kettling" (Dunne et al. 1984). Practice counting and estimation exercises available on *Wildlife Counts* (www.wildlifecounts.com) and other population-estimation software are useful training tools for counters assigned to flocking species. When two or more species are likely to pass in large numbers, simultaneously assigning one or more counters to each species also is helpful.

One critical tool for counting large numbers of migrants is a hand-held, mechanical tally device that can be operated while looking through binoculars. With practice, an individual can operate two tally devices in each hand, and keep track of four species simultaneously, if necessary. Multiple-unit tally counters also can be useful in these situations. Unfortunately, there is little more to recommend regarding how to count extremely large numbers of raptors at migration watchsites because so little has been written about the subject. Watchsites with large numbers of migrants are encouraged to develop and test their own means of counting birds accurately and communicate their results to other workers.

The third complicating factor applies at count sites at water-crossing bottlenecks, such as at the tips of peninsulas. Due to the reluctance of many raptors to cross large bodies of water (Kerlinger 1989), individual migrants may approach and retreat from the peninsula several times before actually making the crossing. Compared with monitoring sites where the migratory flow is consistently unidirectional, these cases either require customized counting strategies that minimize double-counting (e.g., simultaneously tracking both southbound and northbound movements and estimating net southbound flow by subtracting northbound from total southbound counts on a daily basis [C. Lott, pers. comm.]) or explicit recognition that the resulting "counts" represent an activity index rather than an actual estimate of the numbers of individuals passing through (Fish 1995).

The fourth complicating factor concerns situations where raptors migrate across broad coastal plains or otherwise open landscapes in which topographic leading lines do not concentrate their movements along a consistent pathway and, therefore, flight lines shift regularly depending upon wind conditions or variations in thermal development. In such cases, a monitoring setup involving multiple observation sites that effectively sample across the typical expanse of flight lines may be necessary to provide robust and consistent indexes of migration activity. Two primary examples where multisite "picket-line," transect monitoring strategies have been employed successfully are Veracruz, Mexico (Ruelas-Inzunza et al. 2000) and northern Israel (Leshem and Yom-Tov 1996).

## Recording the Count and Additional Data

Basic information recorded in migration counts includes the numbers of individuals seen and their identity to species, or at least to genus if the birds are too far off or are moving too quickly to allow identification to species. Workers also should record flight behavior, the date and times of observation effort (including both the time spent observing and the number of observers), and local weather at the time of observation. Flight-behavior information should include predominant direction of flight and the estimated altitude of migrants (i.e., below eye level, at eye level, and above eye level; birds seen easily without optical equipment, at limit of optical equipment, as small specks, etc.). Sites with considerable vertical relief both below and above eye level sometimes estimate line-of-sight distance to the flight using the same basic categories to estimate distance (i.e., birds seen easily without optical equipment, etc.) that are used to estimate flight altitude.

Weather data should include visibility (estimates of clarity of view plus notes about occurrence of visibility-reducing haze, dust, smoke or fog, if relevant), percent cloud cover, presence and type of precipitation when relevant, wind direction and speed, ambient temperature, relative humidity, and barometric pressure. Consistency across years in the type of weather data that are collected is important. When possible, regional weather parameters should be obtained from the local weather service. All count and additional data should be recorded hourly, with additional weather data collected as needed if conditions change rapidly within an hour. It also is helpful to record notes in a daily journal about the passage of cold fronts, major precipitation events, and reasons for missing observation days or portions of days due to inclement weather or other factors, when such are not readily evident from data recorded during actual observations.

Additional data relevant to migration behavior (e.g., flocking, flight style, altitude of the flight [Kerlinger and Gauthreaux 1985], agonistic behavior [Klem et al. 1985], feeding behavior [Shelley and Benz 1985], etc.) should be recorded whenever possible (Dunne et al. 1984). If feasible, and whenever the objectives of a study require it, the gender and ages of migrants should be recorded as well (Bednarz and Kerlinger 1989). Many migration watchsites provide conditions favorable to the migration of other large soaring birds, such as pelicans, storks, and anhingas. Counts of these, as well as other taxa, also should be made if possible (cf. Willimont et al. 1988). Recording the passage of unusual migrants constitutes additional valuable information. Considerations should be made for collecting additional data in ways that do not compromise the validity of the overall count (e.g., by having a person other than the counter or counters record pertinent notes).

Daily record forms on which all relevant data for each day are recorded can form the basis of a permanent archive of migration count data. The use of standardized forms also is helpful in long-term studies of raptor migration, or for monitoring the status of regional populations (Bednarz and Kerlinger 1989, Titus et al. 1989). HMANA provides an excellent daily report form for recording counts and observations of migrating raptors (Fig. 2). The HMANA form, on which relevant data are recorded hourly, was specifically designed to facilitate the transfer of accumulated data to computerized databases.

Because missing data will affect the interpretation of results, recording all the data called for in the standardized form is especially important. Illegible field notes affect the interpretation of results as well (Fuller and Titus 1990). In the field, some observers prefer using a field notebook or a field version of the standardized form. This allows them to record data quickly without bothering to keep a neat form that will be used as a permanent record. If this is done, it is essential that data be transferred to the permanent record on the same day they were collected, and while the counter's memory of events is still detailed and accurate. As with other types of long-term studies (see, for example, Ralph et al. 1993), proofreading and correcting forms at the end of each count day can help reduce errors in recording, and increase the reliability of the observations.

HanDBase (www.ddhsoftware.com) and other mobile relational databases designed for Palm and Pocket PC devices also can be used to eliminate the need for pen-and-paper data recording in the field and paper-to-electronic database transcription in the office. One potential downside is that data can be lost if the electronic equipment fails during data collection, particularly during periods of extreme weather.

HAWK MIGRATION ASSOCIATION OF NORTH AMERICA

**HMANA DAILY REPORT FORM**

LOCATION ______________________

OBSERVER(S) ______________________ MO_ DAY_ YR_

ADDRESS ______________________

| TIME (STD) | 5-6 | 6-7 | 7-8 | 8-9 | 9-10 | 10-11 | 11-12 | 12-1 | 1-2 | 2-3 | 3-4 | 4-5 | 5-6 | 6-7 | | | Comments |
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| Cloud Cover | | | | | | | | | | | | | | | | | |
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| Height of Flight | | | | | | | | | | | | | | | | | |
| No. of Observers | | | | | | | | | | | | | | | Total | | |
| Dur. of Obs. (min) | | | | | | | | | | | | | | | | | |
| Black Vulture | | | | | | | | | | | | | | | | BV | |
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**Figure 2.** Daily Report Form from the Hawk Migration Association of North America. Forms of this type have been in use since the 1970s across much of North America. Note that all data are recorded hourly. An Excel version of this form is available at www.hmana.org.

## Sources of Variability in Count Data

Variability refers to day-to-day and season-to-season fluctuations in count totals. There are many reasons for such variability (for reviews see Hussell 1985, Bednarz and Kerlinger 1989, Fuller and Titus 1990). For our purposes, we divide potential sources of variability into two categories: those intrinsic to the migration itself (e.g., weather during migration, fluctuations in the size of source populations, etc.), and those intrinsic to the count methods used (e.g., observer bias and observation effort). Observer bias refers to the rates of detection of migrating raptors on the part of an individual, also called observer efficiency or detectability, and to the individual's propensity for making errors while collecting data. Observation effort refers to the amount of time actually spent counting, either in terms of days during the season, or hours during a specific day, and to the number of counters present.

Observer fatigue and attentiveness affect efficiency (Sattler and Bart 1984). As is true for other types of raptor population studies (Fuller and Mosher 1987), rates of detection can be determined by the degree to which an observer is familiar with a species' flight behavior. At a watchsite in Veracruz, Mexico, for example, second-year counters record lower percentages of unidentified raptors than do first-year counters (E. Ruelas, pers. comm.). Differences in methods of data collection among individual observers are a source of considerable bias that also affects the data collected in migration counts (Bednarz and Kerlinger 1989). Finally, one of the more intractable forms of observer bias occurs when few (i.e., one or two) observers are used each season and are then changed when the season changes. When this happens, variance due to different observers cannot be partitioned from variance due to year.

Another factor that can bias a count is the rate of detectability of a particular species. Some species, such as American Kestrels (*Falco sparverius*), are more difficult to detect than other migrants because of their smaller size (Sattler and Bart 1984).

All things being equal, the number of birds counted versus those that actually pass a given point in space is proportional to the time spent counting. Therefore, daily count totals depend upon the number of hours spent counting, and the total count for a season will depend on the number of days in which counts were conducted. Although several well-known watchsites conduct counts every day of a migration season (see Titus et al. 1990), this is not the only way to schedule counting effort within a season (Titus et al. 1989). (See "Sampling Considerations" below for additional information on temporal aspects of migration count efforts.)

Continual and consistent training, clear explanations of objectives, proper guidance, and standardized data-collection and recording protocols can serve to reduce observer bias (Fuller and Mosher 1987, Bednarz and Kerlinger 1989). Consistency in day-to-day and season-to-season counting schedules can reduce variability due to differences in observation effort, as well as make the data comparable over long periods (Bednarz and Kerlinger 1989).

## Sampling Considerations

Migration counts are samples of particular raptor populations (Titus et al. 1989, Dunn and Hussell 1995). Unlike a census, which aims to count all individuals in a specified area (Ralph 1981), samples represent only a portion of the total population. The portion that is recorded depends in part on the logistic circumstances of the particular study and in part on the sampling scheme used to collect the data.

Two considerations determine sampling frameworks: those that are spatial and those that are temporal. Spatial considerations entail determining the places from which samples are to be taken; in the case of migration counts, choosing the exact site where counts will occur. In some cases, watchsite workers have little control over this because there will be a limited number of locations, perhaps only one, adequate for conducting counts. Although it often is difficult to quantify accurately, shifting count sites even relatively short distances (e.g., 100 m) can significantly affect the portion of the observable flight that is recorded. Thus, interannual consistency in both count site location and observation effort is important to ensure comparability across years. Temporal considerations entail determining when samples will be taken in a particular location. In the case of migration counts, temporal considerations are those associated with differences in the degree of counting coverage over the course of a migration season: the number of days or hours during which counts take place (Pendleton 1989). The simplest type of temporal sampling scheme is complete coverage, which entails conducting full-day counts each and every day of the migration season, weather permitting. Systematic or "even sampling" refers to a periodic spacing of count days (i.e., counting once every certain number of days) throughout the season (Titus et al. 1989). Stratified sampling refers to dividing the migration season into time frames of approximately the same length (e.g., blocks of 15 days) (Titus et al. 1989); counts are then conducted systematically in each stratum. Bednarz and Kerlinger (1989), Titus et al. (1989, 1990), and Lewis and Gould (2000) discuss the benefits and costs of various statistical analyses of data collected by means of these different sampling schemes.

Careful sampling design is needed to obtain useful estimates of population abundance. Bednarz and Kerlinger (1989) recommend that complete coverage be attempted if logistic conditions, such as availability of funds and personnel, permit it. The larger the number of samples, in this case the more days in which counts were conducted, the more reliable are results from statistical analyses, such as determining population trends (Bednarz and Kerlinger 1989, Pendleton 1989, Lewis and Gould 2000). Regardless of the sampling scheme used in a particular count effort, sampling schemes should be consistent among years in order to ensure that data can be compared reliably.

## Summarizing Count Data

The audience and the objectives of the summary will determine the way in which data are eventually presented. The easiest way to summarize each year's data is to list the total count for the season of each species. Graphic summaries that demonstrate changes in a species' daily total count over the course of the season can be obtained by plotting dates on the "x" axis and count results on the "y" axis. By using time intervals (weeks, months, etc.) in the "x" axis, histograms can be used for the same purpose. Changes in migration volume during the day can be summarized in much the same way, using hours instead of dates on the "x" axis. When examining seasonal or diurnal (diel) patterns of variation in flight magnitude within a given year, and in cases where variability in daily observation effort is significant within the period of interest, a more accurate picture may be derived by standardizing daily counts based on daily effort (e.g., counts per hour of observation). Similarly, when analyzing seasonal or diel variation across years in cases where interannual variation in observation effort is significant, a more accurate picture may be derived by standardizing daily, or time-interval, counts as the proportion of that year's total flight. See Allen et al. (1995) for details.

It is helpful to include a measure of observation effort, such as total number of hours or days over which counts took place, and the average number of hours per day in summaries of migration count data. Unusual circumstances that may have affected the count during a particular season also should be cited, such as uncommon weather events.

Several international and regional publications include migration count summaries. In the Western Hemisphere, *HMANA Hawk Migration Studies*, the journal of the Hawk Migration Association of North America, publishes regional count totals twice a year. The *Journal of Raptor Research* also includes papers that summarize raptor migration count data and information on raptor migration in general. Local and regional ornithological journals also are potential publication venues for such data.

## Archiving Migration Count Data

Establishing a formal system of managing and storing data generated by migration counts facilitates access to data by watchsite workers, as well as data transfer among watchsites and off-site researchers. Systematic summaries and consistent filing guidelines make the information contained in the data easier to find and to report.

Chronologically archiving permanent record forms makes it easy to find count data from a particular day, set of days, or from an entire season. Seasonal summaries can be placed in these files as well. Each season's file should be arranged chronologically by year. Clearly labeling each file to include the months and year in which counts took place provides an effective way of keeping the files in order. Duplicate archives of all permanent records (both paper and electronic) also should be maintained as a form of record security. Calamities, such as floods, fires, and storms can easily ruin years of work and resources. The duplicate archive should be kept in a different geographic location (i.e., another city or town). Along with recording and archiving the basic count, observation effort, and weather data, it is also very helpful to maintain "metadata" that clearly describe site protocols, including all variables recorded, the observation techniques employed, the qualifications of all observers involved, how observer duties were assigned and conducted, and the nature of any preseason observer training.

## MONITORING TECHNIQUES

**Monitoring** — *to watch, observe, check, especially for a special purpose* (1986, Webster's Ninth New Collegiate Dictionary)

Monitoring ecological or biological events consists of collecting data systematically in order to detect changes in the parameters being measured. There is considerable variation in the terminology used to refer to studies of this nature (Spellerberg 1991) (Appendix 2). We use the term "monitoring" to refer to any study in which data are collected consistently and in the same manner over a certain period of time, regardless of the intent of the study. Thus, a monitoring program results in an accumulated time-series database, to which different statistical analyses, descriptive or analytic, can be applied for many purposes.

Typically, migration counts at watchsites are used to monitor one of two things: regional population trends of migratory raptors or the status of raptor migration. Monitoring raptor population trends entails detecting changes in the abundances of migratory raptors. Monitoring raptor migration also entails determining the reasons for changes in raptor migration, including assessing the potential impacts of habitat and climate change.

In order to discuss the use of migration counts for monitoring population trends, it is useful to place such counts in the context of bird-population studies in general. Studies of bird populations can be grouped into two categories: those concerned with population size, and those concerned with demographic parameters (i.e., natality, mortality, and age-class or size-class distribution) (Spellerberg 1991, Butcher et al. 1993). Studies of population size rely on three main measures: absolute abundance, relative abundance, and density (Jones 1986a).

Density refers to the number of individuals per unit area. Relative abundance measures the number of individuals of a particular species as a percentage of the total number of individuals in a given community; both are associated with particular spatial units (Jones 1986a). Absolute abundance refers to the total number of individuals in a given population and is seldom measured by biologists due to the excessive amount of resources and time required. Instead, biologists usually employ indexes of total population size that are not ascribed to a particular geographic area (e.g., number of raptors counted as a function of the number of days in which counts took place) (Jones 1986a). Because it often is difficult to determine the origins of migrating raptors (Fuller and Mosher 1981, but see for example Meehan et al. 2001 and Hoffman et al. 2002), migration counts are used to estimate only absolute abundance, not density or relative abundance.

Using recorded fluctuations in numbers counted to track changes in the abundances of migratory raptors is the aim of population-trend monitoring. With regard to migration counts of raptors, a trend can be defined as a "statistically significant change in counts over (a certain) period," that implies a change in the numbers (i.e., abundance) of raptors being monitored (Titus et al. 1990). Trends, however, are only one of the types of time-series data of interest to ecologists. Cycles, regular periodic fluctuations, and "noise," or stochastic fluctuations, also need to be considered (Usher 1991).

Population-trend monitoring is sometimes used to refer, specifically, to a process aimed at determining a change in abundance of a certain magnitude (e.g., a 50% change during 25 years) (cf. Finch and Stangel 1993). Used in this sense, the distinguishing characteristic of monitoring is that it sets limits, or thresholds, beyond which change is deemed worthy of conservation attention.

Several recent publications deal with general aspects of monitoring bird populations. These include *Status and Management of Neotropical Migratory Birds* (Finch and Stangel 1993), *Handbook of Field Methods for Monitoring Landbirds* (Ralph et al. 1993), and *Bird Census Techniques* (Bibby et al. 1992), all of which provide detailed descriptions of methods used in bird population studies. Sauer and Droege (1990) offer an extensive treatment of the statistical analysis of surveys, including migration count data. Ralph and Scott (1981) provide an excellent reference on the subject of monitoring bird populations in general.

### Establishing a Monitoring Program

The most critical aspect of any monitoring plan is its design. Appropriate design increases the effectiveness and reduces the costs of a monitoring program by providing a flexible, systematic, and logical approach to the program (Jones 1986b). There are many approaches to designing monitoring programs (cf. Spellerberg 1991, Usher 1991 or Ralph et al. 1993). One of the simplest focuses on asking three basic questions before fieldwork begins: why, what, and how (Roberts 1991). "Why" refers to the objectives of a study, "what" refers to the data that need to be collected, and "how" refers to the methods used to collect and analyze the data.

■ ***Why?*** In its simplest form, the objectives of a monitoring program are the questions that are being asked of the data (Roberts 1991). The answers that are being sought will determine what data need to be collected and what methods will be used to collect them. Since the cost of collecting all possible data is high (Hellawell 1991), it is often practical to collect only those data necessary to answer the questions being posed.

■ ***What?*** The basic data collected at migration watchsites are numbers and types of migrants. Ancillary data include meteorological conditions and factors related to observation effort (see above). However, the particular species that will be counted at a watchsite need to be chosen before monitoring begins. Different species have different detectability rates (Sattler and Bart 1984), mainly due to differences in size (smaller birds being less likely to be detected) and flight dynamics (birds flying closer to the ground being less likely to be detected). It also is important to recognize that limits of logistic feasibility may preclude effective full-season monitoring of some species at some sites. For example, in western North America, heavy snow cover limits the seasonal duration of autumn monitoring at high-elevation, ridgetop monitoring sites, precluding effective full-season monitoring of late-season migrants such as Roughlegs (*B. lagopus*) and Bald Eagles (*Haliaeetus leucocephalus*).

At first, only a very general declaration of objectives is needed. General objectives can then be modified or refined according to the particulars of a monitoring program, such as logistic and resource limitations, the restrictions arising from study design, etc. And indeed, there are cases where a certain amount of data collection without a clear idea of how they are to be used can be helpful in determining what questions should and can be posed (Roberts 1991).

There also are many cases where data have been recorded for one purpose at one time and proved to be useful in answering another question at a later date, a phenomenon Spellerberg (1991) termed "retrospective" monitoring. Therefore, even if the objective of a given monitoring program does not contemplate other uses for the data at the moment it is being carried out, the study design should be such that future data may be compared with those that are presently being collected. When standardizing data collection procedures for a given monitoring program, possible future uses for the data should be considered.

■ ***How?*** Study design entails considering the methodologies that are to be employed at the watchsite.

The statistical validity of migration count data depends largely on the degree to which data collection is standardized and on the sampling scheme used. Standardizing data collection requires a good understanding of the sources of migration-count variability and can mean more intensive training and frequent supervision to ensure that data-recording guidelines are being followed properly and consistently. Even if complete sampling is desired, lack of personnel might negate this possibility, thus making a systematic sampling schedule necessary. Another detail worth emphasizing and considering carefully when planning a raptor migration count is that if the primary objective is to provide robust data for assessing population trends, standardized annual effort across multiple decades is essential.

In some cases, the unique flight dynamics associated with specific monitoring sites may require site-specific sampling methods. For example, the complexity of multi-directional movements at peninsula watchsites often necessitates special counting procedures that produce activity indexes rather than counts representing estimates of actual numbers of individuals. In such cases, it is necessary to recognize that the data collected will not be directly comparable to those collected at sites where uni-directional flow is the rule. Although this precludes direct integration of such datasets into multi-site regional assessments, qualitative comparisons are still possible. In other cases, decisions about adjusting methods to better fit site-specific characteristics may involve tradeoffs. If watchsite coordinators and sponsors consider it more important to maximize statistical power for detecting trends at that site, then adjusting count methods to increase the accuracy and precision of site-specific annual indexes may be the best approach. Alternatively, if the primary motivation for conducting a given count is to serve as one node in a regional monitoring network, then maximizing methodological consistency across sites may be more important, even if it results in reduced site-specific precision.

Interpretation of migration-count data can entail a good deal of statistical analysis. For these analyses to be valid, data must conform to the assumptions inherent in particular statistical methods. Consulting a professional statistician may be necessary to determine the appropriateness of sampling schedules, as well as to determine if resulting data conform to the assumptions of the statistical tests that will be used to analyze them (Lewis and Gould 2000). In addition, to maximize the accuracy and precision of migration-count data for detecting true population trends, especially in cases where sampling effort varies within or among seasons, it may be necessary to employ complex multivariate statistical models to derive robust annual indexes of migration activity to form the basis for analysis of long-term trends (e.g., see Hussell 1985, Hussell and Brown 1992).

Fish (2001) provides a valuable review of questions to be asked and considerations to be addressed with regard to establishing a raptor-migration monitoring effort.

### Exploratory Monitoring

Exploratory monitoring serves several purposes. It can help determine exactly what questions can be answered at a particular watchsite. It also can help determine where in a watchsite it is best to conduct counts from; it can establish the duration of the migration season, as well as peaks of passage for certain species; it is an excellent way to train counters, as well as to establish standard data collection methods that are appropriate for the site, etc. Data gathered during this exploratory phase can be used in trial statistical analyses, as well as to consolidate data-management procedures, and to determine the best way to summarize data at the end of a season. It also provides an opportunity to identify logistic problems and resource limitations that are likely to affect long-term monitoring efforts.

One aspect of exploratory monitoring deserves particular attention: the determination of count location. In some instances, a single counting point is self-evident (e.g., a mountain-top watchsite or one in a narrow mountain pass). In others, possible counting points will be spread out over several kilometers (e.g., at coastal-plain or broad, intermountain-valley watchsites). Transects of preliminary counting points can be established, either at uniform intervals, along lines likely to offer good views of migrating raptors, or stratified according to meteorological or topographic parameters.

It may be necessary to monitor flights for several years from different locations to determine the best place from which to conduct long-term monitoring. Bednarz and Kerlinger (1989), for example, suggest that 5 years may be needed to determine adequately the timing of migratory movements at a particular watchsite.

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## Appendix 1. Techniques for studying raptor migration (with representative pertinent references).

*(After Kerlinger 1989 and Bildstein 2006)*

**1. Raptor migration counts.** Common and widespread; inexpensive and relatively easy to conduct. Documents occurrence, timing, and volume of migration at a site; can be used to document habitat use. Biased towards low-flying migrants; data are affected by a variety of factors including observer fatigue, number of observers, weather, etc. (Bednarz et al. 1990, Shirihai et al. 2000, Hoffman and Smith 2003).

**2. Trapping and banding.** Common, but labor intensive. Determines origins and destinations of migrants, and migratory pathways; can be used for measuring anatomy and physiology, for monitoring migrant health, and for determining causes of mortality. Low band-return and recovery rates result in small sample sizes; potential age- and gender-class biases. Enables application of other cutting-edge techniques, including satellite tracking and stable-isotope analysis of feathers (see below) to determine migrant origins and document migration routes (Hoffman et al. 2002).

**3. Marking.** Uncommon and inexpensive, but labor intensive depending upon capture effort. Documents habitat use and movements of individuals. Low resighting rates; removal of markers by birds can affect results (see Chapter 13).

**4. Conventional tracking.** Uncommon to rare; expensive and labor intensive. Determines habitat use, time of stay, and behavior at stopovers along entire portions of the migratory journey. Following migrants usually presents difficulties (Kenward 2001).

**5. Satellite tracking.** Increasingly common, but extremely expensive. Documents long-distance movement of individuals, sometimes across multiple years. As of mid-2004, transmitter size restricts use of the technique to large (> 500-g) raptors (Fuller et al. 1998, Meyburg and Meyburg 1999, Martell et al. 2001).

**6. Motorgliders and aircraft.** Rare, expensive, and labor intensive. Documents flight behavior and determines geographic distribution of migrants. Affects flying behavior of migrants; biased towards high-flying migrants (Kerlinger 1989).

**7. Visual observations of behavior.** Uncommon to rare, although inexpensive and adaptable. Used to document flight behavior. Biased towards low-flying migrants.

**8. Photography and cinematography.** Rare and, historically, expensive and labor intensive. Documents flight behavior and is used to verify counts made by ground observers. Care must be taken when comparing images (Smith 1980, 1985a).

**9. Radar.** Uncommon, and relatively expensive and labor intensive. Documents flight behavior and geographic distribution. Mobility somewhat limited; results sometimes biased to high-flying migrants. Currently simultaneous visual observations are needed to verify identity of migrants (Spaar 1995, Leshem and Yom-Tov 1996, Gauthreaux and Belser 2001).

**10. Stable-isotope analysis of feathers.** Rapidly advancing new field of inquiry; large samples required, but easily obtained through migration trapping; expensive; relatively few laboratories established for processing, but number growing. Used to identify approximate natal origins of juvenile birds sampled on migration or on wintering grounds (Meehan et al. 2001, Lott et al. 2003, C. Lott and J. Smith, pers. comm.; see Chapter 14 this volume).

## Appendix 2. Monitoring and surveillance defined.

**Monitoring.** Intermittent (regular or irregular) surveillance carried out to ascertain the extent of compliance with a predetermined standard or the degree of deviation from an excepted norm (Hellawell 1991).

**Monitoring.** A systematic collection of data on a particular parameter used to determine changes in its status within a certain time frame (Roberts 1991).

**Surveillance.** An extended program of surveys, undertaken to provide a time series, to ascertain the variability or range of states or values that might be encountered over time, or both (Hellawell 1991).