# Survey Techniques

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## INTRODUCTION

Compared with most other groups of birds and many other vertebrates, raptors often are widely dispersed, and many of their populations exist at relatively low densities across the landscapes in which they occur. Although many species are relatively easy to detect either by sight or by sound, conducting surveys for raptors can be difficult and require a substantial commitment of resources. In spite of these difficulties, investigators have expended considerable effort counting birds of prey (Fuller and Mosher 1987), and have used information derived from their surveys to estimate population size or trend, locate nests and monitor reproduction, assess the population status or distribution of species, monitor raptor populations of particular conservation concern, investigate behavioral ecology, and evaluate methods used to detect and count raptors.

In their review of raptor survey techniques, Fuller and Mosher (1987:37) defined "survey" after Ralph (1981) as *"(1) the process of finding individuals in relation to geographic areas (e.g., continental, regional, local) or habitat features (e.g., physiography, vegetation); and (2) an enumeration ... of abundance of individuals in an area from which inferences about the population can be made."* Inherent in this definition is that observers must be able to ascertain the presence of individual raptors, either directly through visual or aural observation or indirectly by finding recently refurbished nests or prey remains. In addition, surveys inherently have a spatial aspect, in that they are conducted over a discrete area.

How raptor surveys are planned and conducted depends on survey objectives. For example, surveys intended to locate nests (i.e., things that do not move within the same season) may need to be designed differently from surveys intended to estimate the population size of wintering raptors, which may or may not exhibit site fidelity to local areas. Thus, survey objectives should be clearly defined, and surveys should be designed to meet those objectives.

Finally, surveys need to provide reliable results. Poorly designed or implemented surveys that result in imprecise or biased estimates of population size, for example, have limited use. Extending results from such surveys to other areas or comparing such results with those from surveys conducted elsewhere or to address different objectives also may have limited value.

The primary objective of this chapter, then, is to provide an overview of sampling procedures and general survey methods used to count raptors. Specific topics include (1) survey objectives, (2) survey design considerations, and (3) the application of wildlife survey methods to raptors. Because considerations for counting migrating raptors are presented elsewhere in this book (see Chapter 6), this chapter focuses on surveys for raptors during non-migratory periods. Many of the survey considerations discussed herein also apply to surveys for raptor nests. Sources of information for this overview include the summary of raptor-survey techniques by Fuller and Mosher (1987), literature published since 1987 compiled by searching electronic databases (Wildlife and Ecology Studies Worldwide, Raptor Information System, and Web of Science), and my general familiarity with raptor literature. The chapter is not a complete list or summary of all of the published literature, but rather an overview of raptor-survey methods and results.

## SURVEY OBJECTIVES

Objectives of raptor surveys need to be clear and explicit before surveys are conducted. Survey designers also need to consider how their data will be used. Fuller and Mosher (1987) identified two objectives for raptor surveys: determining raptor distribution and determining abundance (both absolute density and relative abundance). In addition, surveys often are used to locate raptors to study population dynamics and other aspects of raptor ecology (e.g., raptor-habitat relations and reproduction), and to provide information for management and conservation.

Surveys to assess raptor distribution occur at a variety of spatial scales, from local study areas to large geographic regions, and entail locating raptors across a defined area, often stratified by habitat type, topography, or other environmental characteristics. Because raptors often occur at low densities, surveys to assess distribution at larger spatial scales usually involve sampling representative subdivisions of larger areas.

Surveys to determine raptor abundance fall into two categories, those designed to determine population size or density and those designed to compare relative abundance, either spatially or temporally. Population size is the number of individuals in a population, where population can be defined biologically (e.g., as a group of interacting individuals of the same species) or spatially (e.g., a group of individuals using a particular area during a defined time period). Density is the number of individuals or groups of individuals, including pairs, per unit area. A complete enumeration of raptors within a defined area, or census, often is not practical because raptors can be difficult to detect (i.e., the probability of detecting a raptor is less than one) and because they are often widely spaced. Finally, delineation of the boundaries and location of the area searched to determine density can influence interpretation of survey results (Smallwood 1998).

In practice, raptor density is generally estimated based on surveys designed to sample a representative portion of the raptor population or area of interest. Sampling biological populations is discussed in detail in Williams et al. (2002) and Schreuder et al. (2004). Sampling considerations pertinent to raptor population surveys are discussed below. One primary concern is that sample surveys be designed so that results can be used appropriately to meet survey objectives (e.g., to estimate raptor density in a particular study area or to make comparisons between or among populations or study areas).

In addition to assessing raptor distributions and abundances, data derived from surveys also are used in population modeling and monitoring, to investigate raptor ecology, including assessing raptor-habitat relations, and to provide information from which to base conservation strategies and activities. For example, Bustamante and Seoane (2004) used raptor surveys to compare distribution predicted from statistical models with existing distribution maps for four species of raptors in southern Spain. Meyer (1994) evaluated whether counts at communal roosts of Swallow-tailed Kites (*Elanoides forficatus*) could be used to monitor kite populations and develop conservation strategies, and Currie et al. (2004) based conservation strategies for Seychelles Scops Owls (*Otus insularis*) on surveys designed to assess distribution and abundance. In these and other cases, surveys must be designed to meet explicit study objectives, and study design should facilitate obtaining reliable survey results. When designing surveys for raptors, it is generally wise to discuss design and statistical considerations with a biostatistician prior to data collection.

## SURVEY DESIGN CONSIDERATIONS

### Factors Affecting Detection

Many factors potentially affect detection of raptors during surveys. These include attributes of the birds themselves (e.g., species, age, sex, behavior, group size, etc.), environmental conditions when surveys are conducted (e.g., weather, degree of illumination, and, in aural counts, factors affecting sound transmission, etc.), temporal variables that affect behavior or distribution (e.g., time of day or time of year), habitat characteristics (e.g., forested versus open landscapes, distribution of perches, etc.), and attributes of observers (e.g., experience, visual or aural acuity, etc.). Results from raptor surveys that do not consider these factors may be difficult to interpret or may not be compared appropriately to results from surveys conducted under different conditions, at different places, or at different times.

Probability of detecting individual raptors varies and can be influenced by raptor size and color (visual-based surveys), type and intensity of vocalization (aural-based surveys), behavior, and factors related to sex and age. Under the same conditions, larger raptors whose coloration contrasts with their background are easier to see than smaller raptors that blend in with their surroundings. Similarly, raptors that call loudly and frequently are easier to hear than raptors that call quietly or less frequently. Behavior also influences detection probability. For example, moving raptors are generally more likely to be detected visually than perched raptors. Sex and age can influence raptor behavior, and consequently, detection probability. In species where males and females exhibit a division of tasks during breeding, the member of the pair primarily responsible for hunting, which is usually the male, may be more likely to be detected away from a nest. In contrast, birds associated with nests may be more likely to respond vocally to conspecific calls broadcast near the nest. Similarly, fledglings may be more detectible than adults while calling when begging for food.

Environmental conditions during surveys can influence raptor detectability directly and indirectly. Weather conditions can influence detection probability directly through effects on visibility (e.g., fog, snow, or rain) and on sound transmission (aurally based surveys). Indirect effects can occur when weather influences raptor behavior, such as when it triggers roosting behavior or is conducive to soaring. As with most wildlife surveys, surveys for raptors are generally conducted during specified environmental conditions (e.g., Andersen et al. 1985), which minimize variation among surveys attributable to environmental conditions.

Detectability of raptors often changes both through the day and through the year. Many raptors exhibit activity patterns where they are more active, away from cover, or more vocal during some times during the day than others. For example, in the temperate zone, soaring raptors, including buteoine hawks and vultures, may not leave roosts until mid-morning, when thermals form. Similarly, raptors may be detected with higher probability at some times of the year, or even within the same season, than at other times. Red-shouldered Hawks (*Buteo lineatus*), for example, respond to conspecific call broadcasts more readily during the breeding season than at other times of the year, and within the breeding season are more likely to respond during courtship than during incubation (McLeod and Andersen 1998).

Habitat characteristics can substantially affect detection of raptors on surveys. Forest-dwelling raptors, even species that are relatively large-bodied and strikingly colored, are notoriously difficult to detect on visually based surveys. Distribution of perches can influence the distribution of raptors that hunt from perches (Janes 1984), thereby affecting raptor detection probability. Perch distribution can affect surveys conducted along roads paralleled by power or communication lines that afford perching by raptors. Similarly, habitat characteristics can influence raptor detection in aurally based surveys by influencing sound transmission of both call broadcasts and raptor vocalizations. The presence of foliage, for example, substantially influences sound transmission in deciduous forested habitat.

The attributes of observers also can influence raptor-detection probability. The number of observers, their experience level, and their visual and aural acuity all can influence the ability to detect raptors. Only a few raptor surveys have considered attributes of observers (e.g., McLeod and Andersen 1998, Ayers and Anderson 1999), but observer effects have been well documented in surveys for other birds (e.g., Ralph et al. 1993).

Many additional factors can affect the detection of raptors on surveys. Investigators need to be aware of factors that may influence detectability, control for these factors when possible, and recognize potential influence of various factors on survey results and interpretation, especially when comparing results among surveys (Andersen et al. 1985).

## Sampling and Sample Size

In raptor surveys there are generally two populations, one biological and one statistical, that must be considered. As indicated above, a biological population is a collection of raptors, and the objective of raptor surveys is to better understand this biological population. In contrast, a statistical population is a collection of sampling units, each of which can be evaluated to ascertain presence, abundance, or some other aspect related to raptors. Sampling is a method of measuring attributes of a portion of a statistical population and using observed attributes of the evaluated portion to make inference about an entire statistical population. How a sample of the statistical population is obtained determines whether inference can be made to the entire population, or whether survey results apply only to that portion of the population in the sample.

The nature of sample units used in raptor surveys depends on many of the factors identified above, and especially on the scale of the survey. For example, if the objective of a particular survey is to estimate abundance or distribution of raptors across a broad area, sample units might be sections of coastline (e.g., Jacobson and Hodges 1999) or large plots (e.g., Hargis and Woodbridge 2006). If surveys are designed to assess abundance at smaller spatial scales such as a well defined study area or landscape, sample units might be routes (e.g., Andersen et al. 1985) or fixed points (e.g., Henneman et al., in press). In either case, sampling entails examining a portion of all sample units contained in the statistical population, and extending the information derived from this sample to the entire population. How this sample is derived is of particular importance, and needs to be considered prior to conducting surveys and when survey results are presented.

Mendenhall et al. (1971) and Cochran (1977) describe sampling methods in detail, Schreuder et al. (2004) provides an overview of sampling methods related to natural resources, and Ralph and Scott (1981) describe sampling methods specific to birds. Regardless of survey objectives and spatial scale, investigators should consult with a statistician prior to conducting surveys for raptors. Simple random sampling occurs when all sample units have a finite and equal chance of being included in the sample. At small spatial scales, raptor surveys might be designed with simple random sampling if raptor distribution and habitat across the survey area are homogeneous. Raptors have been surveyed using simple random sampling where raptor densities are relatively high (e.g., Henneman et al., in press), but other forms of sampling for raptors are used more frequently. Stratified random sampling results when sample units can be grouped based on factors related to raptor distribution; such as habitat composition of the study area, political boundaries that may reflect different management scenarios, etc. The primary advantages of stratified random sampling are an increase in precision of estimates and increased efficiency in sampling. Sampling effort within strata can be allocated based on stratum size, raptor density, cost of conducting surveys, to minimize variance of final estimates, or combinations of these considerations. A proposed bioregional monitoring strategy for Northern Goshawks (*Accipiter gentilis*) is based on stratified random sampling considering goshawk density and accessibility of sample units (Hargis and Woodbridge 2006). Kochert and Steenhof (2004) also used this approach to estimate the number of nesting pairs of Prairie Falcons (*Falco mexicanus*) in southern Idaho.

Systematic sampling involves randomly selecting a starting point to sample, and then sampling additional points based on a regular spatial pattern. Advantages of systematic sampling are that (1) the entire range of variability usually is represented in the sample, (2) logistic efficiency sometimes can be increased, and (3) precision of estimates can be increased compared to simple random sampling (Cochran 1977). Disadvantages are that (1) estimates of precision can be difficult to obtain, and (2) if a spatial pattern in sampling units parallels the spatial pattern in sampling, the resulting estimates can be biased. Systematic sampling within sample units has been proposed as part of a bioregional monitoring effort for Northern Goshawks (Hargis and Woodbridge 2006).

More elaborate sampling strategies include cluster sampling (Mendenhall et al. 1971, Cochran 1977), where a cluster is a group of smaller sampling units that are close together. Double sampling (Mendenhall et al. 1971, Cochran 1977, Bart and Earnst 2002) involves sampling at two spatial scales and using information from one scale to improve estimates at another scale. Haines and Pollock (1998) used this approach to estimate abundance of Bald Eagle (*Haliaeetus leucocephalus*) nests. These and other sampling strategies have potential statistical and logistical advantages, but should be undertaken only after consulting a statistician.

Finally, sampling related to monitoring presents additional considerations. Considerations for initial selection of samples are similar to those discussed above. Sample units examined in subsequent surveys can be the same, a different random sample, or a combination of the same and different sample units (Schreuder et al. 2004). If the same sample units are examined repeatedly through time (e.g., annually), then power to detect changes through time is higher (i.e., variance is lower) than if a new sample is drawn at each sampling occasion. This is because sequential observations at individual sample units are positively correlated (Schreuder et al. 2004). However, as the time interval between the original and a subsequent sampling occasion increases, one has less and less confidence that observed changes in the sample reflects changes in the target population. Without independent evidence that the sample units being monitored continue to represent the target population through time, surveys may reflect only changes in raptors (or attributes thereof) that occur in those sample units, and not the larger population. Again, clear objectives and consultations with a statistician versed in monitoring prior to initiating a monitoring protocol are essential.

### Kinds of Surveys

Raptor surveys can be grouped into several categories based on distribution of the study population and sample units. At smaller spatial scales (e.g., study areas of 10s to 1000s of hectares) surveys often are designed to count all raptors present (e.g., Craighead and Craighead 1956), with adjustments sometimes made for detection probability of less than one (e.g., Anthony et al. 1999). Alternatively, mark-resighting methods may be used to estimate population size on study areas (e.g., Manly et al. 1999). Studies employing such techniques are generally designed to investigate raptor population ecology, and incorporate surveys to identify and describe study populations. Under such design considerations, the sample unit is essentially the study area, and this approach is often used in studies of raptor nesting ecology (e.g., Borges et al. 2004).

At larger spatial scales (1,000s of hectares to regional or continental scales), transects (e.g., survey routes along roads or trails; Andersen et al. 1985, Vinuela 1997) or plots (e.g., Phillips et al. 1984, Hargis and Woodbridge 2006) are the sample units, and detections of raptors in these units are used to make inference about a larger raptor population. Raptor surveys based on transects (e.g., Kenward et al. 2000) are relatively common in the published literature, with fewer examples of surveys based on plots (e.g., Grier 1977, Schmutz 1984, Lehman et al. 1998). However, survey results often can be applied only to the area actually surveyed, and cannot be extrapolated to a larger area if selection of survey locations was not random (see above).

At larger spatial scales, counts or detections at points have been used to document raptor presence (e.g., Kennedy and Stahlecker 1993), community diversity (Manosa and Pedrocchi 1997), and to estimate occupancy (e.g., Mosher et al. 1990, McLeod and Andersen 1998). Advances in statistical methods (e.g., Geissler and Fuller 1987, MacKenzie et al. 2002) have made it possible to use repeated sampling of the same points as a population monitoring tool. These techniques are just beginning to be applied to raptors (e.g., Olson et al. 2005, Seamans 2005, Hargis and Woodbridge 2006, Henneman et al., in press,), but are generally applicable to surveys where raptor detection probability is imperfect (MacKenzie et al. 2002, 2003, 2004; Royle and Nichols 2003). Points, or routes consisting of a series of points, are the sample units, and if sample units are selected to be representative of a larger population, survey results can be extended to a variety of spatial scales.

## RAPTOR SURVEYS

Raptor surveys can be conducted from the ground (e.g., McLeod and Andersen 1998) or water (e.g., Garrett et al. 1993), and air (e.g., White et al. 1995) or, in limited cases, through remote sensing (e.g., radar; Harmata et al. 2000).

### Surveys from the Ground or Water

Raptor surveys from the ground or water generally involve traversing a specified route along roads or trails (e.g., Andersen et al. 1985, Vinuela 1997) or along a shoreline (e.g., Castellanos et al. 1997), while searching a specified area, such as known colonial breeding sites (e.g., Martinez et al. 1997), or visiting pre-identified points (e.g., McLeod and Andersen 1998) and assessing the presence of raptors through direct observation or indirect evidence, such as the presence of nests. Fuller and Mosher (1987) summarized considerations for designing and conducting ground-based raptor surveys and the general applications, advantages, and limitations for different categories of surveys. I provide a brief description of types of ground- and water-based surveys, and summarize survey results and considerations published since Fuller and Mosher's review.

Surveys for raptors often have been conducted along roads where raptors are observed and counted from vehicles (e.g., Andersen et al. 1985). Surveys along roads have been used to describe raptor distribution (e.g., Yosef et al. 1999, Bak et al. 2001), diversity (e.g., Ross et al. 2003), relative abundance in relation to land-use practices (e.g., Sorley and Andersen 1994, Yahner and Rohrbaugh 1998, Williams et al. 2000), and habitat use at broad spatial scales (e.g., Garner and Bednarz 2000, Olson and Arsenault 2000). Studies of raptor behavior (e.g., Manosa et al. 1998, Rejt 2001), food habits (e.g., Dekker 1995, Kaltenecker et al. 1998) or population dynamics (e.g., Kerlinger and Lein 1988, Hiraldo et al. 1995, Bridgeford and Bridgeford 2003) also have been based on surveys along roads. Surveys from roads also have been used to locate nests in natural (e.g., Travaini et al. 1994, Woodbridge et al. 1995, Goldstein 2000) or urban landscapes (e.g., Stout et al. 1998), or to assess conservation status (e.g., Herremans and Herremans-Tonnoeyr 2000, Thiollay and Rahman 2002, Prakash et al. 2003, Sanchez-Zapata et al. 2003) or raptor responses to epizootics (e.g., Seery and Matiatos 2000). Surveys for raptors along roads have been used to describe raptor abundance at specific times of the year (e.g., Andersen et al. 1985, Goldstein and Hibbitts 2004), at different spatial scales (e.g., Sorley and Andersen 1994, Belka et al. 1996, Ferguson 2004), and to assess changes in raptor abundance through time (e.g., Hubbard et al. 1988, Herremans and Herremans-Tonnoeyr 2001, Thiollay 2001).

Ground-based surveys of plots or study areas searched for the presence of raptors have been used to monitor colonial-nesting raptors (e.g., Martinez et al. 1997), and to find raptors to assess breeding ecology (e.g., Gerhardt et al. 1994), habitat use (e.g., Thome et al. 1999), and communal roosting (e.g., Kaltenecker 2001). Surveys for raptor nests often are conducted on foot (e.g., Joy et al. 1994), but may incorporate a suite of survey techniques used to find raptors (e.g., Andersen 1995), including surveys from horseback or all-terrain cycle (e.g., Andersen 1995) and call broadcast and aerial surveys (e.g., McLeod et al. 2000). A combination of ground-based survey techniques often are used to find raptors in a study area (e.g., Craighead and Craighead 1956) and searches from foot often are used to find raptors or their nests in historical nesting areas or habitat patches thought likely to harbor them (e.g., Clough 2001).

Surveys from watercraft have been used to estimate raptor population size (e.g., Anthony et al. 1999) and relative abundance (e.g., Frere et al. 1999), and to find vocalizing owls (e.g., Erdman et al. 1997) and raptors that nest near shorelines or forage on aquatic prey to monitor reproduction (e.g., Gerrard et al. 1990) or to study behavior (e.g., Flemming et al. 1992, Garrett at al. 1993), and to assess responses of migrating raptors to local prey abundance (e.g., Restani et al. 2000). Surveys from watercraft also have been used to assess raptor breeding population change following perturbation (e.g., Murphy et al. 1997) and to document population recovery (e.g., Castellanos et al. 1997, Wilson et al. 2000).

## Raptor Surveys from the Air

Aircraft (primarily airplanes and helicopters, but also ultralight aircraft [e.g., Leshem 1989]) have been used to conduct surveys for raptors. Safety and design considerations for aerial surveys are summarized and outlined in Fuller and Mosher (1987). Aerial surveys, which have been used most frequently to find and identify raptor nests (e.g., Sharp et al. 2001) and nesting aggregations (Simmons 2002), are generally most useful for species with prominent nests, such as eagles (McIntyre 2002) and cliff-nesting falcons (Gaucher et al. 1995). In North America, aerial surveys have been used extensively to find nests and monitor reproduction of Bald Eagles (Jacobson and Hodges 1999) and Ospreys (*Pandion haliaetus*) (Ewins and Miller 1994). Similar aerial surveys have been used to find nests of large raptors in Australia (Mooney 1988, Sharp et al. 2001), Africa (Tarboton and Benson 1988, Hustler and Howells 1988), and Asia (Utekhina 1994). Aerial surveys to find prominent nests of smaller, often cliff-nesting raptors have been conducted in North America (Wilson et al. 2000), Africa (Simmons 2002), Central America (Thorstrom et al. 2002), and the Middle East (Gaucher et al. 1995).

In open habitats, nests in isolated trees, on cliff faces, and on other prominent locations are readily detected from the air (Ayers and Anderson 1999, Wilson et al. 2000). Surveys from aircraft also have been used to find nests in less-open habitats as well (Cook and Anderson 1990), and to supplement ground-based nest searches (Dickinson and Arnold 1996, McLeod et al. 2000) for tree-nesting raptors, but detectability of nests on these surveys generally has not been estimated (but see Anthony et al. 1999, Ayers and Anderson 1999, Bowman and Schempf 1999).

To a lesser extent, aerial surveys also have been used to find and count raptors outside of the breeding season (e.g., Kaltenecker and Bechard 1994, Lish 1997). Even so, because individual raptors can be difficult to detect from the air and because they often are widely dispersed, aerial surveys have not been used extensively.

## Raptor Counts at Fixed Locations

The most widely reported survey technique that involves counting raptors from fixed locations is counting raptors as they pass sites where they concentrate during migration (Kjellén and Roos 2000; Chapter 6). Beyond counts at raptor migration sites, raptor surveys based on counts at specified points have been used to assess population status or trend, often in conjunction with surveys designed to monitor status of bird communities over broad geographic areas (Arrowood et al. 2001, Ross et al. 2003). As with most raptor surveys, those based on counts at points have occurred primarily during the breeding season (e.g., Steenhof et al. 1999, Kochert and Steenhof 2004), although counts at points have been used to assess winter raptor distribution and abundance in the Netherlands (Sierdsema et al. 1995).

Surveys of raptors over broad geographic areas based on counts at points have been conducted in several regions where very little information exists regarding raptor populations. Such counts have been used to assess status, abundance, and distribution of raptors across large areas in Asia (Thiollay 1989a, Thiollay 1998), Asia Minor (Vaassen 2000), South America (Thiollay 1989b, Manosa and Pedrocchi 1997), and Africa (Thiollay 2001). In North America, trends in abundance of some raptors are discernable at broad geographic scales based on surveys at points along routes established to monitor breeding birds (i.e., the Breeding Bird Survey [Sauer et al. 2004]).

At smaller spatial scales, Debus (1997) incorporated counts at points into a survey of raptors in an Australian park, and Sykes et al. (1999) used counts at points to describe distribution and abundance of Swallow-tailed Kites in Florida. Lehman et al. (1998) and Steenhof et al. (1999) incorporated counts at points into surveys for raptors at the Snake River Birds of Prey National Conservation Area in Idaho. Herremans and Herremans-Tonnoeyr (2000) incorporated point counts into a study of raptor distribution in two landscapes in Botswana.

Surveys also have been based on counting vocalizing raptors (Lane et al. 2001) and on broadcasting calls (McLeod et al. 2000) at points to solicit responses from nocturnal (Takats et al. 2001, Crozier et al. 2003) and diurnal raptors (Kennedy and Stahlecker 1993). Surveys for owls often are based on listening at pre-determined points for vocalizations (e.g., Lane et al. 2001, Takats et al. 2001), or broadcasting conspecific calls to elicit responses and, presumably, to increase the probability of detection (Whelton 1989). Broadcasting or mimicking (Forsman et al. 1996) owl vocalizations has been used to locate nests to assess population dynamics (LaHaye et al. 1997), distribution (Mazur et al. 1997) and range expansion (Wright and Hayward 1998), and diet (Seamans and Gutiérrez 1999). Broadcasts also have been incorporated into surveys designed to estimate owl population trends (Shyry et al. 2001, Takats et al. 2001).

Surveys based on detecting vocalizing diurnal raptors have been used most frequently in forested habitats (Fig. 1). Kimmel and Yahner (1990) and Kennedy and Stahlecker (1993) described survey methodology for Northern Goshawks using call broadcasts, and there have been numerous subsequent applications (Watson et al. 1999) and extensions (McClaren et al. 2003, Roberson et al. 2005, Hargis and Woodbridge 2006) of this technique.

**Figure 1.** Broadcasting conspecific calls has been used extensively to survey forest-dwelling raptors. Recently developed statistical methods allow for the use of resulting detection data in population monitoring. *(Photo by David E. Andersen.)*

Broadcasting conspecific or competitor calls has been used extensively to survey forest-dwelling raptors in North America (Rosenfield et al. 1988, Johnson and Chambers 1990, Mosher et al. 1990, Kennedy et al. 1995, Mosher and Fuller 1996, Bosakowski and Smith 1998, McLeod and Andersen 1998, Watson et al. 1999, Dykstra et al. 2001, Gosse and Montevecchi 2001) and, to a lesser extent, in Europe (Cerasoli and Penteriani 1992, Sanchez-Zapata and Calvo 1999, Salvati et al. 2000) and Australia (Debus 1997, Fulton 2002). Listening for spontaneous vocalizations of diurnal raptors near nests (Stewart et al. 1996, Penteriani 1999, Dewey et al. 2003) without broadcasting calls also has been used to detect birds of prey.

### Surveying Raptors Remotely

There are few published examples of using remotely sensed data to estimate raptor abundance or distribution. Harmata et al. (2000) used radar to assess timing and passage rate of birds, including raptors, during fall migration in Montana, U.S.A. Several others including Kjellén et al. (2001) and Gudmundsson et al. (2002) used radar images to study migrating birds, including raptors. However, species identification can be difficult during migration and migrants do not cross large water bodies where radar may be most effective in detecting birds (Gauthreaux and Belser 2003). Boonstra et al. (1995) had some success detecting raptors using far-infrared thermal imaging, and Leshem (1989) reported on using radar in conjunction with ground observations and motorized gliders to assess raptor migration in Israel. Overall, available remote-sensing technology so far has not been used extensively as a survey tool for raptors.

## SUMMARY

Fuller and Mosher (1987) summarized existing information and provided a background regarding objectives of raptor surveys and factors that influence survey design. Since then, several papers have reported results of raptor surveys, and survey methods have advanced considerably. Surveys incorporating call broadcasts have been applied extensively since 1987, and recent statistical advances provide a framework for survey analyses based on occupancy (MacKenzie et al. 2002, 2003, 2004; Royle and Nichols 2003) and factors related to occupancy. Although these methods only recently have been applied to raptor surveys (Olson et al. 2005, Seamans 2005, Hargis and Woodbridge 2006, Henneman et al., in press), their use is likely to increase in the future.

Many of the considerations regarding raptor surveys summarized by Fuller and Mosher (1987) are still primary issues that need to be considered when designing and conducting surveys. First, survey objectives need to be clearly set prior to survey implementation. Survey objectives include determining distribution and abundance, finding raptors to study population dynamics and other aspects of raptor ecology, and providing information from which to base management and conservation decisions. Second, survey techniques must address factors that affect raptor detection, including attributes of raptors themselves (e.g., behavior that makes raptors more or less detectable), environmental conditions, temporal patterns of raptor behavior or distribution, habitat characteristics, and attributes of observers. Third, survey design must address sampling considerations including what constitutes a sample unit, what is the appropriate sample size, and at what temporal and spatial scale surveys need to be conducted. Only surveys that appropriately address these factors are likely to provide reliable results that relate directly to survey objectives.

Surveys for raptors are a part of almost all raptor research and monitoring efforts, as finding and locating their nests or other evidence of their presence is a necessary component of most field studies. By clearly identifying survey objectives and incorporating survey techniques that appropriately address survey objectives, results of raptor surveys are more likely to provide reliable results that can be extended beyond single efforts and compared spatially and temporally.

Because survey objectives can vary considerably, and because logistical considerations affect conduct of surveys, surveys need to be designed differently for different purposes and in some instances, for different locations. Furthermore, in many instances, raptors exhibit characteristics that make them difficult to survey. Foremost among these is that raptors often occur at low biological densities, making it difficult to apply sampling strategies that result in precise estimates of abundance. Since Fuller and Mosher (1987) presented their review, survey methods for raptors have been developed considerably, in part because of a growing need for such work. Indeed, it is more important than ever that raptor surveys be well designed and implemented, so that resulting information can be used confidently, both to understand raptor ecology and to guide effective raptor management and conservation.

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