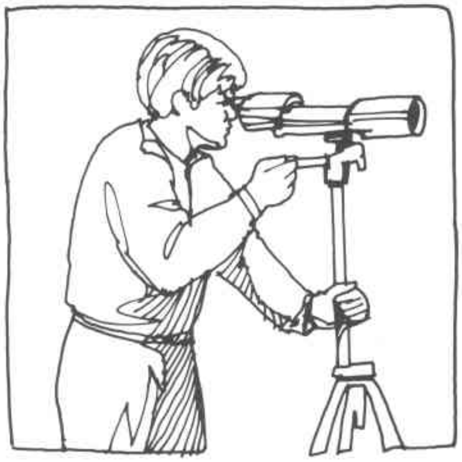

*Chapter 4*

# RAPTOR SURVEY TECHNIQUES

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## INTRODUCTION

T*his* chapter begins with a description of survey objectives and a brief discussion of variability and errors that affect surveys. Next, we present the standard sampling procedures and general survey methods most often applied to raptor surveys. Finally, these procedures and methods are integrated with information on detecting and counting raptors. This final section is organized under the sections: searching for birds, locating nests, counting raptors in colonies and roosts, and counting along migration routes. Readers who are familiar with sources of variability that affect surveys and with sampling and survey design may want to skip the first part of this chapter and read only the final section on raptor surveys. Appendix 4.1 is a comprehensive reference list of raptor survey techniques. Citations are organized according to survey type. Information is also provided on the habitat types in which the technique has been tested, as well as the geographic location of the study and species surveyed.

We define "survey" 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 or index of abundance of individuals in an area from which inferences about the population can be made (Ralph 1981). Observers conducting raptor surveys must be able to see or hear the birds or see bird sign (e.g., nest structure or the "whitewash" of defecation). Compared with most other groups of birds, raptors are rare and often widely dispersed; therefore, raptor surveys require a greater effort (personnel and time) than surveys for many other birds. In this chapter we present an overview of methods used to detect raptors and cite additional references that contain more detailed information on detection techniques. Familiarity with survey techniques and detection methods will allow biologists and statisticians to design effective and efficient raptor surveys.

Survey methods for some birds have become quite sophisticated. However, raptor surveys have not received the intensive evaluations accorded other Aves, largely because of the difficulty in obtaining the large samples required for some analyses. Still, the findings from other avian surveys are important to consider when planning raptor surveys. The proceedings of an international symposium, *Estimating Numbers of Terrestrial Birds* (Ralph and Scott 1981), are a useful source of recent information on terminology, methods of counting, sources of variability, sampling designs, and analytic techniques for avian surveys. More general information can be found in the *Wildlife Management Techniques Manual* (Schemnitz 1980) and in Miller (1984). Caughley's (1977) book is a useful reference for survey methods and analyses for vertebrate populations. Cochran (1977) and Mendenhall et al. (1971) provide statistical methods often used in surveys.

Raptor literature, museum data, and historic information obtained from biologists, amateur ornithologists, falconers, and landowners are useful for planning surveys (Fuller and Mosher 1981). Information about species' geographic distribution and habitats is readily available (see *Introduction to the Raptor Literature* in this manual). Some literature, museum records, and local people can give nest locations. Literature about behavior and activity patterns provides information relevant to detecting raptors.

There are several ongoing wildlife surveys from which raptor data can be obtained. The *Breeding Bird Survey* (Robbins et al. 1986) is conducted yearly in southern Canada and the United States. Breeding bird atlases are being assembled in many states (Udvardy 1981, Bystrak et al. 1982, Laughlin and Kibbe 1985), and surveys of certain habitats are conducted by The Nature Conservancy and by state Natural Heritage programs. The annual Christmas Bird Count is published in *American Birds* (Arbib 1981, Drennan 1981). Information from these surveys can be useful for planning, and sometimes provides data for raptor studies.

## SURVEY OBJECTIVES

Generally, raptor surveys are used to determine distribution, relative abundance or population densities. The allocation of effort and study design are different for each of these objectives. We caution against planning surveys to provide so many types of information that there are too few data to allow supportable conclusions about any single objective.

### Distribution

Raptor distribution within a certain area is shown by plotting the bird locations detected therein. It is not necessary to make extensive counts; the intensity of searches will depend on the survey area size and the people and time available. Mapping the breeding (or non-breeding) range or migration routes of a species often requires surveying large areas (e.g., continent, state, or province). More intensive surveys can be designed when making species lists for smaller areas such as parks or refuges. Also, raptor distributions can be related to the occurrence of habitats. The key to describing distributions is to look for birds in subdivisions (sample areas) that are representative of the vegetation, topography, land use, etc., in the study area.

### Density

Density is the number of units (e.g., individual birds, pairs, groups, nests) per unit area (Ralph 1981). A census is a count of all individuals or units in a specified area and specified time interval (Ralph 1981). Thus, conducting a census requires a very intensive search of an area. Usually, raptor censuses cannot be made because these birds are so widely spaced and difficult to detect that birds are missed during the count. Therefore, density is generally estimated by sampling an area. Density estimates are used for studying population dynamics, monitoring status, and evaluating responses of raptors to changes (natural or human induced) in the environment. For density estimates, the biologist must delineate the study area, organize logistics, and design sampling to account for variables that might affect the estimates.

### Relative Abundance

Relative abundance is obtained when it is difficult to assess the variables that affect the count, and when specific boundaries are not delineated around the count. Thus, relative abundance is distinguished from absolute abundance and estimates of density and can be used only for comparisons in time, among locations, or among species. Surveys of relative abundance require consideration of more factors than do surveys of distributions. Biologists should standardize methods among comparisons and make comparisons only when detectability is similar or when correction factors can be applied.

## VARIABILITY AND ERROR

When planning surveys, biologists must consider the sources of variability that can affect the collection and interpretation of data. High variability associated with low detection rates can produce inaccurate results. There are ample data to demonstrate that the accuracy of most avian surveys is less than 100% (Ralph and Scott 1981). The raptor literature also contains many examples of surveys in which birds (Craighead and Craighead 1956, Sattler and Bart 1984) and nests (Henny et al. 1974, Olendorff 1975) were missed. The extent of this problem is detailed in the section on raptor survey techniques. We present a few examples of sources of variability to alert the reader to factors affecting detectability that must be considered when designing surveys.

### Species Specific Detectability

Detectability varies among species according to body size, activity cycle (i.e., diurnal, crepuscular, nocturnal), habitat use, and flight behavior. Models of sharp-shinned hawks were detected significantly less than those of Cooper's or red-tailed hawks (B. Millsap and M. LeFranc, pers. commun.). Migrating hawks that often soar were detected significantly more than non-soaring species (Sattler and Bart 1984). The social behavior of birds also influences their detectability (Quinn 1981); flocking species (e.g., vultures) or colonial/semi-colonial nesting species (e.g., Mississippi kites, northern harriers) often are easier to detect than solitary species. Species that are aggressive toward the observer at nest sites (Postovit 1979) or vocal and highly visible during territorial displays (e.g., red-shouldered hawks) are more easily detected than those that avoid people. Before biologists compare relative abundance or densities of species they should estimate the detectability of the species and adjust comparisons for detectability differences among species (Millsap 1981).

### Age and Sex

The age and sex of birds also affects their visibility. For example, Hancock (1964) noted differences between detectability of adults (85-90%) and immature (65-80%) bald eagles. Fledgling owls of some species are quite vocal (Allaire and Landrum 1975, Lynch and Smith 1984) and more easily detected than older birds. Differences in detectability between males and females can result from differences in activity, such as incubation (Jones 1979, Cade 1982) or habitat use (Koplin 1973).

### Time of Day

Surveys are often restricted to certain times of the day because the behavior of birds, and thus their detectability, changes through a 24-hour period (Skirvin 1981). Robbins (1981*a*) found that mornings were the best time to count Falconiformes and that as the air warmed, hawks and vultures became more visible. There is daily variation in the activity and extent of movement in the breeding season (Fuller 1979) and during the winter (Bildstein 1979). Also, during a 24-hour period both detectability (Mueller and Berger 1973) and capture rates (Mueller and Berger 1970) of migrating raptors vary. Grier et al. (1981) found that ambient light affected the detectability of nests from aircraft.

### Time of Year

Time of year is a very important factor influencing detectability (Best 1981), because of changes in activity levels (Diesel 1984), behavior and local seasonal fluctuations in density. During migration, many species become concentrated at points along their migratory routes, and in winter some migrants cohabit areas with residents, thus dramatically increasing local density. Flocking and communal roosting behaviors change seasonally (Bildstein 1979, Sweeney and Fraser 1986). Rapid changes in the detectability of birds take place during the reproductive cycle. Raptors are often most vocal and visible while courting and establishing their nesting territories (Rosenfield et al. 1985). Owl detectability varies with seasonal

Detectability varies among species and habitat types. This researcher is placing a red-tailed hawk model in grassland habitat for a species detectability study. (Photo courtesy of M. LeFranc, Jr.)

changes in frequency of vocalizations (Forsman et al. 1977, Johnson et al. 1979, Lynch and Smith 1984). During incubation and brooding the number of breeding birds moving about is effectively reduced by one-half. Designing surveys to accommodate these changes is confounded by lack of synchrony among breeding birds in an area (Craighead and Craighead 1956, Postovit 1979).

### Weather

Inclement weather influences surveys by changing visibility and by affecting bird behavior. Wind velocity and temperature affect winter raptor counts (Brown 1971, Wilkinson and Debbon 1980), and winter weather can affect raptor roosting behavior (Bildstein 1978). Counts and captures of migrating raptors are influenced by numerous local and continental weather factors including wind, visibility and the passage of fronts (Mueller and Berger 1961, Haugh and Cade 1966). Robbins (1981*b*) found that red-tailed hawk sightings along Breeding Bird Survey routes were reduced by 42% in fog. His analysis also showed a positive correlation between wind speed and detections of red-tailed hawks and a negative correlation between temperature and sightings.

### Habitat

The habitats to be searched are an important consideration in planning avian surveys (D.K. Dawson 1981, Karr 1981, Oelke 1981). Raptor visibility from roads or waterways varies with vegetation structure (Craighead and Craighead 1956, Wiemeyer 1977, Andersen et al. 1985). Nest substrate and the surrounding habitat affects visibility of nests (Henny et al. 1974, Phillips et al. 1984). Also, habitat use can vary from year to year. O'Connor (1981) found that Eurasian kestrels (*Falco tinnunculus*) occurred in a greater variety of habitats in years of high density than during low density years.

### Prey Density and Distribution

Newton (1979) cites many examples of how raptor distribution and density are affected by distribution and density of prey. Raptors respond to within-season changes in prey abundance by moving to new areas (Craighead and Craighead 1956, Bildstein 1979). Therefore, even the design of relatively short-term surveys (about 30 days) should consider comparatively long movements (10 km) of birds. This is especially true for flocking or communal roosting birds such as some vultures and kites. Also, adults and fledglings move widely in response to prey availability after young leave the nest. Finally, local densities of prey can fluctuate annually and with them the number of raptors in a local area (Southern 1963, Newton 1979, Hamerstrom et al. 1985).

Detectability of raptors along roadsides is affected by vegetation density. The biologist must consider potential differences in detectability when selecting survey routes and when analyzing data. (Photo courtesy of B. Millsap.)

### Observer Variability and Error

Observer differences are a likely source of variability in avian surveys (Ralph and Scott 1981:326-390). Field personnel should know the survey objectives and be experienced with species, age and sex identification. The observers' familiarity with bird behavior and local habitat use by raptors can increase detection rates. However, experience limited to 1 or 2 methods of search or to certain habitats can produce unrepresentative results if other parts of the study area are neglected. Confusion about use of equipment and procedures not only creates inefficiency, but is likely to cause measurement errors and errors in tabulating, coding, etc., that result in useless and missing data (McDonald 1981). Therefore, training, practice, and discussion of procedures and objectives are useful for reducing variability among observers (Mikol 1980, Kepler and Scott 1981).

Survey designers must consider the factors causing variability and error in detection. Differences in detectability can obscure or exaggerate comparisons of counts. When objectives include a study or management of the natural variability of populations, biologists must be able to separate the biologically interesting variance from the errors and inaccuracy inherent in the survey methods (James 1981). Careful study design helps to control and measure variability associated with raptor detections.

## STUDY DESIGN

Most raptor surveys are conducted in large areas, making censuses impractical. Therefore, biologists should use sampling techniques when designing surveys. We recommend that surveys be planned with the participation of a biometrician. This section of the chapter provides a brief review of basic sampling and survey methods, but before selecting methods, there are several topics the survey planner should consider.

First, the specific objective(s) of the survey and the application of results should be listed. Next, the biologist should choose the time scale and spatial scale (i.e., hectares, $km^2$, county, state/province) and measurements that will be most relevant to the objectives (Wiens 1981). The survey area must be delineated and the biologist should become familiar with the habitats in the area. Biometricians will ask about sources of variability. Survey planners must also consider what hypothesis will be tested, what estimates are needed, and what power will be useful (how small a difference or change must be detected) (Rice 1981). The cost of planning, conducting, and analyzing the survey should be estimated.

General reconnaissance of large areas such as states, national forests and parks, and counties is recommended for surveys of widely dispersed birds such as raptors (Dawson 1981). Pilot studies provide information needed for planning a survey (Mikol 1980, Rice 1981); they can help determine the feasibility, given budgeting and logistics constraints, of conducting the survey and can provide variance estimates.

### Sampling

We provide brief descriptions of common sampling methods. More detail about sampling methods can be found in Mendenhall et al. (1971), and Cochran (1977). Some methods are covered briefly in Miller (1984). Sampling procedures used in avian surveys are presented throughout Ralph and Scott (1981).

*Simple Random Sampling.*—Simple random sampling exists when every unit (e.g., location point, grid square) in the statistical population (e.g., all grid squares on the study area) has an equal chance of being chosen each time a unit is selected. Simple random sampling is seldom applied to raptor surveys. Raptors are rarely distributed randomly over large areas because their habitats are not homogeneous over large areas and because social behavior often results in spacing (Newton 1979). Thus, by chance, randomly selected units might fall mainly in areas of very high or very low raptor density. In either case the resulting estimate will not be very accurate. More efficient techniques exist for surveying.

*Stratified Random Sampling.*—This method allows a biologist to divide the study area into smaller, non-overlapping areas (strata) based on features such as habitat or bird density. Stratified sampling usually increases overall precision, especially if a heterogeneous population is divided into more homogeneous subdivisions. Strata also can be assigned samples according to convenient administrative or political subdivisions (Cochran 1977:89; Miller 1984). Locations for counts within strata can be selected by random sampling. Other sampling schemes can be used to choose locations in strata. Regardless of how locations are chosen, all strata should be sampled, each independently from other strata. The number of samples taken in each stratum can be allocated in proportion to the stratum size or density, or allocation can be optimized for cost and variance consideration (Cochran 1977:89-149). Stratified sampling allows precisions to be calculated for subdivisions of the population.

*Systematic Sampling.*—Systematic sampling involves randomly selecting a starting point and taking samples at equally spaced intervals thereafter. Systematic samples often are recommended for large areas (Kingsly and Smith 1981, Miller 1984), because by spreading the samples over a large, often variable area, one can obtain better estimates of means and gain more precision than by simple random or stratified methods (Cochran 1977:205-206). Conducting systematic samples in the field often is more efficient than other methods because travel paths and intervals are fixed. One drawback of systematic sampling is that estimates of precision can be difficult to achieve.

*Cluster Sampling.*—This method is useful in field situations when the cost of travel between sample sites is an important consideration. A cluster is simply a group of smaller sampling units in physical proximity. When sampling in clusters, field workers can search in several nearby sample units before traveling a longer distance to the next cluster. Mendenhall et al. (1971:111-146 and 171-186) and Cochran (1977:233-273) discuss rationale for assigning the number of units to a cluster.

*Double Sampling.*—Recording information about factors that might be related to raptor occurrence and abundance can increase precision. For example, McDonald (1981) suggests measuring vegetation cover on a large sample of plots as well as on a smaller sample on which birds are counted. The data from these large samples can then be used to adjust the smaller sample to reduce variation. For more information about double sampling consult a biometrician or see Mendenhall et al. (1971) or Cochran (1977).

### Sample Size

When a sampling technique has been chosen, it is necessary to determine how many samples to take. The information needed for this decision includes the degree of variability likely to be associated with the survey, the level of precision or power needed for useful results, and knowledge of the resources available to conduct the survey. As Rice (1981) notes, a pilot study is often useful for obtaining some of this information. Mendenhall et al. (1971) and Cochran (1977) or a biometrician can provide guidance for determining sample sizes based on the requirements of the survey and a particular sampling technique. Rice (1981) warns that for avian surveys in general, large samples may be needed in order to avoid inconclusive results, and he cautions against believing one has arrived at a firm conclusion until statistical estimates of precision have been calculated. The process of considering objectives, study area, likely sources of variation, sampling techniques, sample size, and costs may have to be repeated several times to determine the combination of those factors that permit a useful survey to be conducted.

**General Survey Methods**

There are several methods for conducting searches for raptors. A complete search of a small study area or of small sample units (e.g., grid square) is possible but usually not practical. More likely, each sample unit will be searched from a route(s) or fixed position(s). We use the definitions of Ralph (1981) in the following descriptions of general survey methods.

*Transects.*—Transect refers to a cross-section of a study area along which the observer moves in a given direction. Transects are often used for raptor surveys because large areas can be searched with little time spent traveling to, and finding new sample points. Paths and roads are frequently selected as transects because they facilitate travel. Nonetheless, existing routes can be inappropriate for surveys if they do not occur in habitats representative of the study area. Transects should not follow features such as ridges, valleys, or roadways when correlations between occurrence of birds and these features could cause misinterpretation of the results (Kingsley and Smith 1981). When a transect crosses several habitat types with unequal visibility, the transect can be divided into segments, and measurements can be made to account for differences among portions of the transects. The search area from one transect should not overlap with that of an adjacent transect.

There are 3 basic types of transects: (1) strip (or belt), (2) line, and (3) point (Mikol 1980, Ralph 1981). The sample area for a strip transect is the area on each side of the transect line. The search area can cover: (1) a fixed distance (width) perpendicular to the transect, (2) a variable distance, or (3) unlimited distance. The distance (width) to be searched on both sides of the line is based on the detectability of the birds. Thus, width varies by species, habitat type, and the observer's method of movement (e.g., walking, driving, aircraft). Biologists search for birds along the entire transect. When estimating density, the basic assumption of the strip transect method is that all birds within the strip are seen (Mikol 1980, Burnham et al. 1981). This assumption can be difficult to meet for raptor surveys. The wide-ranging habits of birds of prey also complicate applying the strip method to estimates of density because surveys confined to relatively narrow strips often miss species with large home ranges (Mikol 1980). Therefore, relative abundance, not density, often is an appropriate statistic to derive from strip transect surveys for raptors.

The line transect, by contemporary definition, is designed specifically for estimating density, and is useful when there are variable sighting probabilities along the transect (Anderson et al. 1979, Burnham et al. 1980). The line transect technique allows some individuals to go undetected. The analytical techniques applied to the data account for the variability in detection (Laake et al. 1979, Gates 1980, Burnham et al. 1981). The data are gathered by measuring the distance (and angle if the bird is not perpendicular to the line) to all birds sighted when moving along the transect. Distances to birds can be recorded by categories (i.e., 0-10 m, 11-230 m). There are 4 basic assumptions for line transect sampling: (1) birds on or very near the line will always be detected, (2) there is no average movement of birds toward or away from the observer and no bird is counted twice, (3) distance and angle data are recorded without error, and (4) sightings of different birds are independent events. Gates (1981) discusses ways to optimize effort devoted to line transects. The major difficulty with applying the technique to raptors has been the requirement that on each transect at least 40 birds must be counted and their distances measured. However, the line transect method of survey and associated analyses are considered to be some of the best techniques for estimating avian densities. Therefore, use of line transects should be explored further for raptor surveys (see Andersen et al. 1985; Kochert, in press).

A point transect involves stopping at intervals along a transect for a fixed time, recording detections, then moving to the next stop. No record is made of sightings occurring between stops (as opposed to continuous records during strip and line transects). Stops along the transect should be spaced so the same bird is not counted from 2 stops.

*Point Counts.*—The point count method involves recording contacts from a fixed location for a specified time. The points are not associated with a transect. The location of points is determined by sampling (e.g., random, stratified). The time spent at a point should not be so long that birds move to and from the area and thus are counted more than once (Ramsey and Scott 1981). The area in which detections are made can be of a fixed radius around the point, variable according to visibility of the species (Reynolds et al. 1980), or unlimited. Each point count can be treated as a sample. Point counts are particularly useful in topography and vegetation through which it would be difficult to conduct counts from transects (Karr 1981). Point counts are useful for cluster sampling.

*Spot-mapping (territory mapping).*—For this survey method the locations of individuals are plotted on a study area map to delineate areas of use, home ranges, or territories of birds. The number of areas is an index to abundance. Several visits to the study site must be made to accumulate bird locations and, ideally, make simultaneous observations of adjacent birds in order to delineate the boundaries between their areas of use. Compared to surveys of songbirds (Falls 1981, Franzreb 1981), the mapping method is of limited use for raptor surveys because of low rates of raptor detection. However, if observers cover most of a study area several times a week for several weeks, mapping is useful for accumulating information about areas occupied by birds (Craighead and Craighead 1956).

*Capture and Marking.*—Capture and marking are usually supplements to other raptor survey techniques (see *Capturing and Handling Raptors*, and *Marking Techniques* in this manual). Capturing, marking, and subsequently recapturing (or resighting) some of the marked sample can be used to estimate densities when mark-recapture model assumptions are met (Nichols et al. 1981, Pollock 1981). Capture, marking, and recapture have been used to estimate density (Kenward et al. 1981) and to study reoccupancy and turnover rates of the raptors using an area (e.g., Mearns and Newton 1984). Capture rates of raptors are low except during migration (Fuller and Mosher 1981). Maps of encounter (recovery and recapture) locations obtained after capture and banding of migrants have provided data about the distribution of several raptor species (e.g., Evans and Rosenfield 1985, Clark 1985). Capture of migrants also permits data gathering about age, sex and physical measurements (Mueller et al. 1977, 1979).

## RAPTOR SURVEY TECHNIQUES

This section provides guidelines for applying basic sampling and survey techniques to raptor studies. The section is organized in relation to the field objectives of searching for raptors, locating nests, counting at colonies or roosts, and counting migrants. Under each field objective, the techniques are presented primarily according to methods of travel. Travel mode strongly influences study design when searching for sparsely distributed raptors in large, remote areas or rough terrain. Mode of travel, number of observers, and seasonal time constraints are the factors most likely to influence raptor survey techniques. We describe each raptor survey technique, including its applications, advantages and limitations.

### Raptor Searches

The most common raptor surveys are searches for birds. Locating raptors is the main field objective when mapping distributions or counting birds, and locating raptors is essential in other studies such as habitat selection or predator-prey relationships. Survey design and search results provide the data necessary to determine the sample with which biologists study habitat use, food habits and other behavior.

*Road Surveys.*—Road surveys are used to map raptor distributions, calculate relative abundance, estimate densities, and study habitat use. Roads and trails, which provide convenient access to many study areas, can be used as transects for surveys made from a motor vehicle and allow large areas to be searched efficiently. In open habitats such as desert and prairie, observers can scan extensive areas for raptors. Road surveys are useful in forests and facilitate travel through dense vegetation and rough terrain. For example, in forests of the eastern United States more birds of prey were detected while biologists drove (0.55 contacts/hour) than while walking

Capture, marking, and recapture techniques are often used in nest site fidelity and turnover rate studies. (Photo courtesy of NWF.)

during systematic searches (0.21 contacts/hour) (J. Mosher, M. Fuller, and M. Kopeny, unpubl. data). Kochert (in press) calculated coefficients of variation for 7 road counts and found a range from 6-14%.

There are several limitations of road surveys. Roads do not always occur in topography and habitats that are representative of the study area. For example, roads frequently follow valleys and ridges. The types or successional stages of vegetation along roads and trails can be different from off-road areas. Fences, telephone poles, and other roadside structures create perches and nest substrates (Marion and Ryder 1975) that can influence the distribution of raptors.

Accuracy of road surveys is affected by detectability of birds. Habitat structure is an important influence on detectability (Marion and Ryder 1975, Craig 1978, Diesel 1984, Sferra 1984). B. Millsap and M. LeFranc (unpubl. data) tested detectability with raptor models counted from roads and found that 11-64% of the models were seen in grassland, 2-32% in woodland, and 5-26% in dense forest. Size differences among raptor models accounted for the range of detectability within habitats. Overall, Millsap and LeFranc detected significantly fewer sharp-shinned hawk models than Cooper's hawk or red-tailed hawk models. From experience with repeated road counts, Craighead and Craighead (1956) estimated that they saw 92% of the *Buteo* hawks, 43% of the northern harriers and 33% of the American kestrels and Cooper's hawks within 400 m of roads. Raptor behavior also affects detectability. For example, from roads, Diesel (1984) saw flying red-tailed hawks more often than perched birds, and he detected hawks perched higher than 2 m (in the afternoon) more often than those below 2 m. To minimize differences in detectability among surveys, we suggest standardizing the time of day, season and weather. Counts should be conducted only during periods without persistent precipitation or fog and when wind speeds are less than 13-19 km/hour (Beaufort Scale = 3).

Road survey routes can be selected randomly or from a stratified sample based on habitat and density (Andersen et al. 1985). Separate analyses of data from transects in different habitats allow the biologist to consider potential differences in detectability. However, biologists might not be able to use sampling to select routes when there are limited numbers or distributions of roads. Also, biologists might select roads from which the entire study area can be viewed (e.g., Marion and Ryder 1975). In these situations, data can be pooled from portions of continuous transects or from stops along point transects having similar habitat or density. The pooled data for each habitat type, density strata, etc. can be analyzed separately.

Biologists should become familiar with the study area before completing survey design. Some roads may be unsuitable because of traffic noise, insufficient roadside stops, poor visibility, or seasonal surface conditions. If the transect is subdivided to create a series of sample segments, or if point counts are spaced along the transect, these features should be mapped and verified along the route before the first survey is initiated. Exact starting point or stops might have to be moved a short distance to avoid intersections, dangerous curves, or features that do not fit the sampling design.

Equipment for road surveys includes a vehicle from which observers have good visibility. Observers should have binoculars and a spotting scope to aid identification of distant birds. A range finder can increase accuracy of distance measurements to transect boundaries and to birds. Data can be entered on forms or recorded on a tape recorder. Also, we suggest plotting bird locations on topographic maps.

An observer should record weather (temperature, wind speed and direction, percent cloud cover), start and finish odometer readings, start and finish times, location of bird (odometer reading, map plot), distance and angle to bird, bird habitat use, and bird activity (e.g., perched or flying). Observers should attempt to determine the age and sex of individual raptors.

To conduct strip and line transects, a driver and observer must continually search for birds from a vehicle moving from 17-40 km/hour. The vehicle may be stopped momentarily while birds are identified, and distances and angles are measured. Biologists can use point transect methods when vegetation or topography impede visibility, and for owl surveys for which aural detections are important. Observers should stop at points spaced about 0.8 km and look and listen for raptors during a 3 to 5 minute period. Distance between stops can be adjusted according to the spacing among birds.

The width of strip transects and diameter of plots around point transects should be based on an estimate of each species' detectability along the route. For example, Millsap (1981) determined that Cooper's hawks and sharp-shinned hawks were detected significantly less often beyond 101 m. Therefore, he estimated densities of these species only using detections from 0-100 m.

We suggest using line transects (Burnham et al. 1980) when 40 or more birds can be detected and accurate distances can be measured between the observers and each bird. Transects may be lengthened or data pooled from segments to meet the 40 bird minimum of line transect methodology. With these data, biologists use line transect analyses (Laake et al. 1979, Burnham et al. 1980, Gates 1980) to estimate densities that are adjusted for differences in detectability.

We recommend making counts for relative abundance values when detectability estimates are unavailable and when observers cannot be sure they are detecting all raptors in a strip or circle. Observers should search over unlimited distances to accumulate counts for relative abundance. Comparisons of relative abundance should be made only among surveys which took place under comparable conditions. Again, we suggest standardizing number of observers, habitat and terrain along transect, weather, season, and other factors that might influence count accuracy.

*Broadcasting Raptor Calls.*—Imitating, or broadcasting a tape recording of owl vocalizations can elicit vocal responses or approach (see reviews by Johnson et al. 1981, Fuller and Mosher 1981). There also is evidence that responses can be elicited from some diurnal raptors (Rogers and Dauber 1977; Hennessy 1978; E. Schriver, M. Root and P. DeSimone, pers. commun.). Therefore, in 1979, tests were conducted to determine the effectiveness of broadcasting conspecific vocalizations of several eastern woodland raptors (J. Mosher, M. Fuller, and M. Kopeny, unpubl. data). Broadcasts of conspecific vocalizations produced significant increases in detection rates with Cooper's hawks, red-shouldered hawks and barred owls. Broad-winged hawks were not detected while only looking and listening, but were detected after broadcasting their calls on point count transects. There is evidence from recent studies that these species respond similarly in different geographic areas (Balding and Dibble 1984, McGarigal and Fraser 1985, Rosenfield et al. 1985) and that other species can be detected with similar methods (red-tailed hawks, Balding and Dibble 1984; great horned owls, McGarigal and Fraser 1984).

Furthermore, broadcasts of great horned owl calls have resulted in Cooper's hawk and red-shouldered hawk detections at least as often as from detections elicited with conspecific calls (J. Mosher and M. Fuller, unpubl. data). The use of 1 vocalization (e.g., great horned owl) to elicit contacts with several species increases survey efficiency. Biologists have detected 75-85% of the nesting pairs of great horned owls (Springer 1978) and spotted owls (Forsman 1983) by broadcasting conspecific vocalizations. Therefore, broadcasting raptor calls is useful for increasing detections used for plotting the distribution and obtaining the relative abundance of breeding raptors.

Biologists using calls must consider several factors in addition to those variables affecting other methods. It is not known how different vocalizations and sources of calls affect responsiveness, or if there is accommodation to the recordings, or from what distance birds respond, or what proportion of birds respond to broadcasts. There are differences among species, by age and sex, time of year, lunar cycle, and perhaps across geographic range (see Johnson et al. 1981, Fuller and Mosher 1981). Therefore, some standardization should be employed, and variability among counts should be calculated.

A portable cassette tape recorder and vehicle-mounted speaker can be used to broadcast raptor calls. Broadcasts of conspecific vocalizations have been used to increase detections of several woodland hawk and owl species in breeding distribution and abundance studies. (Photo courtesy of M. Fuller.)

Relatively inexpensive equipment can be used to broadcast vocalizations. A portable cassette tape recorder (e.g., Marantz C-205[1] tape recorder) should include frequency response of about 100 Hz to 10 kHz, a minimum power output of about 1.2 watts at 1 kHz, and an output plug for an external speaker (8 ohm). The speaker can be a 10-20 cm trumpet, or combination of amplifier and speaker (Springer 1978, McGarigal and Fraser 1984). Audio output should be adjusted to 100-110 db at 1 m in front of the speaker. Biologists can broadcast 6 vocalizations equally spaced for a 5-minute period. Standard records are available from published sources (e.g., Kellog and Allen 1959, Hardy 1980). When broadcasting from a vehicle, a cigarette lighter adapter can provide connection to the automobile battery and assure full power to the recorder during the broadcasts. A long wire connecting the speaker and recorder allows removal of only the speaker from the vehicle.

Counts should not be conducted in inclement weather (e.g., precipitation, winds greater than about 15 km/hour). Surveys for hawks can be conducted for several hours after sunrise, and those for owls should begin after sunset. At each stop, observers should play the 5 minutes of broadcasts, rotating 180° the direction the speaker faces after each of the 6 sets of calls, and remain at the stop for 5 minutes after the last broadcast to look and listen for raptors. Initial contacts, visual or aural, with all individuals should be listed during the broadcast and for 5 minutes afterward. By plotting approximate locations of contacts on a map, the chances of recounting the same

[1]Use of trade names does not imply endorsement by U.S. Government, the authors, or the National Wildlife Federation.

bird are reduced, and observers can accumulate a spot-map to aid interpretation of raptor distributions.

To obtain continuous coverage of an area, stops should be spaced at 0.8 km intervals. Some owls might follow the broadcasts along the route, or be distributed such that different spacing is necessary (see Forsman et al. 1977; Johnson et al. 1979, 1981; other references in Appendix 4.1). For breeding season surveys, about 6 replicates of a 10-stop transect should be run and scheduled to avoid counting spring or fall migrants. To obtain data from large areas (e.g., county, state or national forest), a sample with longer transects, or a greater number of transects, conducted less frequently, might better utilize limited personnel.

*Foot Surveys.*—Walking can be the sole method of survey, but usually it is a supplement to other methods (e.g., road surveys) used to identify activity areas. Detection rates while walking are low compared with those from road surveys, but very thorough searches of small plots or study areas are possible by foot surveys. Also, hiking to prominent points in the study area provides an opportunity to watch for raptor flights and displays. Snyder and Johnson (1985), systematically photographed California condors to obtain individual identifications. Walking provides access to roadless tracts (Burnham and Mattox 1984), rugged terrain (Forsman 1983) and dense vegetation. Foot surveys allow observers access to sites to find subtle clues and accumulate detailed observations.

A potential disadvantage of walking is the variety of raptor responses to an observer on foot. When approached, some species, such as Cooper's hawks, might fly silently from a perch or nest before the observer is close enough to detect them, whereas goshawks might aggressively fly at the intruder. When Craighead and Craighead (1956) entered woodlots they flushed roosting great horned owls, whereas Forsman (1983) found that spotted owls can be approached within a few meters. Postovit (1979) found considerable variability among species and suggested that surveys include calculations of visibility biases for each species. Raptors' responses to observers vary throughout the year, but usually they are aggressive only during the breeding season. Habituation occurs with some raptors that are regularly exposed to human activity. For example, ospreys near boating activity often allow people near enough to observe them on the nest. In very remote areas, some raptors, such as arctic falcons, also tolerate an observer's approach. In tundra, prairies, and other open habitats, even birds that flush far from the walker might be heard or seen soaring or perching. Observation of forest-inhabiting species often is not possible, but indirect signs of their presence are useful for surveys.

A useful clue to a raptor's presence is prey remains, particularly the scattered feathers plucked by bird-eating raptors. Some species, especially accipiter hawks (Reynolds 1982), use certain fallen trees, stumps, or limbs as "butcher-blocks" on which to pluck prey before eating it or delivering it to a mate or young. Other raptors often repeatedly use a few perches or roosts where biologists can find prey remains and the regurgitated pellets of undigested food (fur, feathers, scales, bones, exoskeletons). The chalk-like, white feces of falconiforms (usually a streak) and owls (a round or oval deposit) also accumulate at perches and roosts. Molted feathers provide another clue to birds' presence.

Foot surveys permit access to almost any terrestrial habitat, allowing the biologist to consider many sampling options and survey procedures. We recommend that plots (i.e., circles or quadrats) or transects be selected based on stratified or cluster sampling. The observer can follow systematic transects to obtain complete coverage of a plot. Point transects or point counts (within plots or at sample points in a cluster) are appropriate if the observer is going to broadcast vocalizations.

Equipment for foot surveys includes binoculars and a compass for locating sample sites. A battery-powered cassette tape recorder (about 30 × 15 × 7 cm) with built-in speaker is convenient for broadcasts. Maps and notebook should be carried for plotting detections and recording observations.

The observer should record times birds are seen, and their age, sex, activity, direction of flight, and habitat use. Observers should be experienced in finding and interpreting signs of birds' presence (Call 1978). In forests, observers must be able to identify birds seen only at a glance as they flush from perches or fly briefly through openings in the vegetation.

The paths of travel for foot surveys usually are arranged for systematic coverage so the entire area (or sample plot) is searched. The distance between paths should be spaced according to the limits of visibility imposed by vegetation or terrain. The shape of the transects may take a variety of forms, but to avoid re-searching or missing areas, walk along concentric rings or parallel strips. If broadcasting calls to increase detectability, stops along a point transect should be spaced from 0.25 to 1.0 km. The shorter intervals have been used to detect small owls (Johnson et al. 1981, Lynch and Smith 1984, cf. Forsman 1983). When searching for roosting owls, Craighead and Craighead (1956) placed an observer at one end of woodlots so that owls flushing from the woods could be detected when a person entered the opposite end. If searching the entire area is not a goal, transects or point counts should be spaced far enough apart so that it is unlikely a bird from one plot will move to another plot during the survey.

*Aerial Surveys.*—Biologists have used aerial surveys for describing distributions and enumerating large raptors such as eagles and conspicuous, medium-sized birds such as falcons in tundra or deserts. Aerial surveys reach remote areas quickly and cover large areas efficiently. The total cost of some surveys can be reduced and the work completed in less time when aerial searches are used rather than ground searches (Kochert, in press). The precision of several aerial surveys for golden eagles and bald eagles ranged from 14 to 16.5% (Kochert, in press). Winter bald eagle counts from helicopters can be more precise than counts from fixed-wing aircraft (U.S. Dep. Inter. 1983).

The accuracy of aerial surveys varies. Generally, Caughley (1974) considered counts from the air to be of medium to low accuracy. Accuracy decreases with increasing strip width, altitude and flight speed. There are few accuracy data from aerial counts of raptors because it is difficult to obtain ground-truth data. However, Hancock (1964) calculated that he undercounted adult bald eagles by 10-16% and immatures by 20-35%.

Aerial surveys usually follow systematically spaced straight-line routes or trace the shoreline, cliff, or other habitat feature where birds are expected to occur. To sample southeastern Alaska, King et al. (1972) searched for bald eagles in 30 grid squares (166 $km^2$) chosen randomly from pre-selected habitat. To count golden eagles in the grassland and desert shrub habitats of the western United States, biologists randomly chose a starting point, then flew parallel straight-line transects at even intervals (Higby 1975). Transect spacing has varied from 2.4 to 6.4 km to minimize duplicates and to accommodate differences in visibility from various aircraft and among observers, habitats and species. Because aerial surveys cover large areas, transects will likely cross major habitat features, or be of unequal length if they are restricted to a habitat. Transect segments of similar habitat can be treated as samples, or pooled for analysis.

Based on 3 years of aerial surveys for golden eagles, Kochert (in press) found that density estimates from line transects were consistently higher than calculations from strip transects. This suggests that observers do not see some birds in the strip. Line transect analyses (Burnham et al. 1980) will account for differences in detectability along the transect. Bird activity (flying vs. perching), time of day, and background (foliage, snow cover, etc.) affect detectability. Line transect methods are suitable for aerial surveys because the observers are not likely to influence the movements of birds, distance categories can be assigned to locations, and enough area can be covered so that 40 or more birds can be counted.

Observers have worked from a variety of fixed-wing, single-engine planes and helicopters (Kochert, in press). Airspeeds have ranged from about 72 to 160 km/hour in fixed-wing planes and 50 to 100 km/hour in helicopters, at altitudes from 15 to 100 m above ground level. The speed and height of flight depend on the capabilities of

Aerial nest surveys with helicopters, fixed-wing, or ultralight aircraft are often more efficient and cause less disturbance than ground or boat surveys. Flights 50 m above the water and 20 to 100 m from shore are recommended for bald eagle nest searches. (Photo courtesy of P. Nye.)

the aircraft, as well as topography, vegetation, structures (e.g., power lines), and bird or nest visibility. Boeker (1970), Hickman (1972), Grier et al. (1981), and Hodges et al. (1984) have described their planes, techniques and safety considerations. The use of the helicopters has been described by White and Sherrod (1973) and Carrier and Melquist (1976).

Generally, relatively slow air speeds, and low altitudes above the ground will allow observers to see more birds (Caughley 1974), but safety should be the primary consideration. Rotor-winged aircraft allow the biologist to select from a continuum of flight speeds. Helicopters are more stable than fixed-wing aircraft in windy conditions (Call 1978). Helicopter maneuverability is an asset for surveys in canyons and around power lines. Small, fixed-wing planes such as Piper Super Cubs allow lower sustained air speeds than larger aircraft such as the Cessna 180. We suggest contacting government agency or commercial pilots during the planning of aerial surveys. Pilots should determine the best aircraft considering the extent of the survey, topography, weather, and the biologists' needs regarding detectability of the birds. Factors such as topography and distribution of habitats must be considered in the survey design (Boeker and Bolen 1972, Boeker 1974).

When the survey route follows some feature such as a shoreline, or centers on habitat such as a dam where wintering bald eagles occur, flight-lines can be concentric circles or irregular lines moving farther away from the feature with each transect (Hancock 1964, U.S. Dep. Inter. 1983). It can be difficult to follow meandering and convoluted shorelines. Thus, for safety and keeping track of the flight path and location of birds, pilots should avoid very tight turns (see Grier et al. 1981). Biologists should plot flight routes and transects on maps (or transparent overlays) prior to flights. A pre-survey flight can be useful for determining detectability and travel routes, and for working out communication among pilot and observers (e.g., request circling or a second pass to confirm bird identification and location).

One or 2 observers experienced with detecting, identifying, and counting raptors from the air, plus a pilot familiar with the survey design, objectives, and study area should conduct the survey (U.S. Dep. Inter. 1983). Aerial surveys should occur on clear days, without precipitation, and when winds are less than 32 km/hour. These conditions contribute to visibility and observer comfort. Eye strain and general fatigue are concerns. Kochert (in press) recommends flights of 3-4 hour duration, and no more than a total of 6-7 hours per day. Observers should wear hearing protectors (ear plugs). Observers should be assigned to search a portion of the sky and ground. Scanning through that space (rather than fixing the eyes) is recommended. The total space to be searched will depend on the height of the aircraft and visibility of the birds.

All birds within the search area should be tallied, their positions marked on a map, and the distance to birds estimated. During the flight, observers should record plumage and behavior data on forms or tape recorders. These data can be useful for interpreting breeding status (see *Assessing Raptor Reproductive Success and Productivity* in this manual) and interpreting counts. Relative abundance can be calculated by summing all the birds or nests that occur on both sides of the flight line. When the measurements and assumptions of the line transect method are met (Gates 1980, Burnham et al. 1981), an estimate of density can be calculated (Kochert, in press).

*Boat Surveys.*—Most considerations for conducting observations from a terrestrial vehicle are applicable to the use of boats. Additionally, biologists must consider that only the habitats along rivers, bays, and lakes are surveyed because the reduced visibility from low-lying shorelines to inland areas limits the sample area. Nonetheless, in remote river canyons and extensive swamps, marshes, or coastlines, boat surveys might be the only practical way to find birds (Cade 1960, Sykes 1982). For some species, such as snail kites (Sykes 1979), bald eagles (Whitfield et al. 1974), or osprey (Reese 1975, but see Prevost et al. 1978), many birds can be detected from a boat. Often, boat surveys are used as 1 of several methods when sampling a variety of habitats.

### Locating Nests

Nests are the focus of many management plans and studies because nest habitat is essential for birds and because biologists can regularly observe raptors near nests. Consequently, the objective of many raptor surveys is to find nests. Several publications provide information relevant to nest searches. In particular, western North American raptors are discussed in Bureau of Land Management technical publications (Call 1978, Jones 1979, Mindell 1983). Additional technical publications and references about nesting biology can be found in *Assessing Raptor Reproductive Success and Productivity* in this manual.

Raptors do not nest randomly in the environment; rather, they select nest habitat that provides (1) a substrate on which to build a nest or lay eggs, (2) an appropriate microclimate, and (3) protection from predation. Biologists can identify habitats in which to concentrate searches by reading the raptor literature. Limited nest substrate causes some raptors to use the same location year after year. In these cases, biologists can locate nests by studying historic data (e.g., museum records) and by talking to local biologists and birdwatchers.

Before conducting nest surveys, observers should be familiar with the courtship and defense displays of nesting raptors (Brown and Amadon 1968, Burton 1973, Cade 1982). The behavior of birds is a clue to their stage in the reproductive cycle and to the location of nests. Field biologists must know the breeding chronology if their objectives include assessing reproductive success (see *Assessing Raptor Reproductive Success and Productivity* in this manual). Also, observers should know breeding chronology so they can avoid unnecessarily disturbing nesting birds during sensitive periods of the reproductive cycle.

*Road Surveys.*—Road surveys allow large areas to be searched for nests and raptor activities that indicate a nest might be near. Observers can scan woodlots from vehicles to locate stick nests before foliation (Fitch and Bare 1978), and scan cliffs for signs of stick nests and scrapes (Call 1978). Observation of courtship behavior, adults carrying prey, and the food begging calls of young are clues to the presence of a nest (e.g., Reynolds 1982, Hamerstrom et al. 1985). Biologists can plot locations of birds seen on successive road surveys to identify clusters of activities near the nest (Craighead and Craighead 1956, Hamerstrom 1969, Call 1978). When a nest must be located or breeding status must be determined, road surveys are usually followed by searches on foot.

Biologists should cautiously interpret results from road surveys because several factors influence nest and bird detectability. Visibility among nests varies with different size nests, distances from road to nest, and the amount of vegetation obscuring the nest. In deciduous woodlands, stick nests are more difficult to see after leaves emerge. In coniferous habitat and when looking for ground nests, observers usually must rely on bird behavior for an indication of nesting. Bird behavior changes during the breeding season and there are species differences in detectability. For example, in Alberta, Schmutz (1984) observed 1.05 Swainson's hawks and 0.54 ferruginous hawks for each nest he found. Reproductive timing varies within and among species (Craighead and Craighead 1956). Repeated surveys of a study area usually are required when a complete count of the total number of nests is the objective.

Because of the variability associated with road surveys, biologists usually look for nests from vehicles early in the reproductive season and conduct foot surveys later in the season. Road surveys supplemented with foot surveys can be accurate. For example, Craighead and Craighead (1956) estimated they found 85% of the raptor nests in woodlots in central Michigan agriculture lands using combined road and foot surveys. With repeated road and foot surveys, they located all nests. Olendorff (1975) believed he located 95% of the raptor nest in eastern Colorado grasslands using combined surveys. Schmutz (1984) sampled 80 41-$km^2$ plots using vehicle and foot surveys to estimate nest density for a 74,686 $km^2$ study area in southeastern Alberta. Precision (expressed as 0.5 $\times$ 95% confidence interval) of his estimates was 40% for ferruginous hawks and 21% for Swainson's hawks. Schmutz believed the coefficient of variation could be reduced by using smaller plots (15 $km^2$) and stratifying searches based on land use.

The size of the study area and distribution of roads within it are important factors for designing road surveys. When a road network provides a view of the entire area, the biologist can use sampling to select transects for estimating the number of nests or choose routes that provide complete coverage of the area. When road distribution is limited, road surveys for nests might not provide coverage of all representative habitats. Trails and off-road vehicles or horses can provide access in areas with few roads. Schmutz (1984) used trailbikes and foot surveys to obtain complete coverage of sample plots. He searched for nests in large coulees and along eroded banks with 1 observer riding on the top and another along the bottom of embankments.

Observers should know the distribution of habitat and topography on the study area, and they should be familiar with raptor displays such as courtship, defense and food exchanges. Bird locations should be plotted on topographic maps or air photos, and each bird's behavior, flight direction, habitat use, age, and sex (when discernable) should be recorded. Observers must watch for raptors carrying nesting material or prey toward nests and for birds performing courtship over nests that are out of view (e.g., in conifers, on ground). The stick nests used by some cliff-nesting species (e.g., eagles, red-tailed hawks, great horned owls) and white patches from the feces of these birds and falcons often are visible from roads. Orange *Caloplaca spp.* lichens often are associated with feces deposited at cliff nests. However, stick nests can persist from previous seasons, alternate nests are sometimes constructed, and white feces and lichens, which also persist from previous years, can occur at perches and roosts. Therefore, observers should stop and carefully view sign, the nest structure, and bird behavior through binoculars and spotting scopes. Verification of an occupied nest requires specific criteria (see *Assessing Raptor Reproductive Success and Productivity* in this manual).

Road surveys have limited application for finding owl nests. Some species (e.g., great horned owl, long-eared owl) can be seen on stick nests. Burrowing owls can be seen on a mound or fence at dawn and dusk (Call 1978). However, for most owls we suggest using a point transect to broadcast owl vocalizations to elicit a vocal reponse or approach by the bird (see "Broadcasting Raptor Calls" in this chapter). Spot-maps of detection can be used to localize owl activity. Subsequently, foot surveys for nests should be conducted throughout the activity areas.

Broadcasting vocalizations has been useful for localizing search areas for diurnal raptor nests. Spot-mapping detections made while broadcasting calls helps observers identify areas of activity during the breeding season (J. Mosher, M. Fuller, and W. Kopeny, unpubl. data). Imitating or broadcasting great horned owl calls can elicit responses from incubating and brooding Cooper's hawks (E. Schriver and B. Millsap, pers. commun.).

*Foot Surveys.*—Foot surveys can provide complete coverage of sample plots or small study areas in which all nests must be found. Walking allows access to roadless areas, and it permits close and prolonged inspection of areas for clues about bird presence. If potential nesting areas have been identified from historical data, road, aerial or boat surveys, then foot surveys are useful for locating nests.

Repeated foot surveys of study areas, complemented by road surveys, have resulted in location of 95-100% of the nests (Craighead and Craighead 1956, Olendorff 1975). Postovit (1979) used systematic foot surveys in the North Dakota Badlands to locate all raptor nests in 0.65 $km^2$ sample plots. He stratified his study area according to the amount of woodland in plots. From the sample, Postovit estimated the raptor nesting density for a 233 $km^2$ study area. The precision of his foot survey was 24% ($\pm$ 95% confidence interval/density estimate $\times$ 100%). His results allowed detection of a change of 39% or more in nest density.

The main disadvantage of foot surveys is the time, or conversely, the number of people required to search an area. In the Badlands (Postovit 1979), it took about 20 field hours per day (2 people, 10-hour days) for 11 weeks to thoroughly search 76.1 $km^2$. Biologists must schedule searches to detect early breeders (e.g., great horned owls) and early nest failures. In eastern forests, it took 1 person (with occasional help) with experience, or 2 inexperienced people, about 3 months to find all the nests of several hawk species on a 31-$km^2$ study area (J. Mosher, M. Fuller, and M. Kopeny, unpubl. data). Less time would suffice for 1 species or several species with synchronized breeding chronologies. Location of all European kestrel nests in a 100-$km^2$ area required 1 person's effort during the breeding season (Village 1984). Reynolds (1982) suggests allocating 1 person for about 3 months to search suitable accipiter habitat in an area of 35-45 square miles in the western United States. Because walking surveys are the most time consuming, they usually are used to find all nests on a small area, or to survey the "best" nest habitat. Surveys of the best habitat are useful for quickly accumulating nest locations, but are not representative samples of heterogeneous habitat.

Biologists can select foot survey areas by sampling or as a result of previous information. We recommend systematic foot surveys for locating nests. Observers should walk strip transects and base the strip width on the visibility limits imposed by vegetation and terrain. The walking pattern can be parallel strips or circles from a central point such as a suspected nest location (Reynolds 1982).

Before the breeding season, biologists can inspect old stick nests, nest ledges and cavities for clues about nesting. Often, raptors nest in the vicinity of previously used nests. Old stick nests can be misshapen (flattened, less tightly constructed) and filled with dead leaves, whereas a new nest (sometimes added to structures built in previous years) has uniform construction. Observers might see light through new nests and see the light-colored ends of freshly broken twigs (Newton 1982). Some species "decorate" nests with fresh branches and leaves (Lyons et al. 1986). Biologists should use clues cautiously because sometimes raptors make more than 1 nest or scrape in a year. Some raptors, especially owls, roost in cavities. Also, different species build similar nests, or use nests of other species. Therefore, finding a nest or cavity is only a preliminary step for enumerating nests or assessing breeding status.

While walking, the searcher should watch for territorial defense and courtship displays because these behaviors often occur near the nest. Rosenfield et al. (1985) played Cooper's hawk calls in suitable nest habitat and used the responding hawks' flight directions to locate nests. Forsman (1983) suggests imitating or broadcasting calls to aid locating spotted owl nests. Raptors frequently carry prey toward the nest, and make food exchanges and accompanying vocalizations at the nest. Forsman (1983) suggests providing prey for perched spotted owls, then following the bird to the nest. Nests can also be located by listening for the food-begging calls of nestlings and recent fledglings (Reynolds and Linkhart 1984). Prey remains at butcher-blocks in the nest woodlot (Reynolds 1982, Newton 1982) and at the nest will be especially prevalent when nestlings are present. Other signs at the nest include down, molted feathers, pellets, and feces. While feces are very evident when nestlings are growing, heavy rain can wash away the white streaks.

Biologists should view nests from a distance (using binoculars or spotting scope) to identify the birds using the nest and to record their behavior. Prolonged viewing is especially useful at cavity and ledge nests where there are few clues about use (Reynolds and Linkhart 1984). Occasionally, occupancy can be verified only by flushing a bird from the nest. Flight from the nest might occur when the observer approaches, makes noise (e.g., handclaps), hits or rubs a stick against the tree, or climbs to the nest or an adjacent structure. Even these activities might not flush incubating or small owls in cavities. These survey procedures can disrupt breeding. Therefore, the number of visits and length of time near the nest must be limited and selected with consideration of the breeding chronology, air temperature and precipitation (Fyfe and Olendorff 1976). Biologists should be especially aware of potential disturbance associated with complete nest counts that require repeated surveys to account for variability in detection and chronology.

In 2 recent studies the value of capturing, marking and recapturing breeding sparrowhawks and peregrines has been demonstrated for studying longevity and re-occupancy or turnover rates at nest sites (Newton and Marquis 1982, Mearns and Newton 1984). Similar studies of nesting peregrine falcons (W.G. Mattox, in press; R.E. Ambrose, pers. commun.), prairie falcons (D. Runde, pers. commun.) and Cooper's hawks (R.N. Rosenfield and J. Bielefeldt, pers. commun.) have been initiated in North America using mark and recapture. Such studies require a multi-year effort to obtain useful results. The methods for capturing, handling, and marking raptors are presented in chapters in this manual. Capture rates from several studies were quite low (1 bird per 15-40 hours of trapping time, Fuller and Mosher 1981) except during migration. However, capture and marking with colored bands or marks, or radio telemetry, can provide individual recognition without recapture. Color marking and radio telemetry increase accuracy of counts (e.g., Hamerstrom et al. 1985) and can be used for estimating density (Kenward et al. 1981).

*Aerial Surveys.*—Usually, aircraft are used to search for large, conspicuous eagle and osprey nests (Henney et al. 1977, Grier et al. 1981, Phillips et al. 1984), but rotor-winged and fixed-wing aircraft can be used to find stick nests, cavity nests, and nest scrapes of medium-sized raptors (e.g., rough-legged hawks, prairie falcons, common barn-owls) on cliffs (Hickman 1972, White and Sherrod

1973, Craig and Craig 1984). Sometimes aircraft are used to locate stick nests of medium-sized raptors nesting in forests (McGowan 1975, Herron et al. 1985, Looman et al. 1985). Also, aerial surveys are supplements to ground searches for nests (Boeker 1974, Petersen 1979, Gilmer and Stewart 1984). Remote nest locations found from the air can be marked by dropping a radio-transmitter imbedded in a foam rubber ball (Nicholls et al. 1981). The nest then can be quickly located from the ground by using a radio receiver.

Aerial surveys are efficient for searching large areas in a short time. Boeker (1970) estimated it would have required 240 person-days of foot surveys to accomplish a survey that was completed in 42 person-days by combined aerial and ground searches. Kochert (in press) estimated that a helicopter survey would cost 5% less than a ground search, and be accomplished 10 times faster. An additional advantage of aerial surveys is that they cause only limited, short-term disturbance to breeding raptors (Carrier and Melquist 1976, Hodges and King 1982).

Air searches are limited to comparatively conspicuous nest structures and visible birds that can be used as clues to nest locations. Another disadvantage of aerial surveys is the high cost of operation per unit time compared to other forms of transportation. Flight time between study area and airports and among sample units can be very costly. Suitable aircraft and experienced pilots are not always available. Inclement weather precludes aerial surveys because it hampers visibility and jeopardizes safety.

The accuracy of aerial surveys of nests varies with nest habitat, nest size, and whether biologists use an occupied nest (see *Assessing Raptor Reproductive Success and Productivity* in this manual, for current criteria), or nest site or territory (usually defined as containing more than 1 nest structure) as the unit of measure. Henny et al. (1974) used sample ground and aerial survey data in a modified Petersen Estimator to compare visibility of osprey nests on different substrates (e.g., tree, duck blind, channel marker). They calculated the detectability of nests on each substrate then used that value (visibility rate) to correct their estimate of nesting density for the study area. Based on the estimate of total nests, they detected about 69% of all nests from the air. About 6% of the nests were missed in the areas with both air and ground searches. Phillips et al. (1984) found about 91% of the cliff nests and 71% of the golden eagle tree nests in Wyoming. Kochert (in press) reported 96% accuracy from a single helicopter survey of cliff-nesting golden eagles. In California, Henny et al. (1978*b*) found it useful to estimate density based on visibility rates for lakeshore and river habitat. Looman et al. (1985) used an ultralight aircraft to count stick nests in a Utah forest during November. They found that large northern goshawk nests were not counted as accurately as smaller Swainson's hawk nests. They also found differences according to the observers' familiarity with the study area, but from the ultralight aircraft found an average of 70% of the stick nests.

Grier et al. (1981) found 76% of the bald eagle nests in northwestern Ontario with 1 flight and 85% of the nests with 2 flights. Two flights often are required if an objective is to determine reproductive status and productivity (Fraser et al. 1983, 1984; also, see *Assessing Raptor Reproductive Success and Productivity* in this manual). A lack of synchrony among breeding birds in the search area can reduce accuracy, especially when only 1 flight is possible (Henny and Anderson 1979). Grier et al. (1981) found more nest "areas" (85% on 1 flight, 94% with 2 flights) than individual nests, and Looman et al. (1985) found more nest "territories" (81%) than single nests. In most aerial nest surveys, sightings of birds are cues to help locate nests during the breeding season.

Accuracy is enhanced in aerial surveys for golden eagle and osprey nests and cliff-nests when only "primary" habitat is selected for searching (Leighton et al. 1979). Coastlines and shorelines usually are selected as study areas in which to search for bald eagle and osprey nests. Within large study areas (e.g., coastal British Columbia, Hodges et al. 1984), biologists often select random plots from primary habitat. The sample can be stratified by factors such as amount of shoreline or human activity (Grier et al. 1981) or on previous knowledge about the distribution of nesting birds (Hodges et al. 1979, Leighton et al. 1979). Cluster sampling can reduce flight time among sample plots (Grier and Hamilton 1978). Sample plots in large study areas can be based on the Universal Transverse Mercator Grid (Grier 1977) or quadrilateral grids (Hodges et al. 1984). Plot size can be from about 100-200 $km^2$ and a minimum of 30 sample plots is recommended (Hodges and King 1982). Aerial surveys of cliffs usually have coincided with the extent of cliffs in the study area (i.e., complete search). When complete searches of all study area cliffs are not possible we suggest stratified random and cluster sampling to select survey areas.

Biologists choose relatively small, 2- or 4-place, high wing or rotor-winged aircraft for nest searching. Hickman (1972) preferred a Piper Super Cub around cliffs and canyons because the Super Cub flew slower and was more maneuverable than the larger Cessna 180. Piper Cub and Super Cub (Grier et al. 1981) and Cessna 182, 206, and 210 (Henny and Anderson 1979; Henny et al. 1977, 1978*a*, 1978*b*) aircraft were used for bald eagle and osprey nest searches. Float planes also were used (Piper J3, Grier 1977; Cessna 185 Amphibian, Henny et al. 1977). Larger fixed-wing planes such as the Turbo Beaver, were used in extensive coastal areas (Hodges et al. 1984). Looman et al. (1985) cited the following advantages of ultralights over other fixed-wing aircraft: portability, short take-off and landing requirements, slow stall and cruise speeds, maneuverability, and less noise. However, ultralights accommodate only a pilot and 1 observer, and they are fair weather aircraft.

Two and 4-seater helicopters are useful for nest searches (e.g., Bell Jet Ranger, Phillips et al. 1984). Jet-powered helicopters are quieter than those powered by pistons. The loaded weight of rotor-winged aircraft is a major factor limiting their flight range. Thus, larger helicopters (greater speed and range) are recommended for long flights (White and Sherrod 1973; Carrier and Melquist 1976; Kochert, in press).

Preparation for aerial nest surveys includes careful selection of survey routes and flight paths to and from airports. These routes should be plotted on maps that can be carried on the flights. Arrangements for aircraft and pilot should be made during initial planning. The pilot should participate in planning and become familiar with the field procedures. If the pilot and observers are not familiar with aerial nest surveys, and if no data are available about distributions of nests or visibility variables, test flights and pilot studies are recommended.

Observers must be prepared to advise the pilot of minor changes in course and when circling or hovering are needed to complete observations. The observers must accept the pilot's judgment about the flight safety and aircraft maneuvers. Pilots and observers should be rested and alert to ensure safety and maximize survey effectiveness. Locations of birds and nests should be accurately recorded on maps (or transparent map overlays). Information about time of sighting, habitat type, bird behavior, age, etc., should be recorded in notes or on a tape recorder. Responsibility for navigation, mapping locations, and recording data can be divided among people when 2 or more observers participate. We suggest biologists read Grier et al. (1981) for a brief review of operational procedures.

Flights should be made from about 2 hours after sunrise to 2 hours before sunset to avoid shadows and low intensity light that compromise visibility (Carrier and Melquist 1976, Grier et al. 1981). Searches should be conducted during winds less than 25 km/hour, and when there is no fog or precipitation. Surveys of cliffs can be flown from 72-112 km/hour in small fixed-wing planes (Hickman 1972) and 48-70 km/hour in helicopters (White and Sherrod 1973). The approach to a large cliff or canyon should be to circle from above, testing for strong air currents, at a distance of 15-63 m away from the cliff (Boeker 1970). Helicopters can be more stable than fixed-wing planes in gusty air (Kochert, in press). Aircraft should be flown successively lower during searches along tall cliffs.

Aircraft should be flown toward nest habitat from heights and distances that permit birds to watch the approach and thus not be startled from the nest. Circling or hovering might be required to confirm identification after an initial approach. Searches for tree nests are flown in fixed-wing planes at 110-160 km/hour (Grier et al. 1981, Hodges et al. 1984), in an ultralight at 54-65 km/hour (Looman et al. 1985), and in helicopters at 48-70 km/hour (Kochert, in press). The flying height above trees can range from 13-66 m in ultralights and from 20 to 100 m in fixed-wing planes. The flights above water can vary from 15-200 m. Grier et al. (1981) recommend flying 50 m above the water, and 20 to 100 m from shore, for bald eagle nest searches. Altitudes and speeds must be adjusted according to winds, topography, and size and position of nests.

Each observer should scan an assigned portion of the sky and terrain. A 200 m strip, inland from the shore, can be searched for eagle and osprey nests (Leighton et al. 1979). Systematic surveys for complete coverage entail searching strips from 20 m (ultralight) to 800 m in width (fixed-wing aircraft). Observers must watch for raptors, not only because the birds are clues to nesting, but because birds might fly in the path of aircraft.

*Boat Surveys.*—Although boats are not widely used for raptor nest searches, they are essential for a few species and for certain geographic situations. In remote regions, waterways provide convenient access to areas including bay and lakeshore habitat and river banks. Aerial searches can be used to survey remote areas (Calef and Heard 1979, Weir 1982), but aircraft do not permit the prolonged viewing and access to the nest site that are afforded by boat surveys (Cade 1960). Especially in western and arctic North America, banks, cliffs, and trees bordering water provide raptor nest habitat (Call 1978, Mindell and Dotson 1982). There are few data for assessing the accuracy of nest searches from boats because most boat surveys have been attempted as complete searches and no other methods (or repeat boat surveys) were conducted. However, Craig and Craig (1984) found more nests from a helicopter than were found from a boat survey of reservoir shoreline in southern Idaho. Some sites classified as nests by the boat survey crew were classified as perches or vacant stick nests from the air. Craig and Craig (1984) believed the angle of view from the water prevented the boat crew from viewing the evidence (e.g., scrape, empty nest cup, no sticks) needed to correctly classify the site. Hodges and Robards (1982) estimated that from a boat trained observers can locate 90% of the bald eagle nests in southeastern Alaska.

The main disadvantage of nest searches from boats is that only certain habitats are surveyed. Often, the cliffs and shoreline habitats are unrepresentative of a general area and the view from a boat is restricted to a narrow strip of land. Even when species typically nest near water, there are cases where a few nests, and occasionally many nests, occur inland (e.g., osprey, Prevost et al. 1978). If objectives include sampling areas beyond the shoreline, biologists can treat shoreline as 1 strata.

The type of boat needed for surveys will be determined by the type of water, number of observers, and weight and bulk of equipment carried (e.g., camping gear, food). Inflatable rafts or light canoes are suitable for streams, small rivers and lakes. Inflatable boats (4.5 m long), metal boats (5.2 m), and outboard motors (up to 55 horsepower) are required on coastlines of large rivers and lakes (Hodges and Robards 1982, Mindell 1983). Airboats are most effective on large, shallow wetlands (Sykes 1979). Surveys for bald eagle nests along coastlines can be conducted at 5 km/hour from 50-150 m offshore (Hodges and Robards 1982). Observers should look for clues to nest sites, such as the presence and displays of birds, white feces and stick nests. Prolonged observations of behavior, or trips ashore to gather other evidence or gain a different view of a site might be required to distinguish roosts and perches from nests or to identify the species using a nest. Binoculars and spotting scopes are needed for viewing nests high in trees and on cliffs.

**Surveying Colonies and Communal Roosts**

It is useful to locate nesting colonies and communal roosts because many birds can be counted in a short time. Kites nest in colonies and some northern harriers and osprey are semi-colonial. Vultures, bald eagles, northern harriers and several owl species roost communally during the non-breeding season. Therefore, biologists should use the literature, museum records, and local contacts to identify survey areas. However, there can be fluctuations in the numbers of birds using a locale on a year-to-year (U.S. Dep. Inter. 1983), seasonal (Clark 1975, Sweeney and Fraser 1986) and daily (Sykes 1985) basis. These fluctuations are associated with factors such as prey availability, weather and disturbance (Schnell 1967, Steenhoff et al. 1980, Hamerstrom et al. 1985).

Accurate counts can be made at colonies where nests can be enumerated (Glinski and Ohmart 1983) and at roosts where there are few birds. However, accurate counts are difficult when nests are obscured (e.g., northern harriers), and when many birds are milling about and moving in and out of view. Nevertheless, Sweeney and Fraser (1986) found that counts of black vultures and turkey vultures by 2 observers varied only by 1.7-4.0% of the estimated number of birds. Standardization for weather, time of day, and observer experience, etc., increases precision among counts. Statistics (e.g., standard error, confidence interval) calculated from repeated counts provide estimates comparable to other survey results (e.g., Sykes 1982) when inaccuracy and temporal fluctuations preclude useful calculations of density or absolute numbers (Bildstein 1979, U.S. Dep. Inter. 1983). Roost counts and counts at large or cryptic nest colonies should be used for assessing relative abundance.

*Road Surveys.*—Raptor movements and displays around roosts and colonies can be seen from roads along riparian woodlands, forest-edge habitat, and fields or pastures (Weller et al. 1955, Sweeney and Fraser 1986). A good clue for finding raptor concentrations is the flight direction of birds returning to colonies with prey, or to roosts in the late afternoon and evening (U.S. Dep. Inter. 1983, Sweeney and Fraser 1986). Bildstein (1979) made some counts of northern harriers from roads adjacent to fields in which the birds roosted. He counted the northern harriers from a distance of about 250 m from 1.5 hours before sunset until after dark and from 20 minutes before sunrise to about 1.7 hours after sunrise.

*Foot Surveys.*—Biologists can walk to vantage points to view colonies and roosts or enter these areas to attempt complete counts. Estimates of bird numbers in colonies can be made during courtship and when adults are arriving and departing for feeding. The colony can be entered for direct counts of nests (Parker 1975, Glinski and Ohmart 1983), but investigator activity should be planned to minimize disturbance. The birds at roosts also can be counted from a distance (U.S. Dep. Inter. 1983). Sweeney and Fraser (1986) were most successful when counting vultures from 0.5 hour before sunrise to 2 hours after sunrise. Weller et al. (1955) stationed several counters around northern harrier and short-eared owl roosts. Occasionally, an observer might need to enter a roost and flush birds to confirm estimates made from a distance (Weller et al. 1955, Clark 1975, Bildstein 1979). Walking through dense habitat may be the only method of detecting and counting some of the roosting owls (Smith 1981, Bosakowski 1984). Once a night roost has been located, it can be entered during the day to search for clues about relative bird numbers, food habits and habitat use.

*Aerial Surveys.*—Searches from aircraft can be efficient for locating roosts, and for periodic checks to determine if known roosts are being used. Also, aircraft are useful for following conspicuous birds from feeding areas to roosts. In some habitats, bird counts at roost can be made from the air (U.S. Dep. Inter. 1983). Sykes (1979) found aircraft to be unsuitable for snail kite surveys.

*Boat Surveys.*—Snail kite roosts can be found using an airboat to follow foraging birds during the afternoon as they return to the roost (Sykes 1982). The next day observers should go to the roost 1.5-2.0 hours before sunset. When the airboat approaches, birds in the roost will flush. Snail kites arriving later can be counted by strategically placed observers. Counts of roosting bald eagles might be incomplete if conducted only from a boat because many roosts are located some distance inland (U.S. Dep. Inter. 1983).

### Migrant Counts

Many North American Falconiformes and several Strigiformes concentrate at local geomorphological sites while migrating. Observers have found more than 100 concentration areas, especially in eastern Canada and the United States (Harwood 1975, Heintzelman 1975) and have conducted counts for thousands of hours. Biologists have compared yearly counts to detect population changes (see reviews in Fuller and Mosher 1981, Haugh 1986). Interpretation of counts is confounded by many variables most of which are not fully understood. There are large daily and yearly fluctations in the numbers of migrants tallied, but these fluctuations are not solely attributable to changes in population levels.

In addressing variability in counts of migrants, Sattler and Bart (1984) found differences in detectability among some species, by height of flights, and recognized differences caused by the intensity of effort and fatigue of observers. However, they concluded that none of these factors seemed likely to prevent recognition of long-term trends. Kochenberger and Dunne (1985) found differences among species, and variability according to number of birds in the flight, number of observers, and location of observers within the Cape May Point area of New Jersey. Weather is an important factor affecting the timing of migration and magnitude of local concentrations (Titus and Mosher 1982; Kerlinger 1985; Kerlinger and Gauthreaux 1984; Titus et al., in press). Recently, migrant behavior has been correlated with weather and other variables (Kerlinger and Gauthreaux 1984, Kerlinger 1985, Kerlinger et al. 1985*b*, Holthuijzen et al. 1985). Information from these studies has been used in more sophisticated analyses of changes in "populations" and in predicting flight magnitude during certain environmental conditions (Hussell 1985). Furthermore, a network of counts using standardized procedures now provides a means for accumulating a common data base (Fuller and Robbins 1979). Also, new counting techniques, such as photographic sampling of migrants, are being developed (Smith 1980, 1985).

There are few cases in which changes in counts have been associated with known changes in breeding populations. Extreme examples exist, such as the decline and recovery of peregrine falcons (e.g., Ward et al., in press), but among species with less dramatic or more localized declines, migration count data are less convincing (Harwood and Nagy 1977). Interpretation of counts is difficult because there is only general knowledge of the origins and destinations of the migrants seen at concentration points. In most cases, migrants are from broad geographic ranges (Clark 1985; Evans and Rosenfield 1985; Yates et al., in press). Therefore, migration counts hold potential for regional and continental population monitoring, but presently they are not useful for localized monitoring.

Information about raptor concentration points can be found in Heintzelman (1985), and by contacting the Hawk Migration Association of North America (P.O. Box 3482, Rivermount Station, Lynchburg, VA 24503). Guidelines for counting migrants are included in Heintzelman (1975, 1985), and Dunne et al. (1984). Biologists will need binoculars (7 to 10 power) to scan for distant birds and to aid in raptor identification. Data should be recorded directly on standard forms or in a field notebook (then later transcribed to standard forms). A map of the area around the count site and compass are useful for describing the area, documenting flight paths, and estimating distances. Observers should have a watch, thermometer, and wind gauge or strip of cloth or plastic flagging (for estimating wind strength and direction).

Raptor migration occurs from mid-August through December and March through June, with most birds moving in September and October, and March and April. Generally, observers should begin counting about 0800 and conclude about 1700. In addition to count totals of each species, observers should record the following data hourly: temperature, maximum visibility, sky conditions (cloud cover, precipitation), wind speed and direction, flight speed, direction and altitude, number of observers, and minutes of observation. Categories and codes for these data, and brief instructions for gathering the data are available from the Hawk Migration Association of North America.

Capture of migrating raptors provides data about age, sex, measurements of migrating birds involved in differential movements (Mueller et al. 1979; Rosenfield and Evans 1980; Ward et al., in press), and periodic invasions (Mueller et al. 1977). Capture has been used to sample owl migration (Evans 1975). Capturing raptors requires considerable effort, and usually several years are required to accumulate useful quantities of data (see *Capturing and Handling Raptors* in this manual).

## SUMMARY

This chapter can be summarized under 3 general categories: (1) planning, (2) conducting searches, and (3) data needs and techniques development. Because surveys of widely dispersed raptors are often time-consuming or expensive, we have emphasized general survey planning and study design. To maximize the efficiency of raptor sur-

veys, biologists must set specific objectives, delineate the study area, and select a sampling technique and a survey method to cover all representative habitats. Stratified sampling, based on habitat categories, and systematic sampling are the techniques most commonly used. Transportation is an important consideration for raptor surveys. Observers frequently search for birds and nests while driving along roads and trails. Searching on foot is often required to find raptors using dense vegetation. Aerial surveys are efficient for finding large birds and conspicuous nest and roost sites. In many studies more than 1 sampling technique and mode of transportation are used. The chapter appendix is organized by transportation mode and lists references to many survey techniques for species in various parts of North America.

This chapter provides guidelines rather than step-by-step instructions for raptor surveys because survey procedures must be tailored to various objectives; to different spatial and temporal scales; and to the logistical support, time and people available. Biologists should be prepared to use methods for increasing detection rates of sparsely occurring raptors, especially in rough terrain and dense vegetation where visibility is limited. Nests, defecation, and prey remains are clues to the presence of raptors. Biologists can use techniques such as broadcasts of tape-recorded calls to increase detectability. However, surveys must incorporate a balance between adaptability and standardization. Standardization of some procedures is necessary to allow comparisons among surveys and to reduce the variability associated with bird counts. For example, the same observer should conduct counts at the same time of day and same season of year, and counts should not be conducted during inclement weather. If data from different observers, times, or environmental conditions are to be combined or compared, the associated detectability differences should be measured.

Readers will question the applicability of some methods in various habitats or to certain species. There are few data for comparing methods or for comparing the accuracy and precision of a method used in different situations. More development of raptor survey techniques is needed. We suggest conducting pilot studies for testing techniques. In addition, biologists and statisticians should design tests for differences among observers and conduct replicate counts to determine visibility in different habitats and for different species. Double sampling should be tried more often to efficiently reduce variability of counts. Research is needed for developing methods to count the nonbreeding portion ("floaters") of populations and for determining differences in detectability due to age, sex, and season.

Population surveys form the basis of much ecological research, and they provide the data required for many management decisions. Therefore, careful planning and estimation of variability should be applied to raptor surveys, and development of standardized and broadly applicable procedures should be encouraged.

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Appendix 4.1. References for raptor survey techniques, by survey type, habitat, location and species.

| Survey type | Citation | Comments | Habitat | Location | Species |
|---|---|---|---|---|---|
| *Historic* | | | | | |
| Status | Bechard (1981) | | | Manitoba | Ferruginous hawk |
| Status | Evans (1982) | Literature | | North America | 12 species |
| Status | Fyfe et al. (1976) | | | North America | Peregrine falcon |
| Distribution, status | Hickey (1969) | Many papers, historic data and multiple techniques | | North America | Numerous species |
| Nesting, habitat, success | Jackson (1983) | Nest record data | | North America | Black and turkey vultures |
| Distribution, status, abundance | Johnson et al. (1979) | Review of literature and personal experience | Numerous communities | Southwest U.S. | Several Strigiformes |
| Distribution | Kerlinger et al. (1985*a*) | Literature, museum data, winter | | North America | Snowy owl |
| Distribution | Millsap and Vana (1984) | Literature, unpubl. records, personal contacts | | Eastern North America | Golden eagle |

| Survey type | Citation | Comments | Habitat | Location | Species |
|---|---|---|---|---|---|
| *Road Counts* | | | | | |
| Estimate density | Andersen et al. (1985) | Line transect detectability | | Central Colorado | Several |
| Distribution | Bart (1977) | Winter | | New York | Red-tailed hawk |
| Enumeration | Bell (1964) | Listen for vocalizations | | Mississippi | Barred owl |
| Distribution, behavioral ecology | Bildstein (1978) | Winter | Agricultural and woodlots | Ohio | Several raptors |
| Relative abundance by season | Bohall and Collopy (1984) | Habitat use | Several | Florida | Several raptors |
| Distribution, relative abundance, monitoring | Bystrak (1981) | Stratified random point transect, once each year | 80+ physiographic regions | North America | Any detected |
| Relative abundance by season | Craig (1978) | Winter | *Artemisia* spp. and grasses | Southeast Idaho | Several Falconiformes |
| Relative abundance, locate nests | Craighead and Craighead (1956) | Includes mapping | Agricultural, woodlands, forest | Central Michigan and western Wyoming | Several |
| Behavior | Diesel (1984) | Fixed strip; visibility | | Central Missouri | Red-tailed hawk |
| Relative abundance | Enderson (1964) | Transects selected where power poles provided perches | Grasslands | Eastern Colorado and Wyoming | Prairie falcon |
| Locate nests | Fitch and Bare (1978) | | | East Kansas | Red-tailed hawk |
| Detection | Forsman (1983) | Several techniques | Forests | Western U.S. | Spotted owl |
| Distribution | Forsman et al. (1977) | Broadcasts, imitations of calls | Coniferous forests | Oregon | Spotted owl |
| Status | Hubbard (1983) | Multiple observers, long term | | New Mexico | Turkey vulture |
| Distribution, abundance | Johnson and Enderson (1972) | Winter | Grasslands | Colorado | Several |
| Locate nests | Kirkley and Springer (1980) | | Agricultural and woodlots | Ohio | Red-tailed hawk and great horned owl |
| Describe perch use | Marion and Ryder (1975) | | Grasslands | Northeast Colorado | Several Falconiformes |
| Seasonal distribution and relative abundance | Mathisen and Mathisen (1968) | Unlimited strip, 3 years | | Western Nebraska | All Falconiformes |
| Relative abundance | Mills (1975) | Marked birds | | Ohio | American kestrel |
| Distribution, relative abundance by habitat | Millsap (1981) | Stratified, variable strip | Numerous plant communities | Arizona | Any detected |
| Relative abundance | Phelan and Robertson (1978) | Predator-prey relationships | Fields, island | Southern Ontario | Several |
| Distribution and relative abundance | Schnell (1967) | Winter | | | Rough-legged hawk |
| Distribution | Springer (1978) | Compares methods, broadcast | Woodlots | Ohio | Great horned owl |
| Relative abundance | Wilkinson and Debbon (1980) | Fixed strip, weather, winter | Agricultural | Central California | Several |
| Relative abundance | Woffinden and Murphy (1977) | | | Utah | Several |
| *Walking* | | | | | |
| Estimate densities | Cink (1975) | Systematic broadcasts | | Northeast Kansas | Eastern screech-owl |
| Distribution | Forsman et al. (1977) | Broadcasts | Coniferous forests | Oregon | Spotted owl |
| Distribution, relative abundance | Johnson et al. (1979, 1981) | Point counts with broadcasts in high density areas | Riparian woodland | Arizona | Western screech-owl, elf owl |

| Survey type | Citation | Comments | Habitat | Location | Species |
|---|---|---|---|---|---|
| Distribution by habitat | Lynch and Smith (1984) | Point count with broadcasts | Urban open space | Connecticut | Eastern screech-owl |
| Behavior study | Martin (1973) | Broadcast elicited appearance of owls; vocalizations, and displays | Desert grassland | New Mexico | Burrowing owl |
| Distribution by habitat | McGarigal and Fraser (1984, 1985) | Stratified random, point count broadcasts | Forest stands | Southwest Virginia | Barred owl, great horned owl |
| Nest reoccupancy | Mearns and Newton (1984) | Capture and marking | Cliff, heath | Scotland | Peregrine falcon |
| Nest reoccupancy | Newton and Marquiss (1982) | Capture and marking | Forest | Scotland | Sparrowhawk |
| Relative abundance | Nowicki (1974) | Point count broadcasts in randomly chosen quadrats | | Wisconsin | Eastern screech-owl |
| Nest density | Postovit (1979) | Sample designs, effort | | North Dakota | Several |
| Nest location | Rosenfield et al. (1985) | Broadcasts in suspected nesting areas | Woodlots | Wisconsin | Cooper's hawk |
| *Aerial* | | | | | |
| Enumerate birds, nests | Bider and Bird (1983) | Helicopter, waterfowl surveys | Riparian | Quebec | Osprey |
| Locate nests | Boeker (1970) | | | Western U.S. | Golden eagle |
| Enumeration | Boeker and Ray (1971) | Winter and breeding season counts | | Southwest U.S. | Golden eagle |
| Enumeration | Boeker and Bolen (1972) | Random starts, strip transects | | Southwest U.S. | Golden eagle |
| Locate nests | Call (1978) | Sign | Cliffs, nonforested | Western U.S. | Several |
| Enumeration | Fisher and Hartman (1983) | Winter | Grassland, reservoir | Kansas, Nebraska | Bald eagle |
| Nesting density | Grier (1977) | Quadrats sampled | Forest, lakes | Central Canada | Bald eagle |
| Nest density | Grier et al. (1981) | Stratified sample detection, safety | Forest shoreline | Northwest Ontario | Bald eagle |
| Enumeration | Hancock (1964) | Adults, immature | Coastline | British Columbia | Bald eagle |
| Locate nests | Henny and Noltemeier (1975) | Calculate detectability | Atlantic Coast | North Carolina, South Carolina | Osprey |
| Locate nests | Henny et al. (1978*a,b*) | | Forest shoreline | Oregon, California | Osprey |
| Locate nests | Henny and Anderson (1979) | Asynchronous nesting | Desert shoreline | Baja California | Osprey |
| Locate nests | Hickman (1972) | Fixed-wing aircraft | Cliffs, canyons | Northwest U.S. | Golden eagle |
| Enumeration | Higby (1975) | Random starts, systematic transects | | Wyoming | Golden eagle |
| Enumeration | Hodges et al. (1984) | Stratified sampling | Coastline | British Columbia | Bald eagle |
| Enumeration | King et al. (1972) | Breeding birds | Forest coastline | Southeast Alaska | Bald eagle |
| Nest density | Leighton et al. (1979) | Detectability | Forest shoreline | Saskatchewan | Bald eagle |
| Locate nests | Looman et al. (1985) | Autumn, ultralight aircraft | Forest | Utah | Several |
| Locate nests | Luttich et al. (1971) | Fly before foliation | Forest | Central Alberta | Red-tailed hawk |
| Locate nests | McGowan (1975) | Fly before leafout | Forest | Alaska | Northern goshawk |
| Locate nests | Pennycuick (1976) | Motor glider | Cliffs | Central Africa | Vultures |
| Locate nests | Phillips et al. (1984) | Sample areas, detectability | Several | Wyoming | Golden eagle |
| Locate nests | Prevost et al. (1978) | Compare shoreline to inland | Forest, shoreline | Nova Scotia | Osprey |
| Locate nests | Swartz et al. (1975) | | Tundra, cliffs | Alaska | Gyrfalcon |
| Locate nests | Weir (1982) | | Riparian | Alaska | Several |

| Survey type | Citation | Comments | Habitat | Location | Species |
|---|---|---|---|---|---|
| Locate nests | White and Sherrod (1973) | Helicopter | Tundra, cliffs | Alaska | Several |
| Enumerate | White et al. (1977) | Survey pipeline | Forest, tundra | Alaska | Several |
| *Boat* | | | | | |
| Locate nests | Cade (1960) | Float rivers | Riparian | Alaska | Peregrine falcon, gyrfalcon |
| Distribution, relative abundance | Early (1982) | | Ocean—island and shoreline | Alaska | Several raptor species |
| Locate nests | Hodges and Robards (1982) | Boat compared to aircraft | Ocean | Southeast Alaska | Bald eagle |
| Locate nests | Mindell (1983) | | Riparian | Alaska | Several |
| Locate nests | Oliphant and Thompson (1978) | | Riparian | Saskatchewan | Merlin |
| Locate nests | Sykes (1979) | Airboat | Lake, river, marsh | Florida | Snail kite |
| Locate nests | Whitfield et al. (1974) | | Lake and river shore | Saskatchewan, Manitoba | Bald eagle |
| Locate nests | Wiemeyer (1977) | | River shore | Maryland, Virginia | Osprey |
| *Colonies and Roosts* | | | | | |
| Enumeration | Bildstein (1979) | Roost dynamics | Agricultural | Ohio | Northern harrier |
| Distribution, counts | Clark (1975) | Walk and flush from roosts | Fields | Manitoba, New York | Short-eared owl |
| Nest counts | Glinski and Ohmart (1983) | Breeding colonies | Riparian | Arizona | Mississippi kite |
| Enumeration | Parker (1975) | Breeding colonies | Agricultural and woodlots | South-central U.S. | Mississippi kite |
| Enumeration | Schnell (1967) | Winter roosts | | Central U.S. | Rough-legged hawk |
| Enumeration | Sweeney and Fraser (1986) | Year-long sampling, permanent and temporary roosts, compare to road counts | Agricultural and woodlots | Southwestern Virginia | Vultures |
| Enumeration | Sykes (1979, 1985) | Roost and nest counts | Wetlands | Florida | Snail kite |
| Enumeration | Weller et al. (1955) | | Agricultural and woodlots | Central Missouri | Northern harrier, short-eared owl |
| *Migrant Counts* | | | | | |
| Distribution | Clark (1985) | Mapping recoveries | Agricultural and woodland | Southern New Jersey | Merlin |
| Relative abundance | Dekker (1984) | Compare years | Agricultural and grassland | Central Alberta | Peregrine falcon |
| Distribution | Evans and Rosenfield (1985) | Mapping recoveries | Ridge above lake | Northern Minnesota | Sharp-shinned hawk |
| Status | Hackman and Henny (1971) | Compare years | | Maryland | Several |
| Population biology | Hamerstrom (1969) | Broad front movements, age and sex differences | Agricultural and marshland | Central Wisconsin | Northern harrier |
| Relative abundance | Harwood and Nagy (1977) | Variables, interpretation | Ridgetop | Pennsylvania | Osprey |
| Population dynamics | Mueller and Berger (1967) | Timing and quantity of captures | Lake shore | East-central Wisconsin | Northern goshawk |
| Counts | Sattler and Bart (1984) | Sources of variability | Lake shore | Michigan | Several |
| Migratory biology | Smith (1980) | Description of migration | | Panama | Several |
| Relative abundance | Spofford (1969) | Monitor status | Mountain ridges | Pennsylvania | Several |
| Status | Ward et al., in press | Trapping and counts | Barrier islands | Maryland and Virginia | Peregrine falcon |

| Survey type | Citation | Comments | Habitat | Location | Species |
|---|---|---|---|---|---|
| *Multiple Methods* | | | | | |
| Distribution, breeding season ecology | Bednarz and Dinsmore (1982) | | Agricultural and woodland | Iowa | Red-shouldered hawk, red-tailed hawk |
| Abundance | Bock and Root (1981) | Christmas Bird Counts | | North America | Vultures |
| Status | Bonney (1979) | Christmas Bird Counts | | | Peregrine falcon |
| Status | Brown (1964, 1971, 1973, 1976) | Christmas Bird Counts | | | Several |
| Distribution, status | Burnham and Mattox (1984) | Air, boat, walking | Tundra | Western Greenland | Peregrine falcon, gyrfalcon |
| Survey techniques | Call (1978) | Methods, sign, habitat; chronology by species | | Western North America | Several |
| Ecology | Craighead and Craighead (1956) | Road counts, mapping, walking | | Western Wyoming, Central Michigan | Several |
| Distribution | Forsman (1983) | Calling, broadcast, capture, sign | Forest | | Spotted owl |
| Locate nests | Gilmer and Stewart (1984) | Air, road, walking | Prairie | North Dakota | Swainson's hawk |
| Survey techniques | Kochert, in press | Surveys presented by type of technique, personnel and equipment needed, precision | | Western North America | Several |
| Enumeration | McClelland (1973) | Autumn foraging concentrations | Riparian | Montana | Bald eagle |
| Distribution, breeding season ecology | Murphy et al. (1969) | | Desert scrub, cliffs | Central Utah | Several |
| Locate nests | Olendorff (1975) | | Grasslands | Northeast Colorado | Several |
| Ecology | Petersen (1979) | Aerial, road, walking, listening, sign | Forest and agricultural | Southeastern Wisconsin | Red-tailed hawk and great horned owl |
| Status | Pruett-Jones et al. (1980) | | | North and Central America | Black-shouldered kite |
| Locate nests | Reynolds and Linkhart (1984) | Vocalizations, observation of cavities, capture | Conifer forest | Colorado | Flammulated owl |
| Nest density | Schmutz (1984) | Ground vehicles, study design | Prairie | Alberta | Swainson's and ferruginous hawks |
| Enumeration | Smith and McKay (1984) | Consider observer effort and methods on Christmas Bird Count | Numerous | Connecticut | Owls |
| Population biology | Smith and Murphy (1979) | Predator-prey relationships | Desert scrub | Central Utah | Several |
| Census | Snyder and Johnson (1985) | Photography, individual identification | | Southern California | California condor |
| Status | Stahlecker (1975) | Christmas Bird Counts | | Central Colorado | Several |
| Distribution | Stocek and Pearce (1978) | | | Maritime Provinces | Bald eagle and osprey |
| Status | Swenson (1979, 1982) | | | Western Wyoming | Osprey |
| Breeding season ecology | Whitfield et al. (1974) | | | Central Canada | Bald eagle |