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METHODS OF DETECTING AND COUNTING RAPTORS: A REVIEW

MARK R. FULLER[1] AND JAMES A. MOSHER[2]

ABSTRACT.—Most raptors are wide-ranging, secretive, and occur at relatively low densities. These factors, in conjunction with the nocturnal activity of owls, cause the counting of raptors by most standard census and survey efforts to be very time consuming and expensive. This paper reviews the most common methods of detecting and counting raptors. It is hoped that it will be of use to the ever-increasing number of biologists, land-use planners, and managers that must determine the occurrence, density, or population dynamics of raptors.

Road counts of fixed station or continuous transect design are often used to sample large areas. Detection of spontaneous or elicited vocalizations, especially those of owls, provides a means of detecting and estimating raptor numbers. Searches for nests are accomplished from foot surveys, observations from automobiles and boats, or from aircraft when nest structures are conspicuous (e.g., Osprey). Knowledge of nest habitat, historic records, and inquiries of local residents are useful for locating nests. Often several of these techniques are combined to help find nest sites. Aerial searches have also been used to locate or count large raptors (e.g., eagles), or those that may be conspicuous in open habitats (e.g., tundra). Counts of birds entering or leaving nest colonies or colonial roosts have been attempted on a limited basis. Results from Christmas Bird Counts have provided an index of the abundance of some species. Trapping and banding generally has proven to be an inefficient method of detecting raptors or estimating their populations. Concentrations of migrants at strategically located points around the world afford the best opportunity to count many raptors in a relatively short period of time, but the influence of many unquantified variables has inhibited extensive interpretation of these counts.

Few data exist to demonstrate the effectiveness of these methods. We believe more research on sampling techniques, rather than complete counts or intensive searches, will provide adequate yet affordable estimates of raptor numbers in addition to providing methods for detecting the presence of raptors on areas of interest to researchers and managers.

The present paper reviews methods that have been used to detect and count raptors in a variety of geographic areas and habitats. The term "raptor" refers collectively to species of the orders Falconiformes and Strigiformes. In the past, most intensive studies of raptors were conducted by specialists who learned, through experience, methods to locate and count these birds. The methods used were often specific for certain species and limited in application to specific objectives or study areas. The techniques employed for studies of other groups of birds are often unsuitable for raptors. Additionally, the study area is often not large enough to obtain a meaningful sample of the raptor population.

In recent years people other than raptor specialists have been required to detect and count raptors. For example, information about raptors is necessary for comprehensive investigations of avian communities and studies of zoogeography (e.g., Cody and Diamond 1975). Governments at the national, state or provincial, and local levels are more intensively managing tracts of land as parks, reserves, or refuges on which birds of prey may be of special concern (e.g., Olendorff and Kochert 1977, Mathisen et al. 1977). Because raptors occur at low densities relative to birds at other trophic levels, the stability of their populations has been susceptible to persecution and man-caused changes in the environment (see Newton 1979). Laws and international agreements for protection of birds now require governments to monitor the status of avian populations (e.g., Conder 1977, Hilton 1977). In some nations, land-use planners, developers, and resource managers are required to assess the potential or actual impact of their practices on birds (e.g., Mathisen 1968, White et al. 1977). These requirements have led to increased study and management of raptors by people with diverse backgrounds and experience (or lack of it). It is, therefore, useful to provide a review of techniques for locating and counting these birds.

Furthermore, there is a need for much more development of methods for more accurately and efficiently estimating numbers of raptors. At the 1976 meeting (Ithaca, New York) of the Raptor Research Foundation, a special workshop was convened to discuss survey and counting techniques. Specialists encouraged publication of existing methods and research of new methods. More recently, the opinions of ecologists and wildlife managers in North America have focused attention on the need for improved survey and estimating techniques in order to address questions concerning population dynamics and management of raptors (Fuller, in press). The present review will emphasize some aspects of development of methodology that we hope researchers will pursue.

[1] U.S. Fish and Wildlife Service, Migratory Bird and Habitat Research Laboratory, Laurel, Maryland 20811.

[2] Appalachian Environmental Laboratory, Frostburg State College, Frostburg, Maryland 21532.

APPLICATIONS AND REQUIREMENTS OF METHODS

Occurrence

A survey to determine presence or absence is often the first step in evaluating potential impact of land-use on the status of a species. Surveys to detect raptors are also used to associate species with general habitats and resources and to delineate the geographic range of species and describe changes in distribution (e.g., Galushin, in press). These uses of information about the presence or absence of a species in an area do not require careful enumeration of the birds.

Numbers

If it is necessary to know the size of a population on a prescribed area, a census (complete count) or sampling (estimate of numbers) technique must be used. Sample counts are more efficient for large areas or for species that are very difficult to detect, but it is important to understand the variables that affect the accuracy of the estimate of the population. One should consider factors affecting the precision of counts in order to separate actual fluctuations in the size of the populations from those variables resulting from limitations in techniques. Papers published in Hickey (1969), Murphy et al. (1975), and Chancellor (1977) demonstrate the variety of data used to evaluate the status of species or trends in populations.

Population Dynamics

To be most useful, studies of population dynamics, including such factors as reproductive success, natality, and mortality, require censuses or estimates of population size for which the variability of the estimates has been calculated (see Brown 1974, Postupalsky 1974, Fraser 1978). Careful counts are also necessary for thorough descriptions of avian communities, evaluation of predator-prey relations, competitive interactions, and studies of ecosystems.

DIFFICULTIES AND GENERAL VARIABLES

Birds of prey are not, for the most part, easy to study. They nest at relatively low densities; they are usually wide-ranging and rapid-moving; many species habitually avoid areas of human activity; and most owls are more active at night than during the day. These characteristics make it difficult to gather quantitative data about raptors. In preparation for locating and counting birds, one usually assembles general information about the area and the habitats in which the species of interest are known to occur. The possibility for biasing search efforts exists if surveys are conducted only in habitats in which one expects to find birds. Some raptors are among the most widely distributed birds. Barn Owls (*Tyto alba*), Ospreys (*Pandion haliaetus*), and Peregrine Falcons (*Falco peregrinus*) are found over most of the world, and even many species that are more restricted in their distribution, such as Common Buzzards (*Buteo buteo*), Black Kites (*Milvus migrans*), Red-tailed Hawks (*Buteo jamaicensis*), and Great-horned Owls (*Bubo virginianus*), occur over vast areas and in a variety of habitats (see Burton 1973, and Brown and Amadon 1968). Also, some more localized species, such as the Ferruginous Hawk (*Buteo regalis*), have adapted to using a vast array of nesting sites (Call 1978).

The strategy of becoming familiar with habitats in which one is likely to find birds can be very useful, but should be applied with caution. We have met individuals who have developed excellent "search images" for the local habitat in which a species will most likely be found. Some of these experts are so specialized, however, that they may overlook other habitats in which the birds occur.

Observer ability, experience in searching for and identifying raptors, and knowledge of behavior are important factors influencing survey results (Call 1978) and a source of potentially great variability. Furthermore, differences among participants can be compounded when more than one species, in more than one habitat or terrain, is involved. There are often similarities in the "ecological role" of many species of raptors and many share a common susceptibility to certain impacts. Additionally, searches for raptors are often costly, labor intensive efforts. Consequently, surveys and counts frequently include more than one observer looking for several species over large areas of diverse habitat and terrain (e.g., Craighead and Craighead 1956, Rowan 1964, Murphy et al. 1969, Nagy 1977).

Other factors that influence surveys and counts include differences in visibility of birds because of seasonal changes in vegetation, in habitat use, and behavior. The behavior of birds also changes during the course of the day. For example, early in the morning, soaring birds such as buzzards and vultures may remain perched until the air warms and thermals or updrafts are created. Inclement weather may reduce the activity and thus the visibility of raptors if they seek shelter. Variables and assumptions will be addressed in relation to specific methods. It is important to realize that a survey or count conducted by different observers, under different conditions, can produce a great deal of variability in the results. Since an adequate yet affordable census of raptor populations is difficult to obtain under the best of conditions (Grier et al., in press), it is necessary to choose an appropriate sample method in order to avoid variability that may render results useless.

METHODS

ROAD COUNTS

To cover the large areas necessary to sample raptor populations, investigators have often used automobiles for transportation and roadways for transect routes (e.g., Hicks 1933, Winterbottom 1933, Nice 1934, Leopold 1942, Nankinov 1977). This method usually involves driving slowly (10–25 mph; 17–40 kmph) and counting the birds that one or two observers detect, usually within a specified distance (0.25–1.0 mi; 4–1.6 km), on each side of the road (e.g., Craighead and Craighead 1956). Most investigators will stop momentarily if a bird cannot be identified from the moving vehicle. Some road counts include regular stops (e.g., Vian and Bliese 1974, Bystrak 1979). Data can be summarized as number of birds seen per distance driven or the reverse (e.g., km/bird).

Several investigators (e.g., Hiatt 1944, Craighead and Craighead 1956, Cade 1969, L. Brown 1971, Craig 1978) have noted many of the variables that may affect the results of road counts. Most investigators acknowledge that the capability of observers is not uniform for factors such as detection and identification of birds or ability to judge the distance to the edge of the transect. The extent to which differences among observers affect counts has not been determined.

The structure of vegetation, terrain, the roadway, and developments nearby (e.g., fences, power poles, open ground, buildings, human activity) are "habitat" variables that influence the use of the area by birds and their visibility there. For example, *Buteo* hawks, which soar and perch in open habitats, are more likely to be detected than a forest-dwelling *Accipiter* (see L. Brown 1971, Marion and Ryder 1975). Owls generally cannot be counted along roadways. Craighead and Craighead (1956) compared the results of road counts with results of other techniques and established correction values to account for differences in visibility of several species of Falconiformes. Inclement weather and seasonal changes in vegetation and bird behavior may affect the results of road counts. The activity, and thus the visibility, of some birds of prey varies on a daily basis and should be accounted for if routes require several hours to drive (e.g., Bildstein 1978). When comparing routes on different areas, or over periods of time, it is also important to consider that communal roosts (e.g., in winter) and temporal abundances of food may result in "inflated" estimates of density. Similarly, one must be aware of the influx of fledglings on routes or the arrival of migrants. In addition, the presence of one species on an area may influence the behavior and visibility of other species (Craighead and Craighead 1956).

Despite the potential impact of these numerous variables, many investigators have been able to establish routes and conduct counts in a manner that makes the results comparable. Road counts can then provide values of relative abundance of birds of prey (e.g., Siegfried 1966, Rowan 1964, L. Brown 1971, Smeenk 1974, Bart 1977, Woffinden and Murphy 1977, Craig 1978, Phelan and Robertson 1978) or estimates of populations on a given area (Craighead and Craighead 1956, Woffinden and Murphy 1977). Road counts have been conducted to obtain data for particular seasons (Rudebeck 1963, Enderson 1964, 1965; Schnell 1967, Nankinov 1977, Bildstein 1978), or to detect changes in species diversity and numbers of birds during different seasons (Allan and Sime 1943, Call 1975). In several instances the results of road counts have been used to compare the occurrence of raptors in different geographic areas (Hiatt 1944, White 1965, Mathisen and Mathisen 1968, Call 1975). Data from road counts have also provided insight into long-term trends in the numbers of raptors in an area (e.g., Cade 1969, L. Brown 1971, Johnson and Enderson 1972).

A road count survey is a useful method when large areas or many species need to be counted. The Breeding Bird Survey (BBS) of North America is a relatively standardized road count, employed over a vast area (Bystrak 1979). Regrettably, not all raptors are observed often enough on BBS routes to allow the use of statistical analysis for demonstrating changes in numbers. For example, counts of only five species of Falconiformes occurring in the eastern United States and nine species from the western United States were sufficient to test for significant changes in number of birds detected from 1967 to 1971 (U.S. Department of the Interior 1971). We encourage research that will develop techniques, and/or correction factors that will increase the usefulness of road count data for a greater variety of raptors. In the meantime, road counts will be conducted as supplements to other methods for counting birds of prey (Craighead and Craighead 1956, Southern 1963, 1964; Murphy et al. 1969, Misztal 1974, McKay 1976, Rogers and Dauber 1976, Petersen 1979, Sykes 1979).

VOCALIZATIONS

The vocalizations of birds allow many species to be detected along road counts or on study plots. Detection of the calls of raptors, especially strigiforms, has been used in many studies. One approach is to simply listen for the calls of the birds and note or plot their approximate location (e.g., Baumgartner 1939, Bell 1964, Hinz 1969, Petersen 1979, Bystrak 1979). Vocalizations of some species may be elicited by imitating the call(s) of the species (e.g., Miller 1930, Marshall 1939, Simpson 1972, Rogers and Dauber 1977) or by broadcasting a recording of a vocalization (Beatty 1977). It is with this latter technique that the most "standardization" has occurred. The locations from which recordings are played have been from 0.4 to 1.6 km (0.25–1.0 mi) apart. The shorter intervals are used for counting the smaller birds which presumably range over less area. Generally, several calls are played, followed by a period of silence (15–60 seconds) after which this sequence is repeated. Investigators usually stay at each broadcast stop for 4–15 minutes. If the vocalization of more than one species of raptor is being played, it is suggested that the call of the smallest birds be played first because response behavior of some birds may be inhibited by the "presence" of larger competitors or predators. Nowicki (1974), Cink (1975), Forsman et al. (1977), Springer (1978), Ortego (1979), and Johnson et al. (1979), among others, have discussed the rationale for protocols of broadcasting vocalizations.

A number of variables must be considered when attempting to detect or count raptors by listening for calls or eliciting responses. Comparatively little work has been conducted with Falconiformes, so the points discussed below generally refer to owls. Peterson (1979) noted day-to-day variability in whether birds on an area gave territorial calls. Several species are more vocal or more responsive to recordings at certain times during the year, and then, within certain hours of the day (Grant 1966, Nowicki 1974, Smith 1978, Siminski 1976, Berggren and Wahlstedt 1977, Forsman et al. 1977, Springer 1978, Postovit 1979). Johnson et al. (1979) found trends of calling associated with lunar cycles.

Many owls have a repertoire of several vocalizations, not all of which can be heard by a human more than a few meters from the bird, and many of which are given in a behavioral context not likely to be elicited by the investigator. Both females and males of some species are known to respond to recordings (e.g., Marshall 1939, Smith 1978, Forsman et al. 1977); however, for some owls, sexual differences have been found in the number of broadcast calls necessary to stimulate a vocal response, the number of calls given in response, and the distance within which a bird will approach the loud-speaker (Siminski 1976, Springer 1978). Other investigators have questioned whether both sexes call and whether only mated birds respond (Nowicki 1974, Cink 1975). In some instances a bird will approach the source of a call, but not respond by vocalizing (Nowicki 1974). Many species respond to a human's imitation of their calls and to the vocalizations of other species (Miller 1930, Foster 1965, Fitzpatrick 1973, Ortego 1979). At the other extreme, Siminski (1976) elicited fewer responses by Great-horned Owls in Ohio to recordings of calls of the species from New York and Oregon than from the call of another Ohio owl. Thus, local dialects may influence the degree to which a bird responds. There is some literature about behavior and vocalizations (e.g., Marshall 1939, Haverschmidt 1946, Ligon 1968, Emlen 1973, Martin 1974, van der Weyden 1975) with which one should be familiar if surveys or counts of calls are to be conducted, but more research is needed about the factors associated with vocalizations, especially elicited calls.

When broadcasting of a recorded call is used to elicit a response, the variables associated with behavior are compounded by factors related to equipment. Field workers have used many kinds of tape recorders, amplifiers, and speakers, all of which may affect the accuracy with which a call is broadcast and the distance the sound will transmit. "Background" noise produced by the equipment, or in the recording, and environmental noise (e.g., traffic noise, wind) may interfere with efficient transmission. Additionally, the structure of vegetation and terrain will influence sound transmission.

If objectives include an estimate of the number of birds present in an area, it is important to know the range over which the sample is being taken. Several people have compared the number of birds responding to broadcasts with other estimates of the number of owls in the same area and found that from 75.0 to 82.6% responded (Siminski 1976, Forsman et al. 1977, Springer 1978). Numerous investigators have based estimates of the number of owls in an area on responses to broadcasts or imitated calls, or counts of hoots (e.g., Nowicki 1974, Cink 1975, Smith 1978, Garcia 1979) and others have used these techniques as supplements to road counts or nest searches (e.g., Hinz 1969, Rusch et al. 1972, Call 1978, Hennessy 1978, Petersen 1979).

We are presently testing the feasibility of using responses to broadcast vocalizations to estimate numbers of breeding raptors in forested habitats. To date, we have played the calls of Red-shouldered Hawks (*Buteo lineatus*), Red-tailed Hawks, Broad-winged Hawks (*Buteo platypterus*), Goshawks (*Accipiter gentilis*), Cooper's Hawks (*Accipiter cooperii*), and Barred Owls (*Strix varia*) on the study areas of the Central Appalachian Raptor Ecology Program in western Maryland, and in northern Wisconsin, northern New Hampshire, and northern Connecticut. The calls are broadcast from roadside routes that run through the center of study areas encompassing about 32 km^2. From March through June, the study areas are systematically and completely searched on foot for all raptor nests. Additionally, field workers record all contacts made during various searching activities (driving, walking, sit-and-watch, etc.) in order to provide data about the distribution of birds on the study areas, and to allow evaluation of activities that lead to the most contacts for each species.

Based on preliminary results, all species were responsive to calls recorded from commercial bird song records, and these responses enabled us to make more contacts than by only stopping to look and listen for birds on our roadside counts. For example, in 1980 only two contacts were recorded for Cooper's Hawks or Red-shouldered Hawks in western Maryland by stopping to look and listen. However, during and after the sequence of broadcasting calls, 10 Cooper's Hawk and 18 Red-shouldered Hawk contacts were made. The test species appear to be most responsive during the period from arrival on their nest area until egg laying, less responsive during incubation, and moderately responsive during the fledgling period. For example, during the three weeks prior to incubation, eight contacts with Cooper's Hawks (10 with Red-shouldered Hawks) were recorded, compared to two contacts during the first three weeks of incubation (one contact for incubating Red-shouldered Hawks), and one during the two weeks following incubation (four contacts with Red-shouldered Hawks) (Mosher, Fuller, Kopeny, unpublished data). Thus far, the results from responses to the broadcasts are consistent with the distribution of the target species, in that birds are contacted at those stops along the routes near raptor nests. We will be continuing this work during the 1981 field season and establishing additional study areas in northern New York and southern Michigan. We emphasize that these are preliminary results and we expect that standardization and testing of this technique will require several more field seasons, but it may ultimately provide an efficient method of detecting and counting many species of forest-inhabiting hawks and owls.

Searches for Nests

Data from surveys to locate active nests are useful for management and protection of breeding birds (e.g., Mathisen et al. 1977) and have often been used as the basis for estimating the number of birds on an area. In addition, once nests have been located, observation of adults and monitoring of egg-laying, hatching, and fledging, can provide data for studies of population dynamics. Consequently, much of the effort devoted to surveys or counts of raptors has been concentrated on nest searches. Before presenting the nest-search techniques, it is useful to review some of the factors that affect the search process and influence the results.

As always, there are potential differences among the abilities of observers to detect nests. Grier et al. (1981) found that with three experienced observers, the proportion of nests found on a study area varied from 67–87%. Few surveys of birds of prey have evaluated observer bias, but studies have been conducted to determine visibility bias associated with detecting nests on different search forays (Fraser 1978), in different habitats (Henny et al. 1977), in different seasons (Craighead and Craighead 1956, Grier et al. 1981), and in finding nests of different species (Craighead and Craighead 1956, Call 1978, Postovit 1979). Light conditions, altered by time of day or weather, may also alter the visibility of nest structures or of evidence to indicate the presence of a nest (Call 1978, Grier et al. 1981). Logistic limitations of some search methods (e.g., searching from a boat) may inhibit or restrict the observer from seeing areas in which nests may also occur (Craighead and Craighead 1956, Wiemeyer 1977, Call 1978). After a nest has been detected, the structure may blow down (Mathisen 1977), the pair may use an alternate nest, or the nest may have been built by a non-breeding pair (e.g., Ratcliffe 1962, Boeker 1974, Stocek and Pearce 1978). Therefore, many surveys or counts must rely on observations of the behavior of birds at the nest to confirm use of a site, and to verify which species is using it.

The observation of raptors near a nest, especially early in the breeding season, is not always evidence the nest is active (Stocek and Pearce 1978, Hodges et al. 1979). The practices of renesting or multiple clutching by some species further complicate the interpretation of limited observations at a nest (Call 1978). The behavior of raptors near a nest creates visibility biases because birds of some species perch and roost nearby, whereas others are not often seen near the nest. Some species react to intrusion by flying away quietly; others may vocalize or fly about or attack an investigator (e.g., Call 1978, Postovit 1979). Many Falconiformes are territorial at the nest site (Newton 1979), thus, a pair of birds can be counted for each active nest which is found (for species that do not maintain alternate nests). However, large or overlapping hunting ranges (Picozzi 1978, Newton 1979) and the existence of semi-colonial nesting, for example by Ospreys (Mathisen 1977), polygamy, and nest-helpers of some species (Hamerstrom 1969, Mader 1979, Faaborg et al. 1980) complicate the use of nest counts for estimating the number of birds present in an area.

Searching for nests and attempting to obtain observations of raptors at the nest can lead to disturbance and nesting failure. This problem has been addressed by several authors (e.g., Hickey 1969, Fyfe and Olendorff 1976) and is discussed in many of the papers cited below.

The objectives of a study may greatly influence the strategy and time allocated for locating nests. If a study area has been delineated and the objective is to locate *all* nests, of some or all of the birds of prey, there is little choice but to initiate a systematic search of the entire area staggered over the nesting period (e.g., Craighead and Craighead 1956, Murphy et al. 1969, White et al. 1977). A more efficient approach in terms of time and people required is to sample the study area in either a random or stratified manner (Postovit 1979). When only certain species are of interest, and a census of nests is not practical, many investigators preselect certain habitat types in which to conduct searches. Call (1978), Reynolds (1975), Kennedy (1977a), and others suggest learning the habitats of birds and using maps and photos of the study area to identify those habitats in which the birds are most likely to occur. The availability of topographic maps, air photos, satellite imagery, and soil and forest cover-type maps for many areas permits careful reconnaissance before entering the field. Detailed descriptions of nesting habitat exist for many species (e.g., Hickey 1942, Call 1978), but one must be aware of the variety of habitats in which raptors breed (e.g., Hickey and Anderson 1969, Jones 1979) and the existence of local variability by members of some species (Call 1978, Jones 1979). Counts and estimates of population size for areas in which only the "most likely" habitat was searched should acknowledge this bias (e.g., Grubb et al. 1975, Stocek and Pearce 1978, Titus and Mosher, in press).

Historic records

The literature, of course, provides information about general nesting habitat use by birds. For some species or populations which have relatively restricted nest site requirements and use or build structures that last many years (e.g., caves, ledges, large trees), historic data can lead one to specific nest areas or nest sites. Ratcliffe (1972), Lindberg (1977), and others (see Hickey 1969) were able to document the decline of nesting Peregrine Falcons by visiting eyries that had been described in the literature and in records of museums, ornithologists, and falconers. Historic records have played an important role in understanding the status of the California Condor (*Gymnogyps californianus*; Wilbur 1978a) and many other large, conspicuous raptors that are very traditional in their use of nest sites (Newton 1979). The status of nesting populations of Bald Eagles (*Haliaeetus leucocephalus*) and Ospreys has often been monitored with the aid of historic nest site data (e.g., Howell and Heinzman 1967, Newman et al. 1977, Sindelar 1977). In addition, valuable information about other species, such as Barn Owls (Smith and Marti 1976), Common Buzzards (Tubbs 1974) and Harriers (*Circus cyaneus*) (Watson 1977) has also been obtained by examining records (e.g., nest record programs of the British Trust for Ornithology, and the Laboratory of Ornithology at Cornell University) and by contacting people in the area of the study.

Local inquiries and questionnaires

Often, some people who live in an area are familiar with the location of nests of birds of prey. Inquiries of these people (e.g., Brown 1974, Saurola 1976, Roberts and Lind 1977, Sindelar 1977) and questionnaires sent to local wildlife managers and amateur ornithologists have often formed the basis for nest searches or an evaluation of the status of local nesting birds (e.g., Baldwin et al. 1932, Prestt 1965, Oberheu 1977). In the Soviet Union, local conservationists and birdwatchers contribute to a "bounty" fund for those people who locate raptor nests (M. S. Dolbik, A. M. Dorofeev, and V. M. Galushin, pers. comm.). In this system, greater rewards are paid for locations of the rarer species. Foresters, farmers, and other interested people have found previously unrecorded nests of Ospreys, eagles, and other uncommon raptors. Villagers helped Kennedy (1977a) find Philippine Eagle (*Pithecophaga jefferyi*) nests and volunteers participated in locating California Condors (Wilbur 1978b). Utilization of information provided by people in the area of study and historic records may reduce the time and expense spent with other techniques in searching for nests.

Aerial searches

The use of aircraft, though seemingly expensive, is an efficient method of searching for nests over large areas. Planning for use of aircraft, evaluation of types of aircraft, safety precautions, and costs have been discussed in several papers (Hickman 1972, White and Sherrod 1973, Carrier and Melquist 1976, Grier et al. 1981). The nests of species that nest in relatively open situations (e.g., cliffs or tundra) such as Golden Eagles (*Aquila chrysaetos*), Rough-legged Hawks (*Buteo lagopus*), Peregrine Falcons, and Gyrfalcons (*Falco rusticolus*) are often easily detected from the air (e.g., Boeker and Ray 1971, Swartz et al. 1975, Pennycuick 1976, White et al. 1977). Osprey nests, according to Henny et al. (1978), are ideally suited for air searches because they are conspicuous, the nest habitat is limited, and nest cycles are synchronous. Henny et al. (1974) developed aerial visibility rates to correct for differences in ability to detect nests located on different structures (e.g., trees, channel markers) and have since used this technique for estimating numbers of Osprey in several regions of North America (Henny and Noltemeier 1975, Henny et al. 1977, Henny et al. 1978a, Henny et al. 1978b, Henny and Anderson 1979). Wetmore and Gillespie (1977) and Prevost et al. (1978) have also used air searches to locate the nests of Ospreys.

Leighton et al. (1979) derived correction factors for detecting Bald Eagle nests from the air as they searched randomly selected units containing a uniform amount of "primary" nesting habitat. Grier (1977) estimated the population size of Bald Eagles and number of breeding areas on a study area in Canada with 95% confidence intervals, and by stratifying the samples, was able to reduce the variance of the mean estimates by about 22%. Grier and Hamilton (1978) subsampled clusters on a stratified basis and used optimum allocation of samples in an effort to further reduce variance. No significant reduction in variance was achieved, but the survey did reveal a significantly different number of nests in different habitat strata, and the sampling scheme reduced the flight time needed for the surveys by about 15%. Grier et al. (1981) found that about 76% of the nests and 85% of the breeding areas of Bald Eagles were detected by one air search, and a total of 94% and 98% were found on a second flight over the same area. Fraser (1978) also found that not all nests were seen on all flights.

When the nests on a study area have been found, there is usually an opportunity to gather data about reproductive parameters. Fraser (1978) conducted "experimental" two-flight surveys over a well-studied Bald Eagle population and found that errors occur in classification of nest occupancy and activity, in judging the chronology of nesting, in counting young, and in estimating other parameters. He discussed the importance of timing of flights, between year differences in results, statistics for monitoring reproduction, and other factors one should consider before initiating air searches.

Howell (1973), Whitfield et al. (1974), Swenson (1979), and others have used air surveys in conjunction with locating and monitoring nests from the ground, counting active nests, and checking productivity (e.g., Herman 1971). Several people have used air searches to complement other techniques for finding nests. Before the leaves emerge on deciduous trees, the stick nests (or old nests) of forest-dwelling species can sometimes be located or raptors may be flushed and sighted (Luttich et al. 1971, McGowan 1975, Petersen 1979). Visible signs associated with raptor presence, such as the white excreta deposited on the cliff face at nests or perches and the orange foliose lichen associated with these sites, can be useful for locating nests from the air and from the ground (Call 1978).

Searches from automobiles

As with searches from the air, location of bulky stick nests from vehicles can be accomplished in some habitats before leafout of deciduous trees (e.g., Hinz 1969, Boswell 1974, Fitch and Bare 1978, Kirkley and Springer 1980). In open habitats such as shrublands, deserts, grasslands, or cliffs, nest sites or signs such as excreta may be detected throughout the nesting season (e.g., Platt 1971, Call 1978). Also, while traveling relatively quickly over large areas by automobile, the behavior of raptors can be noted (e.g., courtship displays, food carrying, and food exchanges) and sightings of birds can be mapped. In this way it is possible to delineate the area in which one is most likely to find a nest (e.g., Craighead and Craighead 1956, Hamerstrom 1969, Call 1978).

Searches from boats

The nests of falcons (e.g., Cade 1969, Oliphant and Thompson 1978), eagles (Whitfield et al. 1974, Hansen 1977, Call 1978), and Ospreys (Reese 1975, Kennedy 1977b, Wiemeyer 1977) which occur along cliffs, lakes, and rivers, have often been found during surveys from boats. Nest surveys from a boat were used by Sykes (1979) to supplement Snail Kite (*Rostrhamus sociabilis*) nest searches and could be effectively used to locate the nest sites of many other species that nest near the shorelines, bays, lakes, and rivers, and in swamp and marsh habitats.

Searches on foot

Walking through areas, looking for nests, and pausing at vantage points to watch for birds, is probably the most common method of finding the nests of raptors (e.g., Newton et al. 1977, Picozzi 1978). Though time-consuming, searching on foot provides more opportunities to see well-concealed nests, to tap a stick against trees containing cavities in which an owl or small falcon may be incubating, to use a dog to sniff for a ground nest, or to elicit vocalizations or defensive flights of a bird (Call 1978). Areas in which a concentration of sightings has occurred, or where the nest of a previous year has been plotted, can be searched carefully on foot. When walking, one can look for molted feathers, the "butcher-block" or prey plucking areas, or excreta under roosts and nests (Craighead and Craighead 1956, Call 1978). Knowledge of nest habitat and the location of one or two nests can lead to the likely location of other nests. Based on information about spacing between nest sites, or the size of the area used by a pair of breeding birds, it is possible to estimate density for an area larger than one's study area. Newton (1979) reviewed the major factors that are likely to influence the dispersion of breeding raptors. These factors (e.g., nest structure, habitat, prey base) are likely to vary over space and time, therefore caution is recommended in regard to extrapolating densities from a local study plot to larger areas. Sampling of density over this larger area of concern should provide a relatively accurate estimate of breeding density.

Estimates of the number of nests on large areas can be obtained relatively efficiently on foot if one samples a portion of the area. Postovit (1979) used simple random and stratified random samples to search up to 33% of his total study area (233 km^2), and was able to locate nests with 63% precision. He believed that sampling a larger proportion of the area (more field workers to conduct the searches in the short period of nesting) and a correction factor for visibility biases for some of the 13 species he observed, would allow increased precision.

Multiple techniques

To survey large areas in short periods of time, many investigators have used more than one technique to locate nests. The objectives of studies in which two or more techniques were used have included gathering basic information about nesting habitat, breeding chronology and reproductive parameters (e.g., Lahti 1972, Misztal 1974, Kennedy 1977b, Newton et al. 1978, Bednarz 1979, Sykes 1979, Titus and Mosher, in press), determining the status of, or monitoring a population of a species (Brown 1964, Howard et al. 1976, Fyfe et al. 1976, Brown 1977, French and Koplin 1977, Stocek and Pearce 1978, Mattox et al. 1980), and evaluating the relationships between prey density and raptor density (e.g., Craighead and Craighead 1956, Murphy et al. 1969, Phelan and Robertson 1978, Smith and Murphy 1978, 1979; Newton, 1979, Petersen 1979). Counts of prey species, that in some instances are less time-consuming than detecting raptors, may provide indices that are useful for estimating raptor densities.

AERIAL COUNTS

During one breeding season Bald Eagles were counted from aircraft flown over a random sample of 30 blocks (166 km^2 each) in preselected habitats (King et al. 1972). This survey was repeated 10 years later using the same flight techniques and sample plots (Hodges et al. 1979), so that a statistical comparison could be made between the two surveys. Randomly selected aerial transects constituting about 7% of each study area were used to monitor the yearly winter population of Golden Eagles in the southwestern United States. Similarly, the Golden Eagle population in Wyoming was counted by flying over randomly selected transects (Higby 1975). Boeker and Bolen (1972), and Boeker (1974) described flight techniques and discussed variables such as rough terrain, which may affect the aerial counts. Hancock (1964) described his flight techniques for counting Bald Eagles over the major shorelines of British Columbia. He also discussed visibility differences between adult and immature birds and the affects of seasonal movements, and various assumptions on population estimates.

Other aerial surveys include those by Wrackestraw (1973) to count Golden Eagles, Lish and Lewis (1975) and Southern (1964) to supplement ground tallies of Bald Eagles. Presently the National Wildlife Federation (Washington, DC) is coordinating surveys of wintering Bald Eagles. Air surveys flown in conjunction with this effort have revealed several areas where birds were previously not known to winter (M. Pramstaller, pers. comm.). Enderson et al. (1970) counted eagles and Miller et al. (1975) recorded numbers of Snowy Owls (*Nyctea scandiaca*) while on aerial surveys of large mammals.

COUNTS AT COLONIES AND ROOSTS

There are several groups of Falconiformes (e.g., vultures, kites, harriers, and small falcons) in which some species nest colonially or semicolonially, at least in certain parts of their breeding range (L. Brown 1971, Newton 1979). Despite their density, nests in some colonies may not be easy to find (e.g., Eleonora's Falcon (*Falco eleonorae*), harriers), and may be difficult, dangerous and time consuming to reach (e.g., Parker 1975). Because of these factors, and the disturbance to many birds caused by moving about in the colonies, it is often more desirable to estimate the number of breeding birds by counting individuals as they fly to and from the colony. Erwin and Ogden (1979) had an error rate of 13% when estimating the number of four species of nesting wading birds in colonies. Walter (1979) believed that only about 10% of the breeding population may be seen above or near colonies of Eleonora's Falcons, even at the height of reproductive activity.

If we can learn about those variables affecting flight rates (e.g., weather, food requirements, food availability), it may be possible to make good estimates of nesting birds by counting raptors as they fly in and out of breeding colonies. For example, Sykes (1979) made counts of Snail Kites going to night roosts. Many investigators, including Southern (1963, 1964) and McClelland (1973), have counted Bald Eagles at winter roosts. Both Schnell (1967, 1969), counting Rough-legged Hawks, and Bildstein (1979a) counting Hen Harriers, estimated local numbers of those raptors using roost counts and discussed some variables that may affect estimates. Weller et al. (1955) counted Hen Harriers and Short-eared Owls (*Asio flammeus*) at winter roosts. Population estimates by roost count techniques may also be applicable for other species of harriers (L. Brown 1971, Watson 1977), some vultures, Long-eared Owls (*Asio otus*), and several other raptors that roost communally at certain times of the year.

Christmas Bird Counts

Many raptors are found in greater densities on the wintering grounds than in their breeding areas, thus making it a bit easier to count them in winter. In the early 1900's, ornithologist Frank M. Chapman encouraged Christmas-time bird "censuses" as a substitute for traditional annual hunts for raptors, crows, and other "vermin" (Stewart 1954). In the past years, participation in Christmas Bird Counts (CBC) has become very popular, and has resulted in the collection of a great deal of information on local winter bird populations. Results of these winter counts have been published in local birding publications and in *American Birds* (formerly *Audubon Field Notes*). Inherent in the way the counts are conducted are many variables influencing the use of CBC results for estimating avian populations. The implications of these variables for estimating numbers of birds or detecting trends in populations have been discussed (e.g., Stewart 1954, Arbib 1967, Raynor 1975).

The number of parties searching in the prescribed circle (12.1 km radius) and the number of experienced people per party may greatly influence the number of raptors detected on a CBC. In recent years, the number of participants has increased in most areas and frequently some people make special efforts to find birds of prey by searching certain habitats, using tape recordings to elicit responses, etc. Because the extent and type of coverage varies on counts from year to year, it becomes very difficult to interpret CBC data.

Bystrak (1971) and Renaud and Wapple (1977), among others, have drawn winter distribution maps based on CBC data. Brown (1964) noted, however, that a lack of even distribution of counts over the state of Iowa precluded accurate mapping of winter ranges of two buteos. In an effort to reduce variability associated with different numbers of participants over the years, Graber and Golden (1960) included only counts conducted by 10 or fewer people in parties of four or fewer participants. The late W. H. Brown (1971) analyzed count data to detect trends in the number of Red-shouldered Hawks. He "normalized" counts by tallying the number of hawks seen per distance traveled by a party. He also grouped counts according to different geographic regions, but was unable to detect any pattern in the decline in numbers across the country. Brown found that the number of Red-shouldered Hawks and other species of raptors seen on cloudy days was less than observed on clear days, but that the plots of yearly counts were the same shape for data obtained on clear or cloudy days (W. H. Brown 1971, 1973, 1975, 1976b). His analyses of CBC results revealed that a substantial increase in effort and consequently, in numbers of birds counted in a state or province, could greatly affect the shape of curves from national counts. The interpretation of winter counts of vultures (Brown 1976b) was also affected by interruptions in a series of yearly counts. Bildstein (1979b) limited his analysis to data from CBC circles which had been searched each year during the 6-year period with which he was concerned.

Raynor (1975) emphasized the importance of comparing counts conducted in similar habitats, and Stahldecker (1975) chose only circles containing similar proportions of the same habitats. Stahldecker's analyses revealed another limitation of the use of CBC data for some birds of prey; that is, for the plots he used, there were too few sightings of Goshawks, Cooper's Hawks, and Sharp-shinned Hawks (*Accipiter striatus*), so the counts of those species had to be combined before analysis could produce a trend in *Accipiter* numbers. For one area, Bildstein (1978) found that his intensive counts on one study area did not correlate with CBC counts in the same area. A 5-year increase in raptors detected with his estimates was not correlated with weather, number of participants, nor with his mean estimate of the number of birds present in December. He believed day-to-day counts probably reflect previous weather as well as weather on the count day.

These problems with CBC data provide examples of the type of factors one must consider when using counts made by a diverse group of participants, over large areas and long periods of time, and with relatively vague instructions or directions. In addition to these concerns are many variables affecting the distribution of the birds from year to year. In most instances we do not know the specific geographic origins of wintering populations. We do know that the movements of these birds are affected by prey availability, weather, and interspecific interactions not only on the wintering grounds, but also on the breeding range and along the migratory routes (Craighead and Craighead 1956, L. Brown 1971, Newton 1979). Until we learn more about these factors, we must interpret winter count data cautiously and restrict use of trend data derived from these counts to identifying areas for further study and/or to supplement evidence from other estimates of numbers (e.g., U.S. Dept. of Interior 1971).

Trapping

Capture of birds of prey has seldom been used as a counting technique because trapping raptors under most circumstances is very time-consuming. For example, Doerr and Enderson (1965) and Doerr (1968), in their efforts to count Goshawks, captured only one raptor per 40.5 and 31.2 trap-days, respectively. Even when a variety of trapping techniques are used on relatively small study areas (e.g., 1,000–10,000 hectares), capture rates may not be high (1 bird/15.4 days) and recapture of raptors is even more time-consuming (Fuller and Christenson 1975). Because of these difficulties, and the relatively "data hungry" nature of most population estimator models, capture-recapture approaches to raptor population studies have not generally been pursued (see Nichols et al. 1981).

The greatest opportunity to capture large numbers of birds of prey exists during migration, but not all locations are well-suited for capture. Bartelt and Orde (1976) captured only 1 bird/19.4 trap-days in South Dakota. Along migration routes where raptors become concentrated, hundreds of birds may be captured during an autumn season (Evans 1975, Newton 1979). Several people have been conducting trapping and banding projects for a number of years and have provided information about raptor migration and the usefulness of trapping for counts of birds of prey (Gray 1961, Mueller and Berger 1961, Field 1971, Clark 1973, Berry and Ward 1975, Evans 1975). Trapping results combined with observations have been used to address questions about the status of a species or trends in populations (e.g., Berry 1971, Enderson 1965, Ward and Berry 1972, Rogers and Hunt 1975, Mueller et al. 1977).

There are many variables affecting the movements of migratory raptors (Newton 1979) and additional factors affecting trapping results such as effectiveness of types of traps and bait for different species, and different age or sex of birds (e.g., Mueller and Berger 1970). In many instances the trapping data are not used for counts per se but as supplements to sightings and to provide information about the seasonal and daily timing of migration for different species and different ages and sex groups within species (e.g., Mueller and Berger 1967a, 1968, 1973; Catling 1971, Ward and Berry 1972, Mueller et al. 1977, 1979; Rosenfield and Evans 1980). Furthermore, the results of trapping efforts have contributed to our understanding about the effects of weather on the movements of migrating raptors (e.g., Evans 1980). Finally, recoveries and returns from birds of prey banded along migration routes have provided some very valuable data about the origin and destination of migratory raptors (e.g., Enderson 1965, Mueller and Berger 1969, Clark 1976). More data of this nature are needed before counts made of migrating birds can be fully utilized to estimate the size of, and to detect trends in, populations.

Counts of Migrants

Newton (1979) discussed the major factors that influence the movements of Falconiformes. Several of these factors relate to migratory movements and have important implications for interpretation of counts of migrants: (1) populations may remain longer on the breeding grounds in years when food is plentiful there, (2) for some species, birds of different age or sex may not migrate, or they may migrate at different times depending on the availability of food, (3) birds may migrate farther if food is scarce, and (4) separate populations of the same species may migrate along different routes and winter in different areas. Counts of nomadic and cyclic populations (e.g., Shelford 1945, Galushin 1974, Mueller et al. 1977) may vary greatly from one year to the next at any one location on the migratory route. In these instances long-term changes in the status of populations can be evaluated only after accumulating counts for many years. In some areas it may be difficult to count migrants because the distribution of migrants overlaps with that of resident birds (Brown 1971a, Thiollay 1978, Newton 1979).

Movements of raptors are also influenced by many factors along their migration routes. Many species of raptors migrate along certain features of the terrain and may become further concentrated in space and time by weather conditions (e.g., Mueller and Berger 1967c). Both local weather and weather over a regional or continental area may affect movements of the birds (e.g., Bagg 1950, Mueller and Berger 1961, Haugh and Cade 1966, L. Brown 1971, Heintzelman 1975, Haugh 1975, Evans 1980). Not all migratory raptors pass along concentration points, but rather some portions of many populations are spread over larger areas (e.g., Hamerstrom 1969, Hopkins 1975, Dekker 1979). In some areas the autumn flights are concentrated, whereas in other locations the spring migration becomes concentrated (see Newton 1979). The degree to which birds become more or less concentrated in association with various weather or biological phenomena is only generally known. Thus, observers at a specific site cannot know whether a low count is attributable to a lower population or to movements of the birds over a different area.

There are also many unquantified variables involved in the observation and counting of passing raptors; for example, (1) the ability of the observer to detect birds, (2) the ability to accurately count birds, (3) the ability to identify migrants, (4) the effects of multiple observers, (5) the use of optical aids (from binoculars to high-powered telescopes), (6) counting from more than one station in a local area, (7) recounting birds that remain in the area, (8) the effects of weather on visibility, and (9) the extent to which counts are conducted in inclement weather. These factors and others have been discussed by several investigators (e.g., Enderson 1969, Spofford 1969, Heintzelman 1975, Dunne and Clark 1977, Nagy 1977, Harwood and Nagy 1977, Fuller 1979). In an effort to reduce some of the variability of counting techniques and of recording count data and some other relevant information, the use of standardized forms has been encouraged (Harwood 1975, Heintzelman 1975, Robbins 1975, Fuller and Robbins 1979). It is hoped that standardized instructions and forms will facilitate gathering of data which can be pooled for comparisons of different locations, species, years, weather conditions, etc. Certainly not all the pertinent variables can be accommodated on these forms nor will they be applicable in all situations (especially in regions where birds of prey are not concentrated). Rather, the information from the form should be considered as a starting point. The gathering of additional data relevant to factors influencing movements of raptors and initiation of more research on raptor migration is needed.

The methods that can be adopted for studies of raptor migration are diverse. Stearns (1949) viewed hawks from a blimp (dirigible) and Hopkins (1975) used airplanes and subsequently, a motor-glider as suggested by Pennycuick (1975). Radar has been used in several areas (Alerstam and Ulfstrand 1972, Evans and Lathbury 1973, Richardson 1975), and revealed that birds of prey often fly higher and over broader areas than had been detected by observers. Smith (1980) photographed raptors overhead and subsequently made accurate counts of the number of birds in each "sample." These methods reveal basic information on raptor migration that permits more reasonable evaluation of counts.

Numerous authors have emphasized the value of counts made along migration routes for providing relative numbers that can be compared from year to year (e.g., Edelstam 1972, Ulfstrand et al. 1974, Robbins 1975). Indeed, migration counts have been used to help assess the status of certain species (Kruyfhooft 1964, Spofford 1969, Hamerstrom 1969), to help detect population trends (Snyder et al. 1973, Nagy 1977), and as supplements to other estimates of numbers of birds or their status (Hackman and Henny 1971, Robbins 1975, U.S. Dept. of Interior 1971). These counts must be interpreted cautiously (e.g., Harwood and Nagy 1977) until we gather more basic data about raptor migration. Problems associated with enumerating migrating hawks seem worth further study becouse it is relatively easy to count birds of prey during migration and because there are many locations around the world at which concentrations of migrant raptors occur.

Counts of migrating birds of prey have been conducted in Africa (e.g., L. Brown 1971, Moreau 1972, Elgood et al. 1973, Thiollay 1978), in the Mediterranean region (e.g., Simmons 1951, Nisbet and Smout 1957, Evans and Lathbury 1973, Beaman and Galea 1974, Thiollay 1977), in the Middle East (e.g., Safriel 1968, Nielsen and Christensen 1970), in Europe (e.g., Edelstam 1972, Ulfstrand et al. 1974, Roberts 1979), in Central America (e.g., Skutch 1945, Hicks et al. 1966, Smith 1980), in Mexico (Purdue et al. 1972, Thiollay 1980), and in the United States and Canada (see Harwood 1975, Heintzelman 1975). No doubt other concentration points exist along the eastern coast of the Soviet Union and mainland China, and along river valleys, mountain ranges, and at mountain passes on the Asian continent. Thus, there is ample opportunity for making raptor counts during the migration periods, and the potential exists for applying these counts to estimates of raptor population sizes in many parts of the world.

CONCLUSIONS

Birds of prey are generally widely spaced (especially during the breeding season), rapid-moving, and wide-ranging, and are therefore difficult to detect and count. Often, the most reliable estimates of numbers of breeding raptors are the result of intensive searches for nests of breeding pairs. The numbers of some birds of prey, or their nests, have been estimated with more efficient sampling techniques such as counts along transects or searches on random or stratified plots. Generally, however, success with sampling has been limited to those species or nest structures that are conspicuous by virtue of their large size or occur in open habitats or on prominent structures. Even with these species, it is difficult to obtain adequate yet affordable samples (Grier et al. 1981).

The usefulness of partial counts of birds and detection by indirect methods (e.g., vocalizations) remains limited because few studies have been able to relate the "sample" to the actual (or statistically estimated) population size. This is especially true with forest-dwelling Falconiformes and a majority of owls. Most relative abundance indices have also been of limited value because counts were not conducted in a standardized manner or frequently enough to evaluate comparisons of different areas or different times. Birds of prey are often less widely dispersed during the winter and particularly during migration when many species become concentrated along various routes in many parts of the world. Counts are made more easily at these times than during the breeding season; however, the origin of most birds is unknown and therefore count data cannot be related to the population dynamics of particular demes or geographic areas. Interpretation of surveys and counts conducted during the non-reproductive season are hindered by our lack of knowledge about the degree to which variables associated with climatic conditions and biological variability (e.g., food availability) affect the movements of birds. Thus, we cannot differentiate a change in actual population size from our inability to count birds that may have moved elsewhere. Trapping and banding projects, yearly counts conducted at migration concentration points, and studies employing radar, radio-telemetry, air surveys, and other specialized techniques are providing information critical for our understanding of bird movement. However, much more research on the variables affecting counts is needed.

Since birds of prey occur at comparatively low densities, the loss of relatively few individuals may change the status of a population. Unfortunately, raptors are sensitive to the contamination, disturbance, and loss of habitat that often accompany development. Consequently, the conservation of raptors has become the concern of a variety of people involved in land-use planning and resource management. These people, in addition to biologists specializing in studies of birds of prey, need data about the ecology, distribution, and status of raptors.

We encourage more efforts to develop reliable and efficient sampling techniques suitable for use with the diversity of raptor species and their habitats. Because most surveys and counts are limited by time and funds to a relatively small portion of the range of a species, we believe knowledge about raptors, and their management and conservation is best served when the results of many studies can be pooled and compared. As Fraser (1978) has emphasized, the key to successful comparison is often not complete standardization of techniques, but rather standardization of the estimated parameters and inclusion of measures of the variability (e.g., confidence intervals, standard error) associated with the estimates.

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