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SAMPLING IN RUGGED TERRAIN

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ABSTRACT.—Work in rugged terrain poses some unique problems that should be considered before research is initiated. Besides the obvious physical difficulties of crossing uneven terrain, topography can influence the bird species' composition of a forest and the observer's ability to detect birds and estimate distances. Census results can also be affected by the slower rate of travel on rugged terrain. Density figures may be higher than results obtained from censuses in similar habitat on level terrain because of the greater likelihood of double-recording of individuals and of recording species that sing infrequently.

In selecting a census technique, the researcher should weigh the efficiency and applicability of a technique for the objectives of his study in light of the added difficulties posed by rugged terrain. The variable circular-plot method is probably the most effective technique for estimating bird numbers. Bird counts and distance estimates are facilitated because the observer is stationary, and calculations of species' densities take into account differences in effective area covered amongst stations due to variability in terrain or vegetation structure. Institution of precautions that minimize the risk of injury to field personnel can often enhance the observer's ability to detect birds.

Relatively few avian studies have been conducted in areas with rugged terrain. A number of reports based on observational data are available on the altitudinal limits and distribution of birds, particularly in the Appalachian Mountains, where the breeding ranges of certain species extend considerably farther south at high elevations (Oberholser 1905, Wetmore 1939, Murray 1946, Stevenson and Stupka 1948, Tanner 1955). More recent studies have focused on avian community structure along elevational gradients (Alexander 1973, Able and Noon 1976, Terborgh 1977, Noon and Able 1978, Sabo 1980). Other studies and a number of Breeding Bird Censuses have been conducted to investigate the organization of avian communities in montane, bog, or swamp habitats where terrain is uneven or unstable (e.g., Snyder 1950, Salt 1957, Brewer 1967, Breeding Bird Censuses in American Birds 1971–1980).

In the great majority of instances, however, knowledge of avian distribution and habitat preference is limited to habitats and regions easily accessible to the observer. With additional research in areas with rugged terrain, we may find even the more common, well-studied bird species occupying a broader range of habitats than was previously known. For example, in a study in progress in Upper Michigan (unpublished data, U.S. Fish and Wildlife Service), Ovenbirds (*Seiurus aurocapillus*) exhibiting territorial behavior have been located in moist lowlands with dense shrub cover as well as in mature deciduous and coniferous forests. At this time, it is unclear whether these individuals are actually breeders or are unmated males occupying suboptimal habitats. In addition, the Black-and-white Warbler (*Mniotilta varia*), a summer resident of mature, dry deciduous forests throughout much of its breeding range, was commonly found in wooded swamps with high shrub densities, particularly those in which northern white-cedar (*Thuja occidentalis*) was dominant (Noon et al. 1980).

The study of certain species of birds may make work in rugged terrain unavoidable. Palm Warblers (*Dendroica palmarum*) and Northern Waterthrushes (*Seiurus noveboracensis*) nest in bogs or shrubby swamps where travel is difficult; rosy finches (*Leucosticte* spp.) in the Rocky Mountains nest almost exclusively above timberline. A number of the endangered Hawaiian species (e.g., 'O'u (*Psittirostra psittacea*), Kauai 'O'o (*Moho braccatus*), 'Akiapola'au (*Hemignathus wilsoni*)) inhabit high elevation rain forests far from roads or trails. Heavy rainfall, dense vegetation, and steep slopes can make working conditions extremely strenuous.

In addition, the increased pressure to develop fossil fuel resources has necessitated more research in rugged terrain to determine the impact mining and the resulting conversion to a different vegetation type will have on bird populations. Strip mining of peat and coal may center in extensive boglands or on steep slopes where, because of site conditions, terrain, and climate, disturbance has been minimal in the past.

This paper deals with sampling in rugged terrain. Potential problems are identified, and considerations are discussed concerning the choice of a sampling technique, location of study sites, and safety measures. Although emphasis is placed on areas with steep slopes, some of the same problems are encountered wherever terrain is uneven or unstable, or where slash, vegetation, rocks, or other obstacles make foot travel difficult or obscure vision and hearing.

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SAMPLING BIASES INDUCED BY TERRAIN

Work in rugged terrain poses some unique problems that should be considered before research is initiated. Attempts should be made to minimize the effects of these problems because, in conjunction with other variables such as weather conditions, daily or hourly changes in activity and behavior, and differences among observers, considerable bias may be introduced into census results.

RATE OF TRAVEL

When the rate of travel along a census transect is slowed because of terrain, the length of time the observer is exposed to each bird increases. Care must be taken to avoid double-recording of individuals, particularly when no opposition singing is detected. In addition, the likelihood of recording species that sing infrequently is greater. Colquhoun (1940) and Shields (1979) found that the walking speed of the observer influences census results. A fast walker records more species and individuals per unit of time. However, if figures are converted to densities, the numbers will generally be lower than those of an observer traveling over the same area at a slower speed. These factors should be taken into account if comparisons are to be made with census results obtained on level terrain. If a transect is to be covered several times, the time bias can be reduced to some extent by taking extra care in clearing and flagging the routes of travel.

DETECTABILITY OF BIRDS

Besides the physical difficulties associated with work in uneven or unstable terrain, topography can influence the observer's ability to detect birds. When paying attention to the terrain underfoot, it may be difficult to concentrate on observing birds. Additionally, large boulders, ridges, or other physiographic features may obscure bird song and conceal activity. The frequent streams in hilly or mountainous terrain present additional detection problems; census results may show an inaccurate preponderance of relatively loud-voiced species. This factor may be an especially serious bias in roadside counts, as many mountain roads follow streams. Myberget and Strömme (1974) concluded that it is unlikely that obstructive terrain features will cause large errors in population estimates from randomly located line-transects when data collected are based on visual observations. Emlen (1977a) addresses the problem of varying detectability of species and individuals by basing breeding season estimates of density exclusively on song. In areas where terrain obscures sound, the only effective means of alleviating detection problems may be to require that transects cross rather than parallel obstructions, or to deviate from the prescribed route of travel.

EFFECT OF PHYSICAL FACTORS ON CENSUS RESULTS

Physical factors (e.g., slope, aspect, elevation, presence of streams) may also influence the bird species composition of a forest. Species such as the Louisiana Waterthrush (*Seiurus motacilla*), Northern Parula (*Parula americana*), Cerulean Warbler (*Dendroica cerulea*), and Acadian Flycatcher (*Empidonax virescens*) are often found near water, though vegetation characteristics may not be measurably distinct. If the effect of a treatment on bird populations is being studied, study areas should be similar with respect to these physical factors as well as vegetational composition and structure. In studies in which associations are to be made between bird species' presence or abundance and habitat characteristics, physical factors should be included as variables unless no differences exist among areas.

ESTIMATES AND MEASUREMENTS OF DISTANCE

Uneven terrain or dense vegetation can introduce error into estimates of distance, particularly when estimates are based on aural detections of birds. Birds singing across a valley may sound considerably closer, while birds over a ridge or downslope from the observer may sound more distant. Estimating distances and plotting locations of singing birds can be facilitated by plotting landmarks and vegetation changes to scale on field maps of census plots or transects. Setting up a finer grid (e.g., 25 m, as opposed to the more usual 50 or 100 m) in tracts censused by the territory mapping method and prominently marking plot or transect boundaries can also increase the accuracy of plotted locations and distance estimates. Kepler and Scott (1981) also emphasize the value of training observers in minimizing errors in estimates of distance.

If the avian data gathered are to be related to areas defined on maps or aerial photos, measurements made on slopes should be corrected to accurately reflect the horizontal projection. Since the slope can easily be determined with the use of a clinometer, Abney level, or Haga altimeter, the required correction is straightforward; the desired horizontal distance is divided by the cosine of the angle of slope, a figure readily available from a hand calculator or a prepared table. For example, to be equivalent to a map distance of 50 m, the field measurement on a 15°

slope should be corrected to 51.8 m ($x = 50$ m/cos 15° = 50/0.966 = 51.76 m). The significance of such corrections becomes apparent as distance or slope increases. For example, if a 1-km transect is being laid out on a 15° slope, an additional 35 m (a correction of 3.5%) should be added so that the measurement corresponds to the horizontal distance. On a 30° slope, a correction of approximately 15.5% is required. However, if mapping quantitative data is not the objective of the study, slope corrections should not be made, since an overestimation of the area censused, and hence an underestimation of the density of birds, will result.

OTHER CONSIDERATIONS

TIME

Since the period during which avian breeding studies can be conducted is limited, the time involved in collecting census data is a major concern of the researcher. The extra time and physical exertion required for travel in rugged terrain generally mean that daily and seasonal goals of how much can be accomplished must be lowered from those normally established. This should be a prime consideration in the selection of study areas and a census technique, especially when little or no field assistance is available or when field work cannot be extended beyond one breeding season.

SAFETY

The risk of personal injury is inherent in any field situation; however, the chances of injury increase as terrain becomes more rugged. If the project leader cannot meet the necessary provisions for safety of field personnel, a study area should be chosen where hazards are minimal. Institution of safety precautions can often enhance the observer's ability to detect birds.

(1) Field personnel should be in good physical condition.

(2) All field personnel should be equipped with properly fitting footwear that provides adequate ankle support and traction for traversing rough terrain. Clothing should offer some protection in areas with dense vegetation or slash.

(3) Field personnel should be equipped with a compass, topographic map, flashlight, and first aid kit. In remote areas, extra food and a sleeping bag or blanket should be carried. If the route of travel crosses treacherous terrain or if location of study areas requires that individual observers work alone in remote locales, two-way radios should be used. As often as possible, study plots or transects should be close enough together so that another individual is within the general vicinity. In avian studies in Hawaiian rain forests, Scott et al. (1981a) have adopted a field plan in which, for safety reasons, independent but simultaneous counts are made by two observers. They feel that more accurate estimates of numbers can be achieved by dividing responsibilities for counting common species. However, in most situations, sampling by pairs or groups of observers is inefficient and distracting.

(4) A detailed map of the study area with the route of travel and specific hazards marked should be filed with a local individual or fellow employee not involved in the fieldwork. Radio frequencies and a schedule of censuses should be attached, with instructions for action should field personnel not return to their duty station or residence by an established time.

(5) Hazardous areas should be flagged or otherwise marked. Provided that habitat disturbance is minimal, pruning or clearing of vegetation to expose hazards may be warranted. Deviation from the defined straight line of travel is discouraged if the sampling scheme requires accurate measurements of distances and angles (e.g., the line transect method; Anderson et al. 1979); however, fewer observations of birds will be missed if physical obstacles or hazards are skirted.

(6) In planning fieldwork, care should be taken to avoid overestimating the area to be censused each morning; the pace must be slow enough so that observers are not forced to hurry over rough terrain. In addition, if the study area is not easily accessible from a road, field personnel should consider camping at or near the start of the census route on nights prior to censusing to reduce the amount of foot travel before daylight.

SELECTION OF A CENSUS TECHNIQUE

Difficulties are encountered in conducting avian field studies in rugged terrain regardless of the census technique selected. The objectives of the study to a large extent will dictate which technique will be the most efficient. For example, if the intent of a study is to determine species' densities in a montane habitat or to measure long-term effects of an environmental disturbance on bird populations, territory mapping would be the appropriate technique. A transect method would be more suitable in a study of seasonal changes in bird populations or of avian distribution along an elevational gradient.

Robbins (1978a) provides a summary and critique of the most widely used techniques for censusing forest birds. Other authors (e.g., J. T. Emlen 1971, 1977a; Shields 1979) have compared census methods. The researcher should weigh the efficiency and applicability of a particular technique for the objectives of his study in light of the additional difficulties posed by work in rugged terrain.

Territory Mapping Method

Territory mapping (International Bird Census Committee 1970) is the most widely used census technique. Its chief disadvantage, the amount of time required to set up a plot and conduct multiple census trips, is magnified in rugged terrain. To adequately conduct a census, it is essential that the observer traverse the plot; in some instances, this may require recrossing contours or areas with dense vegetation. Attempts have been made to overcome this drawback by establishing elongated census plots so that the centerline lies along a ridgetop (e.g., West Virginia censuses, Reeves 1980). However, the territory mapping plot then in effect becomes a strip transect, with year-to-year variation in the number of territories exaggerated by birds that move short distances, crossing plot boundaries from one year to another (Robbins 1978a).

Sampling error induced by terrain is minimal with this technique. The problem of double-recording of individuals is minimized by repeated coverage of an area. Distance estimates are not required, and the difficulties of detecting birds can be reduced by varying the route of travel on successive visits. Thus, territory mapping is probably the most accurate census technique in rugged terrain.

Transect Methods

In terms of time expended, the transect method is more efficient than the mapping method. This technique, which basically involves counting birds on one or both sides of a line, minimizes the amount and difficulty of walking. Transects can be established along or across contours. The number of observations of birds necessary to provide sufficient data for analysis is probably the best determinant of transect length (Anderson et al. 1979, Conner and Dickson 1980). If terrain or the size or shape of the study area precludes the establishment of long transects, several shorter transects can be used to obtain the desired base of data. A disadvantage of this method in rugged terrain is that, since observations are made while progressing along the transect, it is difficult for the observer to pay attention to his personal safety and to accurately detect and record distances to birds.

Of the various transect methods used for wildlife censuses (Eberhardt 1978), the strip transect method (Emlen 1977a, Conner and Dickson 1980) is the best suited for censusing avian populations in rugged terrain. Unless one is trying to correct for detectability (J. T. Emlen 1971), distance estimates are simplified because the observer need determine only whether a bird is within or outside the census strip boundary. Problems may arise, however, if physical obstacles or dense vegetation prevent adequate coverage of the strip at all points. It may be difficult to settle on a strip width that can be adequately covered and still allow sufficient sampling of rare species.

IPA or Point Count Method

Several researchers (Ferry 1974, Jorgensen 1974, Evans 1978, Whitcomb et al. 1979) have successfully used stationary counts to obtain indices of abundance for comparing bird populations. The basic technique, the IPA count (Indices Pontuels d'Abondance) developed by Ferry and Frochot (1970), involves a count of all birds heard or seen from a point. Subsequent modifications alter the effective area censused. Counts may be restricted to a defined area (fixed plot), or all birds may be counted, with estimates of the horizontal distance to each location used for more accurate calculation of the area censused (variable circular-plot, Reynolds et al. 1980).

The appeal of a technique involving stationary counts of birds is apparent in rugged terrain. When walking is separated from the actual counts, the observer is able to devote his full attention to detecting birds and still concentrate on his personal safety. A stationary observer is also less likely to influence bird activity. However, the effectiveness of this technique in rugged terrain depends on the type of count selected.

Undefined area counts.—Although this technique is the simplest to apply, the influence of topography on the detectability of birds and the area of coverage may make it impossible to combine or compare results from undefined area counts. Criticism has also been levied concerning the appropriateness of using these data for associations between presence or abundance of a bird species and habitat characteristics (Noon, in press). The area sampled varies with the species (e.g., the area of coverage is greater for a loud-voiced species such as the Red-eyed Vireo (*Vireo olivaceus*) than for a soft-voiced species such as the Black-and-white Warbler); thus coordination of vegetation samples with bird territory locations is difficult.

Fixed area counts.—The use of plots with a fixed or defined area enables the researcher to express count results as species' densities. However, the variability in physical factors and vegetation structure characteristic of rugged terrain may cause differences in the detectability of birds, making standardization of plot size difficult. Like fixed width transects, this technique is less efficient with regard to uncommon species, since only birds observed within the plot boundaries are counted.

Variable circular-plot counts.—In extensive surveys in Hawaiian rain forests where rugged terrain and dense vegetation make foot travel extremely difficult, Scott et al. (1981a) have found the variable circular (variable area)-plot technique to be the most effective for estimating bird numbers. This technique takes into account differences in detectability among species and among stations. The distance from the point to each bird observed is estimated and used to calculate the effective area covered for each species at each station. Thus, if topography or vegetation obscure detectability at a particular station, the limits of the area surveyed will be correspondingly smaller. Estimation of distances, which may be burdensome when made while moving along a transect, is more easily accomplished when the observer is stationary. However, because the area added to the circle of coverage increases with increasing distance from the observer, errors in estimates of distance may significantly affect the accuracy of the calculated densities. For this reason, the importance of training observers in estimating distances cannot be overemphasized.

CONCLUSIONS

It is clear that there are disadvantages associated with the use of any census technique in rugged terrain. The variable circular-plot method, currently being used in surveys of Hawaiian forest birds and in other studies, was developed for use in areas where terrain or vegetation hinder travel and detectability of birds, and can easily be adapted for use in other areas. It is likely that with more work in rugged terrain further refinement of present techniques or development of new techniques may effectively minimize potential sampling biases induced by terrain.