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QUAIL METHODOLOGY: WHERE ARE WE AND WHERE DO WE NEED TO BE?

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Abstract: I review and evaluate methods used for population estimation, determination of survival, radio-tagging, habitat analysis and evaluation, and study design and analysis. I conclude that rigorously designed call-count surveys are likely to provide the best information on quail population trends across time and space. More intensive techniques such as line transects and mark-recapture may be appropriate if the resources are available. Radio-tagging can be a very useful technique; however, in many cases, triangulation error and effects of equipment on the birds may render results suspect. Therefore, caution is urged when using radio-tagging. Approaches to habitat analysis and evaluation are described. I discuss the importance of replication in study design and the use of appropriate and rigorous statistics. I suggest we consider statistical power more in the interpretation of results. Generally, we have the techniques available to meet our needs, but implementation has been less than ideal in many cases. Finally, the dichotomy between researchers and managers needs to be bridged. Better communication of needs by managers and cooperation by researchers should lead to positive results concerning our quail resources.

Key words: habitat analysis, population estimation, quail, radio-tagging, statistics, study design.

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That all species of quail are of importance to a large number of people is attested to by the attendance of over 300 professional managers and researchers at this symposium. To effectively research and manage quail requires the application of a variety of techniques. We need to be able to track population trends and demographics, to relate populations to habitat characteristics, to determine the outcomes of management activities, and to make predictions concerning population attributes.

A wide variety of methodologies has been developed over the past 60 years to address these needs. My goal is to review the use and application of major techniques for quail. I review methods used to assess population parameters (density, survival, and sex and age ratios), radio-tagging, and analysis of habitat relationships. I also make comments concerning the application of various statistical procedures and the importance of proper study design. The methods I review reflect my biases and background and may not be the same as those others might choose to address. I do not address the techniques in great detail; such information will be found in the references. Rather, I hope to provide overviews of the use of various techniques and indicate when it is appropriate for their application.

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ESTIMATING POPULATION PARAMETERS

A common concern of managers and researchers centers on determining just how many quail occur on an area; and a considerable amount of effort has been devoted to assessing population parameters such as density, survival rates, and sex and age ratios. Population data may be used to track trends in population levels, guide the setting of regulations, predict fall harvest, evaluate effects of habitat and population management, and assess mortality and survival rates.

The particular approach taken to estimating populations depends on a number of factors. Prior to selecting an estimation technique, the investigator should consider (1) the assumptions of the potential techniques, (2) the particular objectives of the study, (3) resources available (e.g., personnel and money), and (4) characteristics of the habitat that will be sampled. I have placed the major estimation techniques into 6 general groups (Fig. 1).

The first question the researcher should ask is whether the population is closed; i.e., no immigration, emigration, births, or deaths (Seber 1982). If the population is closed and an absolute density is not needed, then one can use any of several population indexes. If investigators require an estimate of the total number of quail on the area of interest, then they need to consider whether all the quail can be counted on the area. If all can be

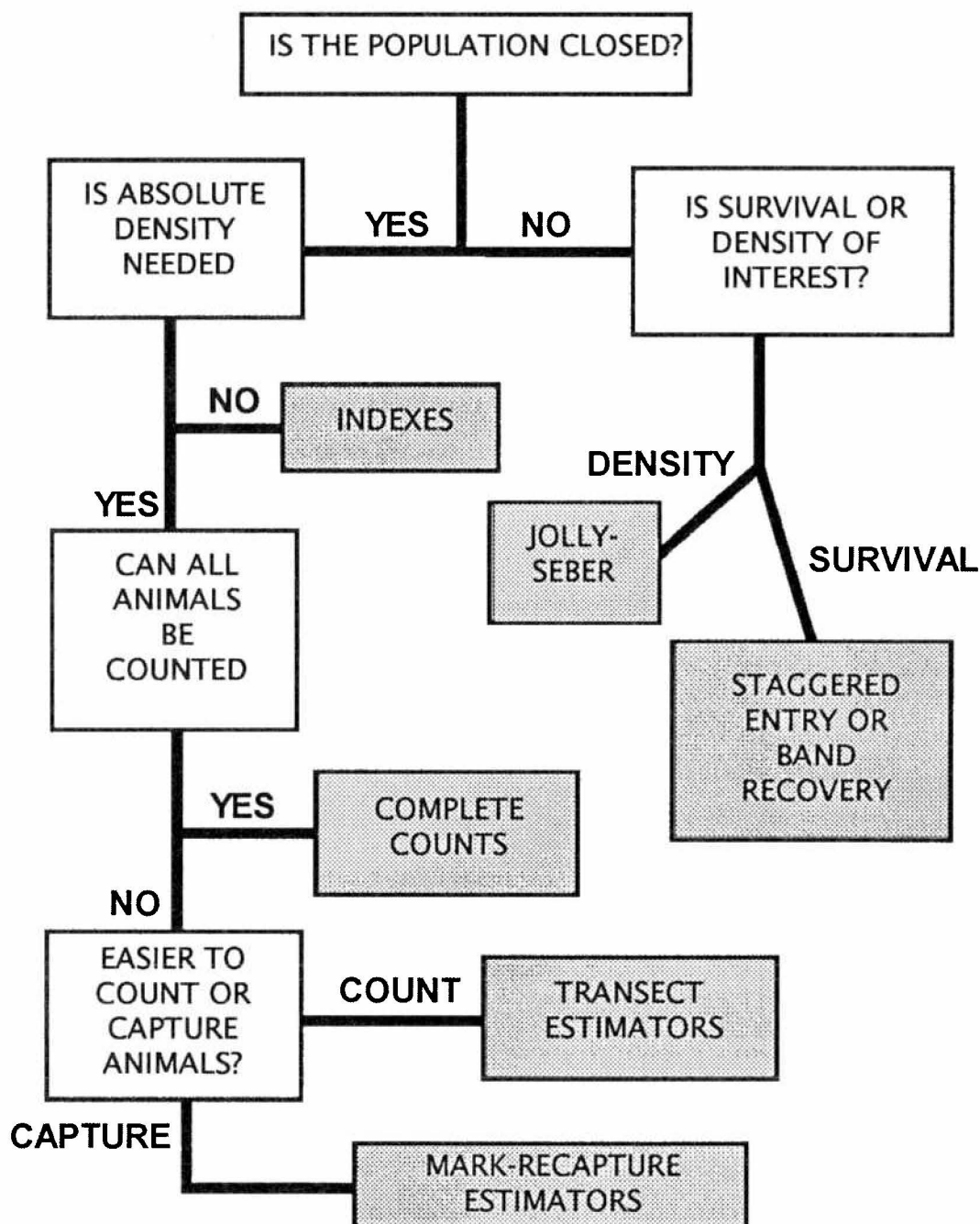


Fig. 1. Decision tree indicating the process of determining the appropriate population estimator for quail that will meet assumptions of the techniques and needs of the investigator.

counted, then a drive count would be appropriate. If all the individuals cannot be counted, they need to consider whether it is easier to capture or observe the quail. If it is easier to observe the quail, a line transect estimator would be indicated; a mark-recapture estimate would be appropriate if it is easier to capture individuals.

Open Population Estimates

If the population is open, the relative importance of population estimates vs. survival estimates needs to be considered. If density estimates are of greatest importance, then some form of a Jolly-Seber estimate would be most appropriate. If survival is of interest, then band-

recovery or a staggered entry approach would be suitable (Fig. 1).

Indexes

When an absolute estimate of density is not necessary, various indexes to population levels may be appropriate. Wells and Sexson (1982) provided an overview of indexes to northern bobwhite (*Colinus virginianus*) density.

They felt that rural mail carrier surveys in October provided the best data for predicting fall harvest parameters. Such surveys can provide data over a relatively large area (e.g., a state). If these data can be standardized in terms of how they are recorded and the conditions under which they are taken, they can be used to track population trends.

Measures of hunter success (e.g., birds shot/gun-hour) have been used to track population trends for northern bobwhite (e.g., Wells and Sexson 1982, Fies et al. 1992) and Montezuma quail (*Cyrtonyx montezumae*; Brown 1979). Such data are relatively easy to acquire by state agencies; however, the quality often is questionable. Because the data source is of variable reliability (hunters) and there is a lack of control over data quality (lack of variance estimates, etc.), I believe it is dangerous to give too much credence to this sort of information. These data do not lend themselves well to statistical analysis, and thus it is difficult to identify real differences between areas or years. At best, I believe we are limited to general statements about population trends from hunter data.

The indexing method that has received the most attention is the use of call or whistle counts. One of the first to use whistle counts was Bennitt (1951), who found that spring and early summer counts of bobwhite provided a reasonable index to fall harvest. Rosene (1957) indicated that call counts provided adequate indications of fall harvest for bobwhite. Smith and Gallizioli (1965) reported that whistle counts of Gambel's quail (*Callipepla gambelii*) correlated well (r values >0.94) with the subsequent fall harvest. However, they noted that spring counts will only work well if hatching success and survival of young is constant from year to year. For scaled quail (*C. squamata*), Brown et al. (1978) found that spring whistle counts were correlated with fall harvest, although weather also was an important factor influencing counts.

Although some researchers have successfully used whistle counts to predict fall harvest, this technique has generated substantial disagree-

ment. Norton et al. (1961) critiqued the use of whistle counts to predict fall populations in bobwhite. They reanalyzed data presented by previous workers and noted: "It must be concluded that the case for usefulness of numbers of whistling cocks in summer to estimate autumn populations is weak and that a better method is needed" (Norton et al. 1961:403). They argued that whistle counts may provide a reasonable index of population densities at a particular time and could be used to monitor trends. However, unless data are available for nesting success, recruitment to the population, and survival, we cannot accurately predict fall harvest. Robel et al. (1969) analyzed call counts for bobwhite in Kansas and developed regressions that adjusted counts for effects of time of year, time of day, and weather. Schwartz (1974) noted the problem of spring counts not accounting for production and found August counts worked better to predict fall numbers in Iowa; he suggested that early summer call counts not be used to estimate fall quail numbers. More recently, in a general review, Dimmick (1992) recommended that call counts not be used to estimate populations of bobwhite. In contrast, Curtis et al. (1989) reported a high correlation ($r = 0.94$) of call counts with fall harvest of northern bobwhite on Fort Bragg, North Carolina. They also reported that call counts were correlated well with total number of quail ($r = 0.89$).

So, are call counts good or poor indicators of populations? It appears that more controlled research, of the nature of Curtis et al. (1989), would be appropriate to help us better understand what exactly call counts indicate. In most cases it probably is risky to use call counts to make predictions concerning potential fall harvest, unless such data are supplemented by information on nesting success and survival. However, I believe that it is reasonable to use call counts to derive indexes to population levels. If acquired under standardized conditions (e.g., time of year and day, no or minimal precipitation and wind, trained observers) and replicated spatially or temporally, I believe that call counts can be used to track trends in population levels over time or to compare *relative* densities between different areas (e.g., Cline 1988). Sauer and Droege (1990) provide an excellent practical and theoretical treatment on estimating populations with indexes. In the absence of another easily applied technique used to census relatively large areas in a short time, I expect call counts to continue to be used in the future.

Complete Counts

Workers trying to determine the number of quail on a relatively small area (i.e., <500 ha) have used drive counts to attempt to completely count all quail. Often, dogs can be used to good effect to help ensure all coveys are located (Bennett and Hendrickson 1938, Loveless 1958, Ellis et al. 1969, Roseberry and Klimstra 1972). Dimmick et al. (1982) used drive counts ("walk census") for bobwhite and noted they are relatively quick and easy to use, although the variance of the population estimate is not known. They found that walk censuses recorded about 50% of the birds that were estimated to be on their area, as determined by a Lincoln-Peterson estimate. Their population estimate from walk censuses was correlated well with the Lincoln-Peterson estimate ($r = 0.96$). More recently, Janvrin et al. (1991), in a controlled study with radio-tagged bobwhite, found that 34% of the time the whole covey was not flushed by walkers. On average, they detected 56% of individuals and 61% of coveys present on the study site at the time of surveys. They recommended that at least 3 counts be taken on an area to derive an adequate estimate and that ≥ 15 counters be used.

Transect Estimators

Population estimates based on observations of animals taken along line transects have been developed since the 1930's (Burnham et al. 1980). Line transect estimators require meeting more assumptions than the previously noted methods, but also result in more rigor in the density estimate. The basic assumptions for transect estimators are: (1) all birds on the transect line are recorded, (2) birds do not move prior to being observed, (3) distances are recorded accurately, (4) flushing observations are independent events, (5) birds are not counted more than once, and (6) the probability of sighting a covey is independent of covey size. Brennan and Block (1986) evaluated the use of line transects on mountain quail (*Oreortyx pictus*) and concluded the technique worked well for breeding populations. Guthery (1988) investigated the use of line transects on rangelands in Texas and concluded the technique worked adequately to estimate northern bobwhite densities and that the assumptions were reasonably well met. However, he did note that a substantial amount of effort was required to acquire enough observations for high precision. Guthery (1988) also noted that line transects are likely to be more appropriate in relatively homogeneous habitats

such as rangelands, opposed to patchy habitats such as croplands.

Shupe et al. (1987) counted bobwhite from a helicopter along transects being used to estimate white-tailed deer (*Odocoileus virginianus*) populations. They concluded this approach would work for relatively large areas. The cost of aerial transects was less than for mark-recapture estimators, but above the cost of conducting drive counts. Guthery and Shupe (1989) found that estimates from line transect and mark-removal estimators were similar and tracked trends in a similar manner. Kuvlesky et al. (1989) evaluated 12 line transect estimators for bobwhite. Their primary conclusion was that these estimators do not work well when populations are relatively low; at least 40 observations (preferably many more) are required for a good estimate (Burnham et al. 1980). Generally, if the assumptions can be met and an adequate number of observations acquired, line transect estimators are likely to work well for population estimation. However, using these techniques will require a greater investment of time and effort than methods to derive indices.

Mark-recapture Estimators

A substantial effort has been devoted to developing population estimators based on analysis of recaptures of marked animals (e.g., Seber 1982, Pollock et al. 1990). Traditionally, mark-recapture estimators have been applied to small mammal populations. These techniques also have been used for quail population estimation. Dimmick (1992) compared Lincoln-Peterson estimates (1 capture period followed by 1 recapture period) to those derived from drive counts, and found that the Lincoln-Peterson estimate tended to be about double the drive count estimate for bobwhite. He believed this estimate provided an unbiased population estimate but, given the unknown level of the true underlying population size, it is difficult to determine exactly how close the estimate was to the true population. In his summary paper, Dimmick (1992) recommended mark-recapture as the preferred method for estimating population levels. The Lincoln estimate also has been used by Shupe et al. (1987) and Guthery and Shupe (1989) and compared well to line transect estimates. O'Brien et al. (1985) compared estimates derived for bobwhite from the Lincoln-Peterson estimate to those from multiple-recapture estimators (Otis et al. 1978). They

concluded that multiple-recapture models probably are not appropriate for bobwhite, primarily because of heterogeneity in capture probabilities, and that the Lincoln-Peterson estimator is approximately unbiased and is the preferred approach. This approach would be most appropriate when different capture approaches are used for 2 samples; for example, using live-trapping for the first capture period, and shooting for the second.

So . . . Which Technique Is Best?

Each of the estimators discussed will work adequately under certain circumstances, if we meet the assumptions and apply the approach correctly. If we simply want to monitor trends or obtain relative abundance estimates, for example to compare different management strategies, an index such as whistle counts should be adequate. I believe these counts, when conducted under standardized conditions, will provide suitable measures of population abundance. These counts, however, are not likely to be adequate for predicting fall harvest unless they are supplemented by additional information such as survival and hatching success. I do not recommend the use of hunter-success data to indicate quail trends. Drive or walk counts, especially if supplemented by dogs, may provide useful indications of the number of quail on a particular area. This approach, however, will require a greater investment of resources for the area covered relative to indexes. Mark-recapture and transect methodologies provide us with the opportunity to more rigorously estimate populations. These techniques require substantial commitment of resources and may not be appropriate for all needs and situations.

More research is needed on methods to index and estimate quail populations. Some questions, such as what a calling male quail actually represents and what the relationship is between an index or population estimator and the true underlying population have not been adequately answered.

Estimating Survival

It is of considerable interest to know what the survival rates are for quail populations. A common approach to estimating population survival is to use age ratios of quail (e.g., Emlen 1940, Marsden and Baskett 1958, Botsford et al. 1988). Such data can be obtained relatively easily from wings provided by hunters or by surveys in the fall. Although the juvenile:adult ratio can be used

to draw inferences concerning survival of young and reproductive success (i.e., a ratio weighted toward juveniles indicates greater reproductive success and/or survival of young birds), such data seldom can be used to validly estimate survival rates. *Only* when there is a stable population (which rarely occurs in quail populations) can juvenile:adult ratios be used to estimate survival. Concerning the use of ratios in this manner, Caughley has stated "These methods tend to provide answers irrelevant to most practical or theoretical problems" (Caughley 1977:105). Thus, although age ratios determined from hunter bags, etc., may provide useful indications of breeding success, they are not appropriate or suitable for estimating survival rates.

Other more suitable approaches for estimating population survival rates are available, but they require effort beyond that needed for age ratios. If one is able to determine population structure at various times, or can follow marked individuals through time, a life-table approach could be taken. Raitt and Genelly (1964) used life tables successfully on California quail (*Callipepla californica*). Pollock et al. (1989a) have demonstrated the use of band recovery data to estimate survival rates for bobwhite populations, using the approach of Brownie et al. (1985). They also have recently presented the "staggered entry" approach (Pollock et al. 1989b). This approach allows the use of radio-tagging data to estimate survival rates and requires at least 20 (preferably more) birds with radios. These approaches are rigorous and generate survival data that can be compared statistically, e.g., between years, sexes, or sites. Quail workers should plan to use marked birds (bands or radios) if they wish to address questions of survival.

RADIO-TAGGING

Radio-tagging represents a relatively new technology in wildlife research. The use of radio-tagging has opened new doors because of the ability to determine the location and status of individuals without having to flush or disturb the birds. White and Garrott (1990) have provided an excellent review of the use of radio-tagging, and anyone seriously using telemetry should refer to this resource. The primary uses of telemetry data are (1) home range analysis (White and Garrott 1990), (2) analysis of habitat use (e.g., Wiseman and Lewis 1981, Cantu and Everett 1982), and (3) analysis of survival and mortality rates (Pollock et al. 1989a, b).

Home Range Analysis

Three basic approaches have been taken in the estimation of home range sizes. The convex polygon home range has been used since the 1940's. This commonly used method simply estimates the home range as that area created by connecting the outermost locations of the individual being studied. Although easily applied, a potential difficulty with this method is that the home range as defined by the convex polygon may contain large areas where no animal observations were made, over-estimating the home range. Jenrich and Turner (1969) proposed the use of the bivariate normal home range. This estimator assumes that observations are distributed in a bivariate normal fashion and provided more statistical rigor than occurred in the convex polygon. However, this approach is valid only when the observations are in fact bivariate normal, a situation that may not often occur.

More recently, Dixon and Chapman (1980) proposed a nonparametric estimator that is based on the harmonic mean of the areal distribution of observations. This approach is attractive because it does not require assumptions about underlying data distributions and it allows the user to define home range contours that represent the intensity of use. This removes the problem of "holes" within the home range. However, this technique is sensitive to the grid scale that is used underlying the observations; thus results may not be directly comparable among studies if different scales are used. White and Garrott (1990) provide details concerning the computation of these and other home range estimators.

The use of radio-tagging data for survival analysis has been addressed above and the application of these data to habitat analysis will be found in the next section.

Telemetry Error and Its Effects

Radio-tagging represents a "high-tech" approach to wildlife research. It is not uncommon for researchers to have committed tens of thousands of dollars to receiving and transmitting equipment. Given this investment in equipment, and the nature of receiving a signal on expensive and apparently accurate equipment from a radio on a quail that may be several km away, we at times may be too trusting of the data we collect. Unless the investigator is homing (i.e., actually visually locating) on the individual being tracked, the bearings taken on transmitters are subject to error. Some factors that may influence the accuracy of the bearing are (1) signal bounce

as a function of terrain or vegetation, (2) animal movement, (3) weather, (4) equipment failure, and (5) user error.

The traditional approach to accounting for error in telemetry studies is to acquire a number of bearings on transmitters of known location after which standard deviation of these bearings is calculated. The error of all observations is assumed to be normally distributed, and the derived standard deviation is applied to all azimuths obtained. Thus, the intersection of 2 or more azimuths on an individual is calculated as a point, and the error assumed for the azimuths is used to calculate a polygon around the point that represents the uncertainty in the location. The size and shape of the error polygon is a function of the average telemetry error, the distance between the azimuth intersection and receiving point, and the angle of intersection.

Because error associated with an observation is likely to be different for each observation, it is not reasonable to assume a uniform error across all azimuths. Lenth (1981) presented an approach to estimating an error ellipse around each set of azimuths for 1 particular observation. This technique allows determination of the extent of error associated for each observation, and can incorporate factors that may have influenced accuracy at the particular time the observation was taken. When possible, investigators should use the approach of Lenth (1981) to determine error associated with their telemetry observations.

Even though an investigator may indicate that error polygons have been calculated, we seldom know the effect of the error on interpretation of home range or habitat use patterns. In a study on red-shouldered hawks (*Buteo lineatus*), Senchak (1991) found that, when taking 3 simultaneous azimuths (with 3 observers) on a hawk, confidence ellipses ranged from 0.06 to 1600 ha; the average 95% error ellipse ranged from 29 to 213 ha for 5 different hawks. Clearly, if we were to draw conclusions concerning home range size, or habitat affinity, we might not be able to do so with great confidence. I would expect a similar range of error for telemetry observations in typical quail habitat. Such error would be especially disturbing if habitat use is being assessed. For example, if error polygons or ellipses were 10-15 ha in size, and habitat patches were <10 ha, we could not make any solid statements concerning habitat use, because we could not be confident about which habitats were being used. Thus, I believe that we need to be cautious in interpreting telemetry data when triangulation is used. When

possible, it is preferable that the investigators home in on the birds (coveys).

In addition to the effect of triangulation error, we need to consider potential effects of actual telemetry equipment on the animals we are studying or our interpretation of data. Sometimes the attachment of transmitting equipment may increase mortality or affect behavior of the animal (e.g., Small and Rusch 1985, Marks and Marks 1987). Thus, it is important to design transmitter packages that minimize behavioral effects. It is also important to retain consistency in equipment used. Burger et al. (1991) reported that the use of 2 different transmitter types on greater prairie-chickens (*Tympanuchus cupido*) resulted in estimates of greater daily movements, within-day movements, and seasonal ranges for the birds with the more powerful transmitters. Their results suggest it would be risky to change transmitter types within a study and that data on movements, survival, or home ranges may not be comparable between studies that use different equipment.

HABITAT EVALUATION

Throughout the history of quail management and research, emphasis has been placed upon habitat. The general nature of habitat analysis and assessment was qualitative for a relatively long time, and is reflected in the literature reporting habitat relationships (e.g., Stoddard 1931, Rosene 1969). In the late 1960's and through the 1970's the emphasis in habitat analysis shifted from qualitative, descriptive approaches to more rigorous, statistically oriented methods. Because of the numerous facets of habitat measurements, multivariate statistics received a considerable amount of attention at this time (e.g., Capen 1981). This trend was general throughout ecological fields, and was evident for quail also. For example, Stormer (1984) used radio-tagging and discriminant function analyses to analyze roost sites of scaled quail, and Brennan et al. (1986) developed multivariate models of habitat use by California quail. I address 2 aspects of habitat analysis: habitat preference assessment and habitat quality assessment (i.e., modeling).

Habitat Preference Assessment

Effective habitat management is predicated upon a knowledge of which particular habitat or cover types are of greatest importance to the quail species being managed. It also is important to know the specific habitat conditions within each type that are preferred, along with the proper

juxtaposition and interspersed of habitat components. Accordingly, it is critical to be able to determine accurately the preference of quail for particular habitat components (disproportionate use of a habitat component, relative to its availability). It is critical to have data on habitat availability for comparison to use; without such information, little can be said concerning preference or avoidance.

Thomas and Taylor (1990) provide an outstanding overview of approaches to determining habitat preference. They identified 3 basic designs of habitat preference studies. In the first design, availability of resources (= habitats) and relative use is estimated for all animals studied; there is no separation of individuals. Such data might arise from a situation where use is estimated from drive counts or observations along road transects, and habitat is estimated from aerial photographs for the whole study area. Design 2 represents the situation when use has been determined for individual animals and availability is estimated for the whole study area. This would arise, for example, when use is determined from telemetry locations for individuals, but habitat availability is estimated for the whole study area. For the third design both use and availability are estimated for each individual being studied. Such conditions might occur when individual home ranges are determined for a covey and availability determined within each home range and compared to the covey locations within the home range.

Use and availability data recorded for any design can be continuous or categorical. For example, continuous variables such as canopy cover of various habitat components or tree and shrub density might be compared at sites used within the study area (or home range) and compared to the same measurements for random sites using either univariate or multivariate statistics (Capen 1981). Presumably, significant differences between use and available site reflects preference on the part of the quail.

Data on the number of observations within particular habitat classifications may be analyzed in a variety of ways. When the relative proportions of habitat availability are known exactly and use is estimated, the approach of Beyers et al. (1984), would be appropriate. When both availability and use are estimated, the approach of Marcum and Loftsgaarden (1980) is preferred. These approaches would work for all 3 study designs noted above. For designs 2 and 3, the approach of Johnson (1980), which uses ranks of

relative use and availability, would be appropriate. Relative merits of these and other approaches have been reviewed by Alldredge and Ratti (1986).

A common tendency when conducting habitat preference analysis, especially when using radio-tagging data, is to combine all use observations (i.e., a design 1 situation). Doing so assumes that each individual studied responds to the habitat in the same way as every other individual. Unless this can be shown (e.g., by a nonsignificant chi-square among birds) there is no justification for pooling birds. I encourage investigators to analyze habitat preference for each individual bird whenever possible. Information such as "*Ten of the 15 birds radio-tagged preferred fallow fields*" is much more informative than saying "*for all birds combined fallow fields were preferred.*"

Habitat Quality Assessment

Once useful information on habitat preferences and requirements for quail at a variety of scales (e.g., landscape level, home range level, and within home range selection) is available, we can evaluate the quality of a parcel of land and determine management needs. Hanson and Miller (1961:75) stated, "The work of game managers would be aided if they could readily identify some attribute of cover that permits rapid estimation of carrying capacity for bobwhite." In other words, they called for the use of habitat evaluation models. Many managers may question the need for using habitat models. Through experience in the field, they may have developed a very good "feel" for the needs of the species they are managing and can assess the quality of habitat on an area without use of formal models. In such a case, a relatively qualitative, mental model is being applied. However, it is not likely that 1 person's mental model is the same as another's. Thus, different people probably would evaluate the same area differently. Using formally developed, more rigorous models, allows standardization and consistency in evaluating habitat. Models also can enhance our understanding of wildlife-habitat relationships and may indicate areas where more work is needed. Additionally, using models allows the simulation and prediction of expected effects of different management strategies on quail populations.

Models of quail-habitat relationships may take a variety of forms. Several modeling approaches and their application have been presented in the symposium proceedings edited by Verner et al. (1986). Brennan et al. (1986) used several statis-

tical approaches to developing habitat assessment models for mountain quail. Schroeder (1985) developed a Habitat Suitability Index (HSI) model for the northern bobwhite. This approach represents a synthesis of all available information into a structure that allows systematic evaluation of a habitat parcel. A modification of this model is being used in conjunction with other HSI models by the U.S. Fish and Wildlife Service to assess effects of the Conservation Reserve Program (CRP) on wildlife habitat. Stauffer et al. (1990) used regression models developed for northern bobwhite to evaluate potential effects of farmland conversion to CRP lands under a variety of scenarios for Virginia. These methods are not used as much as they might be, and it would be useful to develop and apply more models for other quail species in the various regions where they occur.

Habitat models are viewed by some with skepticism. This often is a result of a lack of understanding of the purpose for which models have been developed. A model is not likely to explain *all* the habitat-use patterns seen in a quail population; rather, it is an attempt to summarize the salient aspects of the habitat ecology of an animal, with the intent to provide the greatest amount of information with the fewest variables. Users must be aware of the assumptions and proper application of models prior to their use; if assumptions and range of application for a model are not explicit, the model is likely to be of little use. A common assumption associated with habitat models is that higher quality habitats will have higher population levels. This has been addressed by Van Horne (1983), who pointed out that for some species in some situations this relationship might not hold. She noted that we also should use information on survival and fecundity when evaluating habitat. However, such information is often much more difficult to obtain than some index of density.

Perhaps one of the greatest hindrances to increased use and application of models is the tendency for managers and researchers to move in different realms. Bunnell (1989) has presented a cogent discussion of habitat models and the contrast between managers, who he called "alchemists," and researchers, who were designated "cerebral anarchists." Often communication between these 2 camps is not as strong as it should be. Managers are faced with immediate challenges, must manage populations and habitats, and will do so with the tools at hand. Researchers, however, tend to desire more time for study and

data collection and, once the data have been analyzed, may not provide their results in a form suitable for use by managers. For example, a researcher might develop a detailed discriminant analysis or logistic regression model to predict the probability that an area is suitable for quail, but the model might require data of such detail or difficulty to sample that a manager will not use it. Although we may have learned more about how the animal responds to its habitat, we have not gained in our ability to manage it. In such a case, it might be more suitable to construct a model such as a HSI with fewer, more easily measured variables, that will allow relatively rapid assessment of habitat quality. I believe that greater effort needs to be made to draw researchers and managers closer together. Researchers need to make a greater effort to provide results that are directly applicable by those charged with managing our quail resources. At the same time, managers need to work with researchers to let them know their needs and to better understand the intricacies and limitations of research.

METHODOLOGICAL THOUGHTS ON STUDY DESIGN

Recently, substantial thought has been given to the means by which we as wildlife managers and researchers gain knowledge (e.g., Romesburg 1981, 1991, Murphy and Noon 1991, Sinclair 1991). In the field of wildlife science, we could do a considerably better job in design and analysis of our studies. Research dollars are relatively scarce and we need to put forth the best possible effort with the resources available to us. Romesburg (1981) emphasized the need for more rigor in design and execution of wildlife studies and he championed the use of the hypothetico-deductive method to gain reliable knowledge. Although we cannot always meet his suggestions, we should strive to have clearly stated objectives for studies; too often, even now, studies are undertaken with unclear goals that result in expenditure of time and money with little return.

Hurlbert (1984) helped sensitize researchers to the need for true treatment replicates when conducting studies. Without replication of treatments, it is difficult if not impossible, to make unequivocal statements concerning treatment effects. For example, Cantu and Everett (1982) studied effects of grazing practices on northern bobwhite. They studied 4 pastures, each composed of different habitat (open pasture, dense brush, patchy planted habitat, and open savannah) and each with a different grazing intensity.

Because of the lack of replication, no statement can be made concerning grazing effects; any effect noted could just as easily be attributed to site differences associated with habitat. No degree of subsampling within a site can compensate for the lack of treatment replication. More information would be gained from taking only 2 or 3 samples from each of 5 treated and 5 untreated sites than by taking 20 samples each from 1 treated and 1 untreated site. Even if there is no replication, it may be possible to draw some inferences; however, in such cases the investigator needs to acknowledge the tentative nature of the results (e.g., Webb and Guthery 1982).

The use of statistical procedures has become a necessary evil in quail management and research. Although it may at times seem we are simply seeking "statistical sanctification" for results, the appropriate use of statistics in study design and analysis can enhance our understanding of the processes we study. Hanson and Miller (1961:75) stated, "It is becoming a truism that statisticians may prove more helpful before research begins than afterwards." It is critical that researchers and managers have an understanding of basic statistical concepts, or consult with biometricians or statisticians, prior to undertaking research. No amount of statistical data massage can compensate for poor study design. The use of studies that are replicated and stratified should be emphasized. This is not necessarily a new idea; Kozicky et al. (1956) presented an elegant design for stratified sampling of quail for Iowa.

Traditionally, we have relied on parametric statistics (e.g., *t*-tests and *F*-tests) for analyses that make an assumption of a normal data distribution. Seldom, however, do our data actually meet the assumptions of normality. It is important to be aware of the assumptions of the techniques we use, whether for population estimation, radio-tagging, modeling, or statistical analysis. If we do not meet assumptions, then our results may be suspect. Concerning statistical analysis, the assumption of normality may be met by transforming data in some cases. Other alternatives include the use of nonparametric statistics such as Kruskal-Wallis or Wilcoxon Rank Sum tests. More recently, a new family of procedures, based on permutations of the actual data have been developed (Biondini et al. 1988). These techniques make no assumptions concerning underlying data distributions, and I encourage investigators to use such techniques when possible.

One last statistical concept I wish to address is power, which is the probability of detecting a

difference (i.e., reject the null hypothesis) when in fact a difference exists. The concept of power has been known as long as has the idea of Type I error, or alpha, but it has only recently gained much attention (e.g., Toft and Shea 1983). We often work with relatively small sample sizes and may, as a result, fail to detect significance in a test; at such times, it is useful to be aware of what our ability was to in fact detect a difference. For example, in a recent paper, Janvrin et al. (1991) reported that detection rates of radio-tagged northern bobwhite in a study on drive counts did not differ among field seasons ($X^2 = 9.71$, 3 df, $P = 0.08$) and data were pooled for further analysis. However, the power of this particular Chi-square test was approximately 15% (from tables in Cohen 1988). Thus, in this case, with only 15% probability of detecting a difference, and with a significance level of 0.08, one might infer that in fact there was a difference among seasons and decide not to pool. (By using this example I in no way mean to detract from the very solid data and useful conclusions presented in this paper; this is solely for illustration.) Cohen (1988) presents approaches for determining power for most common statistical tests. I believe it would benefit us all if we considered the power of our statistical tests along with the significance level when interpreting results, particularly when small sample sizes are involved.

CONCLUSIONS

So, where are we in terms of quail methodology, and where do we need to be? We have available to us a variety of methods for estimating population levels and trends. I believe more effort should be directed to developing statistically sound (e.g., Kozicky et al. 1956) approaches to indexing quail populations across space and time, probably with some form of call-count surveys. Such information should allow us to better track population trends. General data such as that gained from hunter surveys and wings should be treated with caution. When the situation requires more rigorous population estimation, transect and mark-recapture approaches should suffice if the assumptions can be met.

Radio-tagging will continue to be an important tool in our study of quail populations. However, we need to improve our awareness of the assumptions concerning use of this and other methods, and especially to be cautious when triangulation error may affect our results. In many instances, we can do a better study design and should address the need for replication of treatments and a

more rigorous treatment of data. Especially, the assumptions of the techniques being used must be understood and met; otherwise much effort may be expended with little return. In many instances, we should be using nonparametric or permutation-based statistics rather than parametric statistics based upon normal theory. When feasible, we also should determine the power of statistical procedures that are conducted and use this information in our data interpretation.

A gap between researchers (at agencies and universities) and managers (in the field) still exists. If progress is to be made in determining approaches to assessing needs and addressing problems concerning quail, this gap needs to be bridged. It is of utmost importance that we establish a better working relationship and better communication between these 2 groups.

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