DESIGN AND ACCURACY CONSIDERATIONS FOR WILDLIFE TELEMETRY STUDIES: SOME EXAMPLES FROM UNGULATES

ERIC R. LOFT, Wildlife Management Division, California Department of Fish and Game, 1416 Ninth St., Sacramento, CA 95814

CHARLES J. EVANS, U. S. Forest Service, Pacific Southwest Forest and Range Experiment Station, 2081 E. Sierra Ave., Fresno, CA 93710

KIM E. RAGOTZKIE, U. S. Forest Service, Pacific Southwest Forest and Range Experiment Station, 2081 E. Sierra Ave., Fresno, CA 93710

JOHN G. KIE, U. S. Forest Service, Pacific Southwest Forest and Range Experiment Station, 2081 E. Sierra Ave., Fresno, CA 93710

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Radio telemetry is commonly used to study movements, activity, and spatial and temporal patterns of wildlife species. Successful completion and validity of wildlife telemetry studies depends upon a clearly-thought-out study design and upon equipment capable of providing the accuracy necessary to meet study objectives. The high monetary and labor costs of telemetry equipment, capture efforts, and monitoring of telemetered animals justifies the need for a carefully planned and executed study.

In this paper, we presented considerations and guidelines we have found useful in designing and conducting telemetry studies of mule deer (*Odocoileus hemionus*) to determine migration patterns, home ranges, habitat use, and activity patterns. Many of these ideas were based on the literature and trial-and-error. Such considerations and guidelines have application to other wildlife species as well.

DEVELOPING A STUDY PLAN

Wildlife telemetry studies are initiated to increase understanding of animal behavior patterns, or in response to a perceived problem related to management. The first step is to identify the problems to be studied and objectives to be met. Meetings with experts on the species of interest and the peer review process can elicit valuable suggestions for conducting a study. Awareness of unforeseen logistical complications related to telemetry may also be brought up by individuals who have conducted work similar to that planned. In discussing the design of telemetry studies, we followed a structured format for each of four study objectives: (a) determine migration routes and seasonal ranges; (b) determine home range area; (c) determine habitat use; and (d) monitor activity patterns.

Defining migration routes, holding areas, and seasonal ranges of deer has perhaps been the most common use of telemetry by state wildlife agencies. Such information serves as a foundation for managing deer and their habitats. Ecological studies of telemetered animals use estimates of annual and/or seasonal home range areas to provide information on behavior, spatial relationships, and energetics. Habitat use and selection studies are more intensive examinations of animal distribution within the home range in relation to available habitats and can provide information on relative preference and habitat requirements. Activity monitoring of animals having tip-switches encased in their transmitters is a more recent use of wildlife telemetry and differs from the other objectives in that knowledge of the animals location is not required as long as the animal remains within range of the receiving equipment.

STUDY AREA CHARACTERISTICS

Telemetry study areas can generally be categorized as 1) areas small enough that study animals can be completely monitored with receiving equipment from at least two of several ground locations for triangulation, or 2) areas so large that no two monitoring sites can reliably receive signals from the entire area.

Study areas may range in size from the discrete fields of small mammal studies (Ostfeld 1986), to well-defined watersheds with excellent line-of-sight distances (Loft and Kie 1988), to entire geographic regions (Major and Sherburne 1987). The larger the study area, the greater the likelihood that it will encompass areas where logistics of monitoring will be hindered by inconvenient access or topography. Consideration should be given to the accessibility of a potential study area by vehicle or on foot. Study animals inhabiting areas where access is possible only on foot are likely to be monitored less frequently, and at a comparatively greater effort, than study animals that can be monitored from roads.

Topography influences the working distances and reliability of signal reception in study areas comprised of steep canyons or ridges by creating signal error such as reflection, refraction, diffraction, interference, and polarization (Kenward 1988) or by weakening signals (White 1985). Hence, if telemetered animals inhabit a large study area of varying topography, it may not be possible to monitor them simultaneously. Tall vegetation has also been known to affect signal reliability (Biggins and Pitcher 1978, Hupp and Ratti 1983) and may reduce one's confidence in signals simply because of the visual obstruction (Loft, pers. observ.).

Vegetation communities in a study area can range from dense forest to open grassland and need to be delineated for habitat use studies. Area of each habitat available in the home range, or study area, must be calculated to estimate selection of habitats.

MONITORING TECHNIQUES

There are three general techniques we considered for monitoring telemetered wildlife: 1) aerial monitoring, 2) ground monitoring from temporary sites either vehicle-mounted or on foot, and 3) ground monitoring from permanent sites. Aerial monitoring is frequently used to track migrations in roadless areas and to obtain locations for estimating home range, particularly for species that range over a large area such as migratory deer or mountain lions (*Felis concolor*) (Krausman et al. 1984, Neal et al. 1987). Mobile tracking systems using vehicle-mounted antennas (Kufeld et al. 1987) can be used to achieve all four of our selected study objectives if road access is good. Ground monitoring using temporary hand-held receiving equipment is the easiest and least expensive method for assessing migration, home range, and habitat use patterns, however some accuracy is lost compared to vehicle-mounted or permanent receiving systems (Hupp and Ratti 1983).

Permanent receiving sites work well for all but migration studies, provided study animals do not travel beyond the range of the receiving equipment during the study period. Permanent antenna sites are most feasible where they can be placed at prominent locations in the study area and when study animals can be completely monitored from any receiving site in the study area. In large study areas, it may be desirable to establish permanent antenna base sites at several locations, such as along road networks, and transport antennas to the receiving sites that will be used for triangulation during any given sampling period. Antennas should be regularly inspected for damage and for orientation to fixed beacons to assure accurate readings.

SAMPLING STRATEGY

The number of animals needed to reliably estimate behavioral patterns partially depends on how much variation among individuals there is within the population. As an extreme, if all the animals of a species acted identically, a sample size of one would suffice. Deer studies in California typically radio-collar 20 animals as a goal, realizing that some will be lost early to mortality, or will not remain within the study area. Preliminary data analyses can help evaluate whether the sample size will be sufficient to achieve desired objectives.

There are a number of considerations to think about in developing a sampling scheme for collecting animal location data. The goal in sampling is to provide an accurate estimate of animal movements, habitat use, or activity without having to monitor animals continuously. A sampling design which is representative of the entire 24-hour cycle is the only way to completely represent daily movement, activity, and habitat use patterns (Biggins and Pitcher 1978, Smith et al. 1981). A replicable strategy of monitoring animal locations, such as random or systematic sampling, is preferred over arbitrary methods (Hegdal and Colvin 1987). Random sampling however, can be difficult because successive sampling periods may be scheduled at short or long time intervals, resulting in either demanding or inefficient work loads on personnel, respectively. Consistency in the collection of data is imperative for making comparisons among animals, seasons, or years.

Determining the sample size necessary to estimate home range area of an animal is no trivial problem and has received considerable attention in the literature (Bekoff and Mech 1984). Bekoff and Mech (1984) suggest 100-200 locations to estimate the home range using the minimum convex polygon method. Methods for determining home range sizes provide more accurate results as sample size increases (Dixon and Chapman 1980, Anderson 1982).

Perhaps more important than number of observations is the time frame and sampling frequency over which the observations are collected (Swihart and Slade 1985*a*). Generally, at least 50 locations that are representative of a seasonal or annual home range and the 24-hour day are recommended. Home range data sets often include outliers. Schoener (1981) recommended eliminating a percentage, such as 5%, of the outermost locations of the home range. We would modify that to eliminating the 5% of locations which enlarge home range area the most, to produce a 95% area (Loft 1988, Ackerman et al. 1989). Of course, some subjective evaluation and interpretation will be required to decide whether outliers are of ecological significance or if they can be deleted with minimal loss of information.

The minimum number of data points necessary

since animals such as deer (Anthony and Smith 1977, Georgii 1980, Loft 1988) are known to exhibit significant habitat preferences.

Telemetry studies can include comparisons of individuals home ranges, habitat use, and activity when subjected to different manipulative treatments or environments (Loft 1988), or include study of intra- and interspecific relationships (Ostfeld 1986, Major and Sherburne 1987). To minimize potential variability, it is important to simultaneously monitor study animals that are subject to differing treatments, more so for habitat use and activity studies than for home range studies. This will help ensure that observed movements or habitat use activities are attributable to the factor of concern and are not due to differences associated with non-simultaneous monitoring such as weather.

Time differences between monitoring one animal, then monitoring another in interspecific or comparative studies may range from a few minutes to several hours depending on the species. For deer and cattle, we used time intervals < 30 min to evaluate interspecific interactions (Loft et al. submitted). Minta (pers. commun.) used data which had time intervals between observations of one badger and then another, that were up to 24 hrs apart because of the badgers reliance on olfactory senses and long-lasting scent marking to establish intraspecific relationships.

For activity studies, it is desirable to know where an animal engages in specific activities, as well as know what it is doing during any given time period (Samuel and Garton 1987). Feeding, resting, and traveling behavior are obtainable from activity sensors (Kie et al. unpubl. data). Monitoring habitat use simultaneously with activity provides more valuable information than either objective alone. Behavioral studies correlate activity and habitat use to determine such things as feeding, breeding or nesting territories.

ACCURACY CONSIDERATIONS

Assessing the accuracy of telemetry equipment is a study in itself (Lee et al. 1985, White and Garrott 1986), and is particularly important in habitat use studies. Accuracy determinations should also be made for home range studies, but are rarely conducted for migration studies because of the comparatively low resolution needed, and the transient nature of migratory animals in any one area. Equipment accuracy from the air should be assessed to determine the most desirable height above-ground for monitoring (Mech 1983, Krausman et al. 1984).

Distance, signal error and bias contribute to the size of error polygons (Heezen and Tester 1967, Biggins and Pitcher 1978, Springer 1979, Lee et al. 1985), which in turn, influence the attainable level of habitat resolution. To accurately place an animal in a given habitat, error polygons must be smaller than the habitat polygons. Ideally, size of error polygons relative to habitat polygons should be determined as early in the study as possible. This can allow modification of habitat classification (fewer and/or larger habitat polygons), or improvement of telemetry accuracy (better vantage points or additional receiving sites), if error polygons are larger than habitat polygons.

Several wildlife tracking systems have been evaluated for accuracy (Hupp and Ratti 1983, Pace 1988). To illustrate the potential differences in accuracy between methods used to gather telemetry information, we compared triangulation data from two studies. McCormick Creek Basin at 2,200-2,700 m elevation in the Sierra Nevada has topographic relief that is roughly analogous to a bathtub. Volcanic cliffs surround much of the study area, providing excellent line-of-sight capabilities. Blodgett Forest at 1,190-1,460 m elevation in the Sierra Nevada has undulating terrain dissected by drainages and is primarily conifer forest habitat.

At McCormick Creek we used permanent, 4-m tall direction finding antenna systems in a well-defined study area. At Blodgett Forest, we used temporary, hand-held, two-element yagi antennas in a well-defined study area with poor line-of-sight distances resulting from topography and dense conifer forest cover. Both studies used two monitoring sites for triangulation.

Mean error arcs at McCormick Creek were 2.18-3.45 degrees. Error arcs at Blodgett Forest were about 14 degrees. This resulted in smaller error polygons at McCormick Creek and confirmed that the monitoring design there was more accurate than the design at Blodgett Forest (Table 1). The size of error polygons are smallest for any given distance when the angle of intersection is 90 degrees (Heezen and Tester 1967, Springer 1979). Temporary, movable receiving sites were used at Blodgett, so we were able to get a higher proportion of locations that had an angle of intersection that was close to the desired 90 degrees than at McCormick Creek. Also, distance from receiving sites to transmitters was shorter, but these factors were not able to overcome the lower accuracy of the hand-held method.

Frequency histograms of the size of error polygons in relation to the size of habitat polygons indicated that a greater proportion of error polygons at McCormick Creek were smaller than habitat polygons compared to Blodgett Forest (Fig. 2). All habitat polygons were larger than the mean error polygon at McCormick Creek. At Blodgett Forest, small habitat polygons were initially defined that ultimately were smaller than the mean error polygon.