Spatial Tracking 14

A. Radio Tracking

Sean S. Walls
Biotrack, 52 Furzebrook Road, Wareham, Dorset BH20 5AX, United Kingdom

Robert E. Kenward
Centre for Ecology and Hydrology, Winfrith Technology Center, Dorchester
Dorset DT2 8ZD, United Kingdom

Radio-tracking has proved to be an essential tool for raptor studies. This is because it can record individual behavior systematically, not just at the nest or on a particular wintering area, but throughout the year. Radio-tracking can provide geo-specific data on foraging, roosting, and interactions with conspecifics or different species with little of the bias associated with observer location in other types of studies. Records of all tagged individuals, not merely those found at nests or dead, can be used to gain relatively unbiased estimates of breeding rates, survival and the proportionality of mortality agents. Radio-tracking often is the only way to reveal timing, routes and destinations of long-distance dispersal and migration. Such data can be crucial for assessing the impact of change in land use, checking the success of release programs, quantifying the effects of raptors on game, and investigating many other things of interest in wildlife management. Finally, radio-tracking is often the most practical method of getting data on experimental treatments and to parameterize biological models.

Most radio-tracking of raptors, which started about 40 years ago (Southern 1964), has been based on VHF (Very High Frequency) equipment. The last 20 years, however, have seen the maturing of Ultra High Frequency (UHF) technology that uses satellites, either to track tags directly or through Global Positioning Systems (GPS). Such systems can substitute for or complement VHF tracking.

VHF tags cost about $200 (U.S.), can be small (a 2.5-g tag can transmit for four months, and a 20-g tag can last 2 to 3 years) and can be located accurately (typically to within 10–100 m) by manual tracking from distances of 100 to 5000 m. UHF tags for tracking by satellite cost more than $1,000, and require additional payments for each location (typically $12–24 per day). The automated tracking saves labor costs, but there is relatively low accuracy for non-GPS units (e.g., 200–2000 m) and only about 60 transmission days for the smallest, 15-g tags. With intermittent transmission, these tags are uniquely suited for providing information on migration routes. GPS tags have the advantages of both automatic data collection and high accuracy (e.g., 10 m). Until recently, lightweight GPS tags were short-lived and had to be retrieved for downloading locations, but now a combination of solar-powered GPS units and a satellite link has created 30-g tags that supply accurate locations for longer periods, depending on the frequency of positions. That said VHF tracking remains the most successful technique for detailed tracking of small to medium-sized raptors in a local area over a long period.

Equipment, field methods and analysis techniques have been extensively reviewed (Kenward 2001, Millspaugh and Marzluff 2001, Fuller et al. 2005). Here we assume that there is a precise biological question to answer, that one or more of the references above will be consulted, and that experienced radio-trackers will be contacted for help with field techniques. We therefore concentrate on general-planning guidance.

PLANNING

The planning needed to ensure adequately tagged animals and useful data is detailed in White and Garrott (1990) and subsequent reviews. One additional planning consideration is the scope for collecting ancillary information. For example, when collecting locations to estimate home ranges and habitat use, information also can be collected on activity patterns and interactions. If tags are used to monitor whether individuals breed or die, it also is possible to test whether birds that were more active or had larger home ranges or foraged in particular areas were more likely to die or have reduced fecundity. Such a holistic approach leads to understanding of the mechanisms underlying population processes. To maximize the value from an investment in radio-tagging, it is worth considering from the outset what ancillary questions might be investigated.

Movements

The most important point to remember when collecting radio-tracking data is that the number of individuals tracked is a far more important component of sample size than is the number of locations. Simply put, it is better to get adequate samples of locations from many individuals than to get excessive detail on too few individuals. Unless standardized data-collection protocols from previous studies are available, pilot work is needed to assess how often to record locations and check whether individuals have emigrated or died.

If range areas or habitat use is required, is it for an annual or seasonal estimate or a series of snap-shots? If the former, locations should be recorded one or two times a week, at different times of day to avoid timetabling bias. If the latter, analysis of autocorrelation can help to decide how often locations can be recorded without spatio-temporal redundancy. In all cases, incremental analysis helps to decide how many locations make a practical standard range (Kenward 2001). If great detail is required from range outlines and cores, then more locations will be needed (Robertson et al. 1998). After a pilot study to establish standards, locations collected at the same rate over the same period enable robust tests for differences among individuals, populations, sites or seasons.

Studies of static interactions between individuals are based on overlap of home range cores or other territory estimators. Studies of dynamic interactions are more appropriate for finding if related individuals or individuals from a communal roost tend to aggregate. Such analyses require standardized recording of locations from different individuals in rapid succession, with careful planning so that no data are missing (Kenward 2001).

Radio-tracking has revolutionized the study of dispersal, by showing when, how and in what social or environmental contexts individuals make long distance movements beyond a study area. It is wise to check the locations of individuals often at the start of a project on dispersal to establish when they leave. This can be time-consuming, however tracking can be less frequent after pilot work has established the main dispersal periods. Subsequent reduced tracking for each individual allows more birds to be tracked in the same period, with intensive fieldwork restricted to short dispersal periods. When searching for dispersed raptors, the tracker needs to find topographical high-points and to have conviction in following faint signals, even when they are undetectable for 20 km or more after leaving a hilltop. Ground-based searches are easiest if a vehicle can be fitted with a pneumatic mast to raise an antenna 5–10 m, but the most cost-effective searching for birds lost during dispersal may involve mounting antennas onto aircraft wing-struts and conducting aerial surveys.

Survival, Forensics and Breeding

Researchers need not search often to estimate the survival and breeding rates of large, sedentary raptors whose tags will last for several years. Three checks per year, one each during winter, incubation, and rearing, are sufficient. Pre-breeders need more frequent checks to minimize losses during dispersal periods. More frequent checks also are needed to study causes of death, as carcasses can decompose quickly and be scavenged. That said infrequent checks may enable division of deaths into those (a) caused by humans (e.g., using sensitive analyses for poisons and X-rays for traces of lead in bones) (Cooper 1978), (b) associated with human artefacts (e.g., elevated wires, roads, wells, etc.), or (c) due to natural causes. Mortality sensors can speed checking, especially if all tags can be detected from topographical high points, so that only those indicating a death need to be found. When monitoring reintroductions or rehabilitated birds, checks can highlight solvable problems. In such instances, the more frequent the checks, the quicker the remedial action and the higher the likelihood of success.

In all cases, it is imperative to find all birds possible on each survey. Not doing so risks over-estimating shorter movements, as well as survival if birds are lost because their death has produced an undetectable signal. Survival data will be most robust if tags and searching are highly reliable, and if visual or other markers are used for re-sighting checks on the fate of birds with lost signals, to provide a correction for bias.

Analysis

Data analysis should be planned at the start of a study, and suitable software then used in pilot work to optimize data collection (see Planning). Software not only should display data but also should make it quick and easy to repeat analyses on many animals. The software ought to (1) provide all analyses needed, (2) handle the volume of data required (which may be large for GPS tags), and (3) input data and export results of analyses easily. It also should have adequate user-support, including integral or e-mail help. Good software is updated regularly, and it is worth keeping in touch with manufacturers to monitor developments (Larson 2001). Software defines the most efficient way in which to record data, which can help avoid too much re-processing from notebooks or palm-top computers.

Incremental analysis is essential for planning home-range studies, and autocorrelation analysis is a convenience for snapshot estimates (see Movements). These help in the efficient collection of locations from many individuals and in avoiding redundant and pseudo-replicated data from too few birds to enable robust statistical tests. Density-based home-range estimators such as ellipses and, to a lesser extent, contours, require the least locations, but their smoothing can be less suitable for species inhabiting coarse-grained (e.g., blocky or managed environments) than are linkage-based estimators such as mononuclear and cluster polygons (Kenward 2001). Once there are standard ranges from many birds, it is possible to quantify habitat association by comparing where birds were found with what is available to them. Availability should be individual-based (home range outlines or within a circle around a center of activity) rather than map-based, because map limits are set arbitrarily. Those interested in habitat analysis should investigate both compositional analysis (Aebischer et al. 1993) and distance-based analysis (Conner et al. 2003). For survival analyses, software needs to handle staggered-entry, censored exit, and the inclusion of covariates such as age, sex and habitat (see, for example, White and Garrott 1990 and references in Millspaugh and Marzluff 2001).

EQUIPMENT

Radio-tracking equipment should be specified carefully before they are manufactured because it has to operate on the correct frequency and must be designed specifically, both for the species in question and the aims of the project. Above all, careful consideration should be given to the welfare of each raptor fitted with a tag. Trapping and tagging often is seasonal. As a result most researchers want tags at the same time of year and, consequently, manufacturers become booked at such times for months in advance.

Receiving Equipment

To receive VHF signals a receiver and an antenna are needed, both of which cover the appropriate frequency band to comply with national laws regarding wildlife telemetry. Receivers also must have enough bandwidth to cover all the tags, typically at 10 kHz intervals. The next most important feature is sensitivity (i.e., the ability to pick up weak signals). In addition to sensitivity, weight, waterproofing, and ability to store and scan through pre-set frequencies all are significant practical considerations. Receivers designed specifically for wildlife research cost $500 to $2,500, which is more than similar-looking alternatives intended for other markets, but they will last for many years and are much easier to use. For example, most commercial "scanning" receivers are designed to "modulate" a signal, keeping the same volume even if the signal is changing, which conflicts with the need to use variation in volume for direction finding. When buying a receiver, both tag manufacturers and receiver manufacturers should be consulted.

The antenna that best combines directional accuracy and gain for tracking raptors on the ground is the 3-element Yagi. Flexible elements are less awkward in thick vegetation and when putting them into vehicles. Yagis attached to aircraft should have solid elements. Additional elements can improve reception and directionality, but are cumbersome to use unless attached to a mast. Vehicles need very good suppression or diesel engines to avoid interference with weak signals when on the move.

Signals to indicate behavior and a bird's presence at feeding stations or nests can be logged without mobile tracking if the tags have sensors. The same is true for physiology. It is simpler and less expensive to record from a receiver tuned to one frequency, but for sampling several tagged individuals a programmable logging system is needed. Loggers usually search (via a connected receiver) through the frequencies of several birds, and record pulse characteristics received on each frequency. Although logging can save labor in the long run, neither set-up nor data analyses are simple, and it is important not to underestimate the time required.

Tag Types and Attachment

Tags should transmit on a frequency compatible with the receiving system and about 10 kHz apart from other tags. Tag manufacturers need to know the frequency bands of receivers available to the researcher and the frequencies of any working tags to avoid. Interference in the study area should be checked before specifying frequencies. Around cities there may be many loud extraneous signals that can damage the hearing of researchers in long-term studies.

Table 1 shows the most common tag attachments for raptors. Researchers should talk with experienced trackers and tag manufacturers about the best technique for the species and project. Minimizing the impact of tags on tagged individuals will contribute to robust and, hence, publishable results, as well as to the welfare of the bird (Murray and Fuller 2000). Tags should be comfortable and entirely humane. One should check that manufacturers have sufficient knowledge of biology or species requirements to produce transmitters without sharp edges or surfaces that may interfere with thermoregulation in cold climates. Tag and harness mass near the upper limit allowable should be avoided for each attachment technique. The allowable mass depends upon the mass and wing-loading of the bird as affected by species, sex, and race. The mass that birds can carry safely determines the battery that can be used, and therefore the life (i.e., the time that it will be active) and range of the tag. A tag that pulses faster is easier to track and a stronger pulse will produce a signal that can

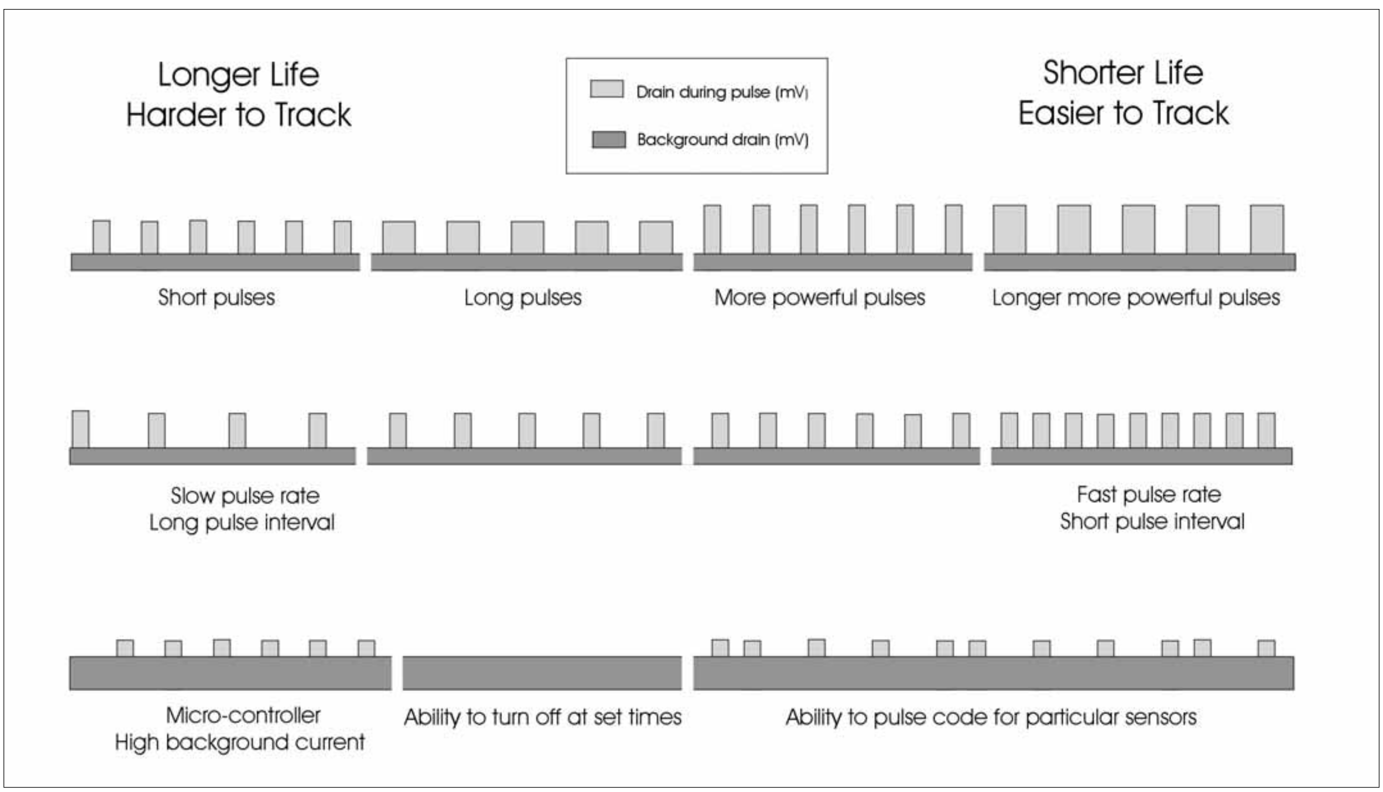

Figure 1. The effects of pulse length, pulse rate and micro-controllers on the life-time and ease of tracking of radio-tags.

Table 1. Techniques for attaching radio-tags to raptors.

Technique	Safety	Considerations
Tailmount	Probably safe if load is less than 2% body mass and attached to two or more feathers.	Feathers must be "hard penned" (i.e., fully grown), therefore one must trap fledglings when out of nest. The tracking stops when the feathers to which the tags are mounted molt.
Backpack	Harness is risky unless carefully fitted.	Can fit to all in the nest just before fledging. Can track for many years and through molts. Tagging at center of lift is best for high-tag mass.
Legmount	No published adverse affects, but might impact hunting.	Tag needs additional protection and a shorter antenna; therefore, life and range for mass of tag are reduced. Can tag all fledglings and track through molt.
Patagial	Only on large raptors with slow wing beat.	Used successfully on condors and large vultures.

be heard from a greater range. However, both requirements draw on battery capacity. To extend the life of the tag, the pulse rate and strength can be reduced to a level at which tracking is more difficult but still practical (Fig. 1). Micro-controllers also can be used to turn tags off during times when there is no need to track, such as during darkness or in winter for migrants. If such controllers are used it is important to ensure that the increased background current of a micro-controller (Fig. 1) does not offset savings from switching off the signal.

Attachment methods must minimize the possibility of entanglement and, where possible, should detach the tag when it stops transmitting. Knowledge of the species is more important than inflexible guidelines or advice from manufacturers. Where possible, potential tag effects should be tested (e.g., by comparison with independent re-sighting data from visual markers on tagged and untagged individuals). If this is not possible, one should consider testing against a low-mass alternative attachment that has little risk of impact, ideally by comparing groups of birds marked in the same season. Doing so is particularly important when using methods that are new or that have known risks. "Tests" also can be based on conservative assumptions. For example, if survival is better than that found with other methods (e.g., banding), effects of tags are probably negligible. Finally, it is worth remembering that males of size-dimorphic raptors may compare best with females if fitted with lighter tags.

LITERATURE CITED

AEBISCHER, A.E., P.A. ROBERTSON AND R.E. KENWARD. 1993. Compositional analysis of habitat use from animal radio-tracking data. *Ecology* 74:1313–1325.

CONNER, L.M., M.D. SMITH AND L.W. BURGER. 2003. A comparison of distance-based and classification-based analyses of habitat use. *Ecology* 84:526–531.

COOPER, J.C. 1978. Veterinary aspects of captive birds of prey. The Steadfast Press, Saul, United Kingdom.

FULLER, M.R, J.J. MILLSPAUGH C.E. CHURCH AND R.E. KENWARD. 2005. Wildlife radiotelemetry. Pages 377–417 in C.E. Braun [ED.], Techniques for wildlife investigations and management, 6th Ed. The Wildlife Society, Bethesda, MD U.S.A.

KENWARD, R.E. 2001. A manual for wildlife radio-tagging. Academic Press, London, United Kingdom.

LARSON, M.A. 2001. A catalog of software to analyze radiotelemetry data. Pages 398–422 in J J. Millspaugh and J.M. Marzluff [EDS.], Radio tracking and animal populations. Academic Press, San Diego, CA U.S.A.

MILLSPAUGH, J.J. AND J.M. MARZLUFF [EDS.]. 2001. Radio tracking and animal populations. Academic Press, San Diego, CA U.S.A.

MURRAY, D.L. AND M.R. FULLER. 2000. Effects of marking on the life history patterns of vertebrates. Pages 15–64 in L. Boitani and T. Fuller [EDS.], Research techniques in ethology and animal ecology. Columbia University Press, New York, NY U.S.A.

ROBERTSON, P.A., N.J. AEBISCHER, R.E. KENWARD, I.K. HANSKI AND N.P. WILLIAMS. 1998. Simulation and jack-knifing assessment of home-range indices based on underlying trajectories. *J. Appl. Ecol.* 35:928–940.

SOUTHERN, W.E. 1964. Additional observations on winter Bald Eagle populations: including remarks on biotelemetry techniques and immature plumages. *Wilson Bull.* 76:222–237.

WHITE, G.C. AND R.A. GARROTT. 1990. Analysis of wildlife radio-tracking data. Academic Press, New York, NY U.S.A.