1986. Pages 679-698 in A.Y. Cooperrider, R.J. Boyd and H.R. Stuart, eds., Inventory and Monitoring of Wildlife Habitat. U.S. Dept. Interior, Bureau of Land Management, Washington, D.C. 858pp.

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RADIO-TELEMETRY

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Editor's Note: Within the past 25 years, wildlife research has moved from subjective field observations to highly complex, objective measurements of animal behavior. The objective measurements, in many cases, are accomplished by use of radiotelemetry. This chapter provides an overview of current state-of-the-art uses of radiotelemetry in locating habitats used by subject animals.

While the urge to use new "gadgets" to learn about animals is understandable, today's biologists should conform to conventional responsibilities toward experimental design and project planning. "Does the end justify the means?" This chapter, therefore, also identifies current processes and equipment needed to plan and execute a telemetry program useful in habitat management, but recognizes the field is continuously expanding.

INTRODUCTION

The development and implementation of radiotelemetry in wildlife research has tremendously broadened the opportunity to examine components of species' natural history and ecology. Since its introduction into wildlife research approximately 25 years ago (Marshall and Kupa 1963; Mech 1983), radiotelemetry use has vastly increased, especially in recent years with the increasing attractiveness of "high-tech" approaches to research, their usefulness and availability.

Today, examples of radiotelemetry research are commonly found in literature. Radiotelemetry hardware, techniques, and uses are continuously being improved and evaluated. The number and diversity of species being studied with radiotelemetry also are continuing to grow and include mammals (Marshall et al. 1962; Mech 1977; Madison 1978; Barrett 1984), birds (Nicholls and Warner 1972; Cochran 1975), reptiles (Carr 1965; Schubauer 1981; Osgood 1970; Kenward et al. 1982), amphibians (Jansen 1982), fish (Winter et al. 1978), and even crabs (Wolcott 1980) and crayfish (Covich 1977). Habitats where these studies have been undertaken range from the polar circle (Kolz et al. 1980) to temperate regions (Verts 1963; Imboden 1975), tropical regions (Bruggers et al. 1983), and oceans (Garshelis and Garshelis 1984).

There are several possible reasons why radiotelemetry may be implemented as part of a wildlife research or management scheme. Accessibility of the species often is a principal reason. Physical characteristics of a species' habitat, such as rough terrain or dense vegetation, may limit the opportunity to seek

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and observe a species. Also, a species may be nocturnal, highly secretive, difficult to trap repeatedly, capable of wide-ranging movements, or even subterranean or aquatic in its habits.

A second advantage of radiotelemetry is that data can take a continuous form rather than the discrete form which occurs for example, through trapping and marking. Once an operating radio transmitter is attached to an animal, that particular animal can potentially be located continuously either day or night. Radiotelemetry also provides the opportunity to remotely follow or census wildlife. Once instrumented, the specific animal can be identified and observed in a non-disruptive manner and, thus, a more accurate depiction of the species' movements, habitat use, and ecology may be acquired.

In contrast, when traps are used to locate an animal, one must assume that a trap is available to capture the animal at a particular location and time and that the animal will enter the trap. Traps (or observers) are typically placed at preconceived (subjective) locations where animals might range, and thus movement data generated from trapping (or direct observation) may be strongly biased. Additionally, trapping often takes on a day or night censusing form, depending on the activity periods characteristic of the species, thus adding to the discrete and limited nature of observations that can be made. Continuous observations also can be made by direct observation; however, without radiotelemetry, locating target animals, distinguishing individuals, and monitoring the activities of many isolated individuals may be far more difficult.

The purpose of this chapter is to discuss radiotelemetry techniques; types of available equipment; and applications for determining movement, migration, and habitat use by wildlife. In addition, we describe potential problems, limitations, and costs.

RADIO-TRACKING EQUIPMENT

Radio tracking should be considered as no more than a technique for extending the range of one's observational powers. Even the simplest equipment requires a significant financial investment. A simple system for tracking about 10 animals with hand-carried receivers and antennas will cost $3,000 to $4,000 (1986 values).

Many improvements have been made since the initial successful studies in the early 1960s, such as more efficient transmitters; better encapsulating materials; lighter, more energy-efficient batteries; solar units; and more efficient, easy-to-use receivers. In addition, all components and complete systems now are commercially available from several sources (Table 1).

Table 1. Possible sources of supply for radio-tracking equipment.[1]

Advanced Telemetry Systems, Inc.
23859 Northeast Highway 65
Bethel, MN 55005
(612) 434-5040

AVM Instrument Company
6575 Trinity Court
Dublin, CA 94566
(415) 829-5030

Cedar Creek Bioelectronics Laboratory
University of Minnesota
Bethel, MN 55005
(612) 434-7361

CompuCap
8437 Yates Avenue North
Brooklyn Park, MN 55443
(612) 424-2373

Custom Electronics
2009 Silver Court West
Urbana, IL 61801
(217) 344-3460

Custom Telemetry and Consulting
185 Longview Drive
Athens, GA 30605
(404) 548-1024

L. L. Electronics
Box 247
Mahomet, IL 53405
(217) 586-2132

Ocean Applied Research Corp.
10447 Roselle Street
San Diego, CA 92121
(619) 453-4013

Smith-Root, Inc.
14014 Northeast Salmon Creek Avenue
Vancouver, WA 98665
(206) 573-0202

Stuart Enterprises
Box 310, 124 Cornish Court
Grass Valley, CA 95945
(916) 273-9188

Telemetry Systems, Inc.
Box 187
Mequon, WI 53092
(414) 241-8335

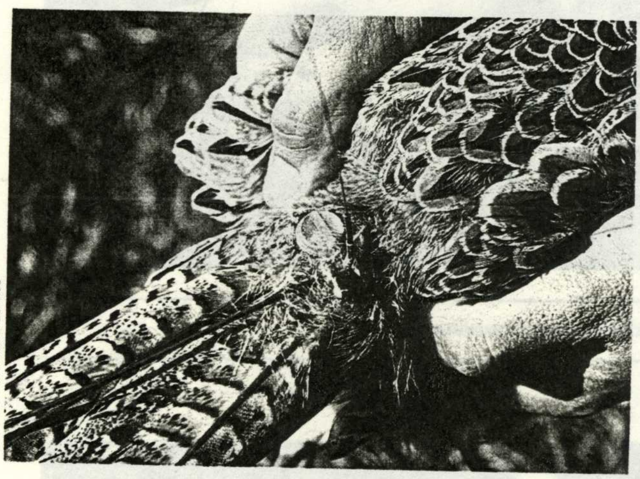
Telonics
932 East Impala Avenue
Mesa, AZ 85204-6699
(602) 892-4444

Table 1. Possible sources of supply for radio-tracking equipment (concluded).[1]

Wildlife Materials, Inc. R.R. 1, Grant City Road Carbondale, IL 62901 (618) 549-6330

[1]Use of companies on this list does not imply Federal Government endorsement.

There are basically two components in a radio-tracking system: a transmitting system and a receiving system. The transmitting system consists of the transmitter which is attached to an animal by an appropriate method such as a radio collar on big game animals, patagial transmitters on birds, and implanted transmitters in fish or snakes. The receiving system consists of a receiver, a receiving antenna, and either an operator or recorder.



U.S. Fish and Wildlife Service

Patagial transmitter attached to a hen pheasant.

Transmitters

The specific type of transmitter chosen will depend on size, morphology, and behavior of the animal under study; possible attachment methods; transmitter availability and cost; necessary transmission range; habitat where used; and the particular data to be collected.

Almost any animal that weighs over 15 g (0.5 oz) can be equipped with a radio transmitter and monitored for at least a short time. Obviously, the larger the animal, the larger the transmitter package can be. Transmitters are available commercially ranging from slightly over a gram (0.03 oz) to several kilograms. The actual transmitter *per se* does not vary much in weight but the power source, packaging material, and attachment material can add substantially to the weight. Weight considerations for the animal usually become important only for the smaller (< 1 kg [< 2.2 lb]) species. This can be the most critical consideration with very small animals (< 20 g [< 0.7 oz]) and especially birds. Generally, the transmitter should be no more than 5% of body weight. The Banding Office of the U.S. Fish and Wildlife Service recommends no more than 3% of body weight for transmitters used on birds. Cochran (1980) stated that many species seem to tolerate a package that is 4% of their body weight and appear to behave normally not too long after such a package has been attached. He also added that there is nothing "magic" about 4%. However, there may be some species that cannot be radio-equipped with these transmitter-weights, or even lighter transmitters, without having significant behavioral or physical effects as a result of instrumentation.

Ordinarily, each transmitter used in a particular study area is on a unique frequency (or channel); therefore, to tune in each animal, the operator merely turns a dial or activates switches on a radio receiver to the appropriate frequency (or channel).

Radio frequency management in the U.S. is based on the Communications Act of 1934. This legislation divided frequency spectrum users into two groups (federal and non-federal). The National Telecommunications and Information Administration (NTIA) controls the federal portions of the spectrum, while the Federal Communication Commission (FCC) controls the non-federal portions of the spectrum for use by state and local governments as well as the private sector. Since segments of the spectrum are shared by federal and non-federal users, operations are mutually coordinated by the Interdepartmental Radio Advisory Committee (IRAC). Each Federal Government agency and the FCC are represented on the IRAC to address spectrum management issues. The IRAC, through NTIA, has authority to approve, disapprove, and cancel any federal radio-frequency assignment. In effect, IRAC is the licensing authority for federal users while the FCC licenses non-federal users.

Two portions of the spectrum have been set aside for wildlife telemetry use (40.16 to 40.20 MHz and 216 to 220 MHz); however, these frequencies have not been widely used by wildlife researchers or managers. Radio-frequency spectrum managers are becoming increasingly concerned about unlicensed operations and the violations of rules and regulations pertaining to radio communications. By law, telemetry users must operate within the rules and regulations because any interference occurring between authorized and unauthorized uses will cause unauthorized use to shut down, resulting in costly losses of time and effort expended on studies. One must have authorization to use a particular frequency before any transmitters can be placed on free-ranging animals. For further guidance and information, see Kolz (1983).

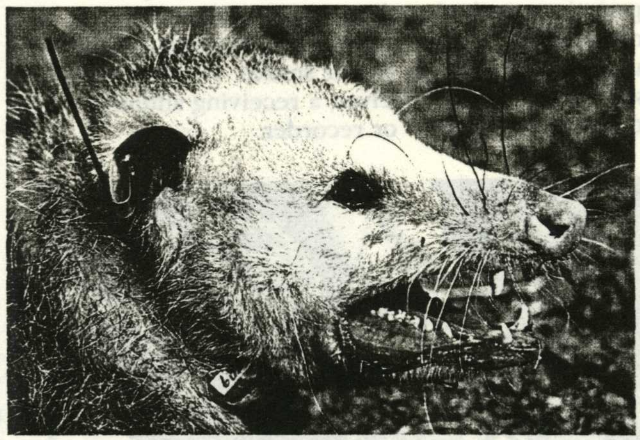
Most transmitters use mercury or lithium batteries to power the transmitter; however, solar-powered units, some with rechargeable batteries, also are available (Cochran 1980). Battery choice must be tempered by the amount of additional weight the animal can carry and the length of time the animal needs to be tracked. If the transmitter is retrievable or the animal recapturable, transmitters can be reused and their longevity extended by changing batteries.

Most simply, activating a transmitter includes soldering a final connection and then potting (covering) that connection with an appropriate quick-setting potting material (i.e., dental acrylic, epoxy patch, or silicone rubber); others are activated by cutting a wire that allows completion of a circuit. Additionally, with some transmitters, placing or removing a magnet near an imbedded switch turns the transmitter on or off. A magnet system is preferred as it does not require any soldering or potting by the user and is more likely to be completely sealed from moisture. Normally transmitters are activated only shortly before attachment to an animal. However, some users routinely turn transmitters on for a few days prior to attachment to assure proper operations. The loss of a few days of battery life may be critical only for small, short-lived transmitters.

Most transmitter antennas are some sort of tuned whip. The most efficient antenna lengths are in quarters of wave lengths of a particular frequency (such as ¼, ½, or whole wave). Except for the high frequencies, most wildlife transmitter antennas cannot be that long (a full wave length at 164 MHz = 1.82 m) and, therefore, are tuned with a coil to whatever length can be tolerated on the animal. Whip antennas are more efficient than loop antennas. However, in some applications, the loop antenna serves as an integral part of the attachment collar.

There are a variety of methods for attaching transmitters to animals, and before any transmitters are attached to any species, one should review available literature on the species, try the attachments, and act on the results of those endeavors. Neck collars are the most common radio-attachment method for terrestrial mammals (Cochran 1980). Harness, ear tag, and implanted transmitters have been used on some mammals that are difficult to collar (Mech 1983). For birds, harness, tail-clip, poncho, glued-on, leg-band, and patagial transmitters have been successfully employed (Bray and Corner 1972; Fitzner and Fitzner 1977; Amstrup 1980; Bruggers et al. 1981). Implantable or ingestible transmitters are useful where external attachment is impractical, such as with fish or snakes (Osgood 1970). Tethers have proven useful for sea turtles and manatees (Timko and Kolz 1982).

A number of factors need to be considered when designing or specifying the type of collar, harness, or other attachment to be used. Shape, width, contouring, durability, flexibility, smoothness next to the animal, size adjustability, compactness, cryptic design, internal or external antenna, and ease of attachment all can be important (Cochran 1980). Sharp edges and points should be avoided or at least placed where there will be minimal irritation from contact or pressure. Without at least considering these factors, routine behaviors such as running, flying, feeding, mating, or even resting may be adversely affected. If necessary, one may have to test various attachments on some species where methods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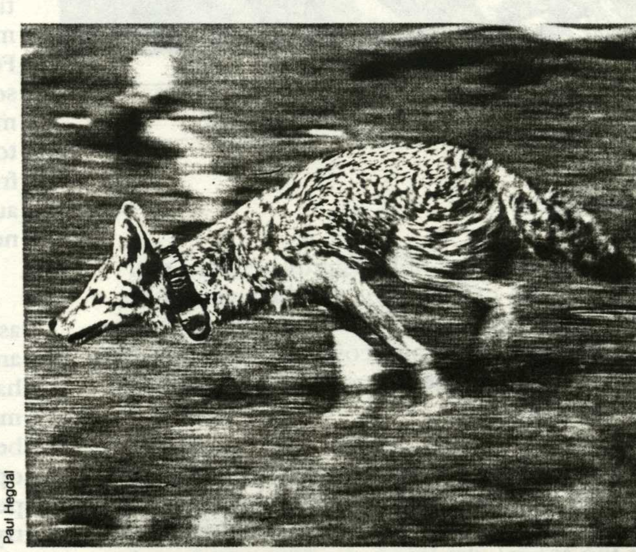
Radio-collared opossum.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Radio-collared coyote.

and designs have not been evaluated by others. Ideally, the transmitter will be on the animal only as long as needed to collect the desired data. Some transmitters are designed to fall off after some predetermined time; however, there have been some problems with premature transmitter loss. With a well-designed attachment, many animals have not had significant problems carrying the transmitter for life. We have had transmitters on owls for over 5 years with no apparent problems.

Transmitters for remote locations generally cost between $100 and $250 each. A variety of special-purpose transmitters have been developed for detecting movement or mortality (Kolz 1975); measuring heart rate, respiration rate, temperature, and blood pressure, as well as conducting electrocardiograms and encephalograms (Amlaner 1978); firing darts on command for recapture (Mech et al. 1984); and some specific behaviors such as frequency of urination. However, these transmitters and receivers are more expensive than transmitters for remote locations.

Receivers

A variety of receivers are available, ranging from $700 for the simpler receivers to about $2,000 for some of the newer, wider band models with programmable automatic switching functions, often referred to as "scanners." However, paying more money for a receiver will not guarantee a more sensitive receiver. Most can be tuned to equal "state of the art" sensitivity (±150 db)—even the $700 versions.

When planning purchases of telemetry equipment, at least one extra receiver should be acquired for the project as a backup. There is nothing more frustrating than having radio-equipped animals and no working receivers to track them. Extra batteries should always be available for receivers and any other equipment used in conjunction with them.

Most receivers have a—

(1) power switch, often with a position for internal or external power;

(2) channel selector (for digital frequency display models, this may be dials or switches for changing the displayed frequency);

(3) fine-tuning frequency dial (on non-digital models);

(4) gain (volume) dial;

(5) sweep switch that allows automatic sweep within a channel or between preset exact frequencies; and

(6) switches for setting frequencies to be searched.

Most receivers also have a variety of input and output plugs for antennas, headphones, external power, meters, pulse-interval counters, recorders, and other attachments.

Earphones are not necessary in many tracking situations. The inexpensive models ($20 or less) are adequate in most cases for hand or vehicle tracking. However, for tracking in aircraft in windy or noisy conditions, earphones are necessary, and it is worth the extra money to get the best—$100 to $200 each. (Long-continued use of earphones at high audio levels has resulted in diminished hearing abilities among some research biologists.)

Antennas

Almost any piece of metal connected to the antenna plug of a receiver will enhance the signal, but properly tuned and tested antennas should be used for maximum efficiency. The yagi antenna is the most commonly used antenna for radiotelemetry studies. A good, single hand-held yagi antenna costs $50 to $100. As frequency increases, wave length decreases and the size of antennas also decreases. Yagi antennas are too large to be very practical for hand-held or vehicle-mounting at the lower (30 to 50 MHz) frequencies but can readily be used on vehicles or hand-held at the higher (over 150 MHz) frequencies.

Antennas can be mounted on towers, vehicles, or aircraft. Two (or more) yagi antennas can be combined in such a manner (called stacking) to increase their range and directional ability. In dual array systems, antennas can provide a bearing accuracy of 1 to 2°. Often, permanent tracking stations consisting of a few strategically placed antenna towers or masts mounted on the highest hills in the study area will yield adequate signals. These towers can be similar to the large, automatically rotating system described by Nicholls and Warner (1972) or relatively simple structures with a coaxial cable left dangling near the base (Merson et al. 1982).

Permanent or temporary tower antennas can work well for sedentary animals; however, the accuracy of radio locations deteriorates near the base line of the antennas (because the angle of intercept nears zero). If additional towers or mobile tracking stations can be employed, this problem can be overcome.

Radio-tracking vehicles (mobile tracking stations) can be equipped with roof-mounted, dual yagi antenna systems. Bray et al. (1975) described a removable cartop antenna system. However, for most studies using mobile tracking stations, we strongly recommend vehicles equipped with a through-the-roof antenna system similar to that described by Hegdal and Gatz (1978). These antennas are rotated from inside the vehicles, and radio bearings are indicated on a 360°, 25-cm (10-in.) protractor by a pointer attached to the antenna mast. The pointer is aligned to the null of the dual yagi antennas. Coaxial cables from the dual yagis are attached to a null-peak switchbox (available from commercial suppliers), which allows switching from in-phase (for maximum signal strength) to out-of-phase (for precise bearings) operation. Additionally, radio communication, a plotting table, auxiliary batteries, and extra lighting installed in the vehicles will expedite tracking studies. Figure 1 shows an inexpensive method for equipping vehicles with a roof-mounted, dual-beam antenna system. If properly balanced, antennas can be rotated easily and animals can be tracked while the vehicle is moving as fast as 55 mph.

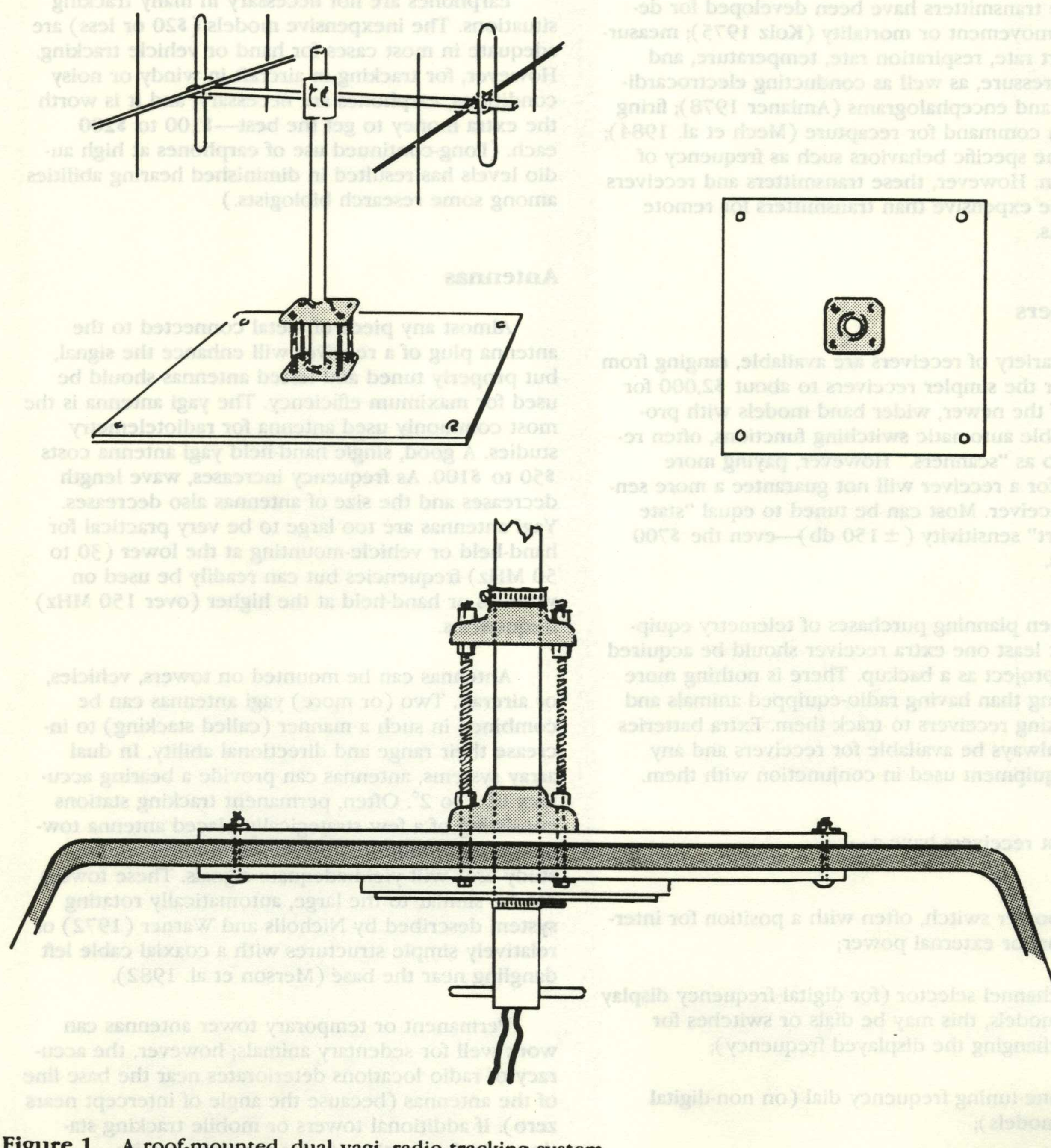
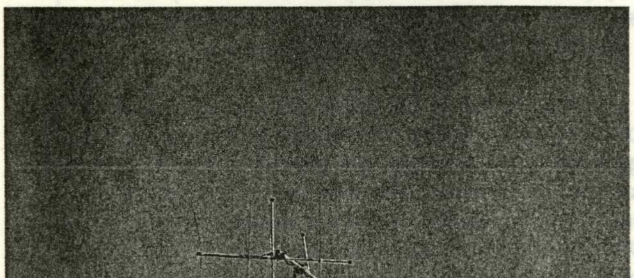


Figure 1. A roof-mounted, dual yagi, radio-tracking system.

On aircraft, antennas are usually mounted on wing struts (with certified antenna mounts) in a "side-looking" fashion, perpendicular to the fuselage (Gilmer et al. 1981). Care also must be taken to ensure that coaxial cables are properly secured with tape, not crimped, and that they and the rest of the telemetry equipment do not interfere with the pilot's operation of the aircraft.

Too often, new (and experienced) radio-trackers do not periodically test and check their antenna system. They may have an extremely sensitive receiver matched to a poorly tuned antenna and therefore have (unknowingly) a very inefficient receiving system.

Coaxial cables are used to connect antennas or other equipment, such as recorders, to receivers. This is a shielded cable (a center wire conductor surrounded by the ground wire). Care must be taken to avoid sharp bends, twisting, and flattening or pinching; distortion of the cable shape can drastically affect or eliminate signal reception.



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A radio-tracking vehicle at a marked tracking station.

Other Equipment

Pulse interval counters are available for about $400 and can be used in conjunction with several receivers. These devices measure the time between consecutive, pulsed radio signals and usually display that value in thousandths of a second. They are especially helpful for identifying pulse rates (animals) when there is more than one transmitter operating on the same frequency (or channel). Recorders can be used in conjunction with automatic switching (scanning) receivers to record presence or absence of radio-equipped animals over time at sites such as dens or nests (Gilmer et al. 1971; Harrington and Mech 1982; Mech 1983). However, as with automatic tracking systems, one must have a good strong signal for most of the recorders and counters to work properly. The human ear can detect signals from the receiver better than any of the available auxiliary equipment.

Satellite radiotelemetry also has been used successfully on a few wildlife species (Kuechle et al. 1979; Timko and Kolz 1982). However, transmitters and receiving equipment are more specialized and considerably more expensive than those we have described, and it is beyond the scope of this chapter to fully discuss these aspects of radiotelemetry.

Advice

We strongly recommend that the telemetry user depend on electronic specialists for constructing and servicing transmitters, receivers, and other specialized equipment. However, the biologist must have a general knowledge of radio signal propagation; factors that affect it; and some skills and equipment for servicing, checking, and repairing parts of the telemetry system. Users should be able to charge power sources for receivers and other equipment; change batteries in some transmitters (some must be returned to the manufacturer); replace coaxial cables and antenna elements; turn transmitters on and off; check power sources, telemetry, and antenna systems for shorts and open circuits; and recognize that such problems exist. Minimal support equipment should include a volt-ohmmeter; battery tester; supply of miscellaneous wire connectors and terminals; soldering gun; solder; wire strippers; and various-sized screwdrivers, pliers, and adjustable wrenches.

DATA SAMPLING

The planning stages of a radiotelemetry study must include decisions on specific use or need of the technology, equipment, personnel availability, and cost. Just as important, however, are decisions on how data will be collected, analyzed, and interpreted. The recording of a single data point in the field can be a simple procedure; however, deciding the value or use of hundreds or thousands of coordinates may not be and should not be left until the field work is complete.

Locating an animal either on a monthly, weekly, daily, hourly, or minute-by-minute basis all may be possible depending on the available hardware, personnel, and funding. However, while a large number of radio-equipped animals can be located continuously, rarely is that done. The specific form and frequency of sampling should be particularly relevant to the specific questions that are being addressed with radiotelemetry use. It may be appropriate to simply monitor general movements or continued survivorship; thus, the sampling scheme may be extensive or random and the radio-tracking results may be presented in a rather descriptive form. In contrast, when evaluating habitat selection or rates of movement, for example, the sampling scheme may have a highly intensive or systematic style with data recorded in more of a quantitative manner (e.g., effort- or time-specific). In the latter case, animals may be located at specific and independent time intervals or continuously tracked within discrete and independent time periods.

Sampling scheme decisions also may be affected by the species being studied. Animals that are capable of wide-range movement or frequent habitat change may have to be located more often to avoid loss of contact than those that are largely sedentary. The length and timing of daily activity cycles of animals, for example, nocturnal versus diurnal, also will affect the length and timing of radio-tracking efforts; the sampling scheme for any given individual may have to be compromised considerably depending on how many other animals are simultaneously radio-equipped. Additionally, more frequent sampling may be needed if the hardware being used includes short transmission-reception range or a limited battery or radio attachment life.

A sampling scheme to evaluate the importance of specific habitat types might be based on the total time an animal spends in each habitat, the number of locations that are randomly or systematically recorded in each habitat type or, in contrast, the number of times an animal enters each habitat from alternative habitats. The time that an animal spends in a particular habitat may not be equated necessarily to the value of that habitat to the species; frequent, but short visits to other habitat types may indicate a greater resource value. In addition, when sampling for home ranges, Smith et al. (1981) stated that it is important to define a large portion of the area over a relatively short observation period. This is because home ranges are really time-specific, meaning they potentially can change with season, habitat, or the animal's reproductive state. Thus, intensive sampling efforts in a specific time period may be necessary when accurately defining a home range.

One additional concern related to sampling is movements recorded immediately following animal instrumentation and release. Such movements should be considered biased (rather than exemplary) because of the disruption created by trapping and handling. Therefore, although tracking an animal immediately following release (e.g., 1 day) may be appropriate, there should be a degree of independence used in the initial observation of habitat or home range analyses.

FIELD-TRACKING

Field-tracking first dictates that one must become an expert in capturing live, uninjured animals of the desired species, which can become a major effort in itself for some species. Secondly, we strongly recommend that those new to radio-tracking and those not using it for 2 to 3 years visit and obtain training from a state-of-the-art ongoing project. Novice radio-trackers, especially, will encounter many pitfalls and these may be avoided by such help. Also, there are new developments annually that may be useful in any radiotelemetry project.

Triangulation is the basic principle in most radio-tracking. It can be accomplished by taking bearings from two locations; the animal is assumed to be near the point where the bearings cross (the location or "fix"). Ideally, bearings should cross at about a 90° angle and be taken simultaneously by two radio communication observers and as close to the animal as possible. As the angle of interception becomes more acute and the distance from the animal to the observers increases, the locations become less accurate and the error polygon increases. For a more thorough discussion of error polygon and means of estimating radio-location errors, see Mech (1983), Lee et al. (1985), and Saltz and Alkon (1985). Considerable experience in the field is necessary to become skilled at rapidly selecting tracking locations for accurate bearings.

When learning to radio-track, one should first practice locating an activated transmitter hidden by someone else. Repetition of this "game" can most readily acquaint anyone with radio-tracking techniques and the sensitivity and capability of the equipment.

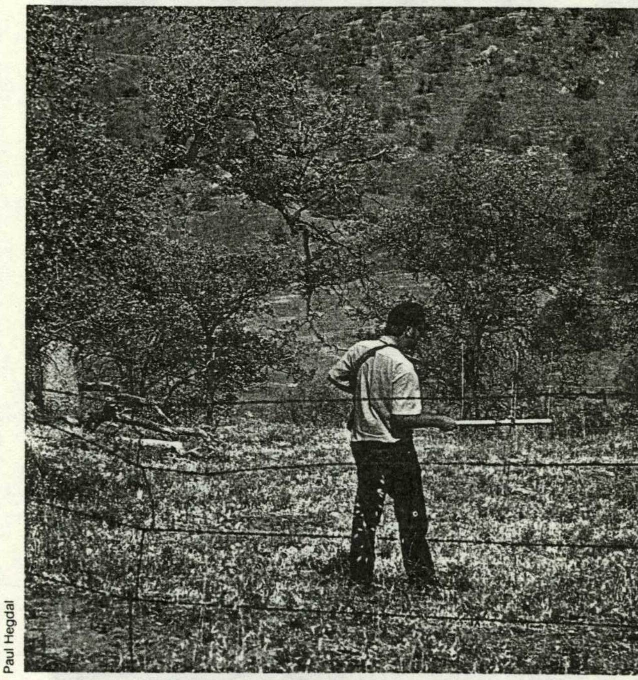
Hand Tracking

In its simplest form, field radio-tracking is done by carrying the receiver and hand-held antenna and "homing in" (walking out) on the radio-equipped animal. Proper "homing" procedures involve determining the approximate direction of the transmitter, tuning in the signal, reducing gain to minimal level, again reducing gain to minimal level, and moving in the direction of the signal. While moving toward the signal, the antenna should be waved in an approximate 120° arc, back and forth, continuing to reduce gain to a minimal level. When gain cannot be reduced further, it indicates the transmitter is nearby. If the animal has not been observed or the transmitter found, it can be located by removing the antenna, turning the gain up so it barely can be heard and, depending on signal strength, determining the location by moving the receiver toward the strongest signal. A small "locator" loop antenna also is useful for radio-tracking at close range. These locator loops are especially useful when digging transmitters from underground burrows.

"Homing" procedures have some obvious drawbacks. For example, the animal may not be observed by the biologist before it has been "pushed" or flushed from roosting, foraging, or loafing areas, and the location recorded may not reflect the habitat utilized prior to the investigator's disturbance. Care must be used to avoid these false locations and artificial or stimulated movements caused by the investigator. Some animals (such as big game, raptors, or animals that are nocturnal) are difficult to observe or approach without disturbing them. This tracking method may be relatively useless for determining movements of nocturnal animals during activity periods, but may (with care) readily be employed to determine specific daytime roosting, denning, or bedding areas during periods of inactivity. When radio-tracking large numbers of animals, hand-held equipment becomes inefficient as it may take several hours to locate some animals by "walking them out." This is especially true in inaccessible areas or in areas of dense vegetation.

With some small, relatively immobile and fossorial species (such as rodents, small birds, and reptiles), virtually all radio-tracking may be done with hand-held equipment. Hand-held tracking will always be necessary to locate and recover dead animals, animals that must be recaptured, or transmitters that have fallen off the carrier animal.

Recovery of lost transmitters or dead animals can be difficult, sometimes requiring considerable digging, use of heavy excavating equipment, or explosives. For example, black-tailed prairie dogs were recovered in South Dakota at depths of 2.5 to 3 m (8.25 to 10 ft—deepest 4.3 m [14 ft]). Also, one cannot assume that radio-equipped animals always will be in normal habitat or locations expected for that species. Finding an animal is often based on what a species is "supposed to do" rather than what it may actually do. Birds, rodents, or most any species can be taken by predators as well as legally or illegally by humans. Animals and their transmitters have been recovered in raptor nests, burrows, under buildings, in car trunks, freezers in homes, and many other unusual locations where the animal being tracked would not be expected to venture.



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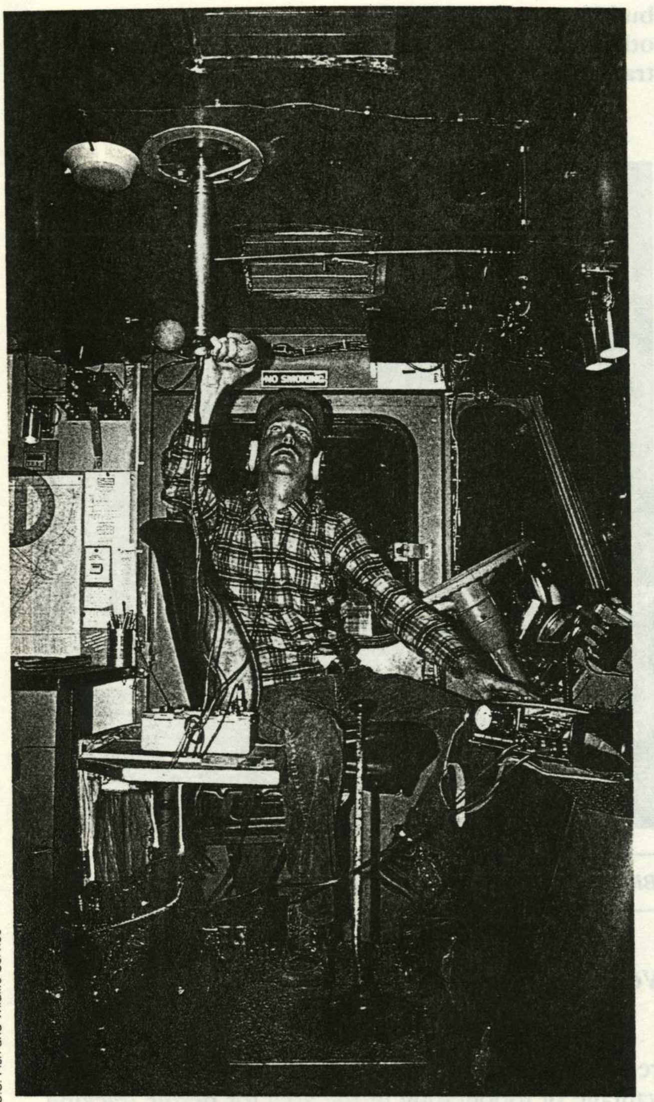
Biologist tracking using a hand-held yagi.

Vehicle Tracking

Mobile tracking stations (vehicles) allow one to reduce the antenna-to-animal distance and take advantage of topography in the area for better tracking points. Vehicle tracking can only be done if there are reasonable access routes within the study area. Mobile tracking stations (two or more), equipped with the described antenna systems, radio communication equipment, auxiliary batteries, extra lighting, and plotting tables, allow investigators to quickly search areas and follow fast-moving animals such as migrating birds in daylight or darkness. During activity, it may be especially important to obtain simultaneous bearings. Since many animals can move rapidly, false interception points may be recorded if there is a time lag between bearings. Most dual-beam antenna systems mounted on a vehicle require a minimum clearance of about 3 m (10 ft). If the study area contains wooded areas with low-hanging branches, it may be necessary to trim several kilometers of road for adequate clearance of the tracking vehicle. In areas where this is not practical, a single yagi should be mounted in a horizontal plane. This will lower clearance requirements and still give fairly reasonable bearings, provided the distance from the tracking vehicle to the animal is short when bearings are taken.



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Turning directional yagi antenna from inside the tracking van.

U.S. Fish and Wildlife Service

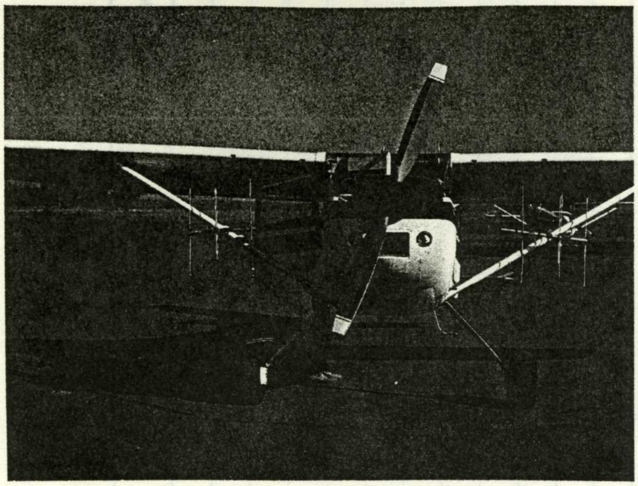
Recording signals on plotter system.

Aerial Tracking

Usually, aerial tracking starts with searching the area for the animal's last known location, increasing altitude to 3,000 m (9,900 ft), and searching in an enlarging circle or flying swaths (20- to 50-km [12.4- to 31-mi.] wide) for complete coverage of the areas (Gilmer et al. 1981). In heavily populated areas near cities, there may be too much radio interference to fly at higher altitudes (over 500 to 1,000 m [310 to 620 ft]). Once a signal is detected, aerial tracking simply can become "homing," similar to "walking out" a radio-equipped animal (reducing gain and lowering altitude as the source of the signal).

The use of aircraft is especially important in large or inaccessible areas and with wide-ranging or migrating species. Additionally, aerial searches for missing or lost animals are usually much more efficient than ground searches. The additional height provided by aircraft greatly increases reception range. For example, our vehicle tracking system has a range of about 3 to 4 km (1.8 to 2.5 mi.) with a 7 g (0.24 oz) transmitter on a bird, while with aircraft, a 35-km (21.7-mi.) receiving range can be achieved.

The first step in aerial tracking is consulting with a certified aircraft mechanic to make sure that the antenna mounting system is certified by the Federal Aviation Administration (FAA). The biologist should be familiar with areas to be searched and review the flight, search area, and procedures with the pilot before the flight. Exact tracking procedures depend on terrain and habitat, as well as the mobility of the species being followed. Experience of the observer and pilot also can influence the efficiency of aerial tracking (Hoskinson 1976).



U.S. Fish and Wildlife Service

Yagi antenna mounting system on aircraft.

Data Recording

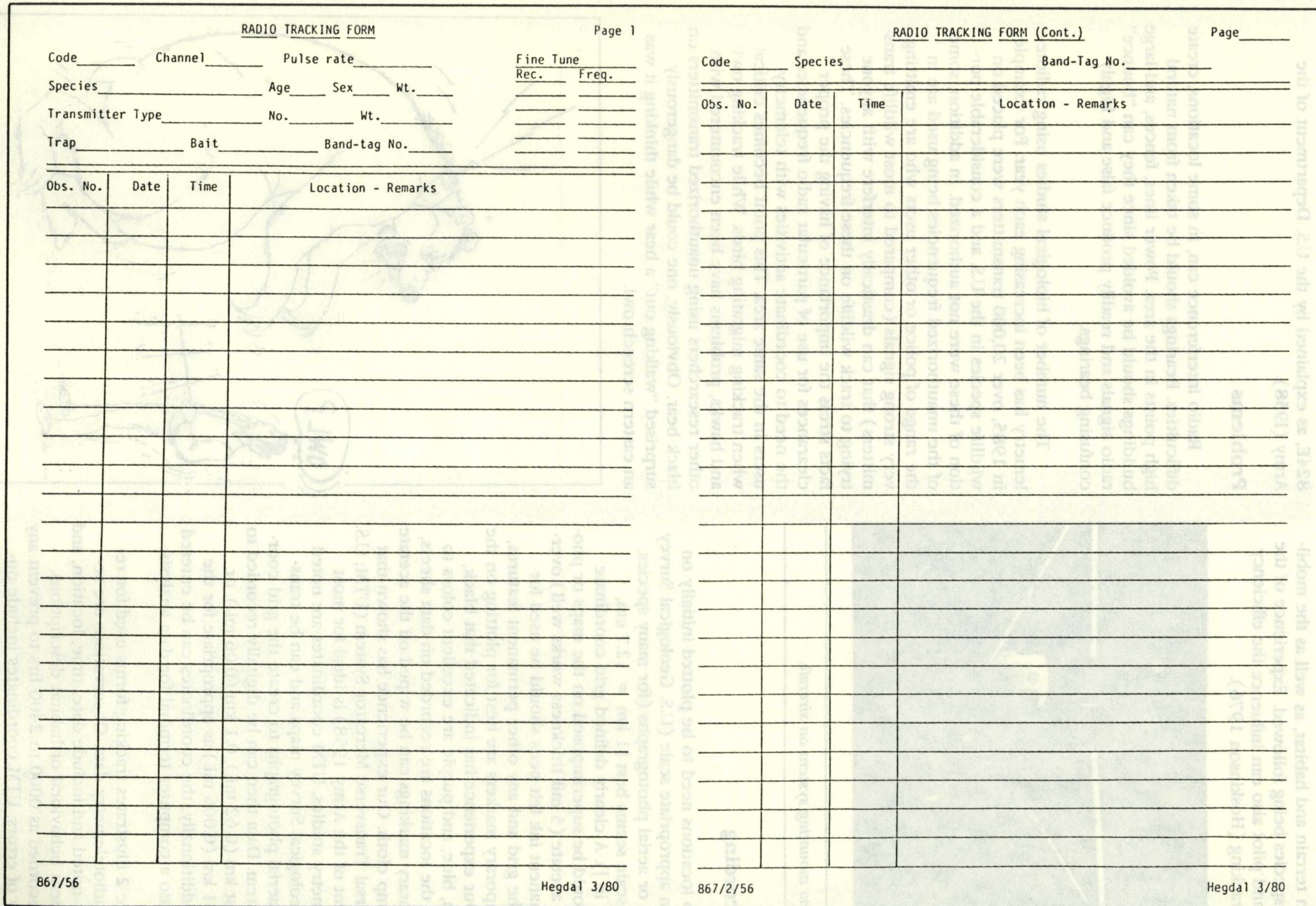
Radio locations need to be plotted initially on maps of an appropriate scale (U.S. Geological Survey 1:24,000) or aerial photographs (for many species, a 1:7,920-scale seems best [1 km = 12.7 cm, 1 mi = 8 in.]). A clearly defined grid coordinate system should be superimposed on the maps or photos, using acetate (5 mil thickness works well) overlays. Permanent ink felt pens should be used for marking the grid and any other permanent features, while temporary markers are best for plotting on the acetate. Our experience has indicated that black, red, green, blue, and purple are excellent colors to use. After the locations are recorded on data sheets, the temporary markings can be wiped off the acetate with a damp cloth. Our experience has shown that the Universal Transverse Mercator System (UTM; U.S. Department of the Army 1958) is ideal for most radiotelemetry studies. UTM coordinates are noted on U.S. Geological Survey maps and can be transferred to aerial photographs to create the grid coordinate system. Data then can be digitally recorded to the nearest km (0.62 mi.), 0.1 km (0.06 mi.), or even 0.001 km (0.006 mi.) as appropriate for the species. Additionally, the coordinates can be entered directly into a computer terminal for data analysis.

Figure 2 illustrates tracking forms used for recording radiotelemetry data. Observations are sequentially noted and include date, time, location, and any pertinent behavioral or habitat descriptions. Time is recorded as 0000 to 2400 hrs to prevent any possibility of errors. UTM coordinates include numerical and directional values, for example, 2760N, 824E, as explained by the U.S. Department of the Army (1958).

Problems

Radio interference can, in some locations, create difficulties. Bearings should be taken from natural high points in the area. Power lines, fences, and large buildings should be avoided since they can "bounce" radio signals and readily produce false and highly confusing bearings.

The number of biological studies using radiotelemetry has been increasing each year. For example, in 1985, over 20,000 transmitters were placed on wildlife species in the U.S. and a considerable portion of these were not authorized. In addition, some of the unauthorized frequencies being used are in the range of police or other users who are emitting very strong signals (compared to most wildlife transmitters) that can drastically interfere with anyone trying to track wildlife on these frequencies. These facts stress the importance of having the proper clearances for use of particular radio frequencies and the need to coordinate activities with telemetry users in the same area. This point becomes critical when tracking migrating birds. While tracking owls and hawks, problems have been encountered with other researchers using unauthorized transmitters on black bear. Obviously, one could be dangerously surprised "walking out" a bear while thinking it was an eastern screech owl.



RADIO TRACKING FORM — Page 1

Code______ Channel______ Pulse rate______

Species______ Age____ Sex____ Wt.____

Transmitter Type______ No.______ Wt.______

Trap______ Bait______ Band-tag No.______

Fine Tune

Rec.	Freq.

Obs. No.	Date	Time	Location - Remarks

867/56 Hegdal 3/80

RADIO TRACKING FORM (Cont.) — Page______

Code______ Species______ Band-Tag No.______

Obs. No.	Date	Time	Location - Remarks

867/2/56 Hegdal 3/80

Figure 2. Radio-tracking data forms.

No matter how well individuals or equipment perform, contact with some transmitters could be lost. To help locate these missing animals, aerial tracking may be necessary. In addition, receiving equipment should be left on at all times (tuned to the appropriate missing frequencies) while traveling in vehicles; missing animals are often located when least expected (frequently near their known home range). A bent transmitter antenna; the orientation of an animal's body and, thus, antenna orientation; or location of an animal in a low or structurally secluded area (such as underground) may drastically reduce reception range and thus cause the animal to essentially "disappear." Some transmitters will come off animals (or be taken off by them) and, depending where they end up, can be difficult to locate. Unfortunately, some lost transmitters are never located and no biological conclusions can be made in most of these situations.

DATA ANALYZING

Radio-tracking data may be reported in several different ways. Initial description of results usually includes the length of time that the animal carried an operating transmitter, fate of the radio-equipped individual (i.e., mortality, lost contact, dead battery), the number of data points recorded, and possibly the number of tracking periods or days. These data are helpful in relating the kind and number of observations made to the amount of tracking time and effort spent.

Enumeration data, reported in either descriptive or tabular form, include the frequency at which various events occurred or when observations were made—for example, the number of times that various types of mortality were documented or the frequency that animals were located at each type of roost or habitat type. Statistical comparisons then can be made between the frequency of habitat use and the availability of those same habitats within the range of the animal, resulting in determining habitat preferences (Johnson 1980).

Measurement data might include rates of movement (e.g., km/h), rates of habitat interception (e.g., number of locations per habitat type per hour), time spent in each habitat type (e.g., number of hours or percentage of total tracking time), distances between nest sites and foraging areas, and home range size. Home range size may be calculated several different ways. The recommended method is reviewing home range analysis techniques before deciding on any one method (Jennrich and Turner 1969; Dunn and Gipson 1977; Dixon and Chapman 1980; MacDonald et al. 1980; Anderson 1982; Hackett and Trevor-Deutsch 1982). However, most often radiotelemetry home ranges have been described as some form of a minimum area or convex polygon created by encompassing the recorded outermost points (see Barrett 1984; Garshelis and Garshelis 1984). Also, computer programs can be used to calculate home range size (Ford and Krumme 1979; Anderson 1982).

Presentation of radiotelemetry data in graphic form is common practice and may offer a reader a perceptive view of movements. To prepare a figure showing radiotelemetry results, tracing paper can be placed over a grid pattern of UTM coordinates marked to scale, and UTM coordinates recorded in the field can then be plotted on tracing paper. Various landmarks or habitat types can be added appropriately to emphasize relationships between locations, movement distances, and environmental features. The completed art work then can be reproduced photographically. Computer-assisted graphics also can be generated.

When diagramming radiotelemetry data, one should consider showing only those data that illustrate a particular point, rather than trying to present all or much of the data since that may not be necessary and can result in a confusing illustration. Movement data presented in graphic form may only exemplify the movement observed during any one tracking period.

Maps showing tracking data may show specific routes or sites where events such as initial capture, migration, nesting, or mortality occurred (Figure 3). Other types of graphics can include "scatter" diagrams that show the range of locations and centers of activity (Figure 4). Also, computer graphics can be particularly effective in relating centers of activity or utilization distributions (Tarter and Kronmal 1976; Anderson 1982), especially if the graphics are in three-dimensional form (Figure 5). Range overlap among conspecifics, or predator range versus that of prey, can be diagrammed and home range sizes presented clearly (Figure 6). Continuous movement patterns can illustrate the rate and directionality of movement (Figure 7), and the same radio-tracking data imposed on habitat types can show distinctly the relationships between movement patterns and particular habitat types (Figure 8). Active videographic techniques allow viewing distribution and movements of many animals in a continual, spatial, and temporal dispersion (White 1979).

Once locations are tabulated or graphically plotted, a critical aspect of a radiotelemetry study must follow, that is, interpreting the findings and answering why an animal was at a particular place at a particular time. Sanderson (1966) made an important point when he stated that researchers must shift their emphasis from concern over the movements of animals to the reasons for the movements. Sanderson (1966) continued by stating that movement patterns are established and regulated by the density of the

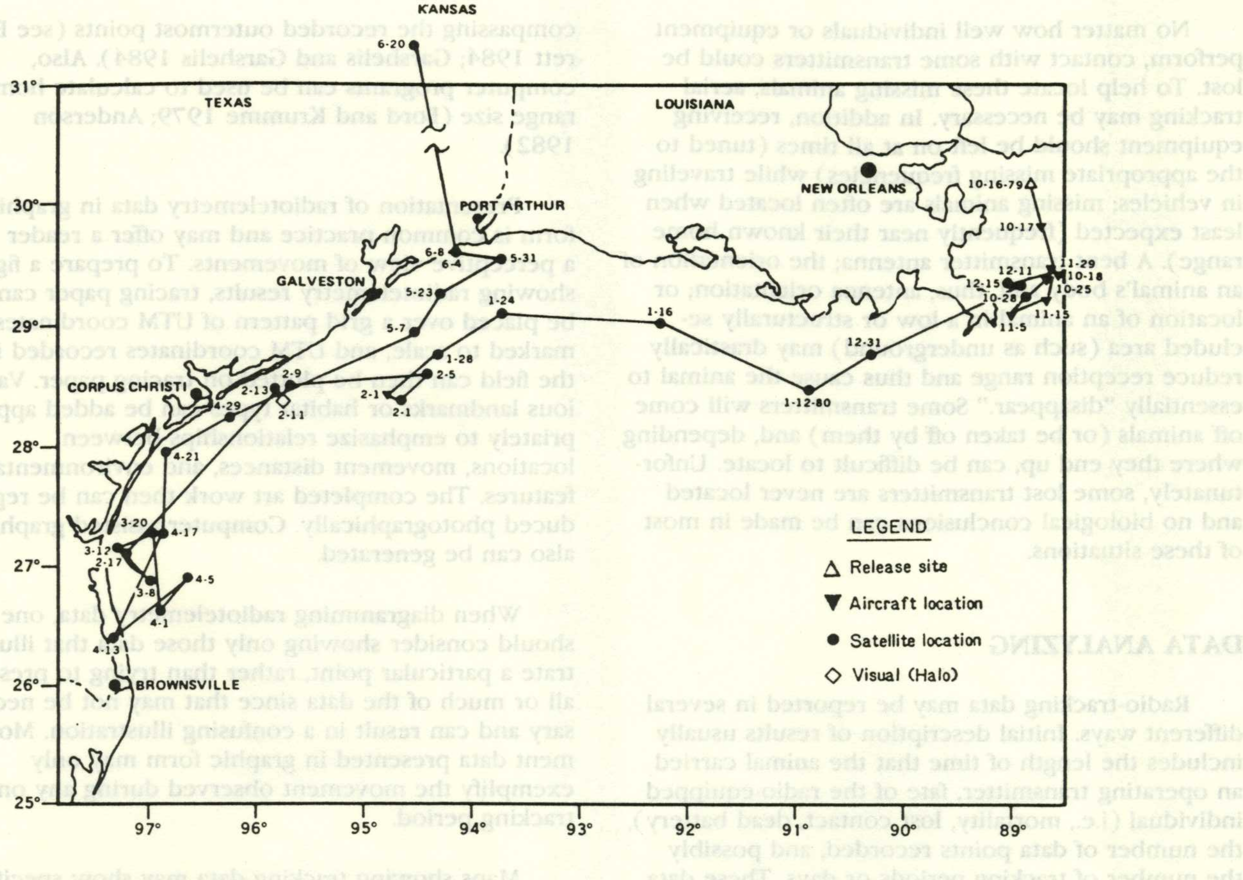


Figure 3. Movement of a loggerhead turtle radio-tracked from October 16, 1979 to June 8, 1980 in the Gulf of Mexico (from Timko and Kolz 1982).

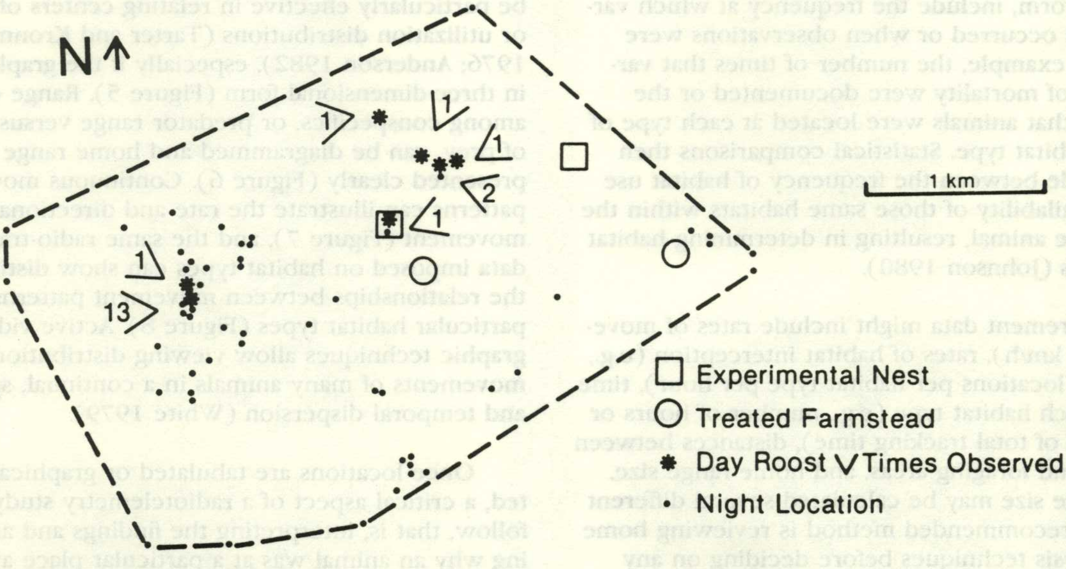


Figure 4. Range, night locations, and daytime roost sites recorded for a female common barn owl with young, 3-10 weeks old, in southwest New Jersey. The owl was radio-tracked randomly from June 2 to July 29, 1982. Dashed lines encompass outermost locations recorded (approximately 977 ha [2,250 a.]; from Colvin 1984).

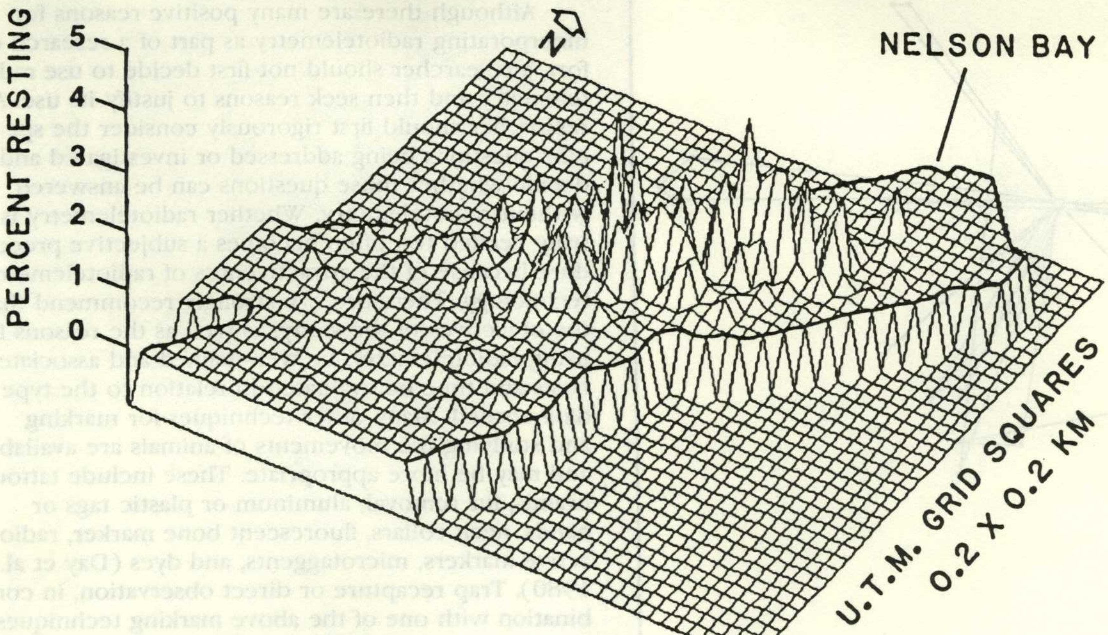


Figure 5. Distribution of resting locations (N = 1,163) of radio-tagged sea otters in Nelson Bay, a male area in Prince William Sound, Alaska, 1979-1981. Preferred rest area was near the center of the Bay (from Garshelis and Garshelis 1984).

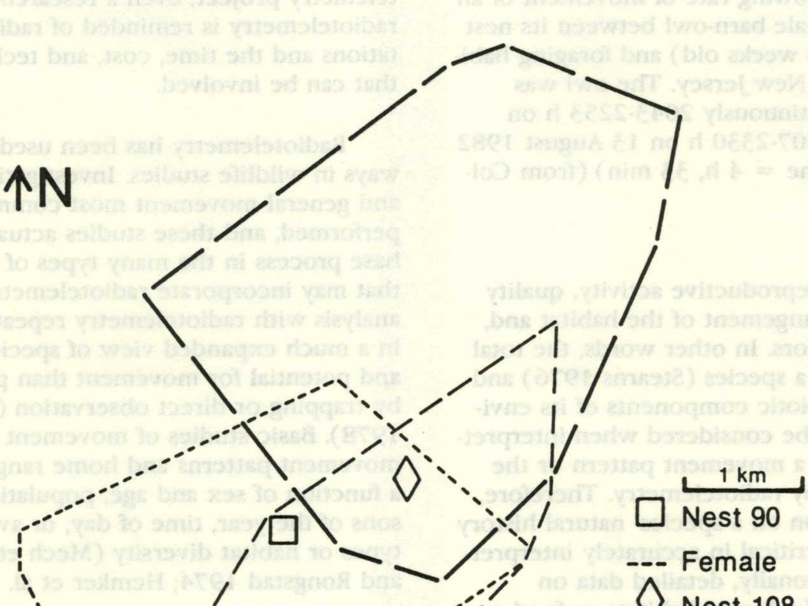


Figure 6. Home range overlap of three adult, common barn owls, radio-tracked in southwest New Jersey, June-July 1982 (from Colvin 1984).

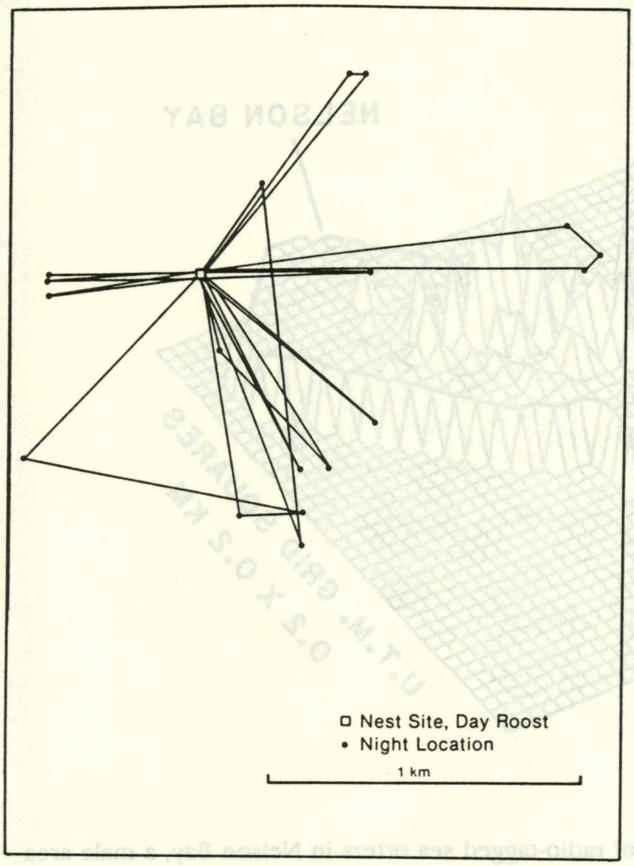


Figure 7. Pattern showing rate of movement of an adult, common male barn-owl between its nest site (3 young, 7.5 weeks old) and foraging habitats in southwest New Jersey. The owl was radio-tracked continuously 2043-2253 h on 12 August and 2107-2330 h on 13 August 1982 (total tracking time = 4 h, 33 min) (from Colvin 1984).

species, food supply, reproductive activity, quality and physiographic arrangement of the habitat and, likely, many other factors. In other words, the total life-history strategy of a species (Stearns 1976) and both the biotic and abiotic components of its environment may have to be considered when interpreting the significance of a movement pattern or the habitat use disclosed by radiotelemetry. Therefore, background information on a species' natural history and ecology become critical in accurately interpreting movements. Additionally, detailed data on weather; availability of selected habitats or food resources; population density; and animal age, sex, and reproductive state all may be essential in evaluating movements and successfully completing the project. Certainly, radiotelemetry locations can be plotted and presented; however, the researcher who interprets the data in context with species' ecology will get the most out of the time, effort, and finances invested in radiotelemetry studies.

DISCUSSION

Although there are many positive reasons for incorporating radiotelemetry as part of a research effort, a researcher should not first decide to use radiotelemetry and then seek reasons to justify its use. A researcher should first rigorously consider the specific questions being addressed or investigated and decide whether those questions can be answered without radiotelemetry. Whether radiotelemetry is truly needed too often becomes a subjective procedure because of the attractiveness of radiotelemetry technology. Therefore, we strongly recommend that the objectives of the study, as well as the reasons for using radiotelemetry, be well-defined and associated costs and time be evaluated in relation to the type of data needed. Many other techniques for marking and studying the movements of animals are available and may be more appropriate. These include tattoos, brands, fur removal, aluminum or plastic tags or bands, neck collars, fluorescent bone marker, radioactive markers, microtaggents, and dyes (Day et al. 1980). Trap recapture or direct observation, in combination with one of the above marking techniques, may prove more appropriate than radiotelemetry given specific research designs, budgets, and personnel constraints.

To the novice, radiotelemetry may appear to be an efficient, simple, and exciting way to study wildlife. However, when considering initiation of a radiotelemetry project, even a researcher experienced in radiotelemetry is reminded of radiotelemetry's limitations and the time, cost, and technical problems that can be involved.

Radiotelemetry has been used in many specific ways in wildlife studies. Investigations of home range and general movement most commonly have been performed, and these studies actually are often the base process in the many types of wildlife research that may incorporate radiotelemetry. Home range analysis with radiotelemetry repeatedly has resulted in a much expanded view of species' home range and potential for movement than previously detected by trapping or direct observation (Taylor and Quy 1978). Basic studies of movement may focus on how movement patterns and home range size change as a function of sex and age, population density, seasons of the year, time of day, or available habitat types or habitat diversity (Mech et al. 1966; Trent and Rongstad 1974; Hemker et al. 1984).

Beyond the initial documentation of movement are important opportunities to investigate habitat use and habitat requirements and to find migration routes, wintering areas, nesting sites, and foraging areas (Marshall et al. 1962; Curtis and Braun 1983; Loft et al. 1984). Also, the positive or negative impact of various land management or land-use practices on wildlife may be discernible from radio-

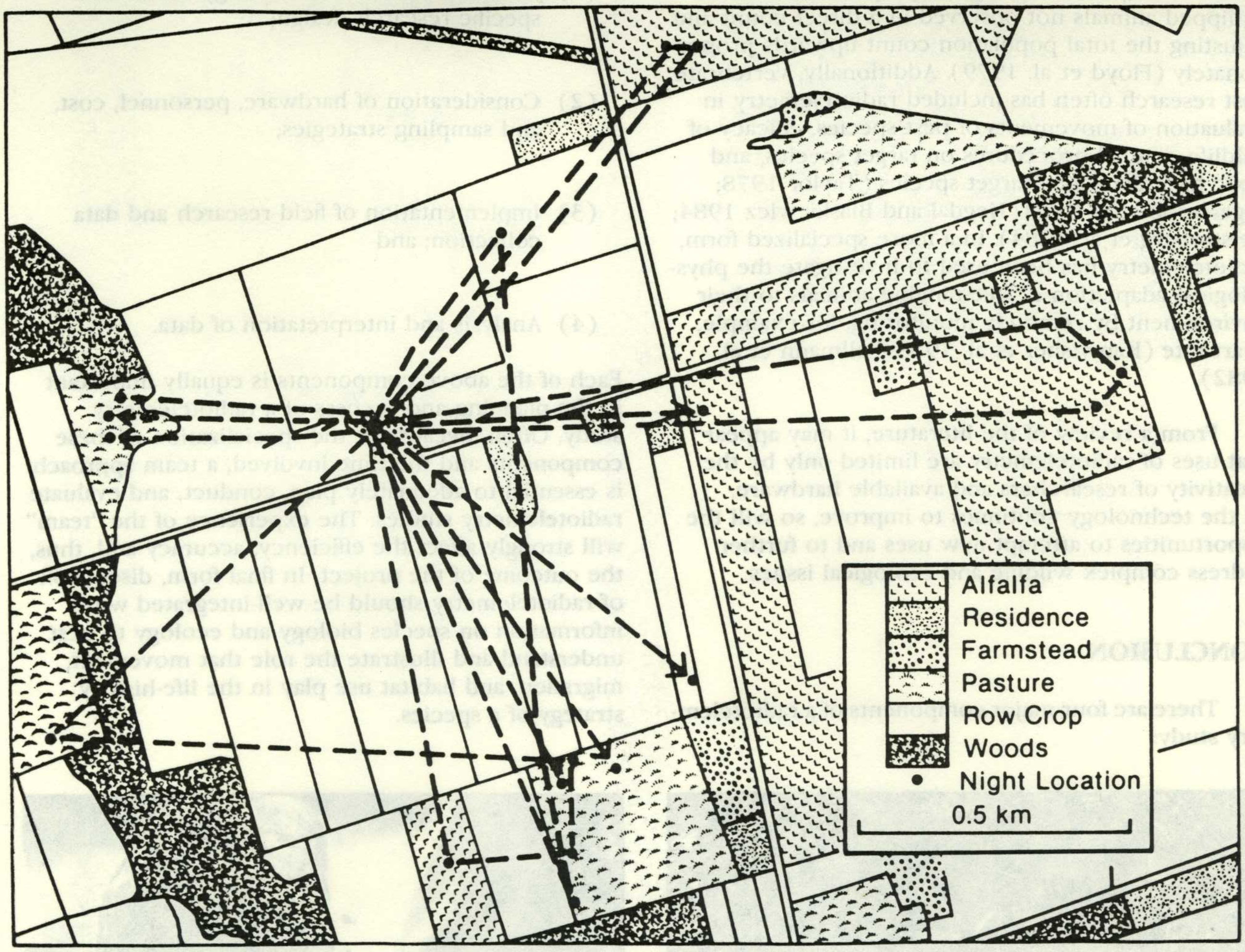


Figure 8. Movement pattern and habitats intercepted by an adult male common barn-owl with 3 young, 7.5 weeks old, in southwest New Jersey. The owl was continuously radio-tracked 2043-2253 h on 12 August and 2107-2330 h on 13 August 1982 (total tracking-time = 4 h, 33 min.) (from Colvin 1984).

equipped individuals that are subjected to a changing environment. When radio-tracking and habitat analysis are conducted in combination, a perceptive view of discrete habitat requirements and relationships between habitat and population maintenance may be achieved (Kohn and Mooty 1971; Jenkins and Starkey 1984; Pierce and Peek 1984; Riley and Dood 1984).

Examination of population dynamics, including age-specific survival rates and mortality factors, has been studied often with radiotelemetry (Stoddart 1970; Cook et al. 1971; Barrett 1984). A radio transmitter allows continued survivorship to be documented or, conversely, mortality to be documented essentially when it occurs. Thus, for example, a more accurate representation of the occurrence of various mortality factors in a population can be determined, compared to when radiotelemetry is not used, and emphasis is placed on those mortality factors that are most easily identified (e.g., car collision). Predator-prey relationships also can be studied and provide additional insight into population dynamics (Mech 1967; Kolenosky 1972; Franzmann et al. 1980; Fuller and Keith 1980).

Radiotelemetry also provides great advantages in endangered species research because radio-equipping a single individual can potentially locate conspecifics in an efficient and non-disruptive manner (Mech 1977; Fagerstone et al. 1985). In addition, because endangered, rare, or threatened wildlife often have highly specific habitat requirements, these "micro" habitats may be more clearly and quickly identified with radiotelemetry and thus protected.

Other uses of radiotelemetry have included monitoring the status and movements of animals involved in translocations or reintroductions (Fritts et al. 1984). Also, population censusing has been conducted by determining the proportion of radio-equipped animals not observed in a direct count and adjusting the total population count upwards proportionately (Floyd et al. 1979). Additionally, vertebrate pest research often has included radiotelemetry in evaluation of movements of pest species, efficacy of wildlife control procedures on target species, and toxic hazards to non-target species (Taylor 1978; Fagerstone et al. 1981; Hegdal and Blaskiewicz 1984; Heisterberg et al. 1984). In a more specialized form, radiotelemetry has been used to investigate the physiological adaptation of free-ranging animals to their environment by remotely monitoring, for example, heart rate (Kanwisher et al. 1978; Follmann et al. 1982).

From a review of the literature, it may appear that uses of radiotelemetry are limited only by the creativity of researchers and available hardware. As the technology continues to improve, so will the opportunities to attempt new uses and to further address complex wildlife and ecological issues.

CONCLUSION

There are four major components of a radiotelemetry study:

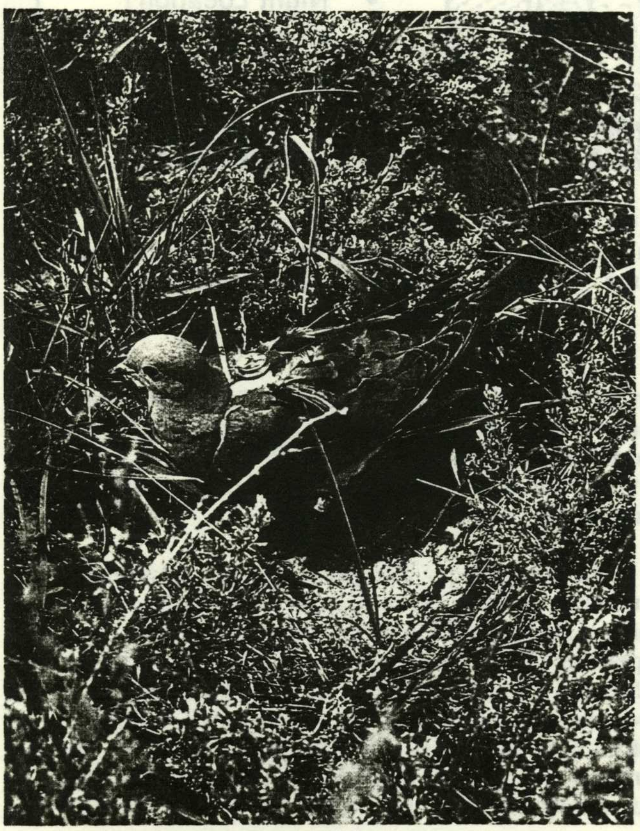
(1) Justified use of the technology based on a specific research design;

(2) Consideration of hardware, personnel, cost, and sampling strategies;

(3) Implementation of field research and data collection; and

(4) Analysis and interpretation of data.

Each of the above components is equally important in the planning and success of a radiotelemetry study. Often, because of the specialization of these components and the time involved, a team approach is essential to adequately plan, conduct, and evaluate radiotelemetry studies. The experience of the "team" will strongly affect the efficiency, accuracy and, thus, the outcome of the project. In final form, discussion of radiotelemetry should be well-integrated with information on species biology and ecology to best understand and illustrate the role that movement, migration, and habitat use play in the life-history strategy of a species.


U.S. Fish and Wildlife Service

Radio-tagged mourning dove.


U.S. Fish and Wildlife Service

Barn owl instrumented with a transmitter and whip antenna.

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