ICBP Technical Publication No. 5, 1985

RAPTOR RADIO-TRACKING AND TELEMETRY

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ABSTRACT

The first part of this paper provides advice on buying or building equipment, on attaching transmitters to raptors and on field techniques. Three attachment methods are described, and data are given on weight, range and life limitations of transmitter packages. The second part describes the types of information available from the radio-tracking of raptors, to investigate movements, range-sizes and habitat-use, predation, the survival of released birds and the population dynamics of wild raptors. Other applications have included the use of transmitters with sensors which modulate the radio signal, for telemetry of foraging and incubation behaviour.

INTRODUCTION

Many raptors live widely dispersed, cover large ranges, and are shy or nocturnal. This makes it difficult to study them outside the breeding season unless they can be radio-tracked. Fortunately, most species are large enough to carry transmitters with several months of battery life. Moreover, the tail feathers tend to be longer and sturdier in raptors than in many other birds, enabling transmitters to be tail-mounted and thus minimize the possible adverse effects of radio-tagging. During the last two decades radio-tracking has been used to study many aspects of raptor ecology. It is hoped that the following brief review of equipment and applications will help those still unfamiliar with the technique and perhaps give some new ideas to those already radio-tagging hawks.

EQUIPMENT

Procurement

The basic equipment consists of the receiving antenna, receiver and earphones or earplug carried by the tracker, and the transmitter attached to the bird. Equipment can now be obtained from at least ten firms in North America and Europe; suppliers found satisfactory by the author and reviewers are listed in the Appendix. Receivers cost from about £300 ($550) upwards, although $250–300 falconry receivers from Biotrack or Wildlife Materials Inc. (see Appendix) may be suitable for those using up to six transmitters. It is not worth wasting time trying to work with home-made receivers or converted broad-band radios. Basic transmitters

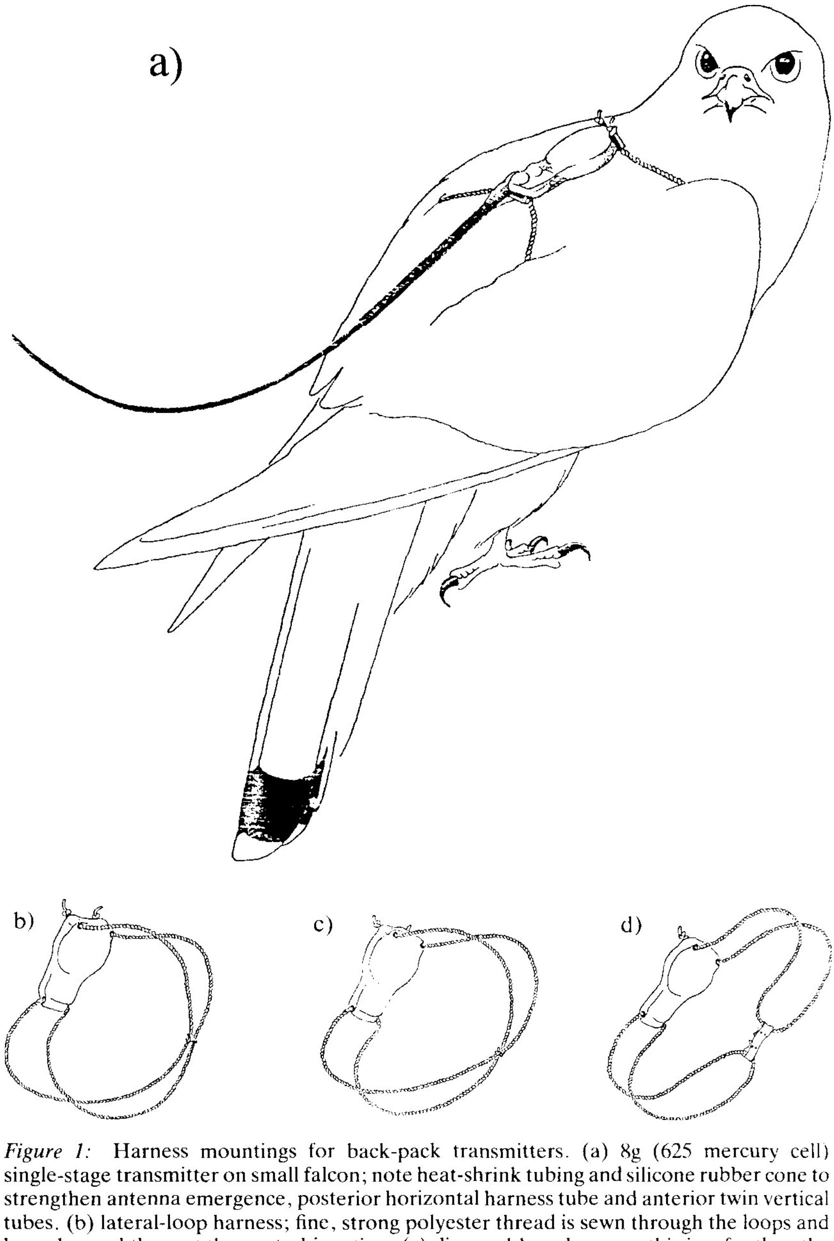

Figure 1: Harness mountings for back-pack transmitters. (a) 8g (625 mercury cell) single-stage transmitter on small falcon; note heat-shrink tubing and silicone rubber cone to strengthen antenna emergence, posterior horizontal harness tube and anterior twin vertical tubes. (b) lateral-loop harness; fine, strong polyester thread is sewn through the loops and bound round them at the ventral junction. (c) diagonal-loop harness; this is safer than the lateral-loop attachment since it is less likely to trap wings if the ventral tie breaks; with large raptors the loops may be tied ventrally at front and back of the sternum, running parallel between. (d) neck-and-body-loop harness, joined ventrally by fabric or plastic strip, which must not break or the raptor may be strangled. If harness loops are joined with dissolving sutures on top of package between anterior tubes, and not knotted, safe detachment of package is likely.

can be obtained from about £20 ($35) upwards, or from £30 ($55) for ready-to-mount packages including batteries and antenna. Circuits are available for building one's own transmitters (Cochran 1967; MacDonald & Amlaner 1980; Church 1980; Keuchle 1982), but much time must be spent finding sources of some components and on learning to build, tune and package the circuits for adequate performance, so it is best to buy transmitters too unless more than about 50 are required.

Adequate instructions for the use of equipment are given by most suppliers, and advice on tracking raptors can be found in falconry journals (Grier 1970; Cochran 1972; Kenward 1980a), and an earlier review (Kenward 1980b).

Radio frequencies

The best frequencies for ground-based raptor tracking are in the region 140–220MHz. Below this range the dimensions of efficient antennas ($\propto$ 1/frequency) become too great for convenience, and above this range signal absorption by vegetation becomes an appreciable problem (although higher frequencies may be useful in barren terrain). It is also important to avoid frequencies that are close to, or close to harmonics of, powerful or inefficient transmitters of the type used by some armed forces and Citizens Band radio operators.

Receiving system

Hand-held receiving antennas are usually three-element Yagi or H-Adcock types (Beaty & Swapp 1978; Amlaner 1980), and should be strong but light. Folding antennas may seem a good idea for easy carriage, but in practice they are usually heavier than rigid types and more easily damaged.

Many receivers have a built-in loudspeaker, but headphones are essential for detecting the subtle signal variations that indicate direction and activity. A single ear-plug is a useful alternative to double ear-phones if one wants to remain aware of other sounds, such as raptor vocalizations or prey alarm calls.

Most receivers will admit water during rain, but this problem can be avoided by placing them when necessary in a transparent plastic bag. An elastic band will close the bag's open end round the antenna and other leads. The bag should be flexible enough for the controls to be moved from the outside, and will probably need replacing frequently. If more than about 15 birds are to be tracked at the same time, and especially if fast-moving searches (e.g. by aircraft) for several 'lost' transmitters are contemplated, it is worth investing in a programmable receiver which can memorize and automatically scan through a number of different frequencies: however, most programmable receivers are unnecessarily large for tracking small numbers of birds. There are further comments on choosing a receiver in Kenward (1982a).

Transmitters

Raptor transmitter packages typically weigh 4–100g (1.5g packages are also available), with a 15–35cm main whip antenna and sometimes a shorter ground-plane antenna. The packages are usually either harness-mounted on the back (*Figure 1a*), fastened to one or two rectrices (*Figure 2*), attached with an anklet to the leg (*Figure 3*), or on a patagial tag on large raptors.

TRANSMITTER ATTACHMENT

Harnesses were used for the first transmitters mounted on raptors (Southern 1964) and have been widely used subsequently, although there are reports of

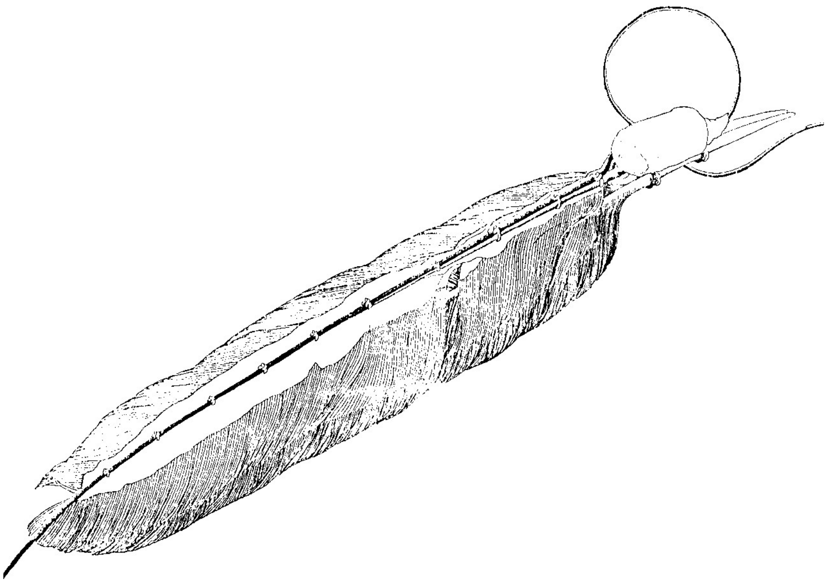

Figure 2: Goshawk tail feathers (shown detached) with 14g posture-sensing transmitter powered by lithium/copper-oxide (Saft-Sogea LCO2) cell. Note main antenna bound and glued to the left feather, to which the package is also sewn and glued; package threads are tied round the right feather and the knots sealed with glue without fastening them to the shaft; also note silicone rubber support cone for ground-plane antenna; position of mercury tilt-switch is shown dotted near main antenna emergence.

raptors becoming entangled in harness straps (Nicholls & Warner 1968; E. Hahn, pers. comm.) and adverse effects of harnesses on behaviour or survival have been recorded for other birds (e.g. Boag 1972; Ramakka 1972; Greenwood & Sargeant 1973; Gilmer *et al.* 1974; Lance & Watson 1977; Amlaner *et al.* 1978; Johnson & Berner 1980). Loops of braided or woven artificial fibre, the softer the better, pass from the 'corners' of the package and are joined under the breast (Nicholls & Warner 1968; Dunstan 1972). Loops which pass diagonally under the breast (*Figure 1b*) or from front to back under each wing (*Figure 1c*) are often easiest to form, but it is important that they are joined under the breast to prevent diagonal loops from slipping or lateral loops from trapping the wings above the back; lateral loops should not simply pass under each wing, a fastening sometimes used for galliformes and other birds with less upstroke than raptors. A third harness fastening is to use separate neck and body loops, fastened by a longitudinal strap under the breast (*Figure 1d*). Dunstan (1972) recommended this method for auto-release harnesses, using dissolving sutures to eventually part the neck loop so that the package falls off backwards without strangling the bird. Such weak-links are notorious for parting prematurely, but otherwise a raptor may carry the package for life. Harnesses should not have protrusions (e.g. knots) held tight against a bird's skin, because abrasion may result.

Anklets for attaching packages to legs should be made of soft but non-stretchable leather or synthetic substitute, and should not be on the same leg as a ring. Whereas harness-mounted back-packs can be five percent of a bird's weight,

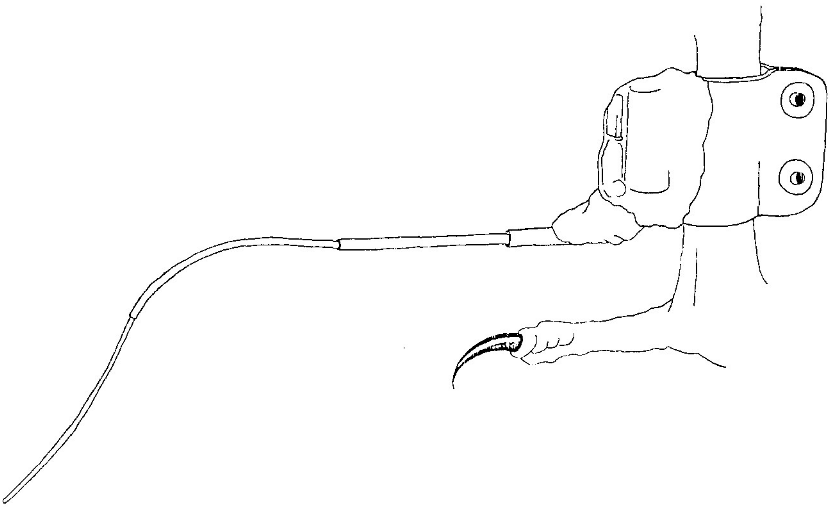

Figure 3: Transmitter package on anklet. Goshawks tend to tear at antenna emergence point, so use of silicone rubber and very tough heat-shrink tubing is essential there.

leg transmitters should probably not exceed two or three percent. Antennas must be shorter than for back-packs, and the signal strength is further reduced by low position and earthing effects when the bird is on the ground. Anklet-mounted antennas should also be stiff enough to reduce the risk of whipping round vegetation, but not so stiff that, if bent by the bird, they will stay hooked and thus liable to entanglement: it is difficult to find a material with these properties, and which does not break from metal fatigue within a couple of months. Best results on Goshawks (*Accipiter gentilis*) have been obtained with dental-brace wire (C. Zachel, pers. comm.) and with 49-strand stainless-steel wire in relatively stiff heat-shrink tubing. It is especially important to avoid a sharp discontinuity where the antenna leaves the package, using a cone of silicone rubber (e.g. Dow-Corning Silastic 732) or of several heat-shrink tubing layers (*Figures 2* and *3*) rather than a spring, which can catch in vegetation.

Tail-mount transmitters (Dunstan 1973; Fuller & Tester 1973; Kenward 1978) are best for most raptors unless (i) rectrices of young birds are not yet fully grown, (ii) monitoring of older birds must continue without a recapture through moult(s), or (iii) the normal maximum tail-mount weight of two to three percent must be exceeded. In case (i) anklets may be preferred because harnesses can damage growing body feathers. Back-packs are necessary in case (iii). Goshawks with tail-mounted transmitters did not differ in weight-changes or recapture frequency from hawks marked only with leg rings (bands), and a male Sparrowhawk (*Accipiter nisus*) with a transmitter at 3.5 percent of bodyweight brought prey to the nest as frequently with a tail-mounted package as beforehand (Kenward 1978).

Tail-mounted packages have been sewn or taped, dorsally or ventrally, to the base of one or two rectrices, with the main antenna free-standing or fastened along the shaft of a feather. In the method now used for more than 200 Goshawks (*Figure 2*), four pairs of braided polyester attachment threads emerge from the corners of the package. The pairs on one side are sewn (using a curved suture needle) through one feather, to which the package is also glued with the main antenna bound along the shaft. The pairs on the other side are tied round the adjacent feather and the knots sealed with glue. Both feathers thus bear the weight, but they moult independently (and the radio can then be recovered if still transmitting). The package is mounted dorsally, for ease of attachment without risk of hindering the hawk's copulation, and is normally fixed to the two central rectrices. Since these are usually the first tail feathers to moult, however, for long attachment the package is sewn to the second innermost feather and tied around the third. Binding the 30cm main antenna to the feather shaft provides support, so that a lighter antenna can be used than if it were free. It is important that a flexible glue which binds well to feather (e.g. contact adhesive) is used, to fasten the antenna to the shaft, spread evenly and with frequent thread ties, because cracks in a rigid glue or other discontinuities provide stress foci at which the feather may ultimately break. The antenna too is stressed at the feather end or at breaks, so a flexible yet strong material is necessary. Multi-strand stainless steel wire is satisfactory, polyester or heat-shrink coated 19–49 strand aircraft control cable being somewhat better than nylon-coated 7–9 strand fishing trace wire, although this fishing-trace (with a silicone rubber emergence-support cone) is adequate for the 20cm ground plane antenna.

A disadvantage of this technique is that the packages take 20–40 minutes to mount. Hawks are not anaesthetized because this risks injury to birds released with (undetected) incomplete recovery, but are wrapped in towelling or more sophisticated jackets (Fuller 1975). Two hawks in more than 200 have died from circulatory failure following a prolonged fixing operation, in each case associated with unusually vigorous struggling and rapid breathing, so signs of distress must be watched for. Another three to four percent of hawks shed their radio-tagged tail feathers within about a week of fixing, probably because of bruising at the feather bases due to insufficient care when attaching packages.

Another technique, for large raptors which do not flap their wings rapidly (e.g. vultures), is to mount a small transmitter as a patagial tag. This technique has been used on Andean Condors without apparent ill-effects.

WEIGHT, LIFE AND RANGE OF TRANSMITTER PACKAGES

Although 1.5g packages could probably be tail-mounted on the smallest falconets, 2.5g back-packs might be preferable. With mercury batteries these would give 10–15 and 20–30 day lives respectively, but it would be better to use the equivalent size zinc-air batteries (Activair A312HP and A13HP), which are a recent development giving about twice the life of the mercury cells. Four-gram tail-mounts, for European Kestrels (*Falco tinnunculus*) and Sparrowhawks, will run for two to three months with 675-size mercury batteries, the shorter life being with high power output. High power output can be obtained for at least three months with Activair A675HP battery, but the manufacturers do not rate this battery for operation more than three months after activation (although one low-power four-gram package has run for six months with this battery). Seven to eight gram packages based on 4.5g (625-size) mercury batteries give three to five months life, but if possible it is best to use 1.5V lithium/copper-oxide cells (Saft-Sogea); the LCO2 lithium cell weighs 7.5g with 1400 mah, 2.5-times the energy density of the 350 mah mercury battery. Goshawk tail-mounts using the LCO2 weigh *c.* 12g and give 9–18 months life (depending on power), and a 14g package including a mercury switch as a tail-position sensor has proved very useful for indicating hawk activity: a capacitative sub-circuit produces a slow signal pulse rate when a hawk is perched, a fast pulse when it flies, and a characteristic irregular pulse when it feeds (Kenward *et al.* 1982). Flight-sensing is also possible using an under-wing thermistor on a back-pack harness.

Using hand-held three-element Yagi receiving antennas with receivers which permit signal detection at 145dB, the Goshawk transmitters give working ranges of 500–1000m from hawks on the ground, 3–5km from hawks in trees, and 10–15km from birds in flight, across flat ground. Range can be greatly increased by raising the receiving system on car roofs or buildings, hills or even aircraft (Gilmer *et al.* 1981), or on collapsible, portable masts (Kolz & Johnson 1975). Perched Goshawks have been detected at 15km and flying hawks at 22km from 40m hills. Use of such high points is essential for successful radio-tracking of wide-ranging species. With 20cm transmitting antennas on smaller hawks, similar single-stage transmitters may give half the ranges of Goshawk transmitters. Where greater transmitter power is necessary for tracking over very long distances or in country that hinders signal propagation (e.g. dense, humid forests), transmitters with higher voltages and one or more amplification stages may be required, but this substantially reduces battery life at the same weight. For instance, a 30g two-stage package might run for six to nine months with twice the range of a 30g single-stage package, but the latter would last for two to three years (with a 3500 mah LCO1 battery).

Package life of several years at relatively low weight is also possible using solar power (Church 1980). Driven by solar panels alone, packages need weigh only 6g (single-stage) to 15g (two-stage), but will stop transmitting at night, in nest-holes, in forest on dull days, and if birds die upside-down. Slightly heavier packages (10.5 and 17g) can be built with 20 mah nickel-cadmium cells, which are charged by the solar panels to provide power in poor light, but Ni-Cads subject to frequent unregulated charging are less reliable than primary cells with no solar input (Ko 1980; Keuchle 1982). Solar-powered packages must also be harness or patagial tag mounted. Since bird, harness and antenna life may well be less than two years, a life attainable with 12g single-stage and 50g two-stage packages, solar power really only gains over primary cells if package life must be at least six months and weight 6–12g (single-stage) or 15–50g (two-stage).

APPLICATIONS

Early radio-tracking of raptors was concerned mainly with movements, range-sizes and habitat-use. The pioneering work of Southern (1964) on Bald Eagles (*Haliaeetus leucocephalus*) was followed by research at Cedar Creek, in Minnesota, on several diurnal raptor and owl species. The automatic tracking facility developed at Cedar Creek was ideal for investigating diurnal and seasonal variation in habitat use by different species, which is important information for conservation land management and particularly difficult to study in nocturnal birds (Nicholls & Warner 1968, 1972; Fuller *et al.* 1974; Forbes & Warner 1974). Great Horned Owl (*Bubo virginianus*) and Red-tailed Hawk (*Buteo jamaicensis*) range and habitat use were determined in Wisconsin, USA, by Petersen (1979) and owl ranges were also studied in Britain by Hardy (1977). Some information was gained on the elusive accipiters by Platt (1973), who studied foraging through the breeding season by a pair of Sharp-shinned Hawks (*Accipiter striatus*), and by Bendock (1975), who noted roost positions of a female Goshawk prior to breeding. Fuller (1979) went beyond the single-species approach in studying how four North American raptors with apparently similar requirements partitioned their use of an area's resources in space and time. The importance of conserving feeding habitats as well as breeding sites was realized in reserve planning at Snake River in Idaho, where radio-tracked raptors which nested on the riparian cliffs were found to hunt far out on surrounding farmland (Chaney 1979; Dunstan 1979). Even towns can be important as unexpected winter habitats for some raptors (Dietrich & Ellenberg 1981). Future studies must consider not just the habitats used by a species in one area at one time of year, but should investigate habitat use in relation to hunting success in different seasons, to determine the minimum components needed for survival as man changes the environment. A start in this direction has been made by Bechard (1982), who investigated *Buteo* hunting during the harvesting of various crops, and in a study of Goshawk habitat use in areas with different proportions of woodland and differing prey densities (Kenward 1982b).

Whereas ringing, trapping and hawk-watching give a broad picture of migration and dispersal patterns, radio-tracking can be valuable for studying the fine detail. The first long-distance radio-tracking of migrating raptors involved following Sharp-shinned Hawks and Peregrines (*Falco peregrinus*) with aircraft (Cochran 1972, 1975), followed by tracking of dispersing Hen Harriers (*Circus cyaneus*) by Beske (1982). More quantitative studies are now being done on habitat use by migrating Peregrines (Hunt & Ward, this volume) and Sharp-shinned Hawks (Holthuijzen *et al.*, this volume) to determine the characteristics of staging areas. Large raptors could carry transmitter packages suitable for satellite tracking (Craighead & Dunstan 1976), which may in future be used to study long-distance movements.

Beyond radio-location work, radio-tagging has also been used to study raptor behaviour. Hunting behaviour of secretive species was investigated without the bias inherent in chance observations (Nilsson 1978; Widén 1981; Kenward 1982b), and transmitters were used to check the validity of sightings in a range-use study of wing-tagged Kestrels (Village 1982). Techniques have been developed for tracking Goshawks to recover their kills for investigation of impact on prey populations (Kenward 1977, 1979; Kenward, Marcström & Karlbom 1981). Comparing kills found in an area by radio-tracking with those detected in visual searches, Ziesemer (1981) has shown that unaided searches may find all kills of species with highly conspicuous remains, such as pigeons, but only a third of pheasant kills and one in eight rabbits.

Physiological telemetry, with implanted electrodes attached to external harness-mounted transmitters, has been used to investigate heart rates and body temperatures in captive and free-living raptors in Estonia and the USA (Keskpaik & Horma 1972, 1973; Sawby & Gessaman 1974; Gessaman 1980; Hayes & Gessaman 1980), while implanted strain-gauge systems have telemetered gastric motility data from owls (Fuller *et al.* 1977). Used in studies of reproduction, useful data on incubation behaviour and temperatures have been gained by radio-telemetry using sensors in artificial eggs of raptors in enclosures and in the wild (Ellis & Varney 1973; Schwartz *et al.* 1977).

Radio-tracking can help in understanding raptor population dynamics. Marquiss & Newton (1982) used the technique extensively to investigate the spacing of neighbouring Sparrowhawk pairs and the mechanism relating breeding success to food availability. Hawks which foraged farthest from the nest were least successful, while artificial feeding minimized the foraging distances. Radio-tagging can also be used to study timing and causes of mortality, for identifying danger-points in life histories, especially where species are too rare for adequate data from ringing or where substantial bias is likely because most recovered rings come from birds killed by man.

In raptor management work, radio-tracking has been used extensively to monitor the survival of released birds. Indeed, it is an essential tool if rapid information is to be obtained on the success of different release techniques with minimum wastage of birds. North American Peregrine breeding and release programmes made much use of radio-tracking in the early stages (Kaufmann & Meng 1975; Sherrod *et al.* 1981), and the importance of falconry for re-establishing British Goshawks has been investigated by releasing radio-tagged trained hawks (Kenward *et al.* 1981). Much more work needs to be done on the success of techniques used to treat and release wild raptors after injury or other incapacitation; hundreds of these birds are released annually, yet only a handful have been radio-tagged (Serveen & English 1976; Redig *et al.* 1981).

For those unfamiliar with it, radio-tracking often seems an exotic and daunting technique, but this need no longer be the case for raptor biologists. Equipment is readily available and techniques have been developed for its use. The cost is not high compared with the labour needed to obtain similar data in other ways, if such data can be obtained at all. No doubt the future will see many improvements in the technology, but radio-tracking will remain an important tool for raptor research and conservation in the years to come.

ACKNOWLEDGEMENTS

I take this opportunity to thank those who helped me start radio-tracking raptors and building equipment, especially C. J. Amlaner, M. Dolan, T. C. Dunstan and M. R. Fuller. I am also grateful to M. Karlbom for radio-tagging and tracking so many Goshawks, to J. L. Holm for drawing the diagrams, and to I. Newton for advice at all stages.

APPENDIX 1: SUPPLIERS OF EQUIPMENT

Advanced Telemetry Systems, Inc., 23859 NE Highway 65, Bethel, MN 55005 USA

Biotrack, Stoborough Croft, Grange Road, Wareham, Dorset, UK

Custom Electronics, 2009 Silver Ct. W., Urbana, IL 61801, USA

Televilt, P1 5226, 710 50 Storå, Sweden

Teleonics, 1300 W. University, Mesa, AZ 85201, USA

Wildlife Materials, Inc., R.R.1, Carbondale, IL 62901, USA

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