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STATE OF THE ART TELEMETRY EQUIPMENT APPROPRIATE FOR VERTEBRATE PEST CONTROL RESEARCH

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ABSTRACT: Constant developments in technology, both materials and methods, allow smaller and smaller animals to be radio-tracked for longer periods of time than was previously possible. Developments in electronic component miniaturization and battery chemistry are primarily responsible for this advancement. Approximately 30 years of field-use of radiotelemetry techniques have led to innovative procedures and uses of materials for the application of transmitters to animals. New technology such as satellite telemetry and recapture collars are only in their infancy and are not, at this time, appropriate for use in vertebrate pest research. Sophistication in receiving systems also allows more accurate and more complete data to be collected. This paper is not intended to be a review of telemetry devices on the cutting-edge of technology or non-field-proven developmental systems, but rather presents an overview of currently available, on-the-market technology appropriate for use by vertebrate pest researchers. As it is a review paper, not a research paper, it does not strictly follow the standard research paper format.

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INTRODUCTION

While I was working on this paper several weeks ago, I looked around my office for inspiration. I saw an eagle backpack, I saw a kit fox collar, and I saw Bernie Peyton, so I verbalized my thoughts and said, "Bernie, are vertebrate pest and endangered species mutually exclusive terms?"

Bernie said, "No, not at all. For instance, I've heard that kit foxes often open live traps on a trap line and eat whatever's in them: antelope ground squirrels, K-rats, anything. So to some people they're pests." This led me to the conclusion that, indeed, the phrases "vertebrate pest" and "endangered species" are not only mutually exclusive, but often characterize the same group of animals.

I then contemplated whether the selection of equipment with which to study vertebrate pests was really any different than the equipment selected to study any other group of vertebrates. This time I answered my own question. There is no difference in the instrumentation; "pest" or "nonpest" merely depends on the perspective of the researcher. How a researcher views a golden eagle (Aquila chrysaetos) may merely depend on whether he is employed by the U.S. Department of the Interior, Fish and Wildlife Service, or the U.S. Department of Agriculture, Animal Damage Control. However, his requirements for the radiotelemetry package he will place on that eagle are independent of the agency that issues his paycheck; they are determined by the needs of his study and by the eagle.

During the course of this paper many unpublished studies will be referred to; some of these studies will be published, others will never be published. There are no data giving information concerning what percentage of studies facilitated by radio instrumentation are eventually described in publication. I can only say that I know that many research projects, including many very good projects, go unpublished. Many graduate students never write their dissertations nor the subsequent papers that are often derived from their dissertation research. This means that their work may never become known.

Employees of state governments appear to be the worst offenders in this area. Many studies done under the aegis of state conservation commissions, state departments of fish and game, or state departments of natural resources result in in-house position papers which are read, noted, acted upon, and filed. Many of these papers never see the light of day outside the agencies by whom their authors are employed. Perhaps this phenomenon is caused by lack of time or by lack of the near-paranoia created by the "publish or perish" mindset prevalent in academia. For whatever reason, it is still a shame that the results of so much research go unnoticed.

My own personal favorite anecdote illustrating this phenomenon is as follows: While driving across the United States several years ago, I camped overnight at a state park in which a state research facility was located. My firm had for many years instrumented an extensive quail (Colinus virginianus) project with the smallest solar-assisted transmitters that had ever been made. I had designed these transmitters for this project and had always taken a keen personal interest in the project because it was so much on the cutting edge of technology. Leaving the campground in the morning, I spied a truck driving toward me with the unmistakable Yagi antennas protruding from the top. I stopped my vehicle, stopped the truck, and introduced myself to the researcher with whom I had, of course, spent many hours on the phone over the years. After chatting for a while, he proceeded to inform me that the coming field season would be the last year for the study. I said, "What are you going to do, then?" It was almost a rhetorical question, as I knew that the reply would be, "I'll probably sit at a desk and crunch numbers for a year or two, given the amount of data we have accumulated over the past 5 years."

But no. He replied, "Pheasants (Phasianus colchicus). We're going to do a pheasant project."

AREAS OF PRODUCT ADVANCEMENT

Factors that separate the current generation of "state-of-the-art" radiotelemetry equipment from the previous generation of equipment fall into four categories:

1. Component miniaturization,
2. Development of more sophisticated power sources,
3. Advancements in attachment methods and/or materials, and
4. Computerized receiver control.

Although the areas of recapture collars and satellite telemetry might be listed by some, these two technologies have not been sufficiently developed to the point where they are marketable to the general research community nor are they of much use to vertebrate pest researchers. Vertebrate pest researchers generally need their equipment to be commercially available, off-the-shelf (or close to it); they need it now, and they often need it in large numbers.

COMPONENT MINIATURIZATION

Component miniaturization allows smaller and smaller study individuals to be instrumented. Component miniaturization also allows previously studied species to be studied with less experimental bias caused by package weight, profile, and volume. In 1967 the idea of radioinstrumenting most rodents and smaller birds would have been unthinkable.

Component miniaturization is perhaps the most easy factor to demonstrate. In order to demonstrate what a 1967 model, one-staged, simple oscillating, nonamplified transmitter looked like so that you could compare it to what is now state-of-the-art, I reconstructed and photographed an example of one.

The transmitters shown in Figure 1 are three forms of the same one-staged transmitter. The S-1 Transmitter was state-of-the-art in 1967. One first notices the HC18-sized crystal, then the transistor in the TO5 can. In order to save space, the oscillator coil was actually wound around the transistor can. This package weighed over 3 grams, before encapsulation, and lasted for 25 days, if we were very lucky.

The standard SM1 Transmitter replaced that S-1 in about 1974. The SM1-Mouse-Style Transmitter, pictured, is identical in size to the standard SM1, but it is called a "mouse style" because it requires no external antenna. Crystal packaging technology was responsible. When the first crystals of this size became available in 1972, they were quite developmental. One crystal alone cost $65 at that time.

The SM1-H Transmitter (Kermeen 1989) is a similar transmitter; the technological advancement here is not that the transmitter is different, but that parts now being used are tiny miniaturizations of the parts used in the two-staged transmitters; they are as durable as the larger parts of which they are miniaturizations. This allows us to power one-staged transmitters with power sources (in excess of 3 volts) that were formerly only able to be used on the larger two-staged transmitters. At a normal current drain, this transmitter can actually achieve the power output of a long-life, two-staged transmitter. The transmitter names used are trade names of AVM Instrument Company, Ltd., as those are the transmitters with which I have the most familiarity. However, the development of commercially manufactured transmitters by others has followed or will eventually follow the same progression.

The higher-powered transmitters, the two-staged transmitters, are transmitters composed of an oscillating circuit and an amplifying circuit. The SB2 Transmitter (Kermeen 1979) dates from about 1975 and is still commonly used today (Fig. 2). The transmitter components are packaged in an HC-6-sized crystal can. Its housing is evacuated, backfilled with dried nitrogen, and hermetically sealed, thus preventing the premature failure often seen in the past when dissimilar metals were soldered together and eventually formed corrosion at the solder joints. This 5-gram transmitter and other transmitters similar to it have been at the core of all transmitter application for mid-sized to large mammals and large birds since the mid-1970s.

Component miniaturization has allowed us to reduce the weight of a full two-staged transmitter from 5 grams to 800 milligrams, producing the P2 Transmitter. Applications of this transmitter have allowed researchers to do projects that were virtually impossible only 2 years ago. This transmitter, coupled, for instance, with solar assisted power, i.e., batteries under continuous charging by photovoltaic solar panels, have allowed us to produce the 9-gram eagle tail mounts and the condor patagial tags.

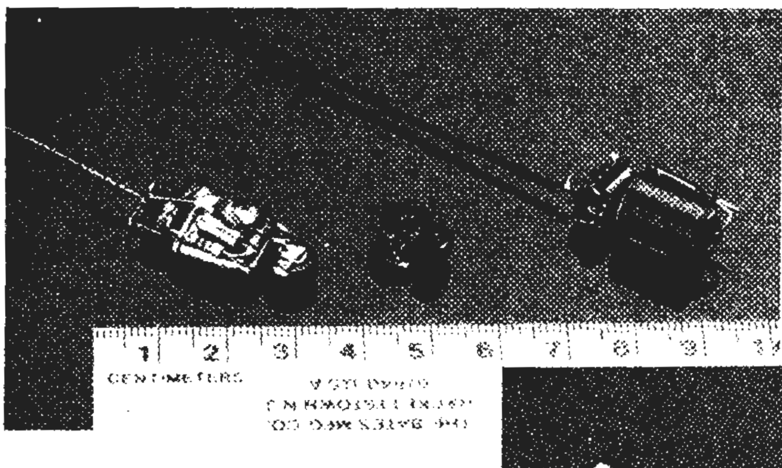

Figure 1. Three one-staged transmitters attached to their power sources: l-r, the S-1 powered by a 800-mg mercuric oxide cell at 1.35 volts; the SM1 transmitter powered by the same cell; and the SM1-H transmitter powered by a 2.7-gram lithium cell at 3.6 volts.

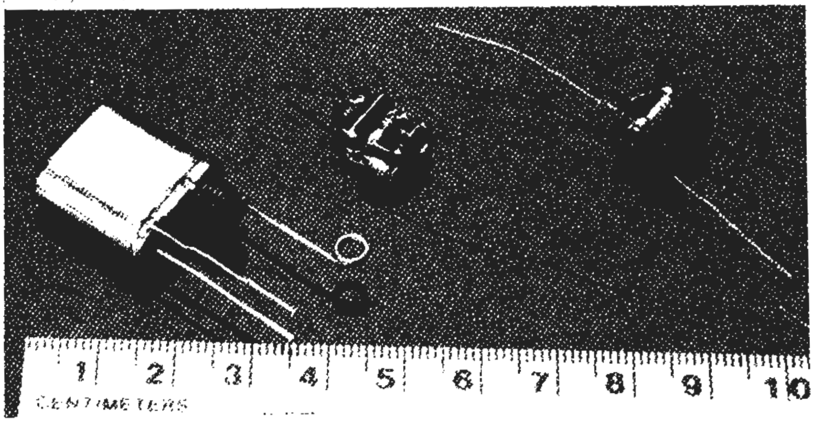

Figure 2. L-R, The SB2 transmitter, the P2 transmitter, and the TCC transmitter, all pictured without power sources.

The TCC Transmitter is similar to a one-staged transmitter controlled by a logic circuit. Although it does not appear to be significantly smaller than the transmitter in the center of the picture, its logic circuit allows it to be run at about half the current drain of the center transmitter. It can provide similar power output to the center transmitter running at low current consumption, but will last twice as long.

POWER SOURCE SOPHISTICATION

In the beginning, 1.35-volt mercuric oxide batteries were always used to power radio transmitters for two reasons: 1) they had the highest energy density, and 2) they had a level, constant discharge curve, i.e., they functioned at the same voltage for their entire working life, then rapidly dropped in voltage to 0 at the end of their usefulness. Carbon-zinc and alkaline batteries both had a linear-sloping discharge curve, meaning that they constantly dropped in voltage as they were used. Thus, at approximately the midpoint of their functional lives, their voltage was already too low to even turn on the transistor of a transmitter.

But mercury batteries were heavy, their shelf-life was poor, and sometimes as many as 6 batteries with a total weight of 240 grams had to be wired as seriesed pairs in parallel to get any kind of reasonable life out of a collar for a large animal.

The next generation was powered by lithium. The energy diversity of three commonly used radio telemetry power sources is provided in Figure 3. Beware of those who speak of lithium batteries without qualification. There are at least 10 different lithium battery chemistries, including lithium iodide, lithium sulfur dioxide, lithium lead bismuthate, lithium manganese dioxide, lithium bromine oxyhalide, lithium polycarbon monofluoride, and lithium thionyl chloride. Some are suitable for radiotelemetry applications and some are not. Lithium sulfur dioxide, produced primarily by the Mallory and Power Conversion Corporations, was the first lithium technology widely used in animal telemetry applications. The use of this 2.8-volt lithium technology was dangerous per se, and coupled with the fact that the individual cells had no internal fusing in their early production, they were doubly dangerous. We were fortunate that neither biologists nor study animals were ever seriously injured by explosions caused by the propensity of these batteries to internally short. This internal shorting caused a number of serious accidents in other areas of use, such as the explosion of an aircraft emergency locator transmitter powered by this type of cell.

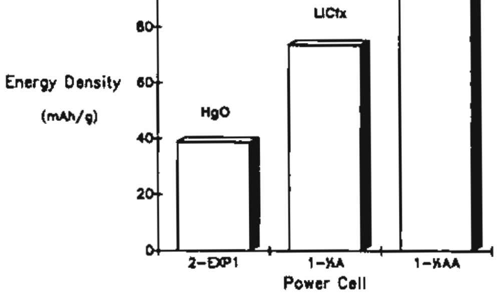

Figure 3. Energy density of three commonly used radiotelemetry power sources.

The second-generation lithium technology widely used to power radiotelemetry transmitters was 3.0-volt lithium polycarbon monofluoride produced by Panasonic and also marketed under the name National. Among the advantages of the use of this technology were that these cells had a very long life on the shelf and that we were now able to use one battery instead of seriesed pairs to provide the proper voltage to run an amplified transmitter. Unfortunately, lithium polycarbon monofluoride cells were subject to voltage drop in cold temperature. The drop was never more than about 0.8 volts, so transmitters almost never shut off due to cold, but they did begin to produce weaker and weaker signals as the temperature fell to near 0 degrees Celsius.

The current lithium chemistry-of-choice is lithium thionyl chloride. The energy density of a lithium thionyl chloride cell is about 2.5 times greater than the energy density of mercuric oxide. At 3.5 to 3.6 volts (usually about 3.4 volts under load), it allowed transmitters to operate at a lower current drain, thus making packages last longer and have higher power output while being powered by smaller, lighter batteries (Marincic 1983).

COMBINING COMPONENT MINIATURIZATION WITH ELECTROCHEMICAL SOPHISTICATION

An example of how component miniaturization and sophistication in power-source technology combine to produce successive generations of instrumentation used to study the same study species can be demonstrated by examining three generations of transmitters designed for use on spotted owls (Strix occidentalis) (Fig. 4). Generation one used a one-stage transmitter powered by a mercuric oxide battery. The typical weight of this package was 22 grams. Although its theoretical longevity was 18 months, one could only rely on it for about 14 months' performance.

The second generation was the miniaturized two-stage transmitter powered by the lithium thionyl chloride battery. At 16 grams, this unit weighed 6 grams less than the previous generation and produced twice the effective radiated power. These two units achieved equivalent life.

The third and current generation is also powered by lithium thionyl chloride technology, but it is now a custom-made cell, powering not a simple oscillator/amplifier combination but a transmitter whose pulsation is controlled by a logic circuit. The logic circuit is not used to monitor a specific parameter of animal behavior or physiology but only used to pulse the transmitter. It draws less current than the standard tantalum capacitor used to pulse a non-logic-controlled transmitter. Even though its transmitter portion weighs slightly more than the transmitter of generation two, it can achieve the same power output and longevity as the generation two unit because it draws only 40 microamps of current in comparison to the 80 microamps of the generation two unit. Therefore it can be powered by a lighter battery. The total package weight of the generation three unit has been reduced to ≤9 grams.

Spotted owls as vertebrate pests? Again, it depends on your perspective. See them as the employees of a timber company see them. I have seen bumper stickers in the Pacific Northwest recommending Kentucky Fried Spotted Owl. These technological advancements can, of course, be applied to many avian pests weighing in excess of about 500 grams.

Integrating component miniaturization, electrochemical sophistication, and cleverness in custom applications leads to specific transmitter packages like those shown in Figure 5. The collar at the left uses an extremely low current drain one-staged transmitter, powered by a lithium lead bismuthate battery. This is a very common combination of transmitter and battery, originally designed for rats (Rattus norvegicus); but until the State of California's Department of Health Services' Environmental Management Branch, "The Plague Patrol," required longevities of 6 months at a weight of approximately 4 grams with which to study chipmunks (Eutamias townsendii) and their ectoparasites, this state-of-the-art collar radiating signal through a capacitively tuned loop antenna, configured for this longevity, was not in common usage.

The collar pictured on the right, designed for a marsupial "mouse" (Phascogale calura) also utilizes a single-staged transmitter powered by an 800-mg mercuric oxide battery. This collar has been fabricated using a standard nylon cable-tie as the collar. Its tiny whip antenna is held in place by two pieces of heat-shrink tubing, one piece running from the transmitter/battery pod to the point at which the antenna exits from the collar, and the other, a smaller piece with a small pinpoint hole in it, extends about 2 mm on either side of the antenna exit point, sealing the distal end of the cable tie so that moisture cannot wick back to the transmitter around the antenna under the first piece of tubing. Weighing only 2.5 grams, this collar is appropriate for all but the very smallest mammal species. Another version of this collar, using an SM1 Mouse-style transmitter, can be made in the under 2-gram range and has been used on many of both Microtus spp. and Peromyscus spp.

Some species such as P. leucopus and P. maniculatus are difficult to collar with even this type of collar and are normally studied with the same battery/transmitter combination, but the instrumentation technique used must be intraperitoneal implantation.

Figure 6 shows a combination of the same transmitter and battery in a very different type of application. Note the small stainless steel arrow (Mauser 1990) attached to the end of the transmitter. Note also that the arrow is asymmetrical, one side being longer than the other.

This particular application has been used on mallard (Anas platyrynchos) ducklings which, of course, are not primarily known as a pest species. Extremely innovative applications often take longer to catch on and become accepted than do applications which are merely variations or combinations of commonly used methods. This application is so unique and working so well in the field that the author would be remiss in its omission.

Application to small birds has been a bete noir to biologists from the beginning of the use of radiotelemetry devices. Dave Mauser, of the Oregon Coop Wildlife Research Unit, developed this very creative technique for low weight, relatively long-life study of duckling survival. The 1990 model, weighing only 1.95 g, will transmit for an average of 60 days (-10, +15).

The attachment to the bird is made by gluing two sutures to the top of the package. Next, a small slit is made in the bird's skin at the base of the neck. The tip of the long side of the arrow is inserted into the slit and the arrow is rotated until the entire long side is under the skin of the bird. Rotation continues until the short side is also under the skin. Once the arrow is under the skin and the package is straightened so that the antenna is parallel to the bird's midline, the two sutures are passed under the transmitter package, under the skin, and returned to the top surface of the transmitter, where they are tied off, clipped, and secured with a drop of glue.

Mauser's descriptive paper on this technique is currently in press, and I do not wish to preempt him, but I think that the suitability of fast and certain attachment to large numbers of birds warrants the consideration of this new technique as being appropriate for the study of many species of smaller avian pests.

In closing this section, the following several clever radio applications are merely mentioned so that their existence will be known. These particular applications all have potential as good research tools, particularly appropriate for the instrumentation of vertebrate pest studies.

1. The installation of radio transmitters on livestock protection collars;
2. The installation of sensing logic transmitters, either temperature sensors or motion detectors, in the eggs of a prey species;
3. The radio tracking of poisoned baits;
4. The radio tracking of baits containing rabies vaccine;
5. The applications of transmitters to prey species in order to track the pest/predator;

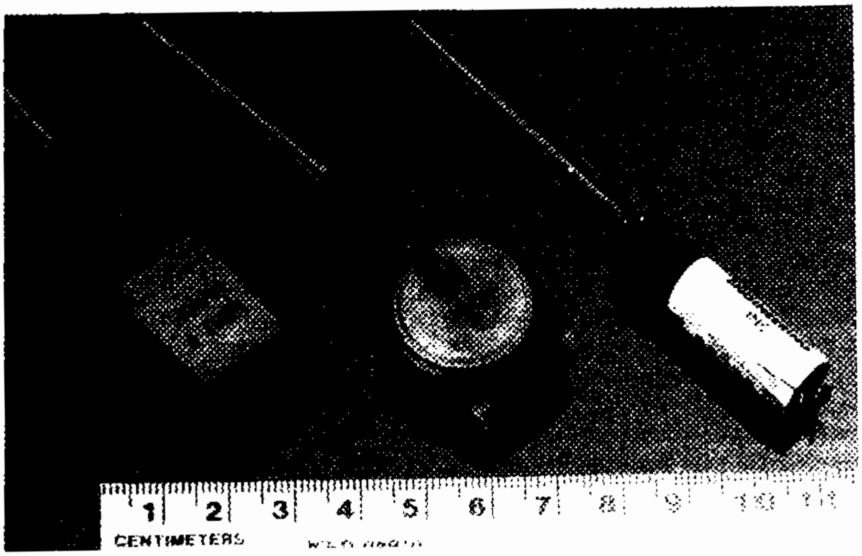

Figure 4. Three generations of transmitters commonly used on spotted owls (l-r): The second-generation P2 transmitter powered by a 6.8-gram lithium thionyl chloride battery at 3.6 volts; the first-generation SM1 transmitter powered by a 13-gram mercuric oxide battery at 1.35 volts; and the third generation, the TCC transmitter (shown unencapsulated) powered by a 5.5-gram lithium thionyl chloride battery at 3.6 volts.

6. The application of both solar-assisted and primary-powered mortality-sensing transmitters to standard cattle eartags as an alternative to the use of expandable collars on immature medium-to-large sized mammals.

All are innovative uses of radiotelemetry; some are old, some are new, but all are worth noting.

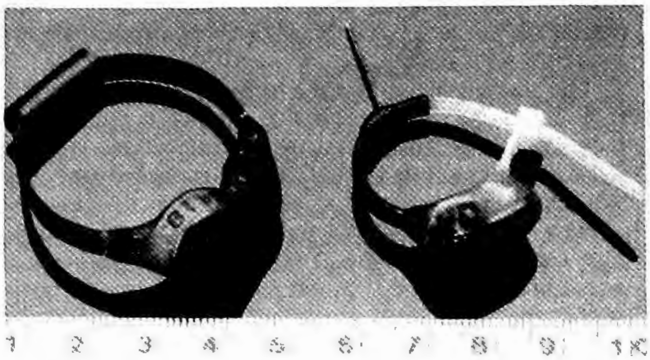

Figure 5. Two one-staged transmitter collars for very small mammals (1-4): A BR Collar containing an SM1 transmitter powered by a 1.2-gram lithium lead bismuthate battery at 1.5 volts, and a CTW Collar containing the same transmitter powered by a 800-mg mercuric oxide battery at 1.35 volts. The excess collar material will be removed and the collar brought into round as it is applied to the study individual.

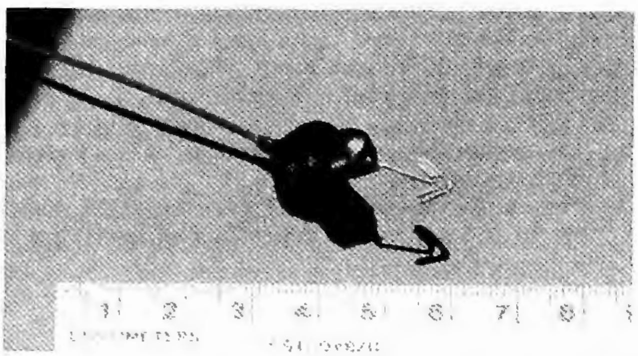

Figure 6. The Mauser Mini-Pack: A SM1 Transmitter powered by an 800-mg mercuric oxide battery and an innovative arrow attachment with a total package weight of ≤2 grams.

COMPUTERIZED RECEIVER CONTROL

Several commercially manufactured receiving systems have optionally available RS232 computer interface ports. Besides availability of such systems from commercial manufacturers, there are a number of papers describing techniques and hardware for interfacing personal computers for both controlling the frequency selection of receivers and for acquiring and storing obtained data. Many of these systems originally used an expanded Apple II computer because of its ease in user-installation of hardware boards. It has now become an option to use either an expanded Apple II computer or an IBM XT. Although these systems were originally designed for physiological parameter monitoring, they are now beginning to be used in systems that detect and record presence or absence of individually identified small mammals in given areas.

Coupled with computerized antenna sequencing devices, such as are commonly used in the Northeast where the vertebrate pests of genus Homo contribute both thermal pollution from power plants and sludge from paper mills and salmon smolt are used by the thousands to indicate the health of the river systems, we are getting closer and closer to field-portable automated telemetry.

SATELLITE PLATFORMS

Satellite platforms are too large (Nakamura and Soma 1979) and too expensive (Tanaka et al. 1979) to be used on most vertebrate pest species. Derek Ritchie, Chairman of the Endangered Wildlife Trust in the Republic of South Africa, states that a satellite platform built by Aberdeen University in Scotland cost L1,700 (pounds sterling), weighed 4 pounds, and brought the African wild dog on which they installed it to its knees. They removed it and put it on a female lion whose behavior was also affected by the package weight, although not as much as the dog. Although Ritchie stated that this was a prototype, commercially manufactured satellite platforms range in weight from 1.23 to 1.6 kg. This technology is obviously too large at this point in its development to be of use in the study of all but the largest vertebrate pests.

RECAPTURE COLLARS

Recapture collars (Mech et al. 1990) are in an even more experimental stage than satellite transmitters. A paper on the progress of recapture collars was given recently at the meetings of the Western Section of the Wildlife Society. The current version of the recapture collar has three functions: 1) to emit a direction-finding signal, 2) to deliver a knock-down drug upon command, and 3) to fall off the animal at command by using a remote-triggered explosive device to blow the collar attachment bolts off.

The major flaws in the system are:

Size--The package is very large and can only be used on large animals such as wolves (Canis lupus) and mountain lions (Felis concolor).

Drug stability--Drugs must be suspended in ethylene glycol for winter use to prevent freezing. Because of drug instability, the animal must be dropped within 3 months of collar installation. Blood testing by Mech indicates that captive animals that were dropped monthly were not adversely affected by the drug; however, it was observed that the animals built up a resistance to the drug and progressively larger doses were required to drop the animal. Summer degradation of drugs has not been addressed.

Reliability of drug delivery--The only known use of commercially produced recapture collars by a researcher group that did not include researchers who were among the developers of the product was by the U.S. Fish and Wildlife Service's Asheville, North Carolina, office in the red wolf introduction project. All units deployed failed to perform in the field.

Danger to humans--The problem of a shed collar or a collar on a dead animal remaining in the field presents a danger due to the presence of residual drugs and/or unexploded explosives.

Cost--The unit costs (approximately $1,500 per collar/$4,000 per control) are high in comparison to typical cost of standard radiotracking collars (approximately $250-350 per collar, depending on the manufacturer, and special functions added/$1,500 per receiver).

CONCLUSION

In conclusion, the research community has instrumentation available to it which is far superior in size, weight, longevity, and power output to equipment that was available only a year or two ago. The virtually universal acceptance of radiotelemetry as a valid research tool has caused transmitters to be purchased in very large numbers; hundreds of transmitter applications are often purchased on one purchase order to instrument one study. This large-volume production gives manufacturers of commercially available telemetry equipment the ability to have critical components custom manufactured to facilitate the custom production of transmitters that fill the specific needs of the biological researcher. The application of currently available high-technology disciplines, such as electronic component production technology, computer technology, electrochemical technology, and photovoltaic technology to wildlife research methods allow us to study more individuals more effectively for longer periods of time. As these and other technologies charge toward the 21st century, biological researchers will be right there using the most up-to-date of these technologies as they have been applied to continuously more efficient wildlife telemetry applications.

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