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Volume***

Kathleen A. Fagerstone and Richard D. Curnow, editors



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Foreword

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Foreword

The Sixth Symposium on Test Methods for Vertebrate Pest Control and Management Materials was presented at Monterey, CA, on 4 March 1988. ASTM Committee E-35 on Pesticides and its Subcommittee E35.17 on Vertebrate Pest Control Agents cosponsored the symposium. William B. Jackson, Bowling Green State University, served as chairman of the symposium. Kathleen A. Fagerstone and Richard D. Curnow, USDA/APHIS/S&T, Denver Wildlife Research Center, served as editors of the resulting publication.

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Overview

The Sixth Symposium on Test Methods for Vertebrate Pest Control and Management Materials was held in Monterey, California, in March 1988 and was chaired by William B. Jackson, University Professor of Biological Sciences, Emeritus, Bowling Green State University. The ASTM Committee E-35 on Pesticides and the Vertebrate Pest Conference Committee sponsored this and the previous five symposia that addressed development of test methods for materials used in managing vertebrate pests. These symposia offer an important forum for scientists and others within government, academia, and industry to communicate innovative, new approaches and findings in the development of test methods.

The manuscripts of nine papers presented in the symposium are contained in this volume. The reader will be impressed with the diversity of subjects and the extent of new information presented by contributing authors.

Development of effective, economical, and safe control measures for vertebrate damage requires effective test procedures. Two papers in the symposium provide protocols for such testing. A new approach to evaluating low-temperature fumigants will be particularly useful to scientists involved in developing and improving rodent control. Also for rodent management, another paper presents procedures for testing ultrasonic devices. These protocols are valuable contributions to the growing body of literature on test methods for vertebrate pest control measures in structures.

A continuing effort is being made by researchers in this field to improve test methods and statistical procedures to provide bias-free, objective information. A commonly used statistic for describing the repellency of a substance, R_{50} , carries with it the chance that erroneous inferences may result concerning the repellency of material. A paper on the use of the R_{50} discusses this potential pitfall and recommends a more statistically acceptable estimator for repellency evaluations in the laboratory.

Field testing of vertebrate pest control chemicals is usually preceded by laboratory and pen tests involving the pest species. From this initial experimentation, designs for field efficacy testing are developed. One paper discusses the minimum size of plots necessary for testing avian repellents within flight pens. Data are presented that demonstrate a threshold size required before blackbirds are able to distinguish treated plots.

Although procedures are documented for assessing the effect of control measures on local vertebrate pest populations at sites where control occurs, literature is lacking on procedures for assessing the total area and numbers of animals potentially influenced by control programs. One paper related to the control of predation by coyotes provides novel insight into the relationship between site-specific control measures and the total area and numbers of coyotes potentially influenced. A mathematical model is described that uses animal density and average movement patterns as inputs.

Techniques for measuring and quantifying economic damage caused by vertebrate pests continue to be of high interest to industry. In a paper concerning tree squirrel damage to electric utilities in Lincoln, Nebraska, a method is discussed for quantifying the economic impact of power outages caused by squirrels. This paper provides a structure for similar assessments in other urban areas.

Nocturnally active pest mammals present significant challenges to scientists attempting to understand how animal behavior can be exploited in perfecting management strategies for damage control. In a paper on remote videography technology and equipment, a system is described for monitoring movements and activity patterns of nocturnal and crepuscular pests. This information should be of interest to those who need to know pest densities, behavioral patterns, and timing of actual damage or nuisance situations. The system presented in this paper was used for observing commensal bats; it could be applied to the study of other nocturnal/crepuscular vertebrates in the field or laboratory.

Physical and physiological marking agents are valuable tools for testing bait acceptance by vertebrates. One paper in this volume discusses the use of radioisotopes as physiological markers in field baiting studies of wild coyotes. Advantages and drawbacks are discussed. The success of this technique for marking coyotes should be of interest to other researchers in need of markers that do not alter the taste, smell, or appearance of baits.

This Sixth Symposium diverged somewhat from the content of the past five. A thought-provoking paper was presented concerning the welfare of animals affected by vertebrate pest research and management. Recognizing the varied public opinions about vertebrate pest control, the author presents a step-wise approach to decision making for pest management strategies, as well as suggested criteria for the selection of toxicants.

We appreciate the willing cooperation and assistance of those who participated in the symposium. The authors and reviewers are commended for their fine efforts and dedication in fulfilling their roles. The ASTM editorial staff and E-35 Committee staff are recognized for their diligent attention to the success of the symposium and production of this publication. We thank Dr. William B. Jackson for his longstanding dedication to this communication process and his willingness to chair the Symposium. The combined talent and contributions of the above individuals and staffs have resulted in this work, which we believe adds substantially to the growing body of information in the field of vertebrate pest control.

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Richard D. Curnow

USDA/APHIS/S&T, Denver Wildlife
Research Center, Denver Federal Center,
Denver, CO, symposium editors.

A. Daniel Ashton,¹

A Method for Fumigant Unc

REFERENCE: Ashton
*Methyl Bromide Fumigant
and Management Mat.*
Richard D. Curnow, Ed.
pp. 3-6.

ABSTRACT: Fumigant
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KEY WORDS: Fumig
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Methyl bromide is an organism that respire. F tions for use when temp control of insects in stor ration rates of insects an stantially reduced.

Methyl bromide also homeotherms, continue pests will continue to be ever, there are only a few ommended temperatures species of rodents confir

Early fumigation stud with various exposure te house mouse, *Mus musc* as 1/2-lb methyl bromide 1 h) produced complete ki! dosage/exposure relatio

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¹ Director and research 49266.

² Entomologist, Great La

A. Daniel Ashton,¹ Kevin Delventhal,¹ and James Sargent²

A Method for Evaluating Methyl Bromide Fumigant Under Low-Temperature Conditions

REFERENCE: Ashton, A. D., Delventhal, K., and Sargent, J. "A Method for Evaluating Methyl Bromide Fumigant Under Low-Temperature Conditions," in *Vertebrate Pest Control and Management Materials: 6th Volume, ASTM STP 1055*, Kathleen A. Fagerstone and Richard D. Curnow, Eds., American Society for Testing and Materials, Philadelphia, 1989, pp. 3-6.

ABSTRACT: Fumigants normally are not used at subfreezing temperatures, because of low efficacy for arthropod control. Rodents, being homeothermic, can be controlled readily during cold weather. However, data are not currently available to judge dosage and exposure variables. A chamber fumigant test procedure using methyl bromide is described, in which dosage and length of exposure can be controlled at ambient temperatures.

KEY WORDS: Fumigant, methyl bromide, low temperature, *Mus musculus*, *Rattus norvegicus*, *Peromyscus leucopus*, rodent, house mouse, Norway rat, white-footed mouse, homeothermic

Methyl bromide is an effective fumigant for control of insects and any other pest or organism that respire. Fumigation with methyl bromide has been limited by label restrictions for use when temperatures exceed 4°C. This reflects the use of methyl bromide for control of insects in stored commodities. Temperatures below 4°C will reduce the respiration rates of insects and other poikilotherms so that effectiveness of the fumigant is substantially reduced.

Methyl bromide also is an effective fumigant for rodent control. Rodents, being homeotherms, continue normal respiration at lower ambient temperatures. Thus, these pests will continue to be affected by methyl bromide at subfreezing temperatures. However, there are only a few studies reporting efficacious use of fumigants at lower than recommended temperatures. Tests conducted during the winter of 1987 in Michigan on three species of rodents confirm methyl bromide efficacy during cold temperature use.

Early fumigation studies with methyl bromide were conducted in fruit storage areas, with various exposure tests using several species of rodents (Norway rat, *Rattus norvegicus*; house mouse, *Mus musculus*; field vole, *Microtus* spp.) at 0 to 1°C [1,2]. Exposures as low as ½-lb methyl bromide per 1000 ft³ (2 g/m³) for 6 h (or 1.0 lb per 1000 ft³ [16 g/m³] for 1 h) produced complete kill or paralysis, with all paralyzed animals failing to recover. Lower dosage/exposure relationships were not investigated.

No standard protocol exists for measuring methyl bromide efficacy as a rodent fumigant. EPA Pesticide Assessment Guidelines (Subdivision G: Product Performance, Section 96-13) cite a paper that describes simulated burrow systems [3]. More recently simulated bur-

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row systems have been described for use with the Bandicoot rat, *Bandicota bengalensis* [4]. However, these are not suitable methods for assessing efficacy in above-ground, field facilities.

It has been noted that efficacy studies supporting a registration may not be representative of the various field conditions under which a material is used [5], although there are possible uses for materials for which the material is not registered. Such is the case for use of methyl bromide under cold temperatures. Consequently, we have developed a method to evaluate methyl bromide as a rodent control fumigant at temperatures below 4°C.

Procedures

A plywood structure approximately 2.5 by 2.5 by 2.5 m (14.5 m³, or approximately 500 ft³) was constructed for use as a fumigation chamber. The chamber, situated inside an unheated 4- by 10-m barn with cement floor, was painted on the interior with an oil-based enamel paint; caulking was applied to seal the chamber. The structure was wrapped in 6-mil black plastic and sealed with duct tape before introduction of the fumigant. A piece of Tygon® tubing, inserted through one wall and sealed with caulk, provided the access point for introduction of the fumigant.

Tests were conducted at ambient temperatures of -7.2, -0.6, and 8.3°C. Temperature was recorded on a thermograph located inside the chamber. Three species of rodents were tested: wild Norway rats, wild house mice, and white-footed mice, *Peromyscus leucopus*. A test group consisted of five males and five females of each species. Rats were caged singly in Tomahawk live traps; mice were group caged in Isocages® by species and sex. Rodents were placed at various levels on straw bales in the chamber and provided with cotton nestlets (a product distributed by Ancare Corp., North Belmore, New York) or straw for nesting material. Potatoes provided a water and food source; Purina 5001 lab chow also was available for food. All animals were held in cages at ambient temperature in the barns for 12 h before test for acclimatization to the lower temperature. Water in bottles was available during the acclimatization period; however, as temperatures fell below freezing, water bottles were removed before the test to prevent breakage.

A similar chamber was constructed in an adjacent unheated shed for use as a control chamber; a separate building was used to prevent any possibility of contamination during the fumigation process. Groups of control animals were maintained in the same manner as the test animals, with each control group consisting of five males and five females of each species. The control chamber was not tightly sealed, and, consequently, temperature readings were similar to external temperatures: -8.3, -1.7, and 7.2°C, or about 1°C colder than the sealed treatment chamber. Temperature was recorded on a thermograph located inside the chamber.

An 8- by 20-cm hole was cut in one side of the test chamber, and a clear plastic container 10 by 25 cm was sealed with caulk against the hole, creating a small viewing port. One additional mouse was placed in this container with nesting material; the mouse was visible from the outside of the test chamber. An indicator mouse was necessary to determine if the fumigation treatment was successful, because there was no light inside the chamber.

The treatment was calculated to provide ¼-lb methyl bromide per 1000 ft³ (4 g/m³). Methyl bromide was provided in preweighed Metho-O-Gas® canisters provided by Great Lakes Chemical Corp. of West Lafayette, Indiana. The contents of the container were evaporated into the sealed chamber via the Tygon tube. The Metho-O-Gas container was submerged in warm water to ensure complete release of the fumigant into the chamber.

The test period was to last 4 h or until the indicator mouse ceased breathing. A person wearing self-contained breathing apparatus opened the chamber at the conclusion of each

test period. An indicator mouse was placed in the chamber from the chamber. A gas detector tube was used to monitor the concentration of the animals. The number of animals that died was recorded at this time. The test was repeated for 24 h upon completion of the test period.

Results and Discussion

Results of fumigation are presented in Table 1. Control mortality rate of ¼-lb methyl bromide under conditions all similar to those of the test animals was -8.3°C (Table 1). This control group was used to determine the cover needed to prevent escape of the fumigant.

Consideration was given to the cost of application and the cost of the fumigant.

TABLE 1—Summary of Fumigation Results

Dosage	Temperature (°C)
2 oz/500 ft ³	-7.2
2 oz/500 ft ³	-0.6
2 oz/500 ft ³	8.3

TABLE 2—Summary of Control Results

Dosage	Chamber Temperature (°C)
Control	-8.3
Control	-1.7
Control	7.2

^aAnimals did not survive.

test period. An exhaust fan, connected to 20 ft (6m) of a continuous form tubular plastic material (similar to large trash bags) was attached to the chamber, and air was exhausted from the chamber and barn. After 30 min, a clearance reading was taken with Kitagawa® gas detector tubes (No. 157 SB) to confirm the chamber was safe to enter. The condition of the animals was noted and recorded. The condition of the control animals also was recorded at this time. The control animals were returned to the laboratory and monitored for 24 h upon conclusion of the test.

Results and Discussion

Results of fumigation on Norway rats, house mice, and white-footed mice are presented in Table 1. Complete mortality was achieved at all temperatures for all species at a treatment rate of $\frac{1}{4}$ lb/1000 ft³ (4 g/m³). Control animals subjected to similar environmental conditions all survived, with the exception of house mice at the lowest temperature of -8.3°C (Table 2). Although mice were group caged and provided with nesting material, this control group did not construct a nest (as had others) and, thus, lacked the protective cover needed to survive the cold temperature. All other controls remained unaffected.

Consideration of a material for controlling a rodent population should include efficacy and cost of application [5] and the relationship of those criteria to environmental condi-

TABLE 1—Summary of mortality patterns on several rodent species during cold weather fumigation with methyl bromide.

Dosage	Chamber Temperature, °C	Species	No./Sex	Time, h	Mortality, %
2 oz/500 ft ³	-7.2	<i>Rattus norvegicus</i>	5M/5F	4	100
		<i>Mus musculus</i>	5M/5F	4	100
		<i>Peromyscus leucopus</i>	5M/5F	4	100
2 oz/500 ft ³	-0.6	<i>Rattus norvegicus</i>	5M/5F	5	100
		<i>Mus musculus</i>	5M/5F	5	100
		<i>Peromyscus leucopus</i>	5M/5F	5	100
2 oz/500 ft ³	+8.3	<i>Rattus norvegicus</i>	5M/5F	5	100
		<i>Mus musculus</i>	5M/5F	5	100
		<i>Peromyscus leucopus</i>	5M/5F	5	100

TABLE 2—Summary of mortality for control groups of several rodent species during cold weather fumigation with methyl bromide.

Dosage	Chamber Temperature, °C	Species	No./Sex	Time, h	Mortality, %
Control	-8.3	<i>Rattus norvegicus</i>	5M/5F	4	0
		<i>Mus musculus</i>	5M/5F	4	100 ^a
		<i>Peromyscus leucopus</i>	5M/5F	4	0
Control	-1.7	<i>Rattus norvegicus</i>	5M/5F	5	0
		<i>Mus musculus</i>	5M/5F	5	0
		<i>Peromyscus leucopus</i>	5M/5F	5	0
Control	+7.2	<i>Rattus norvegicus</i>	5M/5F	5	0
		<i>Mus musculus</i>	5M/5F	5	0
		<i>Peromyscus leucopus</i>	5M/5F	5	0

^aAnimals did not construct nest and, consequently, lacked protective cover.

tions [6]. The use of methyl bromide for rodent control under cold temperatures (below 0°C) could be a practical and useful tool for grain and seed facilities, refrigerated storages, and so forth.

For all grain handlers, fumigation during winter months would maximize the rodent control effort, because fewer rodents would be available to reproduce in the spring. Cold weather fumigation with methyl bromide would not be suitable for everybody, because of the expertise, safety equipment, and appropriate licensing that would be required. However, these procedures demonstrate that the fumigation of rodents with methyl bromide conducted under simulated field conditions, below label temperature requirements, is efficacious.

Besides the specific results for this fumigant, we have developed a testing method that would be useful to evaluate other fumigants or rodenticides or both under simulated field conditions. Issues of efficacy under cold temperatures, water and shelter parameters under subfreezing conditions, and biology of the test species under extreme conditions, were resolved in developing this procedure. This information will prove useful in future testing.

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Protocol for for Rodent

REFERENCE: Jack, W. B., *Tests of Ultrasonic Management Materials*: Curnow, Eds., Ame

ABSTRACT: Testin in contradictory re approximate actual Conducting obser stances in which to tool. Ideally, the ins Rodent activity, m before and after acq roment. Both freq off cycles should be

KEY WORDS: ult lency, efficacy

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² Ecologist, BioCeno

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William B. Jackson,¹ Willard C. McCartney,² and A. Daniel Ashton³

Protocol for Field Tests of Ultrasonic Devices for Rodent Management

REFERENCE: Jackson, W. B., McCartney, W. C., and Ashton, A. D. "Protocol for Field Tests of Ultrasonic Devices for Rodent Management," in *Vertebrate Pest Control and Management Materials: 6th Volume, ASTM STP 1055*, Kathleen A. Fagerstone and Richard D. Curnow, Eds., American Society for Testing and Materials, Philadelphia, 1989, pp. 7-12.

ABSTRACT: Testing ultrasonic devices for rodent repellency in closed environments results in contradictory responses. Without alternative environments, such efficacy tests cannot approximate actual conditions, and can result in erroneous conclusions.

Conducting observations in actual rodent-infested environments provides the best circumstances in which to measure the efficacy of high-frequency sound as a rodent management tool. Ideally, the installation of ultrasonic devices should be the only environmental variable. Rodent activity, measured with tracking patches, food consumption, or motion monitors before and after activation of units, is correlated with sound pressure patterns in the environment. Both frequency and sound pressure are important parameters. Preferably, two on/off cycles should be used.

KEY WORDS: ultrasonics, integrated pest management, Norway rat, rodent control, repellency, efficacy

The use of ultrasonic devices in pest rodent management is not without controversy. Widely encompassing advertising claims by manufacturers and distributors and unsubstantiated testimonials by users have contributed to suspicion and skepticism among pest control operators (PCOs), behavioral scientists, and government regulators. To date, no commonly agreed upon protocol exists for testing the efficacy of these devices.

Because of specific language in the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the Environmental Protection Agency (EPA) does not register devices, and, therefore, it does not require performance data for them as it does for pesticides. Rather, the EPA must demonstrate that the efficacy claims accompanying a device in interstate commerce cannot be sustained. Only then can the government take action to remove the device from the market. Such removal actions are procedurally lengthy and potentially litigious but have been employed for several devices in recent years.

In contrast to the U.S. position, Canada does register devices and does require efficacy data to support such registrations. The protocol required for Canadian registration specifies preference for data collected in actual use situations, not laboratory-type experiments. Two measurements of daily rodent activity (that is, tracks, food consumption, and so forth) are required over a three- to six-week period, and an on/off cycle with the equipment is indicated. Of particular concern here is whether, in the absence of the sound pressure, the

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rodents will reinvade the controlled area during a two-week period when the unit is deactivated [1]. Several ultrasonic devices for use in rodent control have been registered for commercial sale in Canada in recent years with data from such efficacy tests.

Limited experimental test data associated with use of ultrasonic units in rodent management have been published. Most cases present observations of rodents confined in a limited environment and subjected to some pattern of high-frequency sound (see, for example Ref 2). While the most recent procedure to be published is that used by Shumake et al. [3], collected data are not available because of their use in current litigations by EPA. However, because the protocol has been widely distributed, it can be discussed as a typical example.

Shumake et al. [3] used a storage building that was modified to have two similar (but not identical) rooms (approximately 32.5 m²) separated by a harborage area (3.5 m²). A known number (6 male, 6 female) of adult wild Norway rats (trapped in natural suburban habitat) were liberated into the harborage area and allowed to acclimate for 1 to 4 weeks. During this period, ground lab chow was available in the harborage area, and small packets of oat groats (30 to 32 in each observation room) were lightly fastened to the floor in a grid pattern. Rats learned to pull the packets loose and could take them elsewhere (for example, harborage area) for consumption. Determinations of feeding activity (for example, packet removal, bait consumption) were made at 3- or 4-day intervals. Photoelectric cells were used to monitor movements at four distances from the harborage room. The protocol also indicated closed-circuit, infrared TV monitoring of entryways from the central harborage area.

After acclimation and a one-week baseline period, an ultrasonic unit was installed in one of the rooms; the same observations were continued for two and one-half weeks. The unit was turned off, removed, remounted in the other observation room, and, after a one-week baseline period, activated. Observations continued for another two and one-half weeks. No change was made in the rat population. Later, the procedure was repeated, using another group of wild Norway rats.

Several procedural aspects of this test need to be emphasized and discussed. The rats were confined to the experimental setup; emigration from the building could not occur. Even though there were areas with little or no measurable ultrasonic sound present, total escape was not possible. No evaluations of behavioral interactions or dominance patterns were made (for example, which animals in the population were active in the ultrasound-saturated areas). In addition, no observations of food consumption or movements were made in the initial hours after activation of the ultrasonic unit—only after three days. That the rats learned to remove the food packets and could sometimes take them to "sound-shadow" areas was not considered in data analyses.

Because many diverse ultrasonic generating devices for pest rodent management currently are appearing in the marketplace, having methods of collecting comparable data and making efficacy determinations is highly desirable [4,5].

Procedures

In evaluating the efficacy of these devices, it is important to recognize that they are not designed to eliminate rodents in the usual sense—death. They are designed to modify the behavior patterns (specifically movements) of an established population or to prevent the entrance of individuals into certain areas. Therefore, to substantiate efficacy, it is necessary to determine that movement patterns of the target population have been altered so as to eliminate or reduce greatly activity in the target area.

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Characteristics of the sound-generation units, including the basis for calculating output, should be clearly described. The frequency(ies) or frequency range should be identified, as well as the sound pressure output measured at standard distances (for example, 1-, 10-, 20-ft (0.3-, 3-, 6-m) center and at 45° left and right in front of transducer) and the on/off sequence. Measurement devices also need to be described (for example, make, model), and the microphone must be identified as having a flat response curve in the frequency range being used. The scale being used (for example, linear, A, or other) and response mode similarly should be noted. Often equipment used for industrial sound studies is not appropriate for measurement of high-frequency sound patterns.

Site Selection

The test site chosen should be large enough to have both experimental (ultrasound-emitting device(s) present) and control areas (no ultrasound-emitting devices). The areas should be similar but acoustically separated from each other. They may be in separate buildings. Rodents in the treated area should have access to alternate resources. Rodent activity in both areas must be efficiently monitored and quantified before and after installation and activation of the ultrasonic-emitting device(s). The two areas, therefore, should not be so large as to preclude daily data collection. A several-acre warehouse, for example, would be a difficult site because of the large number of observation points needed to monitor rodent activity adequately. Obviously, environmental conditions at the site must be stable, so that the only variable present will be the ultrasonic field. A single species of rodent should predominate.

Each site should be mapped for potential food and water sources, entrance sites, and harborage. Actual rodent activity areas need to be indicated. Past rodent control activities should be documented.

Protocol

Rodent activity must be documented before device installation, but it is not necessary to know the actual number of rodents present at the site. (Obtaining such a statistic requires an extensive, labor-intensive, and, therefore, costly research effort.) Rather, estimates of activity (for example, food consumption, movements, and so forth) are adequate and easily obtainable [6].

Food consumption can be measured with the placement of nontoxic food (for example, dog food, oat groats, corn meal, and so forth) in bait stations or protected containers. However, in food storage situations, placement of new foods, especially less attractive food, may result in unreliable estimates of feeding activity.

We prefer use of tracking patches in the development of an index of rodent activity [7]. Tiles, coated with flour or chalk, are placed in areas of rodent activity—along walls and animal runways. (Note: flour, especially for mice, can be a food source; its use may distort movement activity.) Tracking tiles may be detected (and avoided) by some rodents. Use of tracking dust on a hard natural surface (or simply smoothing a soft surface) may be preferred.

The actual number of tracks per board or patch can be counted. Such counting is not practical in a situation of heavy rodent infestation. Some investigators determine the percentage of tracking surface disturbed; others simply note whether tracks are present or absent at each monitoring site. In any case, an index of activity can be established for each patch and for the area.

TABLE 1—*Schedule of activities.*

Week 1	Survey and map site. Place population index devices (for example, tracking patches, bait stations, traps); determine activity daily (if possible).
Weeks 2-3	Continue until consistent activity pattern is evident. Activate ultrasonic units and map sound pressure patterns. Adjust sound patterns of devices if needed; install additional units as needed. Continue population index devices.
^a Weeks 4-5	Continue population index devices.
Weeks 6-7	Deactivate ultrasonic device(s). Continue population index devices.
^a Weeks 8-9	Continue program.
Weeks 10-11	Reactivate ultrasonic device(s). ^b Continue population index devices.
^a Weeks 12-13	Continue program.
^a Weeks 14+	Repeat deactivation/activation cycle.

^aOptional.^bCanadian protocol does not require reactivation.

Motion detectors provide another tool for quantifying activity [7]. These can be simple electric eye devices or more sophisticated infrared detectors or induction devices. Fecal pellet counts provide still another activity measure.

To allow for possible neophobic responses, baseline data should be collected until a consistent pattern of activity emerges, usually about one week. Data ideally should be collected daily at the same time. Once the baseline activity level has been established, the ultrasonic unit(s) are activated. Data collection should continue for two to four weeks (activate period). The units should then be disconnected (deactivate period), and activity data are recorded daily for a second two- to four-week period. This on/off cycle should be repeated. The procedure is summarized in Table 1.

Ultrasound pressure measurements should be taken at each of the tracking patches, at uniformly spaced points within the experimental and control areas, and in "sound-shadows" near areas of rodent activity. Such measurements should be made at the rodent not human level. Concurrently, it may be desirable to adjust unit installations to produce desired patterns of high-intensity (for example, >85- or >90-dB) ultrasound. Such adjustments, including installations of additional units, are best done before the initiation of formal test observations. These data should be recorded on the site map.

Data Interpretation

Activity index data should be compared graphically with sound pressure readings. We have found grouping such readings at 10-db intervals (for example, >90 dB, 80 to 90 dB, and <80 dB) for plotting to be convenient. Activity index data per patch or per area before, during, and after ultrasound generation should be examined, presented, and compared for the experimental and control areas.

Note should be made of "accidents" when a power failure may result in a loss of repellent effect or an environmental change (like high water) may force unusual rodent movements. While statistical treatment of the collected data may be undertaken, usually it is not necessary. If the ultrasonic units being tested have an effect of commercial value, the contrast in graphical presentation will be sufficient to demonstrate repellent efficacy.

A graphic data presentation (Fig. 1) from a study by McCartney and Jackson [5] illustrates the use of tracking patches, as outlined above. In a rat-infested dairy barn, ultrasonic

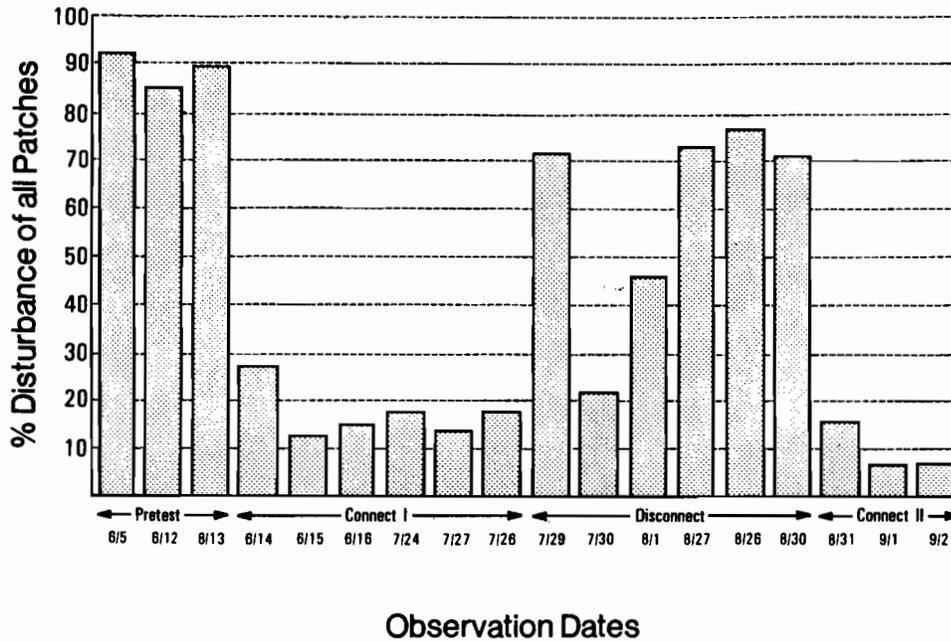


FIG. 1—Summary of rat activity (derived from the mean percent of areas disturbed on six tracking patches) related to "connect" and "disconnect" status of ultrasonic units in dairy building milking parlor [5].

installations were focused on access routes for rats into the milking parlor. Clearly, when the ultrasonic field was in place, rat activity was minimal. When the units were turned off, rats that had been displaced to other feeding areas returned.

Special Concerns

If ultrasonic installations are made in animal quarters, evaluation of responses by non-target species may be of concern. Separate considerations of egg or milk production or reproductive success may be instituted. However, observations to date have not suggested adverse effects on birds or large mammals.

OSHA standards require ear protection or exposure limitation for continuous sound pressures above 120 db. Commercial ultrasonic units fall below this threshold; most units do not operate continuously, and sound pressures (except very close to the transducers) are less than 120 db. Some workers, especially younger females, may be annoyed by the ultrasonic field.

Ultrasonics is a tool for use in an integrated pest management (IPM) program. Reduction of food supply, closure of openings, and other environmental improvement are likely to enhance the effectiveness of ultrasonics or of any other management tool. However, such manipulations during an evaluation program will only confuse the interpretation data. Consequently, for basic efficacy tests, the activation or deactivation of the ultrasonic unit(s) should be the only variable designated. Because actual working situations are used, often this ideal is not achieved. Data interpretation must consider such variations as changes in building use patterns, climate, sanitation, or pest control practices.

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On the Use of the R_{50}

REFERENCE: Engeman, R. M., Otis, D. L., Bromaghin, J. F., and Dusenberry, W. E., "On the Use of the R_{50} ," in *Vertebrate Pest Control and Management Materials: 6th Volume, ASTM STP 1055*, Kathleen A. Fagerstone and Richard D. Curnow, Eds., American Society for Testing and Materials, Philadelphia, 1989, pp. 13-18.

ABSTRACT: R_{50} is a statistic used to describe the repellency of a substance in the manner that an LC_{50} is used to describe toxicity. Although the R_{50} is calculated using the same methods as for estimating an LC_{50} , the data initially collected on individual animals are proportional, not binary. Transforming nonbinary data into binary data is subjective, can result in substantial losses of information, and, consequently, can result in a greater chance for erroneous inferences concerning the repellency of a substance. The subjective nature of R_{50} estimation arises because a test animal is defined as repelled if less than 50% of treated food items are consumed. The R_{50} is calculated as the concentration at which 50% of the population consumes less than 50% of the food times. It is more appropriate and of more direct interest to estimate the concentration of a substance at which an average of 50% of the food items are consumed rather than to estimate the R_{50} .

Problematic aspects of R_{50} estimation are demonstrated in this paper, and alternative analyses are recommended for studying the repellency of a substance. Example data sets are used to compare inferences from estimation of an R_{50} versus use of inverse regression methods to estimate concentrations at which various proportions of food items are consumed.

KEY WORDS: R_{50} , repellency, inverse regression

The lethality of a chemical toxic to an animal species is usually described by conducting a bioassay experiment and estimating the median lethal dose or concentration (that is, the dose at which one half of the population would be expected to die— LD_{50} or LC_{50}). The data collected for estimating an LD_{50} are binary (that is, each animal is recorded as alive or dead—0 or 1). Similarly, a natural parameter for describing a chemical's ability to repel an animal species from a food source is the median repellent concentration (R_{50}), the concentration at which one half of the population would be repelled. However, unlike lethality, the concept of repellency is not well defined. In practice, determination of an individual's repellency has required an arbitrary definition based on the amount of a food item eaten. Thus, a continuous response, such as amount or proportion of food eaten, is reduced to a binary score based on the operant definition. These data are then subjected to analyses for estimating the R_{50} . In this paper, we demonstrate that reducing nonbinary data to binary can result in: losses of information, the need for larger sample sizes, incorrect inferences about the chemical's repellent qualities, and less direct descriptions of the chemical's ability to protect a crop. Alternative analyses are suggested.

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The R_{50} Experiment

We give a general outline of experiments designed to estimate an R_{50} . Additional information on these experimental protocols can be found in Refs 1 and 2. An early reference involving the R_{50} describes the use of preconditioning tests [3]. Untreated food particles are used to condition animals for testing and to determine the amounts of food used for testing. Animals are in some fashion randomly assigned to treatment groups (preferably such that all weight classes are represented in each treatment group). Each treatment group is designated to receive food treated with a particular concentration of the test chemical. Each individual (housed separately) in each group receives food particles treated at that group's level. Usually this means each individual receives an odd number of treated food particles, such as 25 seeds. Animals that consume less than half of the food offered (for example, 12 seeds or less) are considered repelled. Their binary measurement would be 1. Animals that consume more than half are considered not repelled, and their binary measurement would be 0.

To illustrate, consider the artificial data set in Table 1. The estimated R_{50} , using probit analysis (see, for example, Refs 4 and 5), is 87.7 with a 95% confidence interval of 23.6 to 126.6. The R_{90} (concentration at which 90% of the population would be expected to be repelled) is 205.9 with 95% confidence limits of 160.7, 326.3. We also use these data to demonstrate alternative analytical methods and their associated inferences.

Effects of Redefining Repellency

Suppose that one does not wish to consider an animal as repelled if it will eat almost 50% of the treated food presented to it. The animal may be defined as repelled, but the food that the chemical is supposed to protect may be half gone. If we redefine repelled as eating less than 25% (six particles or less in our example) of the food particles eaten, then no animal in Table 1 would be considered repelled and, of course, an R_{50} could not be calculated.

This example demonstrates the ambiguities associated with defining repellency as a binary variable. Another data set with the same R_{50} as our data when repellency is defined as less than 50% consumption would not necessarily have the same R_{50} as our data if repellency is redefined as less than 25% consumption. The R_{50} is supposed to represent the concentration of the chemical at which 50% of the animal population is repelled, but an animal can eat 49.9% of the treated food and be considered repelled. Thus, at the R_{50} , nearly 50% of the treated food presented could be consumed by the half of the population that is repelled and 100% could be consumed by the half that is not repelled.

TABLE 1—Example data of the number of particles eaten when 25 food particles are presented.

Percent Concentration	Animal (Within Concentration) ^a										Mean Percent	
	1	2	3	4	5	6	7	8	9	10	Consumed, %	Repelled, %
30	20	21	25	11	22	12	23	22	12	24	78	30
90	22	12	11	22	21	22	10	12	24	9	66	50
150	18	10	11	12	21	11	12	22	12	11	56	70
210	12	10	11	9	14	12	11	12	9	12	45	90
270	10	8	9	9	7	10	8	11	7	9	35	100

^a A different set of ten animals is used at each concentration.

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Defining repellency is ambiguous, and the concept of the R_{50} is confusing. Because the purpose of a repellent chemical is to protect a crop from being eaten, a more realistic concept would be to study the amount of food consumption directly. The concentration at which 50% of the food would be expected to be consumed could be estimated (and named the FC_{50}). This parameter would relate more directly to a repellent chemical's ability to protect a crop. We consider this approach in later sections.

Loss of Information

When a transformation that is not one to one is applied to data, a loss of information occurs. The fidelity of the transformed data is less than the original data. Transforming proportional data into binary data is an example that is not one to one; that is, each original data value is not represented by a unique transformed value.

Consider, as an example, the repellent study in Table 1. Each animal is offered 25 food particles. If 12 or less are eaten the animal is considered repelled and assigned the value 1. If 13 or more are eaten, the animal is not considered repelled and assigned the value 0. Thus, for example, the 2 animals that consume 1 and 10 seeds, respectively, receive the same repellency score of 1, even though the practical implications of these 2 values may be very different. Obviously, information concerning the repellent property of the chemical is being lost.

Sample Size

The use of a transformation that diminishes the information contained in the data requires more data to make up for the loss. This problem is further compounded because the estimation procedures to be applied to the transformed binary data perform poorly at small sample sizes [4,5]. At the smaller sample sizes (for example, less than 30 total animals, less than 5 concentrations, or less than 6 animals per concentration), the probit and logit estimation methods may not be able to calculate an estimate or the associated confidence limits or both. Although Thompson's moving average method [6] has traditionally been used to calculate approximate estimates in these situations, its confidence limits are not accurate [4].

Consider again the data in Table 1. Suppose only ten animals were available for this study, for example, the first two animals at each concentration. The number of animals out of two repelled at each concentration is now 0, 1, 1, 2, 2, respectively, for the concentrations 30, 90, 150, 210, 270. The estimate of the R_{50} from this reduced data set is 119.7, but finite confidence limits could not be calculated.

Alternate Approach to R_{50} Estimation

We now consider using the proportional data from a repellency experiment, without an arbitrary definition of repellency that leads to a loss of information. Such data can be more efficiently analyzed using linear regression techniques. The proportion of food particles consumed (or, equivalently, the number of food particles consumed if all animals are presented the same number) is treated as the response variable (y) that can be related to the concentration of the chemical applied to the food (x). Inverse regression methods (predicting concentration, x , from consumption, y) could be used to estimate the concentration at which 50% consumption would be expected (FC_{50}) [7,8].

There are many advantages to this approach. No information is lost from applying a binary transformation to the data. Interpretation of the results relates directly to how well

a concentration of a chemical relates to protection of the food particles from consumption. There is no reliance on an arbitrary definition of repellency. Regression methods will produce valid estimates at smaller sample sizes than the bioassay methods. Thus, if only a few animals are available, a valid experiment may still be conducted. Also, for a fixed number of animals, more concentrations of the chemical (values of x) may be studied by using fewer animals per concentration. Trying this in the bioassay (R_{50}) format risks producing data from which valid estimates and confidence intervals cannot be calculated. Inverse regression methods allow the estimation of the concentration level with confidence limits where the expected consumption is 50% (see, for example, Refs 7 and 8). This relates directly to protecting the food. Repelling 50% of a population by limiting that 50% of the population to less than 50% food consumption is confusing and a less direct measure of food protection.

Example 1

Again we consider the data in Table 1. The number of food particles consumed is related to the chemical concentration by the equation

$$y = 20.465 - 0.0435x \quad (1)$$

where y is the number of particles consumed and x is the concentration. The concentration at which 50% of the food particles are consumed is 183.1 with 95% confidence limits of 156.0, 217.7 (or width of 61.7 versus a width of 103 for the R_{50} interval). Recall that the estimated R_{50} was 87.7, which is less than half the concentration at which 50% of the food is protected. This indicates that, at the R_{50} , 50% of the animals may be repelled (according to the arbitrary definition of repellency) but much more than 50% of the food may be lost. Note that at the estimated R_{50} concentration approximately two thirds of the food is consumed.

If we now consider only the data from the first two animals in each group (as we did for the R_{50} estimation), the following equation is estimated for relating number of particles consumed to the concentration of the chemical:

$$y = 21.55 - 0.0483x \quad (2)$$

Note how similar this equation is to Eq 1 where all data were used. Equation 2 estimates the concentration at which 50% of the food particles are consumed to be 187.2 (which is very close to the 183.1 predicted when using all data). The 95% confidence limits are 136.6, 277.7. The width of these limits is more than twice that of the confidence interval as when all data were used. However, in contrast to R_{50} estimation with the same two animals per concentration, these limits are calculable. It is possible that, had we used different sets of two animals per concentration, a less accurate estimate of 50% consumption level and a wider 95% confidence interval would have resulted. However, it is unlikely that an R_{50} with confidence limits could have been calculated using any subset of Table 1 where there were two animals per concentration. These results indicate that acceptable results can be achieved with much less data for the regression methods than for the bioassay methods. For a fixed number of animals, more concentrations can be studied using the regression methods than the bioassay methods.

Example 2

We now consider repellency data originally given in Ref 9 and later published in Ref 10. In this study, four concentrations of methiocarb are considered for repelling rock doves.

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TABLE 2—Three percent consumption data scenarios resulting in identical binary data.

Scenario	Concentration																			
	0.056				0.100				0.178				0.312							
1	50.5	52	51	53.5	53	50.5	51	52	50.5	11	51	53	27	20	34	1.5	1	1	3.5	3
2	96.5	98	97	99.5	99	49	76.5	84	89	96.5	51	49	48	53	49	1	4	1.5	1.5	2
3	53	51	50.5	52.5	53	52	53	53.5	49.5	52	49	47	52	48.5	53	47.5	47	47	49.5	49
Number Repelled	0				1				3				5							

Birds in this study were considered repelled if they ate less than 50% by weight of the food presented to them. Five birds were tested at each concentration of methiocarb. The number repelled at the 0.056, 0.100, 0.178, and 0.312% concentration levels were 0, 1, 3, and 5, respectively. An R_{50} estimate of 0.15 with 95% confidence limits of 0.10, 0.24 was given. However, the values were estimated using Thompson's moving average [6]. Because of the problems noted earlier associated with this estimation procedure at small sample sizes, we recalculated the R_{50} and confidence limits using probit analysis. The resulting R_{50} estimate was 0.16 with 95% confidence limits of 0.11 and 0.31. We will only consider these latter values for discussion.

These binary data could have been arrived at from an infinite number of possibilities of actual proportional consumption. In Table 2, we present three scenarios, all of which result in binary repellency data identical to that given above. The estimated levels where 50% food consumption would occur (and the associated 95% confidence limits) are, respectively, for Scenarios 1, 2, and 3: 0.075 (0.016, 0.108), 0.18, (0.17, 0.19), and 0.19 (0.14, 0.25).

The first value is about half of the estimated R_{50} . This illustrates the situation in which the R_{50} could imply overuse of the chemical, that is, the R_{50} indicates the use of higher concentrations of the chemical than necessary to protect the crop. The 50% consumption level is slightly higher than the R_{50} (12.5 and 18.8%, respectively) for the second and third data sets. This implies that in each of these cases the R_{50} level could imply better protection of the food than actually occurs.

The important point to draw from the data in Table 2 is that three very distinct consumption data sets each lead to the identical binary data set from which the R_{50} is estimated. The data from Scenario 1 indicate significantly greater protection from consumption than the data in Scenarios 2 and 3. Scenario 3 implies little concentration effect in the range the chemical was applied (all consumption is near 50%), whereas Scenario 2 has a much larger response to concentration (a steeper slope of the regression line).

Conclusions

The purpose of a repellent chemical is to prevent the food item on which it is applied from being eaten by an animal. The measurement of the chemical's efficacy is the amount of that food eaten by an animal. These are not binary measurements such as those resulting from lethality experiments with the objective of estimating an LD_{50} or an LC_{50} , and the response being measured is not just the direct effect the chemical has on the animal. The goal of protecting a crop by applying a repellent can only be described if crop protection is measured and analyzed. Laboratory experiments are conducted to provide an index as to how well a particular chemical may approach this goal. Use of the R_{50} does not approach this goal directly and can provide misleading inferences toward that goal.

The R_{50} is a confusing concept. Finding an estimate of the concentration of a chemical at which 50% of the animals eat less than 50% of a food does not directly address how well a food source is protected. By this definition, at the level at which the chemical repels 100% of the test animals, each animal could be consuming 50% of the food presented to them. We have demonstrated methods that require less data, do not lose information through a nonunique transformation of the data, and more reliably produce estimates and confidence intervals that also directly describe the protection provided by the test chemical.

Although the examples and discussion in this paper demonstrate the potential for misleading inference concerning a chemical's repellent properties, it is quite possible in many cases that the R_{50} concentration would be very close to the inverse regression estimate of the level where 50% of the food source is protected. However, to check this for a particular data set would require doing the regression calculations anyhow. In light of the definitional (for example, something other than 50% consumption by each individual), analytical (wide or incalculable confidence intervals), and conceptual problems associated with the R_{50} , there would seem to be little reason to calculate the R_{50} in addition to (or instead of) the regression estimates. We feel that application of inverse regression methods and estimation of a parameter such as the 50% food consumption level (FC_{50}) more directly approaches the objective of interest, that of indexing a chemical's repellent properties for preventing the consumption of a crop.

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Effective Plot Sizes for Testing Red-Winged Blackbird Repellents in a Large Flight Pen

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ABSTRACT: Three plot sizes (36, 78, and 108 m²) were evaluated for testing blackbird seed repellents within a 0.2-ha flight pen. Groups of 12 to 20 red-winged blackbirds were observed as they foraged on pairs of plots within each size category. One plot from each pair was sown with 134 kg/ha of rice seed treated with 1.25-g methiocarb/kg of seed. Plot selection, avoidance, discrimination, and latency to discrimination were determined for each plot size. With the 36-m² plots, there were long delays in selecting untreated plots, treated plots were not avoided, the birds had difficulty discriminating between the plots, and results were inconsistent among replicates. The 78-m² plots were adequate for most purposes, but the clearest and most consistent results were from the 108-m² plots. These plots were readily found by the birds, were accurately discriminated, and had bird pressure similar to that observed in Louisiana rice fields.

KEY WORDS: methiocarb, bird repellent, plot size, repellent testing, *Agelaius phoeniceus*, blackbird, simulated field study, flight pen

Field studies are essential for demonstrating the efficacy of bird damage control techniques. However, before conducting a field test, preliminary development under controlled conditions is necessary [1,2]. Historically, initial tests have been performed in cages [3], and encouraging results have been followed with field tests. However, there are vast differences between the test cage environment and field conditions. The suite of variables that influences the results of cage tests is often replaced by an entirely different set of variables in the field. An intermediate stage that incorporates the experimental control of cage tests with conditions more closely resembling field situations would permit researchers to refine techniques and evaluate hypotheses prior to conducting a major field test. Savings in time and money will result as field tests become more definitive and the likelihood of conducting a successful field test increases.

Suitable plot size has been a recurrent concern for experimental treatments in the field because plots that are small relative to the foraging area of free-ranging birds may not be discovered by the birds or may receive inadequate bird pressure for an effective test. West et al. [4] demonstrated repellency of pheasants from corn fields treated with methiocarb only after switching from small plots to an entire field experimental design. Dolbeer et al. [1] and Stickley and Ingram [2] also suggested more discernible effects would result from

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whole-field treatments than from plots within fields. Hermann and Kolbe [5] recommended a 0.1-ha plot for field work.

However, when the birds are confined, plot sizes can be drastically reduced [6]. The flight pen presents an intermediate test environment between field conditions (free-ranging birds) and caged trials (maximum constraint). The advantages of this have been recognized by others [for example, Ref 7], but specific recommendations, such as plot size, have not been made. Thus, objectives of this study were to determine

- (a) behavioral responses of red-winged blackbirds (*Agelaius phoeniceus*) foraging in various sized plots of seeded rice, and
- (b) the adequacy of three plot sizes for testing repellents in a 0.2-ha (2000-m²) flight pen.

Flight Pen Description

This study was conducted at the Florida Field Station of the Denver Wildlife Research Center (USDA/APHIS/S&T). The flight pen is square (46 by 46 m) with a peaked roof rising from 3 m high on two sides, to 7.6 m at the peak. The roof and walls are covered with 2.5-cm hexagonal mesh wire poultry netting. Two 20- by 25-m cultivated areas exist in the pen, and water is provided by a permanent sprinkler irrigation system (Fig. 1). A temporary decoy trap (3 by 10 by 2 m) is located along the south wall to provide a roost site and to facilitate removal of the birds.

Soils are basic (pH 8) sand-loam with a high percolation rate, and the water table varies between 0.25 and 2.5 m below the soil surface. The surrounding habitat is North Florida Flatwoods [8].

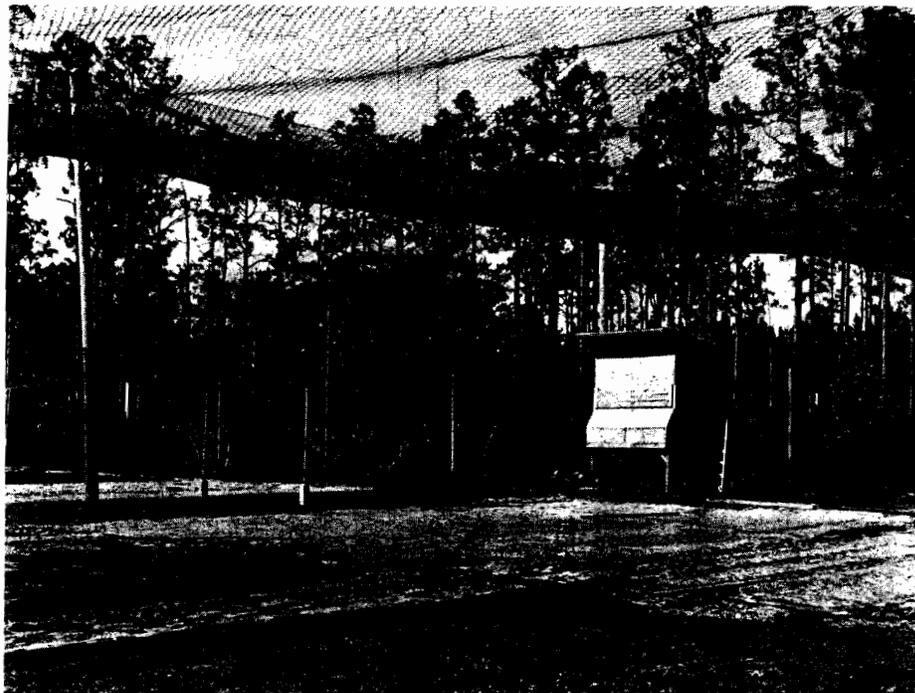


FIG. 1—View of 0.2-ha (2000-m²) flight pen showing tilled test plots, sprinkler irrigation system, and observation blind.

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The behavior of birds within the pen was not overtly affected by other redwings, common grackles (*Quiscalus quiscula*), or northern mockingbirds (*Mimus polyglottos*) that sometimes perched on the pen wire. Hawks occasionally swooped unsuccessfully at the pen, but the effects of raptorial harassment rarely persisted more than a few minutes.

Methods

Experimental Array

Both of the 500-m² arable areas were rototilled and smoothed. While one area was left barren, the other was subdivided into six plots: two plots of 108 m² (9 by 12 m), two of 78 m² (6 by 13 m), and two of 36 m² (6 by 6 m). The plot boundaries were marked with red and blue vinyl flags, 0.3 m high and spaced at 1-m intervals. A 0.3-m-wide walkway separated each plot. The juxtaposition of each plot size and treatment was arbitrarily altered for each replication. The 108-m² paired plots were offered first during replicate I, but the 36-m² plots were offered first during the other two replicates.

For each test, the plots were paired by size and the treated (TRT) plot was sown with 134 kg/ha of rice seed treated with 1.25 g of methiocarb/kg of seed. Methiocarb was in the form of Mesuro[®] 75% (active ingredient [a.i.]) seed treater supplied by Mobay Chemical Corp., Kansas City, Mo. The appropriate amount of repellent was added to rice seed in a rotating tumbler and mixed for 5 min. The matching untreated (UNT) plot was similarly sown with untreated seed. The birds were released one day after planting.

Following a four-day test for a particular plot size, the birds were removed from the pen until the rice in those plots was seven to ten cm tall (seven to ten days after planting). The plot was then rototilled to return it to a barren state. The main advantage in tilling between tests was that the following test could be started almost immediately. However, used plots containing rice seedlings did not appear more or less attractive to the birds than tilled plots.

Bird Preconditioning, Release, and Recapture

Twenty experimentally naive, cage-acclimated, male redwings were selected for each test. Test birds were placed in the decoy trap at the southwest corner of the pen at least two days before release. In the trap, they received unhulled rice and water. Following preconditioning, the birds were released into the pen in the early morning, and the trap was reset. After foraging in the test plots, the birds readily returned to the trap (2 to 3 h for total recapture).

Seed Counts

Quadrats were randomly established within each experimental plot at a rate of one quadrat per 18 m², except for the 36-m² plots, which had three quadrats each. Additionally, two bird-proof enclosures were placed within each plot. Quadrats and enclosures each circumscribed 0.09 m². Seeds were counted at the beginning and end of each four-day trial.

Behavior Observations

The birds were observed continuously each morning of the four-day tests beginning with the morning release from the decoy trap and continuing until $\geq 70\%$ of the birds had returned to roost. Observations ended then because it was discovered that when more than half of the birds were in the trap, foraging activity by the remaining birds was negligible.

A scan sample [9] of bird locations was made immediately following the morning release and was repeated at 4- to 6-min intervals throughout the observation period. Locations were classified as TRT, UNT, periphery (PER), or TRAP. Those data were used for site selection [10], group size, density, frequency of use, and probability of use analyses. Rep-

licates were tested for differences by the *G*-test [11], and treatments were compared by χ^2 contingency analyses and *t*-tests. The significance level was set at $\alpha = 0.10$.

Site selection analysis followed the methods of Neu et al. [10]. Expected plot use was defined as the ratio of the plot size tested to the total foraging area available (2000 m²) within the flight pen. Then, mean observed plot use and the 90% confidence interval around the mean were calculated and compared to the expected value. If the 90% confidence interval included the expected value, no selection or avoidance was indicated. If the lower limit of the confidence interval exceeded the expected value, the plot was selected. If the expected plot use value exceeded the upper limit of the 90% confidence interval, the plot was avoided.

Between scan samples, focal observations were made of birds using TRT and UNT plots. Focal samples were limited to 120 s because longer periods of concentration were too strenuous to be maintained throughout the morning, and at least two samples could be taken between scan samples. The number of focal samples per observation period varied with the frequency and duration with which the birds used the TRT and UNT plots. When birds departed from plots before the 120-s period expired, additional focal samples were taken until time for a scan sample. Samples from each plot were balanced as much as possible, but when all of the birds were using only one plot, samples were taken from that plot until an opportunity was presented to observe birds in the other plot. When possible, preference was given to birds using the plot least represented in the morning's data set.

The variables quantified were: location (that is, TRT or UNT), observation duration, the time the bird spent searching, the frequency of interruptions in the feeding pattern (usually as a result of social interactions), the number of pecks, the number of seeds picked up, the frequency of searching, whether the bird chased or captured insects, and the movement pattern of the bird. Movement patterns were classified as: directional (that is, no change in the general direction) across plot boundaries, directional within boundaries, reflexive (that is, a reversal of direction) across boundaries, and reflexive within boundaries. These data were used to calculate bird pressure and seed removal rates, and to document any evidence of crowding or boundary recognition. Timed variables were measured to the nearest second with a stopwatch, and frequency data were tabulated by an event recorder. Binoculars aided in differentiating behaviors.

Results

Site Selection

Site selection was the primary indicator of plot recognition. Consistent selection of UNT plots and avoidance of TRT plots are requisites for any successful repellent. Results from each replicate are reported (Table 1) because there were significant differences among replicates in selection/avoidance behavior for each treatment ($G \geq 46.57$, degrees of freedom [*df*] = 6, $P < 0.005$). However, replicates were combined to show the mean selection/avoidance pattern for each plot size.

The birds did not avoid the 36-m² TRT plots, and actually selected the TRT plot on Day 3 of replicate III (Table 1). They selected the UNT plot only during the last two days of replicate III. On one of those days, they also selected the adjacent TRT plot, and during the three days that the TRT plot was avoided the UNT plot was also rejected. That pattern was also shown when all replicates were combined.

Selectivity improved with the 78-m² array (Table 1). The UNT plot was selected three or four days of each replicate and was avoided only once. On that occasion (Day 2, replicate II), the TRT was also avoided, suggesting that the birds either had no interest in rice that day or had developed an aversion to both TRT and UNT plots. On Day 4 of replicate III, the birds selected both plots, but selection of the TRT on that day may have resulted

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TABLE 1—Daily selection and avoidance of TRT and UNT plots by red-winged blackbird flocks.

Plot Size, m ²	Treatment ^a	Replicate	Days Avoided	Days Selected
36	TRT	I	none	none
		II	1, 2	none
		III	1	3
	UNT	I	1, 3	none
		II	1, 2, 3	none
		III	1	3, 4
78	TRT	I	4	none
		II	2, 3, 4	none
		III	none	4
	UNT	I	none	1, 2, 3
		II	2	1, 3, 4
		III	none	1, 2, 3, 4
108	TRT	I	1, 2, 4	none
		II	2, 3, 4	none
		III	1, 3, 4	none
	UNT	I	1, 2	3, 4
		II	1	2, 3, 4
		III	1	3, 4

^a TRT: plots sown with seed treated with 1.25-g a.i. methiocarb/kg seed. UNT: plots sown with untreated rice.

from incidental trespass by birds that actually selected the UNT plot. When replicates were combined, the results indicated that the birds selected the UNT plots in preference to TRT plots, but generally failed to avoid the treated area.

The clearest results were demonstrated in the 108-m² plots (Table 1). The birds successfully avoided the TRT plots three out of four days in each replicate. Treated plots were never selected. All 108-m² UNT plots were avoided on Day 1 of each trial—a tendency not shown in the 78-m² plots. Although the birds selected 78-m² plots more often than 108-m² plots, selection and avoidance were stronger during the 108-m² trials.

Discrimination

Although some level of plot discrimination was required to produce the results described above, the birds could have selected a general region without recognizing the specific plot per se. The pattern of use in the plots could have been generated as the birds moved indiscriminantly across plot boundaries. The smaller the plot, the more difficult it would be for the birds to avoid the TRT. To evaluate that possibility, the movement patterns of birds using each plot type were evaluated. The expected frequency of movement types for birds that recognized the contents and boundaries of TRT and UNT plots would include a relatively high percentage of movements within the UNT and out of the TRT.

The expected pattern was clearly shown in the 108-m² plots where 50 of 69 (73%) birds in the UNT plots that encountered a boundary reversed their path and remained within the plot, whereas 39 of 45 (87%) in the TRT plots left the plot upon reaching the boundary (Table 2). Among the smaller plot sizes, birds consistently demonstrated the appropriate reaction to the plot boundary only in the 36-m² TRT plots.

A possible source of error in this analysis is the assumption that the birds used both TRT and UNT plots for feeding on rice seed. Conceivably, the birds could have used the 36- and 78-m² TRT plots for purposes other than feeding on rice, thereby discriminating between plots without showing avoidance of the TRT or reacting to the plot boundaries as

TABLE 2—Movement patterns of birds encountering boundaries between treated (TRT) and untreated (UNT) plots in three size classes.

Plot Size, m ²	Plot Type ^a	Number of Birds	
		Crossing Plot Boundary	Not Crossing Plot Boundary
36	TRT	18	4
	UNT	14	16
78	TRT	20	20
	UNT	29	30
108	TRT	39	6
	UNT	19	50

^a As in Table 1.

TABLE 3—Seed consumption by red-winged blackbirds in 36- and 78-m² TRT plots.

Plot Size, m ²	Replicate	Number of Focal Samples	Proportion ^a of Errors	Mean (SE) Number of Seeds/Sample
36	I	43	0.12	0.3 (0.03)
	II	10	0.50	3.9 (0.6)
	III	20	0.80	8.8 (0.3)
78	I	44	0.61	3.4 (0.1)
	II	22	0.59	1.3 (0.1)
	III	30	0.47	2.2 (0.1)

^a Proportion of errors equals the number of focal observations when the bird took treated seeds divided by the total number of focal observations in the treated plot.

anticipated. However, with the exception of replicate I in the 36-m² plot, birds took treated rice seeds during 47 to 80% of the focal observations (Table 3). These results indicate that the birds were actually using the plots to forage on rice, and the previous conclusion that there was poor TRT plot discrimination with the 36- and 78-m² plot sizes is supported.

Latency to Discrimination

The birds took longer to find the 36-m² plots than the other sizes (Table 4), and only once was there persistent use (≥ five visits per hour). The 78-m² UNT plots were the most quickly discovered plots (\bar{x} = 0.2 h from start of trial). Finding the 108-m² plots took considerably longer (1.8 h; see Table 4). That pattern was even more apparent in latency to persistent use. The 78-m² UNT plots were used almost immediately upon discovery, whereas that was the case only in replicate II for the 108-m plots.

Similarity to Field Conditions

There was little difference among plot sizes in the mean flock size (excluding group size = 0) on TRT plots (Table 5). Flock size was significantly ($P < 0.10$) greater in the 108-m² UNT plots than in the 36-m² UNT plots, but the 78-m² UNT plots did not differ from the larger size. Only in the 108-m² trials was there a significant ($P < 0.10$) difference in mean

TABLE

Time to first

Time to first persistent

^a As in Table 5
^b NO = n

TABLE 5-

Plot Size, m²

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^a As in Table 5

flock size b UNT 78-

a Bird pre-flock's pattern combining was substantial BPI, estimate of bird-minutes to that observation

Discussion

The results show that repellents on untreated plots were not effective. Each of the abilities

TABLE 4—Latency (in hours from start of trial) to first visit and first observed persistent use.

	Replicate	36 m ²		78 m ²		108 m ²	
		TRT ^a	UNT	TRT	UNT	TRT	UNT
Time to first use	I	0.1	0.9	0.3	0.2	0.3	1.1
	II	4.8	4.6	0.3	0.3	0.4	2.6
	III	2.6	2.3	0.4	0.2	1.6	1.7
	Mean	2.5	2.6	0.3	0.2	0.8	1.8
Time to first persistent use	I	NO ^b	NO	3.4	0.2	8.4	7.0
	II	NO	4.6	NO	0.3	4.1	2.6
	III	NO	NO	2.8	0.2	NO	2.8
	Mean	NO	NA	NA	0.2	NA	4.1

^a As in Table 1.^b NO = not observed; NA = not applicable.TABLE 5—Use of various size plots by red-winged blackbird flocks in 0.2-ha (2000-m²) flight pen. Values given are means (SE) of three replicates/treatment.

Plot Size, m ²	Scan Samples	Treatment ^a	Birds Observed	Flock Size	Probability of Use
36	81 (6)	TRT	15 (3)	1.7 (0.4)	0.12 (0.01)
		UNT	38 (31)	2.3 (0.7)	0.14 (0.08)
78	107 (23)	TRT	45 (5)	2.2 (0.5)	0.23 (0.06)
		UNT	124 (9)	3.2 (1.0)	0.43 (0.07)
108	105 (17)	TRT	30 (8)	2.3 (0.5)	0.14 (0.04)
		UNT	184 (49)	5.8 (1.3)	0.32 (0.06)

^a As in Table 1.

flock size between treatments. Probability of use was significantly ($P < 0.10$) greater in the UNT 78- and 108-m² plots than in the corresponding TRT plots or in the UNT 36-m plots.

Bird pressure (bird-seconds of use per square meter) is a function of flock size and the flock's pattern of use in a given area. A daily bird pressure index (BPI) was derived by combining replicates for each treatment and plot size (Table 6). For each plot size, the BPI was substantially greater for UNT than TRT plots. The 78-m² UNT plots had fairly constant BPI, whereas bird pressure tended to increase with time in the other plots. A rough estimate of the average bird pressure observed in Louisiana during 1986 [12] was 28 500 bird-minutes per hectare for eight rice fields (3-ha [30 000-m²] average). This was similar to that observed during the flight pen trials in the 78- and 108-m² plots (Table 6).

Discussion

The results of this study indicate that 36-m² plots are too small for reliable tests of seed repellents within the flight pen. The birds did not differentiate between treated and untreated plots, which suggests that they viewed both as a single food patch. Furthermore, there was inconsistency among replications in the birds' behavioral responses.

Each of the two large plot sizes has advantages. The prime advantage to 78-m² plots is the ability to fit more plots into the pen and consequently create more powerful experi-

TABLE 6—Daily and total bird pressure index (BPI)^a on treated (TRT)^b and untreated (UNT) plots (three replicates each) of different sizes.

Day	36 m ²		78 m ²		108 m ²	
	TRT	UNT	TRT	UNT	TRT	UNT
1	0.12	0.01	2.52	33.84	1.04	0.00
2	0.50	0.64	6.60	37.80	1.44	14.04
3	4.40	17.68	6.30	61.74	3.04	94.68
4	8.80	62.10	7.40	36.75	1.20	88.80
Total	13.82	80.43	22.82	170.13	6.72	197.52
Field equivalent (bird-min/ha)	13 333		28 333		33 000	

$$^a \text{BPI} = \frac{(\text{Mean flock size})(\text{mean duration of use})}{\text{plot size}} = \frac{\text{bird-s}}{\text{m}^2}$$

^b As in Table 1.

mental designs. However, this flight pen can currently provide eight 108-m² plots, either simultaneously or in series, which should be adequate for most study designs. The 108-m² plots have an advantage in differentiation of results among plots. Consistency was also better for the largest plots.

When the study design dictates smaller (78-m²) plots, increasing the plot separation will probably enhance the birds' ability to discriminate [5]. When the plots are adjacent, as during this study, the rate of trespass from one to the other increases as plot size declines. Separating the plots would help the birds avoid accidental use of a nonpreferred adjacent plot and may also help reduce the delay in use of UNT plots that occurs when the birds happen to use the TRT plots first.

Weather was one of the biggest problems encountered during the study. Frequent thunderstorms, particularly during the summer, turned dry, sandy study plots into bogs within hours and raised the water table nearly to the soil surface. When the plots became saturated, tilling and determination of initial seed densities from quadrat counts were impossible without severely disrupting the plots. One possible solution would have been to run the prescribed weight of seed through a seed counter before planting to determine initial seed densities. Residual seed densities presented an additional problem. The thunderstorms often buried seeds, rendering residual counts inaccurate. Solutions include waiting for the seeds to germinate and counting sprouts (extending each experiment and delaying the next), or sifting soil collected from each quadrat to retrieve subsurface seeds.

The same storms that buried seeds and turned sandy-loam soils into knee-deep muck, also invariably flushed insects. The birds readily capitalized on the insects, thereby decreasing their consumption of seed. Spot checks to determine the intensity with which the birds removed seeds from the experimental plots may be necessary to determine an adequate exposure period.

Acknowledgments

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A First Generation Mathematical Model for Calculating Area of Influence and Potential Number of Animals Exposed to Management Programs

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ABSTRACT: Frequently, planning and authorization processes for a variety of management programs require estimates of size of the area or the potential number of animals that might be exposed to, or influenced by, the program(s) under consideration. A mathematical model, using animal density and average movement patterns as inputs, was developed and applied using coyote data from southern Texas. On the basis of this model, it appears that when the area encompassed by the management program is small relative to the average movements of the animals, animals in an area 10 to 50 times larger than the "application zone" may be affected. Even when the application zone is 40 times larger than the average home range, animals in an area 1.7 times larger than the management zone could be exposed. Ramifications and aspects for enhancing the reality of the model are discussed.

KEY WORDS: area of influence, *Canis latrans*, coyote, management effects, mathematical model, numbers of animals, removal

Mobility of free-ranging animals frequently results in the influence of management programs extending beyond the borders of the area to which the management program is applied. As a consequence, both the area and number of animals affected may be considerably larger than casually expected.

Although environmental impact statements (EISs), environmental assessments (EAs), and a variety of other program projections and evaluations frequently require estimates of the size of the area influenced and number of animals that might be affected by particular programs, standardized and defensible procedures for making such estimates are scarce. Such estimates are useful for anticipating the potential impact on "target" and "nontarget" species, can assist in developing management programs, or can aid in selecting among programs with different management approaches.

Our purpose here is to encourage the use of mathematical approaches for assessing bio-

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logic effects by providing an initial set of equations, a simple illustration, and a set of sample results. We also hope to encourage others to expand on these procedures.

Rationale

For our purposes, we consider any animal whose activity area lies entirely or partially within the boundaries of a management area to be *exposed* to the management program. While all animals within the management area at any specific time are exposed, some animals outside the management area at that time will also be exposed because part of their activity area lies within the management area. Thus, to assess the size of area influenced and potential number of animals affected, it becomes necessary to estimate (1) how far activity areas partially within the management area extend beyond the management zone and (2) the portion of animals in a zone around the management area that have activity areas extending into the management area.

Development of Equations

For ease of computation, we assume our animals have circular areas of activity that are stable (that is, there is no response by one animal to the fate or experience of another, neither ingress nor exploratory movements occur, and so forth). We also define the management area as being circular. The management area depicted in Fig. 1 is delineated by Circle A with Radius a . Concentric with A is another circle, C, with Radius c such that $c - a$ is the diameter of the average activity area of the animals. Animals outside C never enter the management zone because, by definition, they do not move linear distances greater than $c - a$ (that is, greater than the diameter of their activity area).

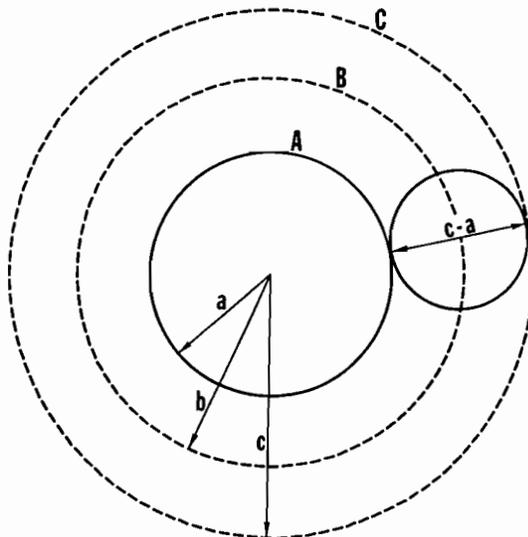


FIG. 1—Diagrammatic representation of a management area, bounded by circle A with radius a , and an adjacent peripheral area, bounded by circle C with radius c , such that $c - a$ equals the diameter of an average activity area for the animal of interest. Circle B is concentric with A and C and located half an activity area diameter (an activity area radius) outside of A.

Area of Effect

The size of the management area, Circle *A*, is calculated as

$$S_A = \pi a^2$$

Similarly the potential area influenced by the management program (that is, the area inhabited by animals that have part of their activity area within the management area) can be defined as the area within *C*, equal to

$$S_C = \pi c^2$$

Number of Animals Exposed

Using an estimate of animal density, *D*, and assuming that animals are distributed uniformly, the number of animals within Circle *A* can be estimated with the equation

$$N_A = \pi a^2 D$$

Similarly, the number of animals in the peripheral area, $S_C - S_A$ can be estimated with the equation

$$N_{C-A} = \pi (c^2 - a^2) D$$

While all the animals comprising N_A are exposed to the management program, only a portion of those comprising N_{C-A} are exposed because some do not have an activity area that overlaps the management zone. Hence, the total number of animals exposed to the program, N_T , could be obtained by summing N_A and that portion (*P*) of N_{C-A} that have part of their activity area within *A*, or

$$N_T = \pi a^2 D + P\pi(c^2 - a^2)D$$

$$N_T = \pi D[a^2 + P(c^2 - a^2)]$$

P can be calculated, but the mathematics are cumbersome. The problem can also be resolved in terms of the centers of activity for the animals. By definition, animals with centers of activity \leq one activity radius outside the management area boundary, *A*, have activity areas that overlap part of the management area and, hence, are exposed to the management program, while those with centers of activity \geq one activity radius outside of *A* are not. Thus, Circle *B* (with Radius *b*), concentric with and halfway between circles *A* and *C* (Fig. 1), encompasses the centers of all activity areas that partially or wholly overlap the management area. Because these centers of activity have a density and distribution identical to those of the animals, the potential number of animals exposed to the management program can be calculated by multiplying the density, *D*, by the area bounded by Circle *B*, or

$$N_T = \pi b^2 D$$

Sample Calculations

If a management program involves an attempt to remove all the coyotes from a management area, we might wish to estimate the total area over which effects on the coyote

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population might be anticipated and perhaps the potential number of coyotes that could be removed. To illustrate the application of this model, we have chosen to use information from a very dense coyote population near Laredo, Texas [1,2]. As might commonly be encountered, this coyote population has two components with significantly different behavioral characteristics; in this case, transient and territorial individuals with much different space utilization patterns. Our solution is to make calculations for each component independently.

Estimates of density and mean sizes of areas of activity are used in the preceding equations to estimate the area over which some change in density might be anticipated, S_C , and the potential number of animals that could be removed, N_T , in removal programs on areas of 1, 5, 10, and 100 km², respectively, of comparable habitat (Table 1).

Resulting calculations suggest that under the conditions stated, and without any adjustments within the coyote population, the effects of coyote removal from an area of 1 km² might extend to an area 65 times larger. The relative size of the peripheral area decreases with larger management areas, but the total area affected is still 2.9 times larger than the management area when the program is applied to 100 km². Although coyote density indicates 2.0 coyotes on a 1-km² area at any one time, our calculations suggest over 23 coyotes routinely use the area. On management areas of 100 km², 1.5 times as many animals use the area compared to the number present at any particular time, as suggested by density estimates.

Even when the management area is 40 times greater than the average activity area of the animals under consideration, an area 1.7 times larger may be affected, and 1.3 times as many animals may be exposed as might be inferred solely on the basis of population density. Attempts at total removal of coyotes from moderate-sized areas of comparable habitat [3,4] suggest these models are not unrealistic.

TABLE 1—Estimates of potential area of influence and number of coyotes exposed to management efforts applied to areas of four sizes.

INPUT PARAMETERS [1, 2]		Behavioral Component of Coyote Population		Total
		Territorial Coyotes	Transient Coyotes	
Diameter of activity area ($c - a$, in km)		1.8	4.0	
Density (D , in number of animals/km ²)		1.3	0.7	2.0
CALCULATIONS				
Management Area Size, km ²	Radius of Management Area, km	Territorial Coyotes	Transient Coyotes	Total
Area of Influence, S_C , km ²				
1	0.56	17	65	65
5	1.26	28	86	86
10	1.78	39	104	104
100	5.64	172	290	290
No. of Animals Exposed, N_T				
1	0.56	9	14	23
5	1.26	19	23	42
10	1.78	29	31	61
100	5.64	174	128	303

TABLE 2—Comparison of the sizes of areas influenced and numbers of animals exposed to management programs applied to 10-km² areas of various shapes.^a

Shape of Mgmt. Area	Length of Perimeter	Potential Size of Area Affected, km ²	Potential No. of Animals Exposed
Circle	11.2	39	29
Triangle (equilat.)	14.4	45	33
Rectangle			
w × w (square)	12.6	42	30
w × 2w	13.4	43	31
w × 5w	16.9	49	35
w × 10w	22.0	58	41
w × 20w	29.7	72	50

^a Mean activity area = 2.4 km² (diameter = 1.7 km). Animal density = 1.3/km².

Other Considerations

Use of circular and stable animal-activity and management areas in developing these equations is perhaps the simplest and most conservative situation, as demonstrated by results of similar calculations for areas of different shape (Table 2). In general, for management areas of similar size, the area affected increases in size as the length of the perimeter increases. Similarly, the relative number of animals with activity areas partially outside the management zone also increases.

The equations and preceding discussion assumed that *risk* could be assigned merely on the basis of whether or not the animal activity areas overlap the management area. In some instances, it might be more appropriate to assign risk based on the degree to which the animal activity areas overlap the management area. This would involve a separate set of equations but could incorporate nonuniform use of activity areas by the animals, changing vulnerabilities associated with differential behavior of animals in various portions of their activity areas [5,6], or different vulnerabilities for different segments of populations.

Incorporating a time element into the equations might make the calculations more realistic (and intimidating!) and would permit inclusion of other aspects of animal biology, such as exploratory movements [7], dispersal, ingress following animal removal, and effects associated with relative duration of management programs.

Much of the forgoing has been couched in terms of assessing the effects of management programs beyond the boundaries of the areas to which treatments might be applied. The same equations may be equally useful in defining treatment areas to create certain effects (for example, defining areas from which predators should be removed to protect a resource, like whooping crane nesting areas, or for planning vaccination programs to protect areas from wildlife-borne pathogens). In these instances, the focus is on defining a treatment area to provide some expected effect on a somewhat smaller management area.

Mathematical approaches to assessing the effects of management programs, as suggested here, more clearly identify the underlying assumptions and provide a more realistic basis for evaluating or projecting the influence of programs.

Acknowledgments

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Assessment of Squirrel-Caused Power Outages

REFERENCES: Hamilton, J. C., Johnson, R. J., Case, R. M., and Riley, M. W., "Assessment of Squirrel-Caused Power Outages," in *Vertebrate Pest Control and Management Materials: 6th Volume, ASTM STP 1055*, Kathleen A. Fagerstone and Richard D. Curnow, Eds., American Society for Testing and Materials, Philadelphia, 1989, pp. 34-40.

ABSTRACT: Squirrel-caused power outages in Lincoln and Omaha, Nebraska, were evaluated by examining company power outage reports and by consulting with power company representatives. Reports showed that squirrel-caused outages at pole-mounted transformers were most prevalent during May, June, and October (48% of total) and between 1 and 4 h after sunrise (38%), patterns that coincide with squirrel dispersal or morning activity periods. In Lincoln, 1980 and 1981, squirrels caused 177 outages per year, which was 24% of all outages and 90% of animal-caused outages. Estimated minimum annual costs were \$23 364 for repairs, public relations, and lost revenue while meters were not running. In Omaha, 1985 and 1986, squirrels caused 332 outages per year, costing at least \$47 144 annually. Squirrel-caused outages at substations cost an additional \$400 (Lincoln) to \$810 (Omaha) annually. Between 1982 and 1985, squirrel guards were installed on all 13 000 Lincoln transformers at an estimated minimum cost of \$20 per guard, or \$260 000 total. Records from Lincoln after all guards were installed (1986 and 1987) indicate that annual costs were reduced 78% to \$5148. Life expectancy of the guards is unknown. The extent of squirrel-caused outages and associated costs may vary among cities and regions. Assessment of these outages as described here can be used for timing biological studies and as a procedural structure for making similar economic assessments in other areas.

KEY WORDS: vertebrate pest control, fox squirrel, urban wildlife, power distribution equipment, electrical outages, *Sciurus niger*, wildlife damage

One problem faced by electrical power companies is maintaining an uninterrupted flow of electrical service to their clientele. Power outages result in customer dissatisfaction as well as repair costs and lost revenue while meters are not running. Outages may be caused by weather, equipment failures, and various animals, particularly squirrels (*Sciurus* spp.) [1-4].

Both fox (*S. niger*) and gray (*S. carolinensis*) squirrels use electrical power and telephone equipment as travel lanes and rest sites, or for other activities [1-4]. When a squirrel climbs on an electrical transformer, it may cross the bare, high-voltage wire leading from the high-voltage line to the transformer. If the squirrel simultaneously touches a part of

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the transformer where there is sufficient electrical ground, the result is a power outage and electrocution of the squirrel. The power outage results from an electrical short, which causes a high current flow on the distribution circuit. Normally a fuse opens, and all residents on the circuit (average about 50) lose power. Squirrels may also cause outages at other specific sites on power distribution equipment but not as commonly as at this site on the transformer.

Faced with the problem of squirrel-caused outages, Lincoln Electric System (LES) and Omaha Public Power District (OPPD), after evaluating alternatives, installed squirrel guards, devices that cover the bare high-voltage wire at the point on the transformer where squirrels are electrocuted. In Lincoln, Nebraska, 1982 to 1985, squirrel guards were placed on all 13 000 pole-mounted transformers.⁵ In Omaha, Nebraska, 1985 to 1987, about 3000 squirrel guards were installed on transformers in areas with squirrel problems, and eventually will be placed on all 59 000 existing transformers.⁶ However, no in-depth assessment was made of costs associated with these guards in relation to costs associated with squirrel-caused outages.

To understand better squirrel-caused outage problems, information was needed on outage patterns in relation to known squirrel biology. In addition, an assessment of costs associated with such outages was needed to provide economic guidelines helpful in development and use of control techniques. Therefore, our objectives were to compare seasonal and diurnal outage patterns with squirrel biology patterns, and to develop an economic assessment of both repair costs and preventive measures currently being used.

Distribution Equipment

In Lincoln and Omaha, power distribution equipment includes a transformer and one or two high-voltage cables (for example, 12 000 V) above the transformer. These high-voltage lines lead, via a fuse, to a transformer where the voltage is reduced to 120 or 240 V and then distributed through service cables, below the transformer, to surrounding houses (Fig. 1). Because one fuse may protect one or several transformers, an outage at one transformer may blow a fuse and cut power to several. Telephone and cable television cables are below the service cables.

Methods

Electric company records from Lincoln (January 1980 through December 1987) and Omaha (January 1985 through December 1986) were evaluated to determine the date, time, and location of outages. These years were selected in part because of availability of records from the power companies. The outage records, which showed the number and cause of outages, indicated squirrel-caused outages only when a repair crew found a dead squirrel at the site. Squirrel-caused outages in Lincoln were plotted on a map.

Economic analysis of squirrel-caused outages was based on information from power outage reports and from consultation with power company officials.^{5,6} These estimates included, for both Lincoln and Omaha, costs associated with squirrel-caused power outages at transformers and the costs of squirrel guard installation. The cost per transformer

⁵ R. E. Reutzler, Supervisor of Systems Control, Lincoln Electric System, Lincoln, NE, personal communication, 1987.

⁶ R. C. O'Neill, Supervisor, Transmission and Distribution, Omaha Public Power District, Omaha, NE, personal communication, 1987.

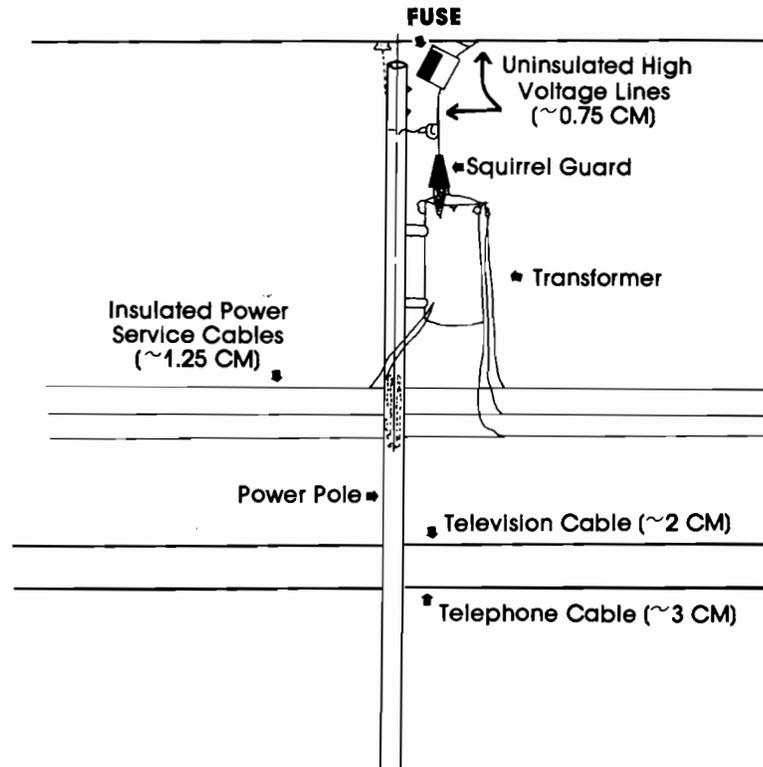


FIG. 1—Power pole arrangement showing an electrical transformer with a squirrel guard installed and various cables with outside diameters indicated.

outage included a repair crew, materials, office personnel, public relations, and lost revenue while meters were not running. Minimum public relations costs, based on customer dissatisfaction, were assumed to be one cent per minute of outage per household. Lost revenue was the average number of kilowatt hours (average kilovolt amperes \times 0.85 \times average length of outages in hours) \times \$0.07. Additional annual costs included expenses from squirrel-caused substation outages or costs other than those accrued when a fuse was blown at a transformer. Installation of a squirrel guard required expenses for an equipped installation crew and the guard. To determine effectiveness of squirrel guards, outage costs in Lincoln before guards (January 1980 through December 1981) were compared to the costs after guards were installed (January 1986 through December 1987).

Results

Records of 667 squirrel-caused outages at pole-mounted transformers in Lincoln (1980 to 1987) and 664 in Omaha (1985 and 1986) showed that 48% occurred in May (193), June (243), or October (202), and 38% (512) occurred between 1 and 4 h after sunrise (Figs. 2 and 3). Of the May outages, 76% occurred in the latter half of the month (15 to 31 May). In Lincoln, before guards were installed (1980 and 1981), squirrels caused 177 outages per year, which was 24% of all outages and 90% of animal-caused outages. After guard installation (1986 and 1987), squirrel-caused outages averaged 39 per year. In Omaha (1985 and

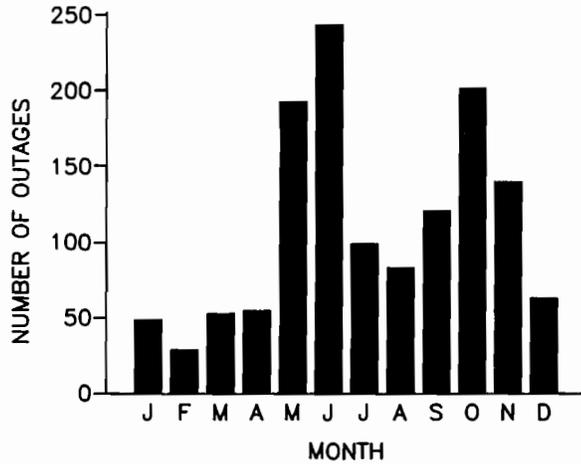


FIG. 2—Number of squirrel-caused power outages by month in Lincoln (1980 through 1987) and Omaha (1985 and 1986), Nebraska.

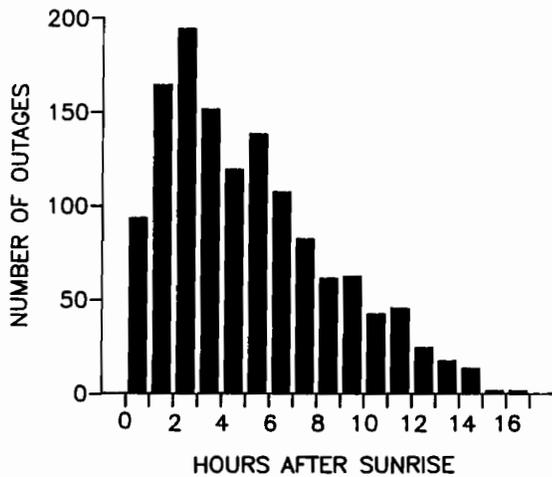


FIG. 3—Number of squirrel-caused power outages by hour after sunrise in Lincoln (1980 through 1987) and Omaha (1985 and 1986), Nebraska.

1986), squirrel-caused outages averaged 332 per year. Average outage length was 60 min in Lincoln and 72 min in Omaha. Average kilovolt amperes during outages were 290 in Lincoln and 294 in Omaha. In general, transformers with squirrel-caused outages were located in older neighborhoods that had large mast-producing trees.

The average cost per transformer outage was estimated to be \$132 in Lincoln and \$142 in Omaha. These estimates include \$50 for a two-person repair crew (1 h at \$50 per hour), \$15 for a fuse, \$20 for office personnel, \$17 (Lincoln) or \$21 (Omaha) for lost revenue during outages, and \$30 (Lincoln) or \$36 (Omaha) for public relations costs (~50 houses per outage per minute). Total annual costs associated with squirrel-caused outages at transformers were \$23 364 for Lincoln and \$47 144 for Omaha.

In addition to the cost per transformer outage, annual costs included \$400 for damage to electrical substation equipment in Lincoln and \$810 for substation repairs in Omaha. Lost revenue and public relations costs associated with these substation outages would be additional. Thus, minimum annual costs associated with squirrel-caused outages in Lincoln (1980 and 1981) and Omaha (1985 and 1986) were \$23 764 and \$47 954, respectively.

Installation of a squirrel guard was estimated to cost \$20, which included the guard (~\$4) and about 20 min labor (~\$16). Thus, estimated cost for installation of the 13 000 guards in Lincoln was \$260 000. The squirrel guards in Lincoln reduced annual costs associated with squirrel-caused outages by 78% from \$23 764 to \$5 148, or a reduction of \$18 616.

Discussion

Squirrel-caused power outages represent a substantial problem as indicated by outage repair costs and by the proportion of outages caused by squirrels. Squirrel-caused outages were most prevalent in late May, June, and October and between 1 and 4 h after sunrise, times that correspond with squirrel biological patterns. May, June, and October follow the two annual squirrel reproductive seasons and are peak months for dispersal of young squirrels [5-7]. Thus, dispersal of young squirrels, which coincides with peak outage periods, may be a biological and behavioral focal point that warrants further study in relation to power outages. A Washington, D.C., analysis indicates November as the peak month for animal-caused outages there, and suggests that this pattern may relate to squirrels retrieving food or other items stored on transformers [2,3]. In their analysis, squirrels accounted for about 16% of all outages and for 93% of animal-caused outages, compared to our results of 24 and 90%, respectively. Squirrel-caused outage patterns and biological relationships may vary among areas or regions but also have certain similarities. Outage records from additional locations are needed to establish overall patterns or to clarify the relationships that exist with the squirrel populations involved. Outages were most prevalent during morning hours, especially between 1 and 4 h after sunrise. This pattern coincides with the daily period of greatest activity for fox and gray squirrels, both urban and rural [8-11]. Overall, understanding outage patterns helps in evaluating the behavioral basis of damage and in focusing biologically based field studies on times when damage is most prevalent.

In general, transformers with squirrel-caused outages were located in older neighborhoods that had large mast-producing oaks (*Quercus* spp.). Hard-mast producing trees, particularly oaks, are the primary food source for fox squirrels, and populations tend to fluctuate in response to acorn availability [5,8]. In fact, basal area of hard-mast trees has been used in rural areas as an indicator of fox squirrel population size [12]. Although the presence of hard-mast trees indicates availability of a food source, it may not correspond directly with squirrel population levels in urban areas. Moreover, other data show that basal area of hard-mast trees does not distinguish transformer sites with squirrel-caused outages from those without such outages [4]. However, with further study, hard-mast availability might be useful on a larger, city-wide scale to indicate neighborhoods most likely to have threshold numbers of squirrels at which outages become common.

Our results indicate that squirrel-caused outages at transformers cost \$132 to \$142 each. During the same time as our study, a Washington, D.C. power company made estimates for similar repairs [2,3]. They reported a range of 488 to 1263 (average 653) animal-caused outages per year from July 1983 through December 1987 at a cost of \$242 per outage [2,3]. Their average of 653 outages per year would cost \$158 026 for repairs. The \$242 per outage included \$75.20 for a 1.5-person repair crew (1.6 h at \$47 per hour), \$9.50 for a fuse (average of fuse types), \$1.34 for lost revenue (based on 1.12 kwh per hour [average use] × 1.6

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Squirrel guard installation in Lincoln reduced damage costs by an estimated \$18 616 per year. At a 0% interest rate, the break-even period for guard installation (\$260 000) would be approximately 14 years. If a conservative 5% interest rate is used, break-even would be approximately 25 years, assuming the guards last that long. Initial types of squirrel guards, which are no longer used, lasted only about 5 to 6 years, largely because of exposure to ultraviolet rays. Squirrel guards currently installed by two companies⁸ [3] are made of plasticlike polyethylene or rubberlike ethylene propylene and vary in shape and installation features. These are expected to last longer, but their life expectancy is unknown. Because of various tax considerations, the financial burden on the company would probably be less than these amounts and the break-even periods would be shorter. However, costs are still considerable. Various types of squirrel guards appear satisfactory but using them is a relatively new technique. We recommend that guard selection include review of available data and consultation with experienced users.

Public relations is a point of critical concern to power companies⁵ [3] and one that our analysis may underestimate. These costs appear to be the most difficult to quantify and possibly the most likely to vary according to customer needs (including business and other high-use customers, effects on computer data, and so forth), attitudes, and tolerance for outages. The unquantified costs associated with public relations help justify the expense for guards.

Squirrel-caused power outage problems warrant additional attention. Although, squirrel guards reduce damage at transformers, they do not eliminate it, and the costs of guard installation on all transformers may be prohibitive for some companies. Squirrels may cause outages at other sites including at lightning arresters (located on or above transformers), cutouts (switches located above transformers), and at switches located on main feeder lines,⁹ as well as at faulty squirrel guards. Moreover, squirrel-caused outages at substations, although less frequent than on distribution equipment, are usually more costly and may affect considerably more customers. For example, one squirrel-caused substation outage near Washington, D.C. in 1987 resulted in 9000 customers without power for >30 h and loss of significant substation equipment.⁷ Additional understanding of squirrels in relation to electrical power equipment, and viable damage control options, are needed.

Evaluation of power company records and consultation with company representatives provided the information needed to assess squirrel-caused outages. However, pertinent

⁷ B. J. Zellmer, Transmission and Distribution, Potomac Electric Power Company, Washington, DC, unpublished data.

⁸ S. L. Young, Senior Engineer, Distribution, Lincoln Electric System, Lincoln, NE, personal communication, 1988.

⁹ B. J. Zellmer, Transmission and Distribution, Potomac Electric Power Company, Washington, DC, personal communication.

outage records from some years were not available. We encourage all companies that experience squirrel-caused damage, including power, telephone, and cable television companies, to maintain records of the cause, date, time, specific site, associated costs, and other pertinent information. Only with such records can damage patterns and costs in relation to controls be understood, and cost-effective solutions developed. Moreover, if records were available over many years, outage patterns could be evaluated in relation to squirrel population cycles, size of mast crops, and other variables.

This study has provided, for two Nebraska cities, date and time patterns of squirrel-caused outages and an economic assessment of these outages. Results can be used in developing other biological studies and as a procedural structure for making similar, and needed, economic assessments of the problem in other cities.

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Stephen C. Frantz¹

Remote Videography of Small Mammals Under Conditions of Dim Illumination or Darkness

REFERENCE: Frantz, S. C., "Remote Videography of Small Mammals Under Conditions of Dim Illumination or Darkness," in *Vertebrate Pest Control and Management Materials: 6th Volume, ASTM STP 1055*, Kathleen A. Fagerstone and Richard D. Curnow, Eds., American Society for Testing and Materials, Philadelphia, 1989, pp. 41-51.

ABSTRACT: A method is described for high-resolution videography of crepuscular and nocturnal mammals under field or laboratory conditions. The closed-circuit television camera provides a usable image in daylight as well as dusk/dawn applications. Infrared or red light illuminators must be used for darker conditions. A monitor interfaces with a motion detector and time-lapse video cassette recorder to allow fully automatic recording of activity. The on-site camera can be located more than 60 m from the controls for pan/tilt positioning and lens adjustment. Although the components are not particularly small or lightweight, the system is reasonably portable and functions in a wide range of temperature/humidity conditions. Detailed, remote monitoring and recording of small mammal (or other animal) behavior are possible under conditions not conducive to the presence of, or perhaps intolerable to, human observers.

KEY WORDS: video method, low light observations, activity monitoring, pest control evaluation, mammals, bats, rodents, vertebrate pests

The study of crepuscular and nocturnal animals (for example, bats and rodents) presents a unique situation in that the subjects to be observed are not readily visible with the naked eye. With many conventional photography and videography methods one can record only images of animals engaged in specific behaviors at specific points in time. However, ongoing behavior patterns often cannot be recorded without disturbing or otherwise altering the animals' behavior due to electronic flash or other bright, visible light; and/or the mere presence of an observer. Also, study conditions for the observer often are not hospitable (for example, a hot, humid attic) and not without health risks (for example, working high on a ladder or roof after dark; chronic exposure to allergens, aerosolized animal droppings, and so forth).

Basically, a system was needed to observe and record covertly the detailed behavior of small mammals (especially commensal bats) under natural conditions. Specific requirements are that the system be: functional in the dark, twilight, or daylight to cover all possible activity periods; operational under a wide range of temperature and humidity conditions; weather resistant for outdoor studies; remotely controlled to remove the observer from the immediate area of activity; and reasonably portable (within the demands of bat studies in and around buildings).

A number of night viewing devices (NVDs) and closed circuit television (CCTV) systems were considered at the outset of this project in 1982. Many of the components pro-

¹ Vertebrate vector specialist, New York State Department of Health, Wadsworth Center for Laboratories and Research, Albany, NY 12201-0509.

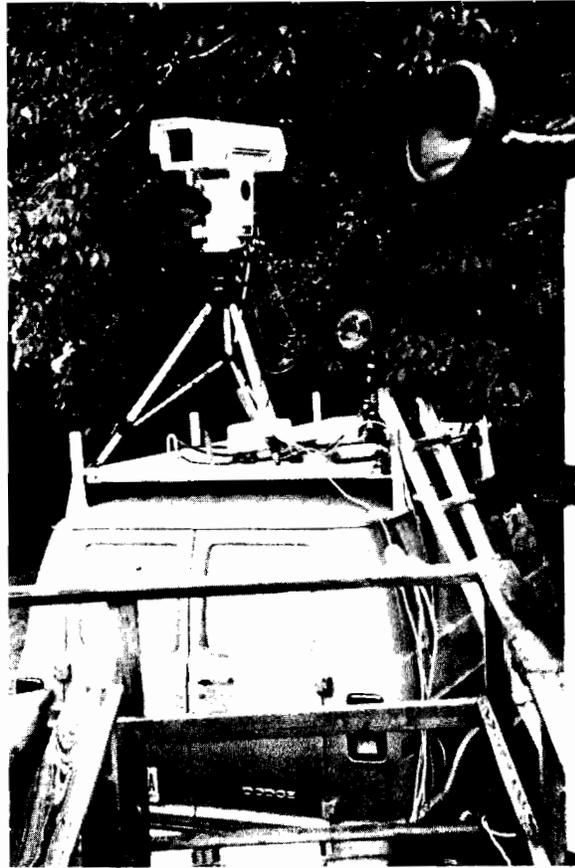


FIG. 1—The basic exterior components of the CCTV system include the camera and zoom lens in an environmental housing, motorized pan/tilt drive mounted on a tripod, and three illuminators (one on the camera housing and two on light stands). See text for details.

vided excellent low-light sensitivity, but lacked the necessary high-resolution image quality, were not operational at the summer temperature and humidity conditions characteristic of house attics, and/or were too costly. Professional, industrial CCTV equipment was chosen to meet criteria for observing commensal bats, but the system is applicable to other nocturnal/crepuscular mammals as well.

System Overview

The basic exterior (or sensor) part of the CCTV system consists of the camera with lens in a weatherproof housing mounted to a pan and tilt drive (Fig. 1). These components are kept assembled as one unit in order to reduce set-up time in the field. On location, the "unit" is mounted onto a tripod and placed so as to best observe the animals under study.

The basic interior (or receiving) part of the system consists of the CCTV monitor and the video cassette recorder. These components are kept mounted on a video cart together with control switches and power outlets (Fig. 2). At the time of application, the video cart can be moved to a convenient location for observation as long as all the interior compo-

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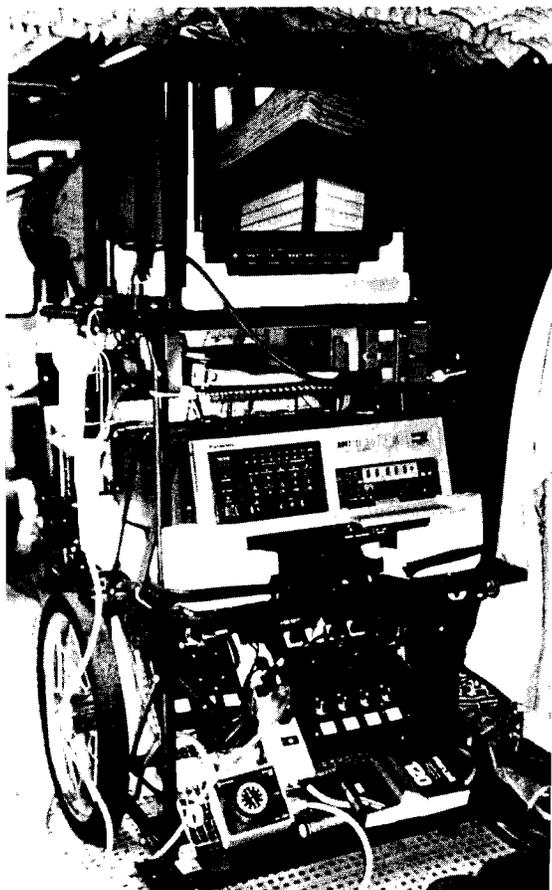


FIG. 2—The basic interior components of the CCTV system include a monochrome monitor, motion detector, controls for camera lens and pan/tilt unit, and time-lapse video cassette recorder, all of which are mounted on a mobile video cart. See text for details.

nents are kept dry. The basic system and other components are described below in greater detail.

Exterior Components²

Camera

The black-and-white, high-resolution, CCTV camera³ (Panasonic® WV-1850) is designed specifically for low-light situations [1,2]. It uses a 2.54-cm (1-in.) extended-red Newvicon® pick-up tube (S4119), which provides a positive video image and shows high sensitivity in the near infrared region. The full spectral sensitivity of the camera ranges

² The mention of manufacturing companies or of their proprietary products does not imply that they are recommended or endorsed by the author, the State of New York, or the publisher.

³ Manufactured by Panasonic Industrial Co., Secaucus, NJ 07094.

from visible light (400 to 700 nm) into near infrared (700 to 940 nm). The pick-up tube has virtually no sensitivity beyond 940 nm. Thus, the camera is functional in full sunlight through twilight without supplementary illumination. For applications in darkness, or to improve image quality, illumination can be provided in the spectral range below 940 nm.

The camera affords a horizontal resolution of >800 lines at center. Special circuitry enhances the video image in poor contrast situations, as commonly occurs with brown-black colored bats on brown-black roof beams in a dark attic. Camera performance is improved further by: extremely low blooming (a light flare effect that occurs when bright light sources are brought within the field of view) and low image retention (a "comet trail" or streaking effect, due to lengthened phosphor decay time, which follows bright objects or moving animals within the field of view). The latter characteristics are especially important for night videography outdoors, which inadvertently may include streetlights, automobiles, lighted windows, and other bright or moving objects.

Lens

A motorized zoom lens⁴ (Fujinon C10X16A-SND-P) provides a continuous focal length range of 16 to 160 mm [2]. This high-quality lens retains nearly 90% of the camera's resolution and has a light transmission efficiency of about 90%.⁵ With the lens wide open ($f/1.8$), the WV-1850 camera gives a usable image with a minimum illumination (with 2800K incandescent lamp) of about 0.22 lx; however, the recommended illumination would be in the range of 2.15 lx. Faster lenses of shorter, fixed focal length are available for which the minimum illumination could be decreased; for example at $f/1.4$ the minimum is 0.11 lx. The problem with a shorter focal length lens is that the working distance (camera to subject) would be reduced, with a concomitant increased probability of influencing the subjects under study. In both cases above, the illumination requirement standard is based on a scene reflectance factor of 75% (roughly that of white porcelain enamel); however, dark animal fur and dark, rough wood beams would be much less reflective.

An automatic iris adjusts for variations in the amount of incoming light. This feature removes the tedious process of constantly adjusting the iris manually for minute changes of scene illumination. Most of the time the auto-iris is highly desirable, however, there is no override control on this particular lens. Therefore, a darker-than-desired image results when the subject under observation is in a dark area and the surrounding area or background is brighter and causes the iris to close down. This difficulty occurs, for example, when a bat is under an overhanging roof with a surrounding, brighter twilight sky also in the field of view.

The minimum working distance of the Fujinon zoom lens is 1.8 m (5.9 ft) [2]. The horizontal angular field of view is $43^{\circ}36'$ at 16 mm (or $4^{\circ}35'$ at 160 mm); the vertical is $33^{\circ}24'$ at 16 mm (or $3^{\circ}26'$ at 160 mm). Thus, at a distance of 9.14 m (30 ft) the field of view at maximum wide angle (16 mm) is 7.2 m (23.8 ft) horizontal and 5.4 m (17.8 ft) vertical; at maximum telephoto (160 mm) it is 0.7 m (2.4 ft) horizontal and 0.5 m (1.8 ft) vertical. Field of view at closer working distances would be directly proportional to the reduction; for example at 3.05 m (10 ft) and 16 mm focal length, the view is reduced one third in both dimensions from that at 9.14 m (30 ft). The zoom lens is preferred over a fixed focal length lens because the former is adaptable to working in confined spaces as well as in large activity areas. It allows viewing the general area of activity or close-up behavior without chang-

⁴ Manufactured by Fujinon Inc., Wayne, NJ 07470.

⁵ A. Chesler, personal communication, Panasonic Industrial Co., Secaucus, NJ 07094.

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FIG. 3—The videography system is used commonly with an extended van that has been especially adapted for field studies of commensal bats. See text for details.

ing lenses (an otherwise impossible task for remote applications). Pushbuttons control lens zoom (in, out) and focus (near, far) functions; speed adjustment for lens controls is provided by a panel-mounted switch (Fig. 2). This CCTV system employs the Vicon® V100C (P8) zoom lens controls.⁶ (Our lens has auto-iris circuitry eliminating the need for the iris control buttons on the control panel.)

The actual size of the subject under study on the CCTV monitor screen is an important consideration in assembling the components for small mammal videography. In this CCTV system, the Fujinon 10X zoom lens is used in the field with a Panasonic WV-5410 monitor (discussed below). Returning to the working distance example of 9.14 m (30 ft) used previously, an object measuring 7.6 cm² (3 in.²) will be only 0.3 cm² (0.1 in.²) at maximum wide angle (16 mm) and it will be 2.8 cm² (1.1 in.²) at maximum telephoto (160 mm) on the monitor screen. Hence, most details of small mammal (for example, bats, mice) behavior will not be differentiated easily when the working distance exceeds 9.14 m because image size on the monitor screen will be too small even when the lens is at maximum telephoto.

Camera Housing

Observation of small mammals outdoors requires that equipment be protected from the elements. For bat studies, there is the additional requirement that components be protected from the corrosive effects of bat urine and guano excreted during flight. In this system, the camera with lens is mounted inside a weatherproof Vicon® Environmental Enclosure⁶ (V8000H) specifically designed for outdoor work (Figs. 1 and 3).

The off-white enclosure is constructed of structural foam molded plastic; its cover can be opened from either side or removed altogether for convenient access to the contents. A

⁶ Manufactured by Vicon Industries, Inc., Melville, NY 11747.

plate glass window protects the lens at the front of the housing. To help maintain the proper operating temperature for the enclosed camera (upper limit = 50°C [122°F]), an internal thermostatically controlled fan draws air (100 cfm) in through a bottom rear, screened opening and exhausts it through an upper front baffle, across the housing window to prevent fogging. The thermostat is set to activate the fan at temperatures above 32.2°C (90°F) and to deactivate automatically when temperatures drop below 26.7°C (80°F).

Pan/Tilt Unit

To remove the observer from the activity area, a remote motorized pan and tilt drive is used to adjust the camera position (Fig. 1). The drive⁶ (Vicon V330 APT) provides angular travel of 350° maximum pan and ±90° maximum tilt. It functions well for positioning the camera to not only observe areas of primary interest, but also for surveying the surroundings. A single joystick⁶ (Vicon V113APT [P8]) controls both pan and tilt functions from the observer's remote location (Fig. 2). Diagonal joystick deflection enables operation of both functions simultaneously. The drive unit is weatherproof and has an operational temperature upper limit of 74°C (165°F).

Tripod

As mentioned previously, the camera and pan/tilt unit are used on a tripod. A cast aluminum projector platform⁷ (Bogen® 3290) is kept mounted on the tripod⁷ (Bogen Universal Tripod 3068) to provide a large surface to accept the base of the pan/tilt drive. At time of use, the drive unit base is attached with bolts and wingnuts into holes drilled through the aluminum platform. The combined weight of the camera, lens, and pan/tilt drive is 33 kg (73 lb), which renders the field assembly process somewhat awkward and delicate for one person, especially when carrying the unit up a stepladder, across a roof, and so forth. Once all is attached to the tripod, the legs of the tripod can be spread to allow a minimum camera elevation of about 76 cm (30 in.). By extending the legs, the camera can be raised to about 1.8 m (71 in.); however, because of the significant weight load, the tripod legs are usually kept unextended to improve stability.

Lights

The final exterior portion of the CCTV system is lighting equipment. Although the low-light sensitivity of the camera lens is excellent (that is, recommended minimum of 2.15 lx at f/1.8), additional illumination provides better shadow detail and increased depth of field under dark conditions.

The weatherproof lights used are 12-V, Collins Dynamics® quartz halogen units.⁸ The lights are connected to converters (NC-1) so as to operate on standard 110 to 120 ac household current. One FX-12 deck light is mounted beneath the front of the environmental housing (Figs. 1 and 3) to provide lighting coordinated with camera pan and tilt. Two CL-12 handheld lights are positioned elsewhere (Figs. 1 and 3) to provide maximum shadow detail and modelling effect. The latter lights are mounted on either a Bogen Master Stand⁷ (No. 3082), extendable from 1.1 m (3.5 ft) and 4 m (13 ft) vertically, or a Bogen Magic Arm⁷ (No. 2930), extendable to 50 cm (19.7 in.) in virtually any direction. For either method, the light is attached to the support with a Bogen Magic Clamp⁷ (No. 2915).

⁷ Manufactured by Bogen Photo Corp., Fair Lawn, NJ 07410-0712.

⁸ Manufactured by Collins Dynamics, Aurora, CO 80010.

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Each light has both spot (100-W) and flood (55-W) capability within the same housing. One can choose spot or flood by an external switch; if only flood is required (as in much of my bat research), a flood bulb also can be used in the spot bulb holder to provide an instant replacement if the other flood bulb burns out. For each Collins Dynamics light, the illumination rating of the unfiltered spotlight is 750 000 candlepower, and for the floodlight it is 2000 candlepower.⁹ Thus, even at a working distance of 30.5 m (100 ft), the flood light could provide the recommended minimum illumination of 2.15 lx for the CCTV camera. At the working distance of 9.14 m (30 ft), more than enough illumination (23.7 lx) is provided by the unfiltered spotlight if used at full power. However, because white light is too disturbing for bats, an infrared glass or red Plexiglas filter is used on each light. The filter is held in place over the clear lens of a light with a heavy, shock absorbing Hypalon® rubber ring, all available from Collins Dynamics. The infrared (IR) filter provides IR illumination in the range of 800 to 1200 nm, peaking at 900 nm, which is within the maximum sensitivity of the camera (940 nm). The deep red, Lexan™ (No. 2423) filter provides visible light mostly at 575 to 700 nm.¹⁰ In practice, all three lights are operated through a variable voltage transformer at 60 to 80% capacity depending on ambient illumination. Operating the bulbs underpowered lowers their filament temperature, thereby producing a further red color shift; the resultant spectral range has not been measured.

The IR illumination is preferred in the research because it is largely beyond the spectral sensitivity of commensal bats, estimated at 800 nm. However, most bat research is conducted in environments with dark-colored wood, slate, and so forth that absorb much of the IR illumination and thereby reduce the depth of field for videography. Thus, it is often necessary to use the deep red floodlights to illuminate broadly the area under study. Outdoors, bats appear to be most sensitive to the red illumination early in the evening unless the lights are operated at about 60% capacity. As the ambient illumination decreases, or as working distance increases, the operating voltage can be increased without apparent disturbance to the bats.

Interior Components²

Monitor

The CCTV monitor³ (Panasonic WV-5410) is designed especially for surveillance or studio work (Fig. 2). It provides monochrome video images at a horizontal resolution of >850 lines at center [2,3], a resolution well-matched to the camera. A polarizing filter is mounted over the monitor screen to reduce glare from extraneous light sources.

The actual, visual screen size of the monitor is 32.4 cm (12.8 in.) measured diagonally. This size was chosen as the upper limit for comfortable, extended viewing at the close range necessitated by space limitations of the van in which the monitor is commonly used. In addition, manipulation of the pan/tilt and lens controls requires viewing within an "arm's length." The effective field of view on video monitors is typically at least 5% less than the calculated value (see section entitled "Lens," above) because monitors generally overscan by a factor of at least 5%. The WV-5410 monitor has a compensation switch for 5% over (= normal) or 5% under (= total field) scan size.

Operating ambient temperatures for the monitor must not exceed 50°C (122°F), and permissible relative humidity is less than 90%. Therefore, use of the monitor for daytime, outdoor, summer videography may require some mode of cooling. For example, this

⁹ D. Sinblade, personal communication, Collins Dynamics, Aurora, CO, 80010.

¹⁰ W. Collins, personal communication, Collins Dynamics, Aurora, CO, 80010.

CCTV system often requires the monitor to be housed in the laboratory van that is not air conditioned. Daytime temperatures inside the van commonly exceed 50°C in the summer; a roof exhaust vent fan and opened doors and/or windows ameliorate otherwise intolerable temperatures. On rainy days, the relative humidity inside the van has exceeded 90% with no apparent ill effect on the monitor.

Video Cassette Recorder (VCR)

A 1.27-cm (0.5-in.) VHS time-lapse video cassette recorder³ (Panasonic AG-6050) completes the basic CCTV system. Although a time-lapse VCR will not allow interchanging recorded programs with a standard VHS unit, other recording features are included that are convenient or necessary for scientific applications. The AG-6050 provides monochrome recording at 350-lines horizontal resolution [4]. Although not as high in resolution as by directly viewing the monitor, the recorded resolution is quite good and is still usable for close analysis in the still playback mode.

Nine recording modes are possible; however, only 2-h (real time) and 12-h (time-lapse) modes are of much use for behavior data, and only these two modes allow simultaneous audio recording. The video record interval for the 12-h mode is 0.1 s, compared to 0.017 s for the 2-h mode. Although the resultant motion in 12-h mode is disjointed, it is useful for obtaining simple counts such as the number of animals that enter/exit a hole in a wall. A one-shot mode (discussed later) is also available and is particularly useful as applied to the bat studies.

A built-in time and date generator automatically superposes the month, day, year, recording mode, hour (24-h time system), minute, and second on each frame during recording. The time and date display can be moved anywhere on the frame so as not to interfere with the subject under study. The display brightness also can be adjusted to establish proper contrast with the background.

A timer recording mechanism can be used to activate recording during the same time every day (daily timer) or during one to two time periods on each day of the week (weekly timer). For example, in observing commensal bats' responses to exclusion measures applied to roost exit or entry holes, the VCR is programmed to record automatically for a few hours at dusk when bats leave the roost, and for a few hours at dawn when bats return from foraging. A manual override control allows recording at time periods other than those programmed. Timer recording helps to ensure that an important observation period will not be missed.

A key feature of this CCTV system is alarm recording, which allows recording only when activity occurs; this conserves videotape and effectively extends the monitoring period of an individual tape. This feature involves the built-in programming capabilities of the VCR and a separate motion detector⁶ (Vicon V222MD), which senses motion in the camera's field of view.

The motion detector can be set to monitor one or two sensitized areas, which can be positioned virtually anywhere on the monitor display. The areas may be: one short horizontal rectangle or one or two horizontal or vertical configurations, and may be used independently or in dual pairs. In addition, full-screen sensitivity (80% of screen area) can be selected. Sensitivity is individually adjustable for each area.

For alarm recording in commensal bat studies, the VCR first is programmed via the timer recording mechanism to activate at two specific time periods each day. The recording mode is set on one-shot, which keeps the VCR on, but not recording (every 5 min the tape is advanced one frame in order to not damage the recording head). Meanwhile, the motion detector monitors the selected area(s) of the camera's field of view and trips an alarm

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(visual and/or audible) when significant motion occurs. The motion detector becomes inactive for about 15 s after the alarm is tripped and then resets itself if additional motion has not occurred. When the alarm signal is received by the VCR, it automatically switches the recording time mode from one-shot to 2-h (12-h can also be used). Recording continues for 20 s (variable from 10 s to 6 min, or to end of tape) before the VCR returns to the one-shot mode until the next alarm cycle. Keeping the recording time (20 s) set to overlap the alarm sensing time (15 s) ensures that virtually all detectable motion will be recorded.

Thus, this CCTV system design allows automatic monitoring of a particular situation. However, alarm recording is limited by the size and direction of the object in motion and whether it constitutes enough change in the sensitized area to trip the alarm. For example, at a 9.14-m working distance the system works very well, especially with the lens at maximum telephoto (160 mm) and full-screen sensitization. One bat moving across the field of view is more likely to trip the alarm than a single bat moving away from the camera. The probability of one bat being missed (not recorded) is greater than when more than one bat is within the field of view. Overall, counts made directly on the monitor compare very favorably to counts made on the recorded videotape, the difference between two such counts is rarely more than one bat.

The rate at which tapes must be changed depends on the number and length of the observation (monitoring) period and the number of animals active. Someone must be present much of the time, even during automatic recording, to ensure that the VCR has unrecorded videotape available. The VCR's upper temperature and humidity limits for operation are 40°C (104°F) and 80% RH, respectively. While these limits are more restrictive than for the other CCTV components, the methods described earlier for ventilating the van have allowed use of the VCR whenever necessary with no apparent negative effect.

Video Cart and Supplementary Equipment

The interior components of the CCTV system and controls are all mounted on a heavy-duty video cart¹¹ (Portabrace™ G2 Grip) (Fig. 2). The cart rests on large diameter (40.6-cm [16-in.]) wheels with semipneumatic tires, which make it easy to move the cart over irregular surfaces, on stairs, and so forth, and provide some cushioning for equipment carried. The cart is sturdy enough to carry up to 136 kg (300 lbs), allows convenient adjustable arrangement of equipment, and is compact enough to fit in an upright position for use inside the van.

The top shelf of the cart holds the CCTV monitor and motion detector (mounted against the left side of the monitor). Controls for the lens and the pan/tilt unit are mounted on the underside of the top shelf. The VCR fills the second shelf. The bottom shelf holds electrical connections. Each component rests on a 2.54-cm (1-in.) high-density foam pad, which also rests on a styrofoam base; this provides cushioning against vibration, which can be excessive in the lab van. All equipment is secured in place on the cart with adjustable nylon straps (bolted to the steel shelves) and/or rubber shock cords.

The cart has been modified somewhat from the original design. A box-frame of angle iron was constructed to protect the monitor and motion detector on the top shelf (Fig. 2). When in transit, a protective aluminum grid fits into the front of the frame to cover the monitor screen. A frame of heavy steel mesh covers the rear of the cart to protect video components and cable connections, and to hold two hardwood glider rails. The gliders make it easier for one person to slide the cart in and out of the van without damaging the

¹¹ Manufactured by K and H Products, Ltd., North Bennington, VT 05257.

cart, video equipment, or van. A gooseneck, high-intensity lamp (with dimmer switch) is mounted on the top shelf to provide illumination for controls.

Another frame of heavy steel mesh forms a slanted, bottom shelf (Fig. 2). Two electronic isolators provide individually filtered ac sockets to protect all CCTV components against interference signals, equipment interaction, powerline spikes and surges. A single plug leads from the bank of isolators to the ac power source at the study site. All three Collins Dynamics lights lead into a variable transformer (not shown in Fig. 2) connected to a timer (Fig. 2, bottom left), which plugs into the cart's multioutlet strip; this strip requires a separate lead to the ac power source. Thus, only two ac power leads are required for the complete CCTV system.

Van Alterations

The van (Figs. 1 and 3) is often used in the commensal bat project and has a number of custom-designed features for videography. Inside the rear, left corner (Fig. 2, top left) is a reel mechanism, which holds 61 m (200 ft) of coaxial video cable (for camera), control cable (for camera lens and pan/tilt unit), and power cable. Note that cable length for the system is optional; only 61 m were used because this meets current study conditions. The three cables are taped together to make it convenient for one person to handle, to enhance feeding it through the hole in the other side of the van, and to reduce on-ground clutter between the van and study site. The exterior of the cable hole has a flange with a downward-angled projection (Fig. 1, lower center right) to keep out rain. The reel of cable is also removable from its van-mounting for those cases when the video cart is located elsewhere.

The roof of the van (Figs. 1 and 3) is covered with a sheet of exterior grade plywood (1.5 m [5 ft] by 3.0 m [10 ft]), which is painted white to reflect heat, edged with heavy angle aluminum to protect the edge from physical damage, and mounted just above the roof surface on a rack to provide shade while allowing air flow. The platform serves as an excellent location for positioning the camera or lights or both for outdoor videography (for example, regarding bat exit or entry holes at the eaves of a building).

To further reduce heat inside the van on sunny days, a white vinyl cover attaches over the windshield and front door windows (Fig. 3). Other windows are covered inside with a neutral-gray film; and when on location an additional inside cover of reflective aluminum foil is used (Fig. 1). The ceiling and walls inside the van are partially covered with insulation to reduce both heat and noise. For similar purposes, the floor of the van is covered with plywood and a polyvinyl chloride (PVC) mat. The grid-type mat (Fig. 2) also provides a safe (nonslip, self-draining, nonconductive, light-colored), cushioned, floor surface. Before adding the floor mat and padding all components with high-density foam, vibration (from driving long distances and/or on rough roads) occasionally caused the loosening of screws holding circuit boards in the camera and loosening of the zoom lens. Thus, cushioning is very important for all CCTV components carried in the van.

When the video cart is in position for use, as shown in Fig. 2, space is very limited inside the van. Because of this limitation, the driver's seat has been mounted on a swivel pedestal allowing it to be turned around to face the cart for videography purposes. A comfortable seat of proper height (for example, the van seat) is highly recommended for any long-term videography. In my bat studies, observations of several hours to all night are common.

General Conclusions

The CCTV system and methods for using and transporting it have improved over the years since this project was initiated. It is well-suited for indoor and outdoor work and is

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- [4] Operating 1985, 301

reasonably portable in spite of its bulk. The components do require a few hours for one person to assemble fully on location, which renders the system unsuitable for rapid, on-the-spot applications. In addition, the camera scans at the NTSC standard, 60 fields/30 frames, which does not allow detailed recording of very rapid motion. The VCR allows frame-by-frame analysis, but rapid motion (for example, wing beats) is blurred on individual frames. However, the excellent resolution of the components produces high-quality recorded videotape that is very good for general behavior studies. In developing a low-light system, one should carefully consider their specialized needs for a study and any recent developments in videography components that might better satisfy those criteria. The current cost of the components of the system described is U.S. \$12 000 to \$14 000; price may vary considerably with vendor.

The videography equipment and techniques described herein have been used to record manually or automatically over 100 h of bat activity under both field and laboratory conditions. The motors for lens focus and zoom and for camera pan and tilt produce low-level audible sounds (not measured as of this writing), which do not appear to affect the behavior of bats under observation. The components selected have withstood the test of rugged field conditions and transport. While design emphasis has been for use in commensal bat research, the basic system is adaptable to other studies of small mammals, especially commensal rodents.

Acknowledgments

Numerous people were helpful at various stages during the development of the CCTV system described. In particular, the author wishes to acknowledge: Gary McCracken and M. Kitty Gustin (University of Tennessee, Knoxville) for encouragement at the outset of this project; Aaron Chesler (Panasonic Industrial Co., Secaucus, New Jersey) and William Collins (Collins Dynamics, Aurora, Colorado) for consistently accurate and detailed technical advice; and Harry Kwarta, Steve Rzany, and Don Dopp (NYSDH/WCL&R, Griffin Laboratory, Slingerlands, New York) for continued assistance in improving the mobility and overall performance of the system. Thanks are also due to those individuals who have cooperated in video applications on their premises and, thereby, helped the system evolve to its present state.

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Evaluation of Some Radioisotopes as Marking Agents for Monitoring Bait Consumption

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ABSTRACT: Minute quantities (1 to 20 μ Ci) of six gamma-emitting radioisotopes, manganese-54, zinc-65, selenium-75, iodine-125, iodine-131, and cesium-134, incorporated into nontoxic baits were found suitable as marking agents to detect bait consumption by coyotes (*Canis latrans*). The small quantity of isotope required minimizes detection of the marker by coyotes and potentially provides a bias-free procedure for simultaneously comparing the relative efficiency of several bait delivery techniques. Presence and identity of specific markers were determined with a multichannel analyzer on the basis of the energy level of emitted radiation. Differences in relative distribution of these isotopes among body tissues were noted. Other potential applications and constraints are discussed.

KEY WORDS: baiting, *Canis latrans*, coyote, oral markers, radioisotopes, Mn-54, Zn-65, Se-75, I-125, I-131, Cs-134

Studies related to baiting wild animals commonly involve incorporating a variety of agents into bait materials as a means of identifying the animals that ingest the bait. Such marking agents have varied from inert substances that simply adhere to or pass through the alimentary tract and are deposited in the feces [1,2] to materials that are absorbed by the body and accumulate in particular tissues and are recognizable because they "stain" [3-6] or chemically alter tissues [7-9] in ways that can be detected.

Although radioisotopes have been used in various ways to mark or identify animals [10-12] or their excretory [13-17] or reproductive [18,19] products, they have seldom been mentioned as marking agents to detect oral ingestion. Since most radioisotopes are recognizable by unique energies of emitted radiation, the number of potential markers is large compared to other types of oral physiological marking materials.

Three conditions must be met for oral marking agents to be useful in baiting studies, including (1) not deterring animals from ingesting the bait and (2) producing "marks" that

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are readily and individually detectable and distinguishable with (3) "marks" persisting for the required period of time [9]. Additionally, to avoid bias among baits, the marking agent should not be detectable by the target animal. With radioisotopes, concern about the first requirement is minimized because very minute quantities of isotopes are usually adequate to produce effective marks. The relative energies of radiation emitted from individual isotopes provide unique "signatures" which meet the second requirement if there is sufficient activity to raise radiation counts above background radiation and the active material has an adequate physical half-life and remains in the body long enough to meet the third requirement. Detectability is influenced by the length of assay (counting) time.

Preliminary evaluations of ten isotopes, sodium-22 (Na-22), manganese-54 (Mn-54), cobalt-57 (Co-57), zinc-65 (Zn-65), selenium-75 (Se-75), strontium-85 (Sr-85), yttrium-88 (Y-88), iodine-125 (I-125), iodine-131 (I-131), and cesium-134 (Cs-134), indicated four (Na-22, Co-57, Sr-85, and Y-88) were markedly less promising because they did not appear to produce lasting marks or were expensive or difficult to obtain. Herein we report subsequent evaluations of the other six isotopes.

Our specific objective was to assess the utility of Mn-54, Zn-65, Se-75, I-125, I-131, and Cs-134 as oral marking agents for use in coyote baiting studies by: (1) determining how well small quantities of the materials could be detected in the animals, (2) determining the tissues in which the strongest and most persistent marks occur, and (3) assessing the relative retention of marks over a 20-day period.

Methods

Subjects

Four adult coyotes (two males and two females) reared in the USDA Predator Research Facility at Millville, Utah, were transported to holding facilities of the Arid Land Ecological Reserve near Richland, Washington, where they were housed as pairs in cages 4 by 5 by 2.5 m. They were fed 1500 g per pen daily of a food ration prepared commercially for fur-farming operations and had water ad libitum.

Procedures

A series of 7.5-g baits made from beef tallow were used to facilitate ingestion of the desired amount of radioactive material. Baits were molded into a cone shape from melted tallow and a 1-cm³ cavity created in one end. A measured amount of radioactive material (dissolved in a very dilute acid) was placed in the cavity with a micropipette and the liquid allowed to evaporate overnight. The cavity was then filled with melted tallow and allowed to harden. Two experimental treatments were used with both coyotes in each cage receiving the same treatment. One treatment consisted of force-feeding tallow baits containing 10 μ Ci of Zn-65, 20 μ Ci of Mn-54, and 2.5 μ Ci of Cs-134 to both coyotes in one pen. Coyotes in the other pen each received baits containing 10 μ Ci of Se-75, 1 μ Ci of I-125, and 2 μ Ci of I-131. The dose of each isotope was determined empirically on the basis of published data on the physical half-life and gut-to-blood absorption rates (Table 1) [20,21].

Immediately before treatment, and on Days 2, 5, 10, 15, and 20 post-treatment, each coyote was anesthetized with an intramuscular injection of 100 mg of ketamine hydrochloride to facilitate transport to a laboratory and assay analysis. A 7-mL sample of blood was drawn into an evacuated collection tube and 100-s gamma radiation counts taken of the abdomen and throat regions with a multichannel pulse-height analyzer (Nuclear Data ND-60) attached to a germanium-lithium detector (Princeton Gamma-Tech 2) that was

TABLE 1—Comparison of physical and biological characteristics of isotopes^a evaluated in this study

Isotope	Half-Life, Days			Gut-to-Blood Absorption Ratio	Physical Half-Life, Days
	Physical	Biologic	Effective ^b		
Mn-54	300	25	23	0.1	300
Zn-65	245	1959	218	0.1	245
Se-75	127	24	20	0.9	127
I-125	60	138	42	1.0	60
I-131	8	138	7.6	1.0	8
Cs-134	840	140	120	1.0	840

^a Values presented from Refs 20 and 21.

^b Effective half-life incorporates physical half-life and biologic retention time.

cooled with liquid nitrogen. In the case of the abdomen, the animal was laid on its back and the detector placed slightly forward of the pelvis and directed dorsally and anteriorly toward the region of the kidneys and liver. Throat counts were made with the detector ventral to the neck and directed 1 to 2 in. (2.5 to 5 cm) below the larynx (region of the thyroid). This analyzer provided a printed output of the number of counts registered in each of 1024 channels representing an energy spectrum of 0.0 to 2.05 MeV. Since radiation energy from I-125 is too low on the energy spectrum to trigger the germanium-lithium detector, the thyroid region of the throat was also assayed with a single-channel pulse height analyzer (Ludlum Model 2200) attached to a low-energy scintillator (Ludlum Model 44-3 thin-window sodium iodide detector) with a threshold setting of 275 and upper discriminator setting of 300, based on calibrations determined from a standard I-125 source. Counts were registered directly on, and recorded from, a light-emitting diode (LED) display on the device.

Subsequent to blood sampling on Day 20, the animals were euthanized with an intravenous injection of T-61 Euthanasia Solution (American-Hoechst, Inc.) and the thyroid and 5- to 8-g samples of skeletal muscle (hip region), liver, and kidney were removed, placed in individual plastic tubes, and stored under refrigeration. Logistical problems with the multichannel analyzer did not permit isotope assays of blood and tissue samples until 39 days after the tissues were collected. We compensated for this delay by using an assay time of 4 min each for the tissues. During assay, the tissue samples were left in the storage tubes and placed in a standard position 1 in. (2.5 cm) in front of the detector. Lead bricks partially shielded the detector from ambient radiation. Results were printed as described above.

Assays for Isotopes

Tallow baits containing the individual treatment doses of Mn-54, Zn-65, Se-75, I-125, and Cs-134 served as "standards" and were assayed with the multichannel analyzer to provide a sample of the unique pattern of radiation energies associated with each isotope (Fig. 1). By design, each of the isotopes tested had at least one diagnostic photopeak or "spike," in the spectrum of radiated energies that was not ambiguous with the other isotopes. In addition to the diagnostic "spike" in radiated energies, the isotopes also produced a general increase in radiation as a result of scatter (Compton effect), especially in low energy portions of the energy spectrum.

Since we were primarily interested in a qualitative assessment (presence/absence) of isotopes, we routinely checked the calibration of the analyzer with known sources (standards) and

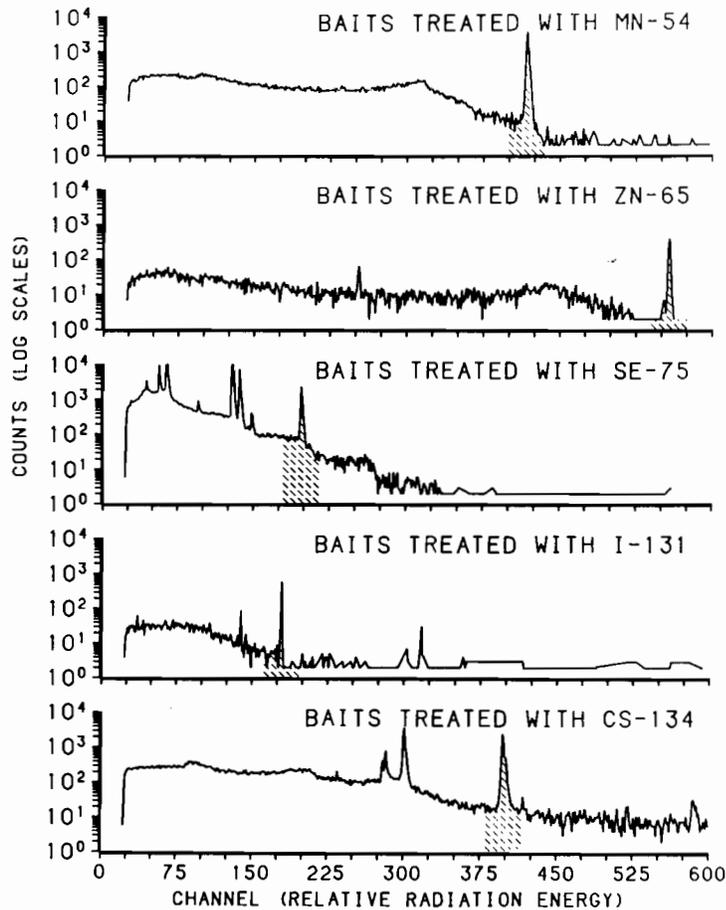


FIG. 1—Unique patterns of radiation energies for five of the six isotopes (incorporated in tallow baits) evaluated in this study based on total counts for 100 s with a germanium-lithium detector attached to a multichannel analyzer (measurements truncated at Channel 600 (1.20 MeV)). Hatching indicates the diagnostic energy spikes used in this study.

used the numerical count recorded at our diagnostic energy channels for each isotope as a measure of the *peak* value. To assess the relative height of the peak with regard to the *adjacent channels*, we used the maximum and minimum radiation counts among ten channels above and below the peak energies, insuring that the adjacent channels did not include “shoulders” of the diagnostic spike (Fig. 2). Results were graphed on log-linear scales to provide sensitivity at low counts as well as a measure of the peak values.

Results

Location of Isotopes in Tissues

Radiation assays of blood, kidney, liver, muscle, and thyroid tissue collected 20 days after treatment revealed that, as expected, each isotope had stronger affinities for some tissues than others (Fig. 3). Kidney and liver tissue were excellent locations to detect Se-

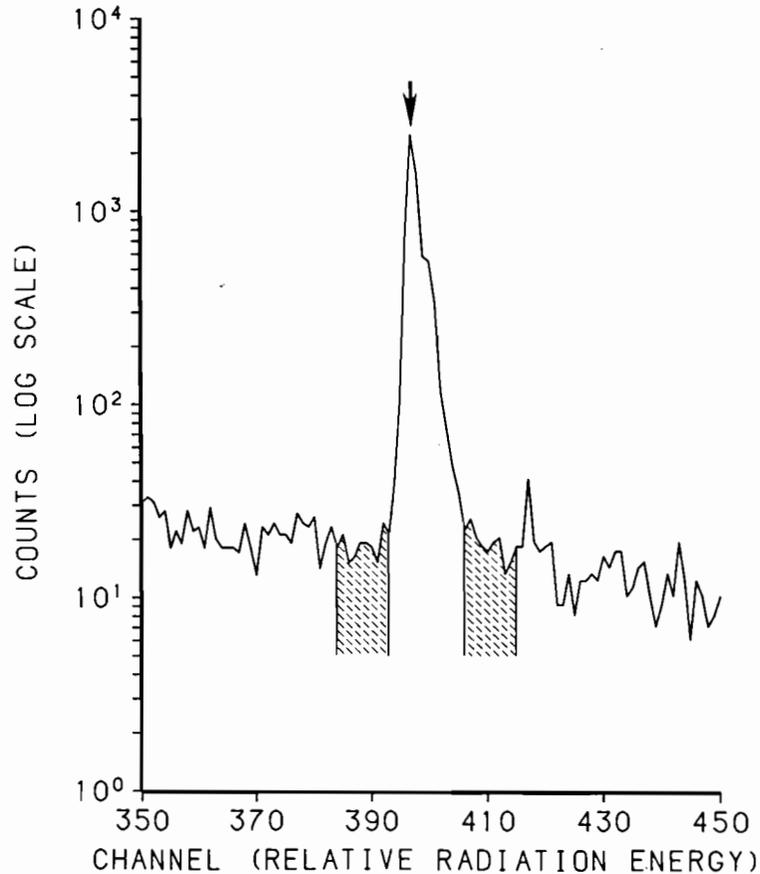


FIG. 2—Illustration of measurement locations for the diagnostic "spike" (arrow) and "adjacent channels" (hatched) from radiation energies of Cs-134.

75, Mn-54, and Cs-134, although the latter was most readily detected in muscle. Radiation levels from Zn-65 were highest in liver and muscle tissue. Both I-125 and I-131 were easily detected but after Day 5 were detectable only in the thyroid.

In general, blood collected 20 days after treatment was not effectively marked by any of the isotopes and only I-125 and I-131 produced satisfactory marks in the thyroids.

Durations of Marks

The marks produced by Mn-54, Zn-65, Se-75, and Cs-134 were easily recognized throughout the 20-day post-treatment period in both abdominal and throat assays of the live animals (Fig. 4). I-131 was also readily detected with the germanium-lithium detector, but only in assays in the region of the thyroid. In each case, peak radiation counts within the diagnostic energy channels were 10 to 100 times higher than the radiation counts in the energy channels adjacent to the peaks.

Assays for I-125 with the thin-window, NaI detector showed that pretreatment counts of the throats of the coyotes were low, but nearly double that of background (Table 2).

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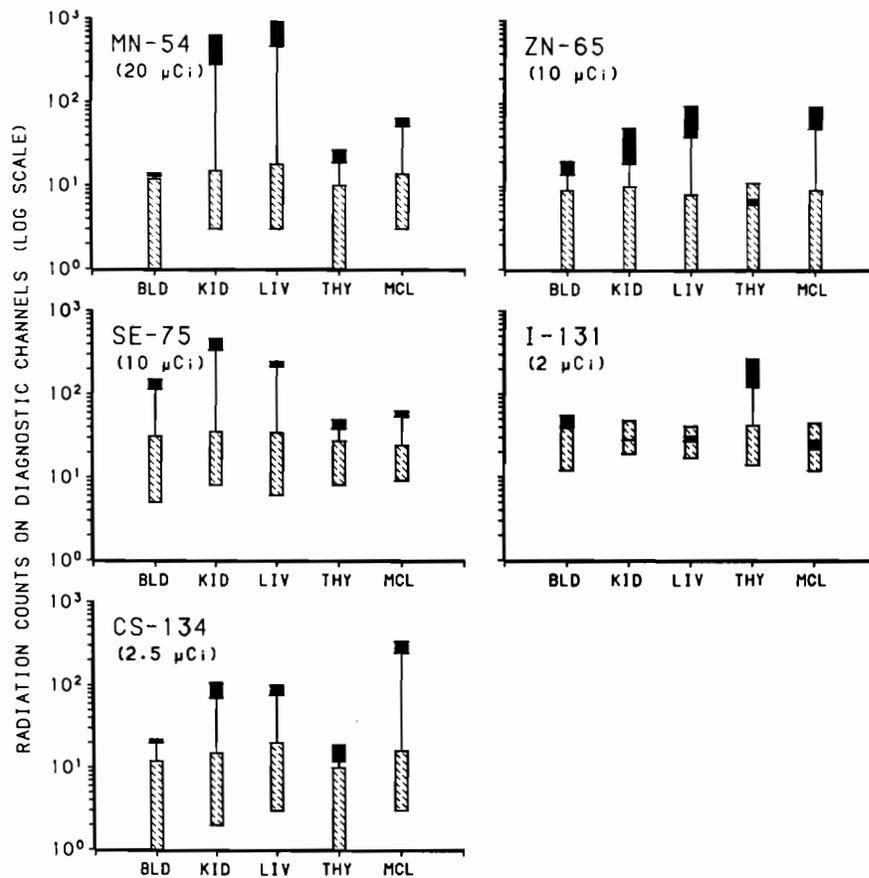


FIG. 3—Ranges of 240-s radiation counts among tissues (BLD = blood, KID = kidney, LIV = liver, THY = thyroid, and MCL = muscle) from two coyotes. Differences between readings at diagnostic (solid) and adjacent channels (hatched) are indicated by the connecting lines.

Throughout the post-treatment period, throat counts of the 2 coyotes not treated with I-125 were 7 to 9 times greater than background probably as a result of radiation scatter associated with their treatment with other isotopes. Throat counts of the I-125-treated coyotes were 10 to 15 times higher than animals not treated with I-125, whereas counts on the excised thyroids from these animals were 130 to 150 times higher (Table 2).

Assays made 20 days after treatment revealed that counts for I-125, Mn-54, and Zn-65 ranged mostly from 70 to 100% of that detected on Day 5 (Table 3). Counts for cesium-134 exceeded 50% of that recorded on Day 5 while those for Se-75 and I-131 were generally below 50% (Table 3).

Discussion

Our goal was to assess qualitatively the practicality of using Cs-134, I-125, I-131, Mn-54, Se-75, and Zn-65 as oral marking agents that would be effective for ≥ 20 days in coyotes. All 6 isotopes ingested at the doses indicated exceeded the prescribed requirements.

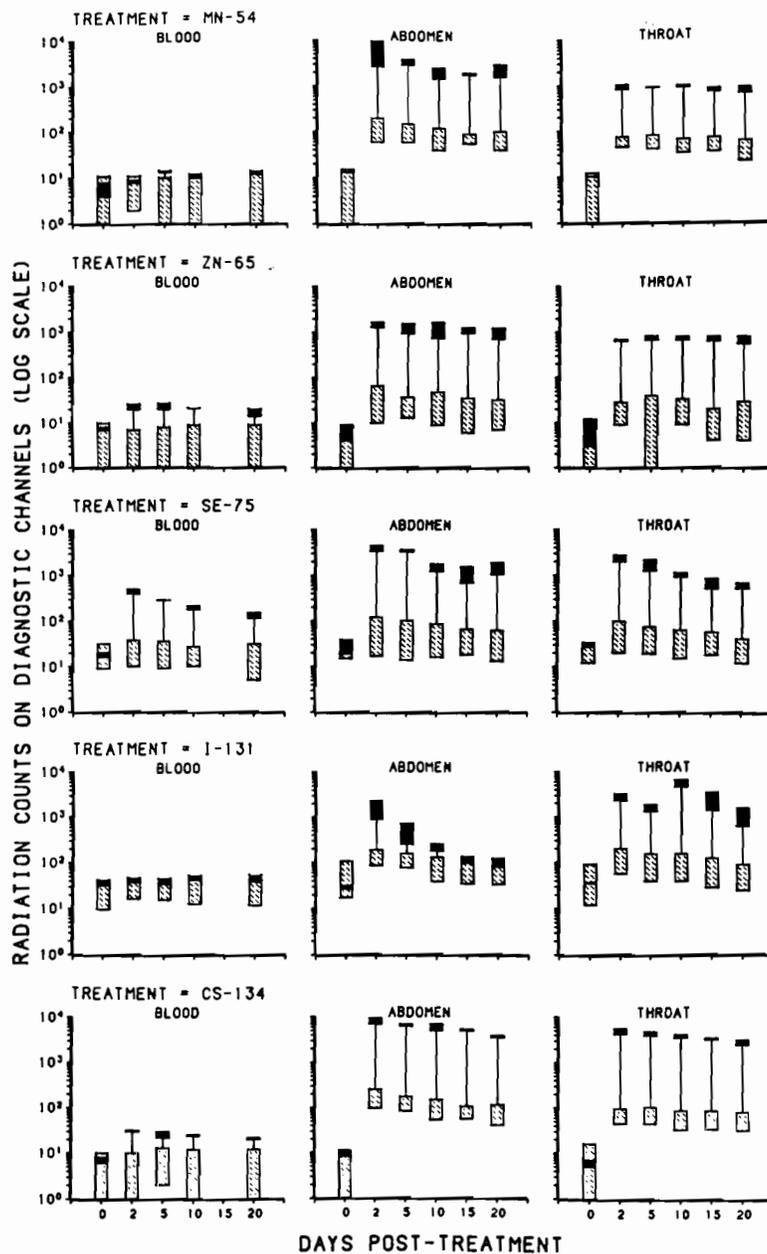


FIG. 4—Ranges of total radiation counts at the diagnostic (solid) and adjacent channels (hatched) in two live coyotes for each of five isotopes before and during the post-treatment period. Differences between readings at diagnostic (solid) and adjacent channels (hatched) are indicated by the connecting lines. The 100-s assays were made with a germanium-lithium detector attached to a multichannel analyzer.

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TABLE 2—Comparison of 100-s total radiation counts of the thyroid region of control and I-125-treated coyotes made with a thin crystal sodium iodide detector.

Day	Treated Animals		Untreated Animals		Background Counts ^a
	3191	3245	2569	3205	
0	88	97	54
2	978	1 052	451	375	...
5	6 269	4 934	276	232	25
10	6 321	3 974	246	208	28
15	2 328	3 469	225	222	31
20	4 529	6 658	188	184	27
20 ^b	13 726	15 862	102	75	...

^a Determined immediately before, or after, subject counts.

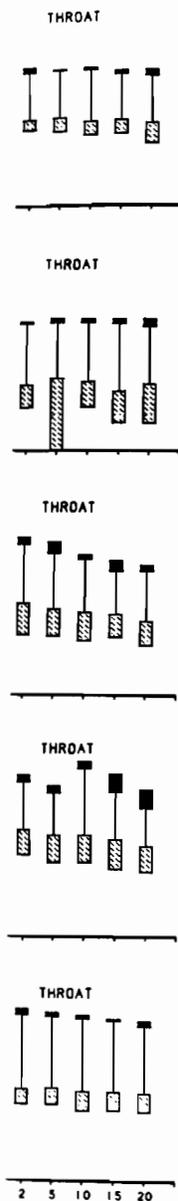
^b Excised thyroid glands.

TABLE 3—Radiation count (100 s) at diagnostic peak energies for six isotopes on Day 20, expressed as a percent of the comparable peak count on Day 5.

Isotope	Survey Location					
	Abdomen			Throat		
	Animal		\bar{x}	Animal		\bar{x}
A	B	A		B		
Mn-54	78	55	67	100	72	86
Zn-65	78	73	76	100	82	91
Se-75	57	29	43	31	41	36
I-125	72	135	104
I-131	31	17	24	46	80	63
Cs-134	56	56	56	78	50	64

Very strong, unambiguous marks associated with the radiation "signature" of each were readily discerned, even in the presence of the other isotopes. Substantially smaller doses would also have been readily detected over the prescribed interval.

The observed differential distribution of these elements within the body agrees with previously published information (for example, Refs 20 and 21) and underscores the need to understand anatomical and physiological fates of specified elements and compounds. Blood was generally a poor tissue to assay for the six isotopes we tested because of low concentrations of the markers. The thyroids are likewise poor assay locations except for the isotopes of iodine, in which case they are the essential tissue to assay. Liver, kidney, and muscle were all suitable to detect isotopes of Mn, Zn, Se, and Cs, with the preferred tissue varying slightly among the elements. If direct access to the detector with the animal is practical, all three tissues can be assayed simultaneously in an intact animal by placing the detector close to the abdomen and directing it toward the region of the liver and kidneys. More precise assessments are possible if the appropriate tissues are excised and submitted for laboratory analyses where more sensitive techniques and better shielding from background radiation can be achieved. This also translates into smaller dose requirements for creating a detectable mark.



and adjacent channels during the post-treatment channels (hatched) in a germanium-lithium

In many cases the utility of a marking agent is related to the effective duration of the mark. In the case of isotopes, persistence of an identifying mark is a function of (1) the physical half-life of the isotope, (2) the biological half-life of the element in the animal, (3) the effective dose of the isotope administered, (4) the length of the assay (count) time, and (5) the inherent efficiency of the detector. Our primary interest involved recognition of the specific radioisotope mark rather than a quantitative measure of the radioactivity present. Our use of external detectors on live animals and the attendant difficulties of maintaining precise geometry between the detector and the various body organs decreased the precision of our quantitative assessments among assays. Thus, our comments regarding longevity of these isotopic marks are constrained by the procedures by which they were obtained.

The physical half-life is an inherent characteristic of individual isotopes and not subject to manipulation. Similarly, manipulation of biologic half-life in any given species is limited primarily to the molecular form in which the isotope is administered and the fate of such molecules in the body. On the other hand, the dose administered, tissues assayed, type and sensitivity of the detector(s), and the duration of the assay (counting time) are usually amenable to manipulation to meet the needs of specific studies.

Selection of isotopes for individual studies must include several considerations. The relatively long physical half-life of Mn-54 and Zn-65 are offset by low gut-to-blood absorption rates (Table 3). The other 4 isotopes evaluated all have high gut-to-blood absorption, but I-131 has a short (7.6-day) effective half-life, and I-125 requires a special detector because of its low energy emissions. Dose adjustments can partially compensate for a low effective half-life, but treatment with relatively low amounts of radioactivity is usually preferred. Our results suggest that the doses used here produced marks in coyotes which could have been recognized several months later, or that considerably lower doses would have been adequate for the 20-day test period.

Advantages of Isotopes as Oral Marks

There are a variety of radioisotopes that may be suitable as oral marking agents. Our original screening included ten, of which we subsequently tested six. Finding more is a matter of matching test requirements with the physical characteristics of the isotopes (half-life, types and energies of emitted radiation, and so forth), the biological attributes of the chemical form in which the isotope is available [20,21], the types of detection equipment available, and potential interference from naturally occurring sources of radiation. Multiple isotope markers could be important in the design and execution of many studies.

Analyses for radiotracers can be fast and relatively simple, and permit simultaneous assays for multiple marks if a multichannel analyzer can be used. Normally, sample preparation time is minimal and sacrifice of the subject is not necessary. The extremely small quantity of material needed to create the marks virtually eliminates concern about the marker itself influencing ingestion.

Constraints on Use of Radioisotopes as Marking Agents

Among the disadvantages associated with using isotope markers are stringent licensing requirements. Federal (Nuclear Regulatory Commission) or state (usually through the state Departments of Health) licensing and approval of individual projects is mandatory, and strict procedures and accountability are enforced regarding use, handling, and disposal of radioactive materials. Requirements for license approval and reporting need to be taken into account in the planning phases of studies.

Use of radioisotopes also requires significant commitments to "clean" technique and

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protocol for the safety of the investigators and the integrity of the studies. Careful monitoring of personnel for contamination is essential. As with most aspects of "good laboratory practices," this is a matter of personal attitude and discipline. Planning each activity and contingency can mitigate most problems. It should also be recognized that use of isotopic markers in species or in applications that could enter human food chains is inappropriate.

Radioisotopes may not be practical for many studies or baiting situations. On the other hand, they offer advantages of multiple markers and simple assay, while minimizing much of the concern about animals changing behavior toward the bait materials as a result of the marker materials.

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