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## Proceedings: SEVENTEENTH VERTEBRATE PEST CONFERENCE, Rohnert Park, California, March 5-7, 1996 (Complete Work)

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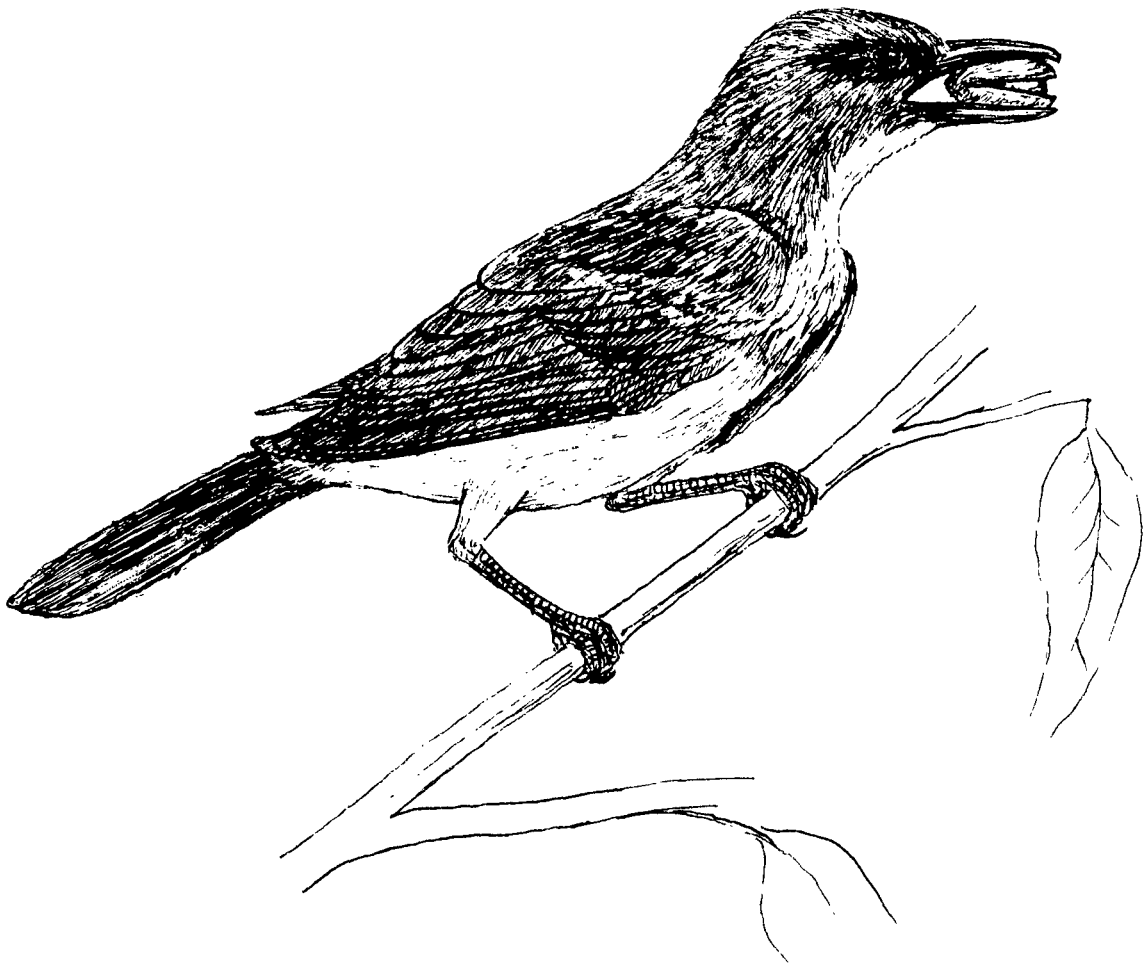
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Proceedings

SEVENTEENTH  
**VERTEBRATE  
PEST  
CONFERENCE**

March 5-7, 1996  
Rohnert Park, California





Proceedings

# **SEVENTEENTH VERTEBRATE PEST CONFERENCE**

Red Lion Hotel  
Rohnert Park, California  
March 5-7, 1996

Arranged by the  
VERTEBRATE PEST COUNCIL of the VERTEBRATE PEST CONFERENCE

Editors  
ROBERT M. TIMM and A. CHARLES CRABB

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Editors' note: In the preparation of the proceedings, editorial liberties were taken on very few papers. For the most part, papers appear as originally written except for instances where minor changes were made for the sake of clarity and uniformity of style.



## OPENING REMARKS - SEVENTEENTH VERTEBRATE PEST CONFERENCE

**ROBERT M. TIMM**, Superintendent and Extension Wildlife Specialist, Hopland Research & Extension Center, University of California, Hopland, California 95449.

Proc. 17th Vertebr. Pest Conf. (R.M. Timm & A.C. Crabb, Eds.) Published at Univ. of Calif., Davis. 1996.

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It is my honor and my pleasure to greet you this morning, and to welcome you on behalf of the entire Vertebrate Pest Council.

You have come from throughout California, from across the United States, and from many corners of the world to gather here for the purpose of sharing information, expertise, and wisdom in dealing with vertebrate pest problems. Our common purpose is to find yet better methods for preventing and resolving situations in which wildlife comes into conflict with humans. The Conference's mission remains one of education. We learn from each other, and we strive to find better ways of applying our knowledge to real-world problems.

In recognizing that the value of a conference such as this often lies as much in the informal interaction as in the scheduled presentations, the Council this year has structured the Conference to provide you a number of opportunities to meet your fellow participants. I invite you to the complimentary buffet reception this evening beginning at 6:30 p.m., and also to tomorrow evening's wine tasting at the Wine and Visitors Center, which is adjacent to the Red Lion Hotel. For those of you able to

stay an extra day to enjoy northern California, I am pleased to let you know that there is still space available on the Friday sightseeing tour. Details are available at the VPC registration desk.

The wildlife conflicts which occur in northern California are as diverse as its agriculture and biotic communities. Those of you on yesterday's field trip saw some of our challenges—from blackbirds to mountain lions, from rodents to coyotes. Those of us who live in the north coast area of this state enjoy not only the diversity of our surroundings, but we are also often challenged by the array of conflicts between people and wildlife.

I wish to thank those members of the Council, whose names are listed in your program, who took responsibility for the many aspects of this year's program. The conference is truly a joint effort, and we all benefit from the committee chairpersons' thoughtful and careful planning.

Let us know what we can do to make your experience here more valuable. Again, on behalf of the entire Council, welcome to the Conference.

## OPENING REMARKS - SEVENTEENTH VERTEBRATE PEST CONFERENCE

### THE FUTURE OF WILDLIFE DAMAGE MANAGEMENT—AND WHY I WANT TO BE A PART OF IT

SCOTT R. CRAVEN, Department of Wildlife Ecology, University of Wisconsin-Madison.

Proc. 17th Vertebr. Pest Conf. (R.M. Timm & A.C. Crabb, Eds.) Published at Univ. of Calif., Davis. 1996.

Welcome to the 17th Vertebrate Pest Conference; THE conference for those of us who work in the field of vertebrate pest management. Actually, I prefer the term wildlife damage management to either animal damage control or vertebrate pest control, but as long as one takes a broad perspective on the definition of wildlife, there is really no difference except perhaps in perception. I do not mean to suggest that the name of the Vertebrate Pest Conference should be changed. It should not be changed. However, I do suggest that no matter what umbrella term you operate under, we are all in the same business.

Speaking for myself, I am very pleased to be involved with wildlife damage management. Explaining why is what I hope to accomplish during this opening address for the 17th Vertebrate Pest Conference.

The premise behind my remarks this morning is really quite simple. No matter what we choose to call it, working with vertebrate pests in a nuisance, damage, or human health or safety context is a "growth industry." We have opportunities and challenges not available to some segments of the wildlife management profession.

As an Extension Wildlife Specialist, I have had the opportunity to interact with the public at many different levels over the past 18 years. That experience, plus more recent work with the Wildlife Society's Wildlife Damage Management Working Group (WDMWG), The National Animal Damage Control Association (NADCA), and the various wildlife damage conferences including the VPC, has allowed me to develop a list of opportunities and challenges for your consideration.

Perhaps an obvious question at this point is how can I be so positive and upbeat in the face of government gridlock, downsizing and stagnant budgets? The answer lies with the following observations, in no particular order of significance.

1. NADCA has become a revitalized force in wildlife damage management. NADCA leadership has increased membership and broadened the organization's perspective. Various NADCA committees now work with career placement, continuing education, position statements, and other professional activities. The recent merger with the Nuisance Urban Wildlife group further strengthens NADCA.
2. The genesis of the WDMWG has been a big step forward for our subdiscipline within The Wildlife Society. Membership is growing, and working group sponsored technical sessions at the TWS Annual Conference have elevated the profile and positive recognition of wildlife damage management.
3. The creation of the Berryman Institute for Wildlife Damage Management at Utah State University is a

huge step toward bringing wildlife damage into our college and university curricula where it belongs. Students are now exposed to wildlife damage management principles and policies in schools that had no such program a decade ago. The Institute has increased the stature of wildlife damage management through its research, awards program, and the profile of its staff, people like Mike Conover and Robert Schmidt, at meetings across the country.

4. The nuisance wildlife control business, NWCO's as its practitioners are called, has exploded, especially in eastern states. New York State alone has over 1000 NWCO's and the largest franchise company, Critter Control, has about 100 offices nationwide. Attendance at training workshops for NWCO's hosted by the University of Kentucky in Lexington and by Wildlife Control Technology outside Chicago, both within the last two months, has been large, enthusiastic, and suggests a strong demand for such opportunities.
5. Wildlife damage management is on-line with the e-damage, electronic bulletin board. On a daily basis, information is sought and given on a wide range of problems, policies, and procedures.
6. There are now three major conferences devoted to our field; the Vertebrate Pest Conference, the Great Plains Wildlife Damage Conference, and the Eastern Wildlife Damage Conference. They are all well attended and a fantastic opportunity for wildlife damage professionals from academia, government agencies, and the private sector to come together, share ideas and expertise, and build productive networks. In a recent issue of Wildlife Control Technology, Robert Schmidt shared a vision of an even larger, national conference on wildlife damage management.
7. The active role of USDA-APHIS-ADC has been a force in wildlife damage management well beyond the day-to-day operations of their own programs. ADC employees have a high profile at national meetings such as this one. The Denver ADC facility is a key source of new technology, and working under memoranda of understanding with various state agencies, ADC is the primary contact for wildlife damage in states like my home state of Wisconsin.
8. Sources of information are readily available, current, and complete. The 1995 edition of the Handbook of Prevention and Control of Wildlife Damage (University of Nebraska) is an excellent example. The Humane Society of the United States is working on a new manual on Euthanasia which should be especially useful. The WDMWG is working on a

review of wildlife translocation and surveys and other data collection efforts are underway.

9. Finally, although I am sure the list could be expanded, there is encouraging news about new products and techniques. Various types of contraception still hold great promise, methyl anthranilate has emerged as a tool in the escalating battle with urban flocks of Canada geese, and perhaps recent work in New York with invisible fences will help keep some apples out of reach of growing deer herds. Every little bit helps, and I am confident this bit of positive news will be expanded by many of the authors presenting material here at the VPC.

Those represent some of the observations that lead me to conclude that the future is good for wildlife damage management. I think we can solidify that future if we seize a few of the opportunities that are laid out before us. Let me offer several examples for your consideration.

I believe one of our greatest opportunities is to assume a broader role in wildlife conservation. Some "traditional" wildlife managers are anxious over real or perceived erosion of support for consumptive activities such as hunting and trapping or a loss of identity as title changes such as "conservation biologist" or "landscape ecologist" become more commonplace. At the same time some of our colleagues are apprehensive about their programs, those of us who deal with often overabundant species could find ourselves in a position of increased demand and profile.

In a recent essay in "Conservation Biology," Robert Garrott and others explored the problems created by overabundant and expanding native species (Garrott et al. 1993). These problems included the spread of infectious diseases and parasites, alteration of plant and animal species composition, and even local extinctions caused by interspecific competition. Examples cited included the impact of introduced red fox on endangered Light-Footed Clapper Rails and California Least Terns here in California, predation by California sea lions on endangered steel head runs in Puget Sound, and the widespread impacts of white-tailed deer herbivory on ecosystem diversity and rare plants. The authors listed numerous native species that have been able to capitalize on anthropogenic landscape changes including raccoons, Canada geese, beaver, white-tailed deer, red winged blackbirds and others. Thus, these native species are implicated in ecological problems as well as more traditional damage to crops, structures, or human health.

Noted entomologist and conservationist E. O. Wilson made a parallel case for problems caused by exotic species in a recent issue of National Wildlife Magazine (Wilson 1996). Wilson concluded that the introduction of exotic species represents one of the four apocalyptic horsemen of extinction and, in fact, one of the worst. Exotic species can change ecosystems and overwhelm indigenous species, leading to reduced biodiversity.

In both cases, the message is clear; one key way to attain conservation goals for the preservation of biodiversity is to control the deleterious impacts of exotic or overabundant native species. Not because they are damaging crops or threatening human health, but because they are affecting other species.

Garrott went on to chastise the public and the conservation community for avoiding these issues because "actions required to correct these situations entail the killing of animals." Animal population reduction has been described in the conservation literature as "repugnant," "odious," and "nasty." As a result, some contemporary conservation issues are not being addressed, species are suffering, and the problems caused by exotic or native species are aggravated. If most wildlife managers or conservation biologists are unwilling or unable to address conservation dilemmas that involve population control, who better to step in and fill the void than the wildlife damage management community. We have the skills, the experience, and the network to make a real contribution. By doing so we add ecological damage control to our list of goals, establish an important link to the contemporary conservation community, and we improve recognition and support for wildlife damage control in general.

Of course, some of this is already underway. Cowbirds have been controlled to aid recovery of the Kirtlands' warbler and other species, great horned owls have been locally eliminated to provide secure hacking sites for peregrine falcons, coyotes have been controlled in black footed ferret reintroduction areas, and brown tree snake control programs are based on ecological problems. But there are many more opportunities for us to contribute. Our traditional clients and problems will not diminish in importance or frequency, and this notion of ecological damage control could be a major focus for our collective future.

I believe another opportunity involves education; education of future professionals through our colleges and universities; education of the public on problem avoidance and acceptable, viable solutions; and education and training of the rapidly growing private sector in wildlife damage management. In all cases, both the wildlife resource and the profession will benefit.

As an Extension specialist, education is my focus and wildlife damage has always been fertile ground. Concentrating on the public for a moment, I view a wildlife problem as a "teachable moment." The client rarely knows much, if anything, about the species involved, the cause of the problem, or possible solutions. By explaining the behavior of the animal and reviewing solutions, I am usually able to help them help themselves or find someone who can. But more importantly, it is possible to affect their attitudes toward the animal and the problem. Thus, a simple physical change in the situation or a change in their behavior may solve the problem and move toward "peaceful coexistence" and tolerance. I believe this is especially important in the urban environment. Opportunities are admittedly different in a large scale agricultural or industrial situation, but always take a moment to educate the client about their problem and the implications of various control alternatives through consultation, a brochure, fact sheet, or whatever works for you.

Education and training of and for private sector professionals is also very important. For one thing, the number of species involved, the laws, and the diverse control tools and strategies make wildlife damage management a complex field. Also, I believe there is

more and more incentive for states to license or certify private wildlife control practitioners in a more systematic and in depth way than has been done to date. Minimum standards and training for the private sector will protect the wildlife resource and the citizens who need assistance. It does not need to be contentious or burdensome to either the regulatory agencies or the private sector. I hope that either NADCA or the WDMWG or both can play a role in establishing guidelines for minimum competencies that could be adopted easily, leading to consistency among states.

I would like to switch gears to a discussion of several challenges in wildlife damage management, which could also be viewed as opportunities. Several challenges deal with human dimensions. For one thing, as professional wildlife managers, we are trained to think primarily in terms of viable animal populations. For the most part, this is exactly opposite of the way most people think and react. To us a captured raccoon on a residential roof is a possible rabies vector or a nuisance waiting to ply its trade elsewhere and it is insignificant in the bigger population picture of such an abundant species. However, to the homeowner and family members, it is an individual animal whose well-being is of concern. In working on a position statement on the issue of nuisance wildlife translocation for NADCA and TWS for the past two years, it has become quite clear to me that a broad ban on nuisance wildlife translocation would be clean and neat, but unacceptable to many people and very difficult to enforce. Because of this, I now believe that any position statement we create must be flexible enough to accommodate species-specific issues and judicious use of translocation under guidelines that minimize the problems associated with translocation and maximize the survival chances of the released animal.

Related to this are broader concerns over animal rights issues. Wildlife Damage Management programs come under frequent attack, especially when animals are killed. Examples include mountain lion control, fish-eating birds around aquaculture facilities, wolf control to protect ungulate herds, and many others. In some cases, it would appear that some segments of society are more concerned about the animals involved than about the health or livelihood of their fellow citizens. This may very well be the case for some people, but I believe they represent a manageable challenge.

The solution lies not with the individuals who criticize wildlife damage control, but with the majority of the public who are simply uninformed. The key is public recognition of the need for a wildlife control program in the first place, coupled with recognition that the populations of the targeted animals are not dramatically affected. Or, if they are, that they should be as in the case of abundant exotic species or overabundant native species where population reductions may be desirable. If we can successfully convey the need for control to the public, then when faced with barriers to programs created by what we and an informed public would perceive as unreasonable demands to spare animals at any cost, the public must stand up and say "enough is enough," we need the help, let the program proceed.

I believe we all realize that non-lethal methods are preferred over lethal, all other factors being equal.

However, we also realize that there are circumstances of urgency, efficacy, and practicality wherein lethal control is the method of choice. If we conduct a project in an efficient, humane way, guided by our professional code of ethics, we should be on solid ground. The emphasis of our actions should be on problem solving, with de-emphasis of killing and "control."

There are two other areas in which we could improve our public support base. The first deals with perception versus reality. Particularly in the arena of agricultural animal damage, some control programs or requests for assistance are initiated because species are perceived as a problem when they are not. For example, in Wisconsin a growing population of wild turkeys was viewed by farmers as a major threat to a variety of crops. That perception was fueled by word-of-mouth and rumor. After all, turkeys are large, diurnal, gather in large flocks, and spend considerable time in crop fields; they had to be doing something! There are certainly circumstances (unharvested corn over winter grapes, etc.) where turkeys can be a serious problem; however, most field inspections of complaints turned up another culprit or no damage at all. In cases such as these, perception has to be managed as if it were reality; but, if perception and reality are brought together by education, some problems may go away.

The other area deals with a caution about gadgetry and exploiting public fears. In cases involving the two taxonomic groups people seem to fear the most, bats and snakes, or in cases with very difficult solutions such as moles in a well manicured lawn, it can be rather easy and tempting for the less scrupulous in our society to capitalize on the situation. For example, in one case in Wisconsin we encountered a bat control service whose technicians would, for \$500, spread a few pounds of naphthalene in an attic and on the way out the door remind the client to seal up all bat access points in a couple of weeks. I suspect we could all recount stories of miracle gadgets with incredible claims to solve many frustrating pest problems while causing no harm to children, pets, "good" animals or the environment. Until such gadgets are subjected by law to the same kind of efficacy testing and registration that chemical products are, problems will continue. Bad experiences with unethical practices like the \$500 bat control or with gadgets that cannot deliver promised results spread like wildfire; success stories do not. We need to police our own ranks and make sure these kinds of practices are exposed. If a selected control technique has only a 50-50 chance of success, tell the client up front and explain why. At the same time get the word out to your colleagues on new developments, new applications of old techniques, and things that work for you. The profession and our clients will benefit. That kind of sharing is one of the great benefits of gatherings such as this one.

At the outset of this presentation, I mentioned the development of new tools and techniques. While that certainly is good news, we must also be careful to protect tools we already have. Chemicals in particular are under constant scrutiny. For example, Fenthion, primarily used in bird control perches, is apparently in trouble because of growing numbers of reports of secondary poisoning, primarily of raptors. An especially damaging situation

occurred in New York only a month ago, when a farmer (in clear violation of the Fenthion label which called for burial or incineration of dead target birds) spread Fenthion-killed starlings in a field with his manure spreader. A hunter then discovered dead crows and red-tailed hawks in the field. The resulting story in the New York Times (January 29, 1996) was very damaging. Two weeks later I found out that Wisconsin will not issue Fenthion use permits until the secondary poisoning issue is cleared up. The point is, we must know our tools inside and out, do everything humanly possible to prevent misuse, and defend safe, useful products whenever they come under attack. This gets back to my comment about educating the public about the need for damage control activities.

Finally, just a couple of additional thoughts. Virtually all wildlife management programs and land use decisions have wildlife damage implications, especially in the urban/suburban environment. We need to work toward communication and team building so we, as wildlife damage professionals, are in the loop at the outset of such decisions. If we are proactive rather than reactive, I believe we can avoid some train wrecks at some places; not all, but some. For example, urban Canada goose and urban deer problems are widespread and very complex. Where such problems are just beginning, successful control or problem resolution is much more likely than when the problem reaches crisis proportions and all interest groups are strongly sensitized and polarized. Local government teams, citizens' task forces, and other groups should all have wildlife damage management professionals on board as resources and part of the decision making process.

A final area in which we can be proactive is the potential challenge of friction between the growing NWCO industry and Cooperative Extension, USDA-APHIS-ADC, or other public agencies. I have no solid evidence that this has or will occur, but using Wisconsin as an example, I do believe it is possible. Over the past few years, I have averaged about 1,500 wildlife nuisance or damage calls per year. A relatively new nuisance hotline, an 800-number, toll-free service operated and staffed by USDA-ADC biologists, has handled over 8,000 calls. To the extent that clients are empowered to solve their own problems through consultation, print materials, or other technical assistance such as my free live-trap loan service, potential customers are lost to NWCO's. I and ADC biologists do frequently make referrals to local NWCO's when a client cannot or does not want to deal with a problem on their own. Nevertheless, I think we should be aware of this concern.

In conclusion, I repeat my opening contention; the future of wildlife damage management looks very good. On balance, the good news and the opportunities overwhelm the challenges and even the challenges contribute some vitality to our field. I hope I have set a positive tone for the next several days. Keep up the good work and enjoy the conference!

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## INTRODUCING THE NATIONAL WILDLIFE RESEARCH CENTER

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**ABSTRACT:** The paper summarizes the background and historical events leading to the creation of the National Wildlife Research Center (NWRC) and describes the status of its research program and facilities development in Fort Collins, Colorado. Also, the relationship of the NWRC to the Denver Wildlife Research Center is presented.

**KEY WORDS:** animal damage control, research, wildlife management, birds, mammals, agriculture.

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I appreciate the opportunity to introduce the National Wildlife Research Center to the 17th Vertebrate Pest Conference.

### BACKGROUND

Adequate research facilities are critical to provide scientific information and to develop methods for resolving problems caused by the interaction of wild animals and society while at the same time maintaining the quality of environments shared with wildlife. Assessments of the Denver Wildlife Research Center (DWRC) in the late 1980's by the Animal and Plant Health Inspection Service (APHIS) and other groups identified inadequate and sub-standard indoor and outdoor animal research facilities. The short-term solution was to cease using facilities that were sub-standard, thus severely limiting the Center's ability to develop alternatives to existing control methods. The General Services Administration (GSA), which has authority over space and facilities presently occupied by the DWRC on the Denver Federal Center (DFC) in Lakewood, Colorado, informed APHIS that outdoor animal facilities are incompatible with the urban real estate development planned for the DFC. Extensive discussions between GSA and APHIS architects determined that renovation of facilities to comply with animal care standards and to meet GSA requirements would be prohibitively expensive and short-lived. GSA would not agree to guarantee the continued use of such facilities beyond five years and requested annual consultations with APHIS to "assess progress of your agency's plans for the eventual removal of the animal holding facilities from the DFC." The outcome of these assessments and discussions was a decision by APHIS and resultant Congressional support to enhance the Center's research capacity and ability to achieve its mission through construction of modern facilities on or near a university campus.

APHIS promptly developed a Master Plan for new wildlife research facilities, and on February 20, 1990, an 80-year land lease was signed with Colorado State University (CSU) for 43 acres on the CSU Foothills Campus in Fort Collins, Colorado. The CSU location offered APHIS a highly suitable, improved research environment for the Center. Congressional appropriations for fiscal years 1990, 1992, 1994, and 1996 provided

funding for the design of all needed structures and for partial construction of animal research facilities.

Because of the Fort Collins location for the new research complex and the pending closure of the DWRC, a new name was needed for the center—a name that would capture its purpose and national, if not international, breadth. A variety of names was considered. The one most favored and subsequently chosen by DWRC employees and APHIS administrators was the National Wildlife Research Center (NWRC).

### HISTORICAL PERSPECTIVE

Research conducted by the Federal government to resolve conflicts between wildlife and human endeavors dates back to 1886 in the early days of USDA's Bureau of Biological Survey. Research on methods of controlling damage by wildlife had its beginning when Dr. A. K. Fisher experimented with various toxicants to control damage to agriculture caused by coyotes, bobcats, jackrabbits, prairie dogs, and other mammals. In 1905, S. E. Piper started field and laboratory experiments with toxicants, traps and other methods for controlling rodents. This activity was headquartered at Albuquerque, New Mexico, for a period before 1920, and in June of that year was transferred to Denver, Colorado, as the Control Methods Research Laboratory.

Investigations of the food habits of wildlife and of some diseases, particularly botulism, that affect wildlife were initiated in the 1920s. These activities became a part of the Food Habits Laboratory which was established in 1931 at Denver to study the food habits and economic relationships of predators and other mammals and birds in the West.

In August 1940, with the merger of USDA's Bureau of Biological Survey and the Bureau of Fisheries to form the new Fish and Wildlife Service (FWS), the two Denver-based laboratories—Control Methods with a staff of ten scientists and Food Habits with a staff of two—were combined to form the Denver Wildlife Research Laboratory. With the reorganization of FWS, as authorized by Congress in 1956, into the Bureau of Commercial Fisheries and the Bureau of Sport Fisheries and Wildlife, the Laboratory expanded and took on added responsibilities. Relationships between wildlife populations and their habitats on public lands, and the

effects of grazing, timber management, and other land uses were new areas of research.

The decade starting in 1958 was a period of growth and change for the Denver laboratory. In 1959, in recognition of the broad responsibilities of the major research stations of the Bureau of Sport Fisheries and Wildlife, the Denver Wildlife Research Laboratory was renamed the Denver Wildlife Research Center. Starting in 1958 with a staff of less than 20 employees, the Center had grown to more than 100 by 1969. Much of this growth was due to the addition by Congress in 1958 of the Pesticide-Wildlife program and to substantial increases in damage control research concerned with birds, forest animals, Hawaiian rats, predators, pocket gophers, nutria, and jackrabbits. Also, in 1967, the Secretary of the Interior and the Administrator of the Agency for International Development, Department of State, signed an agreement providing for an international research program aimed at discovering, developing, and applying new and better ways to protect world food crops from the ravages of rats and other animal pests. The DWRC was assigned responsibility for this world-wide research effort.

During the decade between 1968 and 1978, the research program of the DWRC expanded to include several new investigations on wildlife ecology on public lands and animal damage control. In 1972, cancellation of a number of toxicant registrations that had been important tools for managing some wildlife damage situations, resulted in renewed efforts to develop and register chemical methods for managing wildlife damage under the regulations of the U. S. Environmental Protection Agency.

The breadth of DWRC's research program again expanded significantly in 1980 with the merger of the DWRC and the FWS National Fish and Wildlife Laboratory (NFWL). The NFWL conducted a broad array of vertebrate systematic investigations, ecologic and zoogeographic studies, and marine mammal investigations. During the early-1980s, the DWRC had approximately 210 employees located at its headquarters and at 23 field stations in the United States and in three foreign countries.

In the 1970s and early 1980s it became obvious that maintenance and upgrading of the Center's research facilities were falling behind the changing needs of the agency and that new or renovated facilities would be needed. Changing regulatory requirements as well as scientific and legal standards for conducting research, particularly with captive wild animals, exceeded the Center's capacity to maintain the productive, directed research program that the Animal Damage Control (ADC) and other FWS programs needed. Several modernization initiatives were considered during this period; however, because funds were not appropriated for facility renovation or construction the problem became increasingly critical.

On December 19, 1985, Congress transferred the ADC Program, including the DWRC with only its wildlife

damage research projects, to USDA's APHIS. The ADC Program immediately undertook a number of changes to improve efficiency, decrease administrative costs, and draw the ADC Program elements together into a cohesive unit. DWRC research responsibilities were redefined to place emphasis on maintenance of existing ADC Program tools, development of expanded uses of existing tools, and development of alternative methods for resolving wildlife damage problems. APHIS completed the Master Plan for new wildlife damage research facilities and received its first construction appropriation in fiscal year 1990. Also, in 1990 APHIS and CSU reached agreement on the site for the new research center.

#### CURRENT STATUS OF THE NWRC

On September 1, 1993, ground was broken for the first structure of the NWRC, an indoor animal research building. This structure was completed in January, 1995. The first NWRC scientist was assigned in Fort Collins in December, 1994. Other staff quickly followed and by late-1995, 31 employees had been transferred from the DWRC to the NWRC in Fort Collins. Temporary office and laboratory space has been leased in Fort Collins while the permanent office/laboratory structure is being designed by APHIS, to be constructed by CSU's Research Foundation. Ground breaking for this building is scheduled for July, 1996, with occupancy planned for September, 1997. The remaining NWRC components still to be constructed in Fort Collins are the outdoor animal research facilities, the animal research support building, a garage/shop structure, a warehouse building, and a chemical storage building.

Research at the NWRC has expanded rapidly with arrival of the 31 research staff. Investigations include immunocontraceptive approaches for suppressing reproduction in deer, coyotes, rodents and birds; repellents for managing bird and mammal damage; improved capture and restraining systems for predators; integrated management strategies for resolving mammal and bird damage problems; registration of chemicals for wildlife damage applications; control methods for brown tree snakes; applications of geographic information system technology for understanding ecological and agricultural aspects of wildlife damage; and behavioral characteristic of birds and mammals that could lead to new methods for managing damage.

When the NWRC's main office and laboratory building is completed in 1997, the remainder of the DWRC staff in Denver will be transferred to the NWRC in Fort Collins, DWRC field stations will be designated as stations of the NWRC, and DWRC will be closed. The NWRC then will be fully staffed with a focus on research and methods development on new, alternate solutions for resolving wildlife damage problems. I proudly welcome the arrival of the National Wildlife Research Center and what it offers the field of wildlife damage management and the public.

# THE STATUS OF NUISANCE WILDLIFE DAMAGE CONTROL IN THE STATES

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**ABSTRACT:** State fish and wildlife agencies and nuisance wildlife control operators must work together whether or not they actively choose to. In this paper, their relationship is likened to a marriage between two (not so likely) partners. In an attempt to assess the status of this relationship the International Association of Fish and Wildlife Agencies, The Wildlife Society's Wildlife Damage Management Working Group, and the National Animal Damage Control Association developed a survey that addressed the level of state agencies' oversight of nuisance wildlife control operators (NWCOS). Responses were received from 47 states, 1 territory, and 17 ADC state offices. This report concentrates on the responses from the U.S. states and territories. Currently 77% of states perform nuisance wildlife control activities. Private agents may euthanize nuisance animals for property owners in 95% of the states, and are allowed to relocate nuisance wildlife in 91% of the states. Most states do not require NWCOS to carry general liability insurance. Some states do not have a well-defined method for monitoring compliance with laws and regulations dealing with nuisance wildlife control activities. There appears to be a great deal of gray area in the relationship between NWCOS and the state agencies. National guidelines for the nuisance wildlife control industry may help clarify the responsibilities of the states and NWCOS with respect to each other and the private landowner.

**KEY WORDS:** state wildlife agencies, pest control operators, guidelines, standards, USA, vertebrate pest control

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## NWCOS AND THE STATES: WHAT IS THE RELATIONSHIP?

What is the relationship between nuisance wildlife control operators (NWCOS) and state wildlife agencies? To tell you the truth, I am not sure. Though I am not the only one who has pleaded ignorant to this question. However, most people will agree that state agencies and NWCOS do have a relationship, but they cannot easily define it. The roles in this relationship appear unclear and inconsistent, and these gray areas create tension between the two parties. For example, the state fish and wildlife agencies are supposed to assume the regulatory role in the relationship, but often have to call on the services of private operators to take care of a wildlife damage or nuisance complaint. NWCOS, on the other hand, may feel some contempt at being asked to do something, but told how they can and cannot do it. Thus, they may feel like letting the states take care of their own problems.

Both parties probably feel as if it would be easier to just go their separate ways. Unfortunately, they cannot divorce themselves from each other. The state agencies and NWCOS are married, whether they like it or not, till death do them part. This pairing, however, was never coordinated or planned by either party ... the relationship just developed; it was a shotgun wedding, if you will.

So, a relationship exists, but what is the extent of it? As I said earlier, it is not easily defined. I am sure you will agree that a successful marriage requires an understanding, by each partner involved, of their mate's needs. How to fulfill their needs while getting their own met is important ... it is a delicate balance based upon a lot of introspection, discussion, and exploration. The International Association of Fish and Wildlife Agencies,

The Wildlife Society's Wildlife Damage Management Working Group, and the National Animal Damage Control Association developed a survey to begin to understand this relationship from the states' perspective. I cannot say the results provided a clearly defined understanding of the role that states play in this relationship, but I can say that we now have a glimpse of the level of state agencies' oversight of the nuisance wildlife control industry. More importantly—I think we have a better understanding of what additional information is needed before any general statements are made or recommendations are proposed.

The survey was sent to directors of the 50 state fish and wildlife agencies, 4 territorial agencies, and 39 Animal Damage Control state offices. Questions asked covered the extent to which states allow property owners to euthanize and relocate animals responsible for property damage, nuisance, or other conflicts with humans; the authority of state wildlife and conservation departments to license nuisance wildlife control businesses; the regulations that states maintain on handling of animals or techniques used for nuisance and/or damage control; the animal species that are most commonly reported in nuisance complaints, property damage, and human health and safety issues; and the amount of support that exists for the development of national guidelines for the nuisance wildlife control industry.

The response to the survey was quite encouraging—we received responses from 47 states, 1 territory, and 17 ADC state offices. The high response rate of 89% from the U.S. state and territorial agencies combined, allows us only to report with confidence on these partners (herein referred to as "the states") for our discussion of how this marriage works.



## WHO PERFORMS NUISANCE WILDLIFE CONTROL?

Currently, 37 states (77%) perform nuisance wildlife control activities as part of their regulatory duties (Table 1). Other agencies involved include the State Department of Agriculture, State Department of Natural Resources, APHIS/ADC, county agents, and the State Department of Health.

Table 1. Responses from U.S. state and territorial fish and wildlife agencies to the question, "Do any of your state's public regulatory agencies perform nuisance wildlife control activities?"

	<i>n</i>	Percent
No	11	22.9
Yes	37	77.1
Regulatory agencies specified:		
a. State Wildlife Division	28	52.8
b. State Dept. of Ag.	9	17.0
c. APHIS/ADC	4	7.6
d. State DNR	5	9.4
e. Some combination of above	1	1.9
f. County agents	4	7.5
g. Dept. of Health	2	3.8

Property owners also have the freedom to take the problem into their own hands. Ninety-four percent of the states allow property owners to euthanize animals responsible for property damage, nuisance incidents, or other conflicts (Table 2). At least five states reported that all nuisance animals, regardless of species, can be euthanized by property owners. Other states place restrictions on game animals and/or federally protected species. Relocation, however, is less available to property owners as an alternative to managing nuisance wildlife (only 69% of the states allow relocation by personal property owners; Table 3). Yet, while fewer states allow relocation than euthanization by property owners, more states allow owners the freedom to relocate any species of concern (eight states do not restrict the species that are relocated).

Now into the pot, we add in the private nuisance wildlife control operator. Designated private agents are allowed to euthanize nuisance animals for property owners in 39 states (95%; Table 4), while 32 states (91%; Table 5) allow such agents to relocate nuisance wildlife.

From this information it appears that there are, not just two, but many hands in the pot including those of different state agencies, private landowners, and a variety of private control operations. Whose hands are responsible at any one time would be difficult to say. I

would worry that if a concerned citizen called to report a wildlife damage incident he or she would be routed around agency to organization to operation before they got a definite answer to their question or request.

Table 2. Responses from U.S. state and territorial fish and wildlife agencies to the question, "Does your state allow property owners to *euthanize* animals responsible for property damage, nuisance, or other conflicts with humans?"

	<i>n</i>	Percent
No	3	6.2
Yes	45	93.8
Allowable species:		
a. All species <i>except</i> game animals, Fed. protected species (all unprotected species)	16	24.6
b. Other small mammals	14	21.5
c. Not T&E species	4	6.2
d. Deer	4	6.2
e. Animals causing damage	12	18.5
f. Rock doves, starlings, crows, grackles, blackbirds, English sparrows, etc.	4	6.2
g. Other	6	9.2
h. All	5	7.7

Table 3. Responses from U.S. state and territorial fish and wildlife agencies to the question, "Does your state allow property owners to *relocate* animals responsible for property damage, nuisance, or other conflicts with humans?"

	<i>n</i>	Percent
No	16	31.2
Yes	33	68.8
Allowable species:		
a. All species	8	8.3
b. Not T&E/protected species	13	13.5
c. Nuisance animals	4	4.2
d. Depends on species & prevalence of disease (case by case)	12	12.5
e. Other small mammals	36	37.5
f. Not game animals	13	13.5
g. Other	10	10.4

Table 4. Responses from U.S. state and territorial fish and wildlife agencies to the question, "Does your state allow property owners to designate a private agent (not a public employee) to *euthanize* animals responsible for property damage, nuisance, or other conflicts?"

	<i>n</i>	Percent
No	2	4.9
Yes	39	95.1

Table 5. Responses from U.S. state and territorial fish and wildlife agencies to the question, "Does your state allow property owners to designate a private agent (not a public employee) to *relocate* animals responsible for property damage, nuisance, or other conflicts?"

	<i>n</i>	Percent
No	3	8.6
Yes	32	91.4

#### WHO THEN, IS ACCOUNTABLE?

Any agency or group in particular? All organizations that perform these duties? Are the state fish and wildlife organizations responsible for any work that is done no matter who does it? Or will the blame be shifted just as the request from this citizen was? This lack of understanding can lead to a lot of intermarital strife.

#### STATES' RESPONSIBILITIES

Most states (88%) do not require NWCO's to carry general liability insurance (Table 6). I interpret this to mean that the states are, therefore, the responsible party, but in reality this may not hold. The states may be accountable for what the NWCO's do; they may not. An interesting and important point is that seven states (12%) either did not know who was responsible, or did not have a well-defined method in their state, for monitoring compliance with laws and regulations dealing with nuisance wildlife control activities (Table 7). Thus, it appears that "liability" and "responsibility" are two subjects that lie in that important gray area.

Table 6. Responses from U.S. state and territorial fish and wildlife agencies to the question, "Does your state require nuisance wildlife control businesses to carry general liability insurance?"

	<i>n</i>	Percent
No	42	87.5
Yes	4	8.3
NA	2	4.2

Table 7. Responses from U.S. state and territorial fish and wildlife agencies to the question, "How does your state monitor compliance with laws/regulations applicable to nuisance wildlife control activities (e.g., through a control or licensing board, Conservation Dept., Agriculture Dept., Better Business Bureau, law enforcement, etc.)?"

	<i>n</i>	Percent
State/Federal wildlife conservation agency	10	17.5
State Dept. of Agriculture	5	8.8
State Dept. of Natural Res.	6	10.5
Wildlife law enforcement or game warden	27	47.4
Other	2	3.5
NA, or no well-defined method	6	10.5
DK	1	1.8

So, looking at this marriage from the State Fish and Games' points of view, they might feel that although they are required to watch over their mate by regulating the actions of NWCOs they either know little about what NWCOs are doing or have no good method for implementing and enforcing the state's regulations. For example, only 46% of state wildlife or conservation departments require licenses from NWCOs (though another state agency might handle the licensing; Table 8), and only 53% of the states have prerequisites for obtaining a license or permit (including completion of a trapper training course, investigation by agency personnel, or an application review process; Table 9). More states (56%) require businesses to keep records of actions taken and the disposition of animals removed, and all but one of these states require that these records be submitted to the regulatory agency (Table 10).

Table 8. Responses from U.S. state and territorial fish and wildlife agencies to the question, "Does your state wildlife/conservation department license nuisance wildlife control businesses (including individual operators)?"

	<i>n</i>	Percent
No	26	54.2
Yes	22	45.8

Table 9. Responses from U.S. state and territorial fish and wildlife agencies to the question, "Does your state have prerequisites for obtaining a permit and/or license (for wildlife control)?"

	<i>n</i>	Percent
No	22	46.8
Yes	25	53.2

Table 10. Responses from U.S. state and territorial fish and wildlife agencies to the question, "Does your state require nuisance wildlife control businesses to keep records of actions taken and the disposition of animals removed for nuisance and/or damage control?"

	<i>n</i>	Percent
No	18	37.5
Yes ...	27	56.3
... required to be submitted to the regulatory agency	26	
... <u>not</u> required to be submitted to the regulatory agency	1	
NA	3	6.3

Now, if we are to look at this relationship from the private operator's point of view, think of how you would feel to be asked by your spouse or significant other to do them a favor, but then be told that if you are going to do it you need to do it "just like this"? This example appears to fit in 81% of the states where regulations exist on the handling of animals or techniques used by wildlife control operators (e.g., type of traps allowed, required trap check intervals, general hunting and trapping regulations, etc.; Table 11). Ninety percent of the states also restrict the species that may be captured or handled by non-agency personnel [only five states (11%) have no species restrictions; Table 12]. Finally, 79% of the states and territories regulate the disposition of animals removed for nuisance control—including relocation, euthanasia, and carcass disposal (Table 13).

Table 11. Responses from U.S. state and territorial fish and wildlife agencies to the question, "Does your state regulate the handling of animals or techniques used for nuisance and/or damage control (e.g., types of traps allowed, required trap check intervals, etc.)?"

	<i>n</i>	Percent
No	9	18.8
Yes	39	81.2
Specified regulations:		
a. Guns/lights at night restricted	4	6.2
b. Legal trap type, live traps only	17	26.6
c. Poisons regulated	5	7.8
d. Trap check intervals	16	25.0
e. Snares restricted in certain area, killing snares regulated size of snares	3	4.7
f. General hunting/trapping regulations	7	10.9
g. State/ADC recommendations	6	9.4
h. Other	6	9.4

Table 12. Responses from U.S. state and territorial fish and wildlife agencies to the question, "Does your state wildlife agency restrict the species of animals which may be captured or handled by non-agency personnel?"

	<i>n</i>	Percent
No	5	10.6
Yes	42	89.4

Table 13. Responses from U.S. state and territorial fish and wildlife agencies to the question, "Does your state regulate the disposition of animals removed for nuisance and/or damage control, including relocation, euthanasia, and carcass disposal?"

	<i>n</i>	Percent
No	10	21.3
Yes	37	78.7

#### STATE OF THE MARRIAGE

One notable and disconcerting characteristic of the responses to this survey is the inconsistency between states in their answers—it appears the relationship between the state division of fish and wildlife and NWCs is not the same state by state. Therefore, the one generalization that we can make with respect to the findings of this survey is that we can not generalize.

So, here we have a marriage between (at least) two groups that know little about each other, much less about themselves. Yet, these two groups must work together. Why? Because they are responsible for keeping their child, the private citizen, relatively safe and secure. The citizen must feel that when they cry, or voice their wildlife complaints, NWCs and the states will do their best to reassure them that the "monsters" that are hiding under their bed (or in their attics, pastures, foundation, crops) will be taken care of.

#### NATIONAL GUIDELINES?

One idea that may help clarify the responsibilities of the states and NWCs with respect to each other and the private landowner is the development of national guidelines for the nuisance wildlife control industry. National guidelines may help this marriage to run smoother by helping the states and NWCs to accept each other and their role in the relationship. Guidelines would no doubt help define the gray areas, thus lessening the tension between the groups and creating a system in which the private landowner is promptly and satisfactorily served.

In our survey we asked the states if they would support such guidelines. Seventy-five percent of the states said they would (Table 14). States gave many reasons for their pro-guideline stance including: 1) the belief that guidelines would promote professionalism; 2) benefit the consumer; 3) help agencies in addressing

complaints against individual operators; 4) allow states to better work with each other; 5) make administering permits easier; 6) allow for set guidelines within the state; and 7) help avoid potential problems. When asked which agency or organization they would prefer take the lead in guideline preparation, 38% of responding states supported the International Association of Fish and Wildlife Agencies, 19% said The Wildlife Society's Wildlife Damage Management Working Group, 14% supported USDA/APHIS' Animal Damage Control, 12% said the National Animal Damage Control Association, and 17% stated that another group (a combination of the above organizations or the U.S. Fish and Wildlife Service) should take the lead (Table 15).

Table 14. Responses from U.S. state and territorial fish and wildlife agencies to the question, "Would your state support the development of national guidelines for the nuisance wildlife control industry?"

	<i>n</i>	Percent
No	10	20.8
Yes	36	75.0
DK	2	4.2

Table 15. Responses from U.S. state and territorial fish and wildlife agencies to the question, "If national guidelines for the nuisance wildlife control industry are developed, which agency/organization should take the lead in their preparation?"

	<i>n</i>	Percent
Intl. Assoc. of Fish & Wldlf. Agencies	16	38.1
USDA/APHIS, Animal Damage Control	6	14.3
The Wildlife Society's Wldlf. Damage Mgmt. Working Group	8	19.0
Ntl. Animal Damage Control Assoc.	5	11.9
Other ...	7	16.7
... some of the above	6	
... U.S. Fish Wldlf. Serv.	1	

The 21% of the states that did not support the establishment of guidelines (Table 14) argued that: 1) it would be too difficult to obtain conformity on a state by state basis; 2) the guidelines would not reflect local or traditional methodologies; 3) guidelines would not be able to successfully deal with regional variations in public attitudes and species specific problems; 4) the issues involved are too complex; and 5) this is a poor time for the state government to implement more requirements on private business.

#### HAPPILY EVER AFTER?

Will this relationship, born of a shot-gun wedding, have a happy ending? This study, like every other, reveals that state fish and wildlife agencies still have a lot to find out about NWCOs (and we could safely assume the reverse is also true). We are not telling those involved to love, honor, and obey, . . . only to accept the relationship, approach their mate with an open-mind, and consider how the relationship might run more smoothly. Sitting down and laying out some (national) guidelines might also be of help—consider it a bit of marriage counseling if you will.

#### ACKNOWLEDGMENTS

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# ANALYSIS OF VERTEBRATE PEST RESEARCH

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**ABSTRACT:** Research on vertebrate pest control is mostly empirical, focusing on control of species X in location Y using method Z. Such an approach is needed. The science of vertebrate pest research is developing some generalizations across species, locations, and methods. This paper further explores such generalizations by discussing six questions asked by Hone (1994), the answers to which are relevant to vertebrate pest research world-wide. Several case studies are examined, with emphasis on control of damage by small mammals and predation control. Suggestions are made for future research.

**KEY WORDS:** analysis, economic damage, efficacy, evaluation, vertebrate pest control

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## INTRODUCTION

The emphasis in this paper is on ideas common to many areas of vertebrate pest research on damage and control. In particular, the author asks six questions on the analysis of vertebrate pest control as highlighted in Hone (1994). The questions are linked by being explicit or implicit in any economic evaluation of vertebrate pest control. Hence the questions are generic and underlie much of vertebrate pest research. The aim is to summarize current knowledge and identify future areas of vertebrate pest research including suggesting how different analyses can be better integrated. The research is relevant to control by lethal and non-lethal methods. Non-lethal control may include immunocontraception as described by Tyndale-Biscoe (1994).

### 1. IS THERE A RELATIONSHIP BETWEEN THE ABUNDANCE OF PESTS AND PEST DAMAGE?

Vertebrate pest control has a fundamental assumption that there is a positive relationship between the number of pests and the damage they cause. The existence and form of the relationship has been explored theoretically by several authors, such as curved (Izac and O'Brien 1991) and linear and curved (Braysher 1993; Hone 1994; Bomford et al. 1995). The study of Hone (1994) collated empirical data from 21 studies and reported only 13 (62%) as showing a significant linear relationship. Further collation and analysis of data shows that 21 (54%) of 39 studies show a significant linear relationship. The most likely reasons for non-significant results are that variables may be measured with low precision and so a type II error has occurred, the underlying relationship is a curve not a straight line, what has been measured as damage is not linearly related to actual damage, or that other sources of variation were not included in the analysis so the strength of any underlying relationship between damage and pests has been underestimated, and hence a type II error has again occurred. Hone (1994) developed a mathematical model of the relationship.

Headley (1972), in describing pests in general, assumed a positive but curved relationship (concave up). A concave down curve was hypothesized for feral pigs (*Sus scrofa*) and damage in Australia by Izac and O'Brien (1991). Five (13%) of 39 studies have reported a curved

relationship between pest abundance and pest damage, so a total of 26 (21 + 5) studies (67%) have reported a significant positive relationship. Feare (1974) calculated that increasing numbers of rooks (*Corvus frugilegus*) in northeastern Scotland resulted in increases in damage to crops of oats and barley. The damage increased at a decreasing rate. A similar trend in the relationship was reported for lamb predation by feral pigs in southern Australia (Choquenot and Lukins 1995).

There appears to be only one study (Croft 1990) which has tested the relationship of rabbits (*Oryctolagus cuniculus*) and it was reported that there were significant effects (plant height, sheep liveweight, and fat depth) and non-significant effects (plant species composition and greasy fleece weight). There was no significant linear effect of rabbits on the fiber diameter of wool, but there was a significant curvilinear effect on fiber diameter. Rabbits were experimentally held at high densities in that experiment. For studies of predation of livestock, Wagner (1972) considered there was a significant relationship between coyote (*Canis latrans*) abundance and predation in the western USA, but did not test it.

### 2. IS THERE A RESPONSE OF PEST DAMAGE TO CHANGE IN PEST ABUNDANCE AFTER PEST CONTROL?

The logical follow-up to question 1 is to ask the above question. In other words, if pests are reduced in numbers by pest control, is damage reduced? This question is ripe for experimental picking. There are surprisingly few tests of the question (Table 1) and what tests have been made give mixed results.

Brown (1993) reported some significant effect of rabbit control on pasture biomass but also many non-significant effects in an area in southern Australia. In the same experiment Williams and Moore (1995) reported significant and non-significant reductions in rabbit abundance depending on control treatments. The results, in Table 1, of Foran et al. (1985) and Tobin et al. (1993) are sobering reminders of the distinction between the response to pest control (rabbits and rats, respectively) of pest abundance (in both studies significant) and of pest damage (non-significant in both studies). Both results could be explained by a concave down relationship

Table 1. Studies where the responses to vertebrate pest control, of both pest abundance and pest damage, have been estimated as statistically significant ( $P < 0.05$ ) or not significant (NS,  $P > 0.05$ ).

Pest	Pest Abundance	Pest Damage	Reference
Rabbit ( <i>Oryctolagus cuniculus</i> )	Significant	NS	Foran et al. (1985)
Rabbit	Significant, NS	Significant, NS	Williams and Moore (1995), Brown (1993)
Feral pig ( <i>Sus scrofa</i> )	Significant, NS	Significant	Hone (1987)
House mouse ( <i>Mus domesticus</i> )	Significant, NS	Significant	Twigg et al. (1991) Singleton et al. (1991)
House mouse	Significant	Significant	Mutze (1993)
Rat ( <i>Rattus spp.</i> )	Significant	NS	Tobin et al. (1993)

between pest abundance and damage. That shows that substantial changes in pest abundance could occur with little or no change in pest damage if pre-control abundance was high.

Kinnear et al. (1988) reported a study of foxes (*Vulpes vulpes*) and predation of rock wallabies (*Petrogale lateralis*) in southwestern Australia. The results have been widely cited, for example Bomford et al. (1995), Burbidge and Wallace (1995), Morris et al. (1995), and Pech et al. (1995), and used to justify fox control and hence predation control. The study, however, did no statistical analysis of the effects of fox control. Usher (1989) commenting on the same data, stated, "This experiment, with replication of controlled and uncontrolled alien predator populations on five rocky hill outcrops, should provide valuable information when all of the monitoring data are analyzed." Hone (1994) independently noted the lack of analysis and has reported the results of two analyses, which found a significant or non-significant effect of fox control depending on the response variable analyzed (rate of increase and abundance, respectively). Obviously, more data were needed in the original study, as was an analysis. Saunders et al. (1995) provide more data and clearer trends, but still no analysis. Caughley and Gunn (1996) were critical of the experimental procedure.

An effect of fox poisoning on abundance of chuditch (*Dasyurus geoffroii*) in southwestern Australia was reported by Morris et al. (1995). Indices of chuditch abundance were reported over several years in two areas; one with 1080 poisoning of foxes and one with no 1080 poisoning. There was apparently no statistical analysis of the data (D. Choquenot, pers. comm.), yet the authors concluded that fox control was beneficial for chuditch. The observed rate of increase of each chuditch population can be estimated by the regression of the natural logarithm of indices over time (Caughley and Gunn 1996), using data for October or November in 1991-1993 inclusive in Table 1 of Morris et al. (1995). Chuditch are seasonal breeders (Strahan 1983), so data only from the one time of year were used to estimate rate of increase.

In the experimental control area (no 1080 poisoning) the observed rate of increase was 0.92 per year, but the regression was not statistically significant ( $df = 1$ ,  $P > 0.05$ ). In the treatment area (1080 poisoning occurred) the observed rate of increase was 0.76 per year, but the regression was also not statistically significant ( $df = 1$ ,  $P > 0.05$ ). Both regressions were approaching significance but used few data, so more data are required to reach a more definite conclusion (more statistical power), about the effect of predator (fox) control. The point to emphasize here is whether effects of fox predation control have been clearly demonstrated. There may well be a big effect but without a statistical analysis, and a more powerful analysis, it is difficult to separate the message from the noise.

Harris and Saunders (1993) were critical of the poor evaluation of canid control operations. They described the results of many studies from around the world only some of which had measured a response in predation and only a subset of those had tested for a significant effect.

### 3. WHAT IS THE SPATIAL FREQUENCY DISTRIBUTION OF PEST DAMAGE?

The question focuses particularly on whether all areas or sites have similar damage or not. Hone (1994, 1995) reported several studies that showed a highly skewed (mostly negative exponential) frequency distribution of damage. That is, many sites had no damage, some had little damage and very few had a large level of damage. So what? Obviously, if control is applied uniformly it will be wasted on the many sites that have no damage. If control is targeted to those few sites with high damage, then it should be more economic.

Study on rabbits in New Zealand has ranked areas "rabbit proneness" (Williams 1977, Kerr 1991). "Rabbit proneness" is the same concept as the frequency distribution of damage but a coarser measure of it, particularly if rabbit abundance is used rather than specific measures of rabbit damage. Crawley and Weiner (1991) reported that parameters of the frequency

distribution of sizes of wheat plants varied in response to rabbit grazing in a study in Britain, so there is potential for spatial variation in such effects.

Six studies reported in Hone (1994) assumed the spatial frequency distribution of predation of livestock in the western USA followed a Poisson or Poisson-type distribution and hence predation occurred at random. However, nobody actually tested the goodness of fit. Hone (1994) did for the one data set that presented the raw data, and showed a significant difference from a Poisson distribution. Data on the spatial frequency distribution of damage by other predators is limited. Rowley (1970) presents data on estimates of lamb predation by foxes in Australia. Collation of the data on the number of healthy lambs killed by predators as a percentage of all lambs, shows a skewed frequency distribution of predation though the conclusion is limited by the small sample size. The estimated losses and their frequencies were 0 to 5% (n=6), 5.1 to 10% (n=2), 10.1 to 15% (n=1), and 15.1 to 20% (n=1).

The spatial variation in damage to pistchio orchards in a part of California varied with species of bird (Crabb et al. 1994). Damage by scrub jays (*Aphelocoma coerulescens*) was randomly distributed, but damage by American crows (*Corvus brachyrhynchos*) was aggregated. Both distributions were statistically tested by examination of the variance to mean ratios.

#### 4. WHAT IS THE RESPONSE TO PEST CONTROL OF THE SPATIAL FREQUENCY DISTRIBUTION OF PEST DAMAGE?

The question is a logical consequence of question 3. The question appears not to have been answered for vertebrate pests and their damage. The practical interest in the question and the answer comes from attempts to determine the economics of pest control; is control economic in all areas or only in some areas. Several responses are possible as shown in Hone (1994). The pre-control distribution could be shifted to the left, or altered to become a bimodal distribution depending on where control occurred and its effects. The model of Crawley (1983) of herbivore damage could also be used to study the dynamics of any change in frequency distributions. Anderson (1982) and Anderson and May (1982) applied a model of parasites and reported that the most efficient control was achieved by applying control to hosts (areas) with highest numbers of parasites (pests).

#### 5. WHAT IS THE RELATIONSHIP BETWEEN THE LEVEL OF PEST CONTROL EFFORT AND THE NUMBER OF PESTS KILLED?

If research on control changes from asking "what is the effect of control" to "what is the effect of different levels of control," then question 5 is appropriate. It is expected that the relationship will be positive (more effort, more killed). Hone (1994) listed 14 models that have been or could be used to study the relationship. Six models made some explicit assumption (linear or curved) about the relationship. The other eight models in Hone (1994) assumed the number of pests killed was independent of effort. The models have not been

thoroughly compared. The practical interest in the relationship is that the level of effort is presumably a major determinant of cost and potential benefit of control. Linear and curved forms of the relationship have been reported for shooting of feral pigs (Saunders and Bryant 1988; Hone 1990, 1994) and feral water buffalo (*Bubalus bubalis*) (Skeat 1990).

Headley (1972) described an inverse relationship between cost (time) per kill and pre-control pest abundance, and Tisdell (1982) critically reviewed the idea and illustrated what may influence it. Such inverse relationships have been reported for several vertebrate pests, such as feral water buffalo (Ridpath and Waithman 1988), feral donkeys (*Equus asinus*) (Choquenot 1988), feral goats (*Capra hircus*) (Parkes 1993), and feral pigs (Hone 1994; Bomford et al. 1995; Choquenot and Lukins 1995).

The practical significance of the results is clear—as pest abundance is reduced, the cost per kill increases exponentially and may be a reason why pest eradication is sometimes not achieved (Bomford et al. 1995).

#### 6. WHAT LEVEL OF COSTS OF PEST CONTROL MAXIMIZES THE ECONOMIC BENEFITS OF CONTROL?

The question, or its many cousins and other relations, would appear to be the most fundamental of questions in vertebrate pest research. Yet, it hardly appears to have been answered. Underlying question 6, and its answer, are each of the previous questions. The nature of the response of damage to control will be determined by the underlying relationship (questions 1 and 2) and its variation in space (questions 3 and 4) and the link between control effort, costs, and kills (question 5).

Hone (1994) reviewed many of the general principles and concluded there is a need for further research on the topic. The study of the response of pronghorn to control of coyotes (Smith et al. 1986) is a notable exception to the deficiency. Field data on trapping and shooting were combined with a computer model of pronghorn (*Antilocapra americana*) dynamics and control. As several control strategies were simulated, one could identify the strategy (level of costs) which maximized benefits and then compare the net benefits and the benefit:cost ratios, though the latter were not calculated in the original paper but were described by Hone (1994). Choquenot and Lukins (1995) used a similar mix of field data and modeling to estimate the benefit:cost ratios for control of lamb predation by feral pigs. Bomford et al. (1995) showed that incorporating discount rates into an economic analysis of eradication may delay the time until the benefits of control exceed the costs of control. The higher the discount rate, the longer the delay.

#### CONCLUSIONS

The researchers tend to study aspects of control of species X, in location Y, using method Z. They need to do that. They also need to generalize a bit more to identify common ideas and results. The continued development of a rigorous science of vertebrate pest research requires successful attempts at generalization. The analysis of vertebrate pest research can be improved

by doing statistical analyses and interpreting their results rather than solely interpreting the original data, using field data to test the assumptions and predictions of models, and greater use of economic analyses by involvement of economists, similar to how biometricians are (or should be) involved.

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# TOWARDS "BEST PRACTICE" VERTEBRATE PEST MANAGEMENT IN AUSTRALIA

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**ABSTRACT:** Australia has 26 species of introduced pest mammals that cause extensive damage to agriculture and the conservation of native wildlife. Past efforts tried to eradicate them. This focus on reducing pest numbers rather than the outcome, reduced damage, has had limited success. Under its Vertebrate Pest Program, the Bureau of Resource Sciences has developed principles and a strategic approach to managing pest damage. Close cooperation with land managers as co-researchers and co-learners is an essential element, as is a coordinated group approach to pest management. The approaches is illustrated with an example.

**KEY WORDS:** pest animals, pest control, pest management, pest damage

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## INTRODUCTION

The 26 species of introduced vertebrate pests represent approximately 10% by species of Australia's mammal fauna (Wilson et al. 1992). Pest problems were recognized early in Australia's settlement, but despite considerable effort, pests such as rabbits, feral pigs and feral goats still cause extensive damage to agriculture and to the conservation of native wildlife.

Past research concentrated on pest biology and controlling pest numbers. While it appeared to serve us well at the time, we now realize that there were flaws in this approach. An understanding of pest biology and their response to control is important, but we have neglected to quantify pest damage and the relationship between pest density and damage. Without this information, it is difficult to know how much effort should be put into pest control, or indeed whether the effort is reducing damage.

The challenge is to clearly identify what we want to achieve from pest management and where and how we apply our limited resources to obtain maximal return. This requires a more strategic and coordinated approach to managing pest damage. This paper outlines the approach to pest management adopted by the Bureau of Resource Sciences through its Vertebrate Pest Program. The principles of pest management are explained and illustrated with an example.

The final question is "where to now?" We suggest that it would be better to adopt a coordinated and strategic approach and work cooperatively with private and government land managers to address this nationally significant problem.

## AUSTRALIA'S VERTEBRATE PESTS

A vertebrate pest can be defined as an animal that has a significant net deleterious impact on a valued resource. It is important to note that pests are a human concept and that pest status changes as human perceptions and values change. For example, if feral goats were worth \$25.00 a head, they would be a valued resource, not a pest.

Between 1840 and 1880 more than 60 species of vertebrates were introduced into Australia (Myers 1986; Redhead et al. 1991). Many were introduced by English immigrants to bring a semblance of England to the new colony (Rolls 1969; Lever 1985). Others were introduced

to spread the world's useful and bountiful species (Myers 1986). Some, like foxes, trout and deer, were introduced for sport, others as biological control agents (e.g., mongoose, *Herpestinae*). Some established feral populations from captive stock (e.g., cat, horse, pig, goat, camel) or from pets or ornamental species (e.g., goldfinch, *Carduelis carduelis*).

Luckily, many introductions failed despite the efforts of acclimatization societies (Rolls 1969; Myers 1986; Long 1991; Bomford 1991; Redhead et al. 1991; Wilson et al. 1992), but others prospered. A major factor in the success of some species was the creation of disturbed habitats such as cultivated or urban land. The rabbit is a good example. Myers (1986) suggests that its establishment and spread was enhanced by the increased availability of grasses and the availability of burrows formerly occupied by some native species. The fox also undoubtedly benefitted from the spread of rabbits which provided its main food. Similarly, the pastoral industry, by establishing numerous water points and improving pasture, helped the successful establishment of other species such as the feral horse, donkey and goat.

For about the first 150 years of European settlement, the links between human land use, environmental damage and vertebrate pest impact were not widely acknowledged. Early control centered on destroying pests by shooting, poisoning, trapping, exclusion fencing, or, with rabbits, by encouraging the spread of cats and other predators. Legislation required land owners and occupiers to control and to destroy pests on their land. Laws also prohibited the keeping of declared pests. Similar legislation is still in force throughout much of Australia.

Pest control was often heavily subsidized through the provision of cheap equipment, government labor, and through government bounties. For example, the Western Australian Government spent \$25 million between 1901 and 1907 to build a rabbit-proof fence 1700 kilometers long to prevent the westward movement of rabbits (Rolls 1969). It failed. In 1885, the South Australian government paid \$1.6 million in bounties for rabbit scalps (Newland 1971), while Queensland, in the period 1945 to 1959 paid bounties on 240,000 fox scalps at a cost of \$0.9 million (Fennessy 1962). The main objective was to

kill as many pests as practical and, if possible, to eradicate them. Landholders were not accountable for government funds expended on their land, and as a result, there was little pressure on land managers to ensure that pest control funds were spent wisely.

## PROBLEMS WITH PAST MANAGEMENT

### Focus on Numbers

While early efforts sought to eradicate pests, it is now known that there are sound reasons why it is rarely possible. Bomford and O'Brien (1994) have outlined these. Briefly, for eradication, the pest must be removed at a rate greater than replacement at all densities. There are a number of criteria which must be satisfied to achieve this:

#### Essential

- Immigration must be zero.
- All individuals must be at risk from the control techniques used.
- The animal must be able to be monitored at low densities.

#### Desirable

- The socio-political environment must be suitable.
- Discounted cost-benefit analysis favors eradication over control.

The failure of eradication as a goal is clearly illustrated by the fact that no pest has been eradicated from mainland Australia. An indication of the cost is provided by the removal of rabbits from Phillip Island, a 200 hectare island off Norfolk Island. Although costs were not fully documented, it took about 700 field-person days. The manager of the national park at the time also states that rabbits were eradicated twice, once in 1986 and again in 1988.

If eradication is not feasible, then in most instances managers need to adopt a strategic approach to meet defined outcomes.

## HOW MUCH CONTROL IS ENOUGH?

Past pest management in Australia has been hampered by inadequate knowledge of the impact of pests, and inadequate knowledge of the effect of control activities on the level of damage. For example, what is the impact of feral cats on Australian fauna? The answer is that we do not really know. Studies of cats' diets tell us what cats eat and little more. They do not tell us about the impact of cats on the population of prey species. Diet studies are a necessary first step, but are insufficient for developing an understanding of the impact of cats on prey populations.

We also have limited knowledge of the effects of control on damage. For example, we do not know what effect 1080 baiting for foxes has on livestock losses, although that is a very rapidly growing practice in parts of Australia (Saunders et al. 1995). We now know that more emphasis needs to be placed on quantifying pest damage and the relationship between pest density and damage.

However, for most pests, the level of damage has not been quantified, let alone the relationship between density and damage determined.

## WHY IS KNOWLEDGE OF THE RELATIONSHIP BETWEEN PEST DENSITY AND DAMAGE IMPORTANT?

We need to keep a clear focus on pest animal impact and be concerned about the level of impact that we consider acceptable or desirable. The number of animals is not our focus—rather it is their impact on things we value. Because pest density and damage are not always directly matched, we need to focus on damage management. For example, rabbits at a density of less than one per hectare, an almost imperceptible density, can eat all seedlings of some native plants and prevent regeneration of some trees in the semi-arid rangelands. Reducing rabbits to two or three per hectare may not help tree regeneration in these areas and may be a wasted effort.

Figure 1 shows three hypothetical relationships between pest density and damage. Line "A" might represent the damage feral goats cause to palatable endangered plants that they seek out even when goats are at low densities. Line "B" could represent direct competition between feral goats for a limited resource. Line "C" could occur if there is little competition between feral goats and sheep for pasture at low goat densities. The shape of these lines will depend upon the type of damage and other variable such as stocking rate and seasonal conditions.

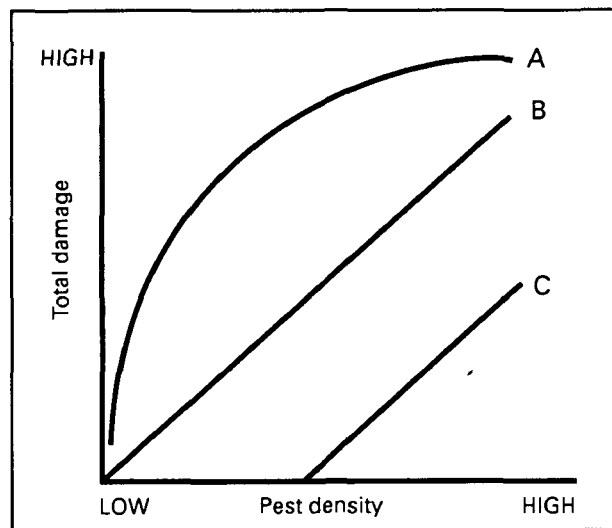


Figure 1. Possible relationship between pest density and damage.

## COMPLEXITY OF PEST ANIMAL MANAGEMENT

In addition to our inadequate knowledge, there are several other reasons why managing pests animals is complex.

- Widespread and common. Pests occur throughout Australia from the tropics to alpine areas. Most are mobile and can breed rapidly. A feral rabbit can produce 25 young a year.
- Pests of agriculture. Pigs can take up to 40% of lambs born in an area. Rabbits are estimated to cost \$16 million annually in South Australia alone.
- Pests of the environment. In Australia's rangelands, especially during drought, rabbits can strip and ringbark native plants. Even at very low densities rabbits can prevent regeneration of long-lived species such as mulga (*Acacia aneura*).
- Exotic disease threat. Australia is free from many serious exotic animal diseases. Many pests came from domestic livestock and can carry similar diseases, which they could spread if they were to enter Australia. While difficult to quantify, the cost could be as high as \$6.6 billion annually from lost livestock exports should a disease such as Foot-and-Mouth Disease become established over a significant part of Australia.
- Commercial use. Commercial use of wild animals is worth in excess of \$73 million annually, primarily as export. Feral goats alone are worth more than \$19 million a year. At present, commercial and pest management objectives are not well integrated. We need to investigate management that uses the value of the pest to achieve the broader goals of protecting agriculture and the environment.
- Animal welfare concerns. The welfare of pest animals is already a major community concern and the subject of international attention. Future solutions to pest animal management are likely to receive increasing scrutiny from this perspective. Failure to give adequate consideration to the social and animal welfare implications of control techniques may result in the loss of some techniques and thwart the introduction of new ones. Appropriately, there is now much wider consultation with animal welfare organizations concerning pest control.

## VERTEBRATE PEST PROGRAM

In recognition of the need for a more strategic and coordinated approach to managing vertebrate pests in Australia, in 1991 the Bureau of Resource Sciences, in cooperation with Australia's national Vertebrate Pests Committee, commenced the Vertebrate Pest Program (VPP).

Under its VPP, the Bureau of Resource Sciences (BRS) is developing a series of guidelines for managing the damage caused by Australia's major vertebrate pests (Braysher 1993; Dobbie et al. 1993; Williams et al. 1995; Saunders et al. 1995; Choquenot et al. in press; Parkes et al. in press). The Bureau has worked closely with the States and Territories and relevant community groups including farmers, conservationists, animal welfarists and the Aboriginal Community in this program. The

guidelines promote cost-effective management of vertebrate pests through better coordination, planning and implementation of control programs based on current scientific and technical information. Pests being addressed are the feral horse, rabbit, fox, feral pig, feral goat and rodents.

To encourage adoption of "best practice" pest management, BRS has supported several large-scale, field-based projects to demonstrate the principles and strategic approach to pest management developed under the VPP. We will explain these further later in the paper.

The basic elements for planning and implementing a program to manage pest damage are explained in Braysher (1993) and summarized below:

- Defining the problem in terms of the desired outcome and determining major stakeholders and all major factors operating.
- Collecting the information necessary to clarify the problem.
- Setting clear, quantifiable and, if possible, time-limited objectives and developing performance criteria.
- Identifying management options and, if practical, experimentally testing the alternatives.
- Implementing the strategy.
- Monitoring effectiveness and efficiency of the management strategy against the objective.

## RELIABLE KNOWLEDGE—ADAPTIVE MANAGEMENT

It would be trite to say that pest animal management should be based on reliable knowledge in the future, if it was not so clear that much of our past activity was not. We need to obtain reliable information about impact and about the response of impact to control. Obtaining reliable knowledge is a difficult task. One very promising way is the use of adaptive management, or large-scale experimentation. This involves conducting experiments within the management systems that are currently used for pest control. Champions of this approach, Walters and Holling (1990), refer to it as "learning by doing." In pest animal management and elsewhere in agricultural and rural science, we have tended to keep the learning and the doing (usually called the research and the management) separate. It has compromised the relevance of the former and the progressiveness of the latter.

Involving land managers as co-learners and co-researchers is being encouraged in the demonstration projects supported under the VPP. State government agencies and Landcare groups have been supported to determine and demonstrate "best practice" pest management for various situations. Most projects are large-scale, involve several properties, and compare several management strategies. Rather than simply providing land for the research, land managers are an integral part of the projects and help determine management options for their particular area. Their involvement also facilitates the dissemination of project findings to other land managers.

The approach will be illustrated with a hypothetical case study taken from the soon to be published feral pig management guidelines (Choquenot et al. in press).

Example of the strategic planning process centered on the Wet Tropic World Heritage Area of north Queensland:

#### Scenario

A typical example of the problems of feral pig management in the wet tropics region of northern Queensland could occur anywhere between Townsville and Cooktown. The region covers about 125,000 square kilometers and consists of three major geomorphic areas; a belt of coastal lowlands, an intermediate Great Escarpment, and the Tablelands of the Great Divide. Mean annual rainfall varies throughout the region from 1,200 millimeters on the western edge to over 4,000 millimeters near the coast, and occurs mainly during the wet season (December to April). The dominant native vegetation consists of rainforest species, which occur largely as a continuous belt along the Great Escarpment, with pockets on the Tablelands and coastal lowlands. Most areas of forest, which represent about 80% of the remaining rainforest in Queensland and contain many plants and animals unique to the region, are included within a World Heritage Area (WHA). The majority of the adjacent lowlands are used for production of sugar cane, bananas and other tropical fruits. There are a number of tourist resorts or high focus visitor areas along the coast only a few hours by road transport from an international airport. Feral pigs occur throughout the area but are mainly confined to the forests during the wet season and roam more widely, particularly to sugar cane crops, during their search for food in the dry season (May to October/November).

#### Defining the Problem

Feral pigs are estimated to cause at least \$0.4 million damage to sugar cane crops in the region each year as well as an unmeasured amount of damage to bananas and other crops. They also pose substantial threats to WHA values, particularly protection, conservation and rehabilitation of the environment, even though there is little objective information available on their impact. In addition, they may have an actual or potential role as hosts or vectors of a number of important endemic and exotic diseases and parasites of animals, including humans, in the region.

The main problem with feral pig management in this region is that adjacent landholders regard the WHA as the source of the pigs affecting their crops and mostly expect the authorities responsible for the WHA to control the pigs within the WHA. This is generally not practical, given the large and elongated size and shape of the WHA (9,000 square kilometers), its often rugged, steep topography, and the difficulties and constraints involved in using control techniques for pigs within the WHA, particularly during the wet season.

#### Objectives

The objective of feral pig management in a region including both conservation and agricultural land uses should be to reduce their impacts within and outside the conservation area to acceptable levels, and to maintain this situation. This requires studies to quantify the impact of feral pigs on WHA and other values such as

agricultural and horticultural and experimental reduction of pig populations through adaptive management, to determine threshold densities for acceptable levels of impact. It will also require basic research, including modeling, of the likely outcomes of outbreaks of exotic diseases in feral pigs in the region, and greater public education over the risks of people being infected by diseases and parasites from eating or handling feral pigs.

#### Management Units

Because of the large size of many conservation areas, the diversity of values that pigs can affect, and the likely costs of control, a ranking system is necessary to decide which particular areas should receive priority pig control. This system could include measures of potential or actual impact on biological, agricultural and other values, and should involve all major interest groups concerned. Once these areas are selected, decisions need to be made on whether local eradication or sustained control of pigs is the appropriate action. In deciding this, the following factors need to be considered:

- level of future financial support;
- when to conduct control;
- degree of population reduction necessary to achieve program objectives; and
- what control methods and strategies are best.

Decision analysis models can help to determine whether different management or control techniques are economically desirable, technically possible, practically feasible, or socially and environmentally acceptable (Norton and Pech 1988). These authors also describe pay-off matrices which can be used to determine the outcomes or benefits associated with using particular control methods and strategies for different types or levels of impact by pigs.

#### Control Strategy

A combination of techniques may be necessary for effective control of feral pigs in many areas. Poisoning, although potentially the single most effective technique for the region, is generally not acceptable in the WHA and sometimes on adjoining properties, where captured or shot pigs are subsequently used for food. Poisoning could be used in certain areas (for example, margins of the WHA) if more specific poisons, baits, or delivery systems were used. Trapping techniques require extensive free-feeding prior to the establishment of traps, are very labor intensive and are not practical for larger, more remote areas, but are potentially effective for many small areas or local situations, particularly as part of coordinated programs between government authorities and landholders. Ground hunting, with or without dogs, is generally considered to be ineffective for sustained control or eradication, may affect non-target animals, such as cassowaries (*Casuarius casuarius*), but is a way of life in the region that will not be stopped by legislation. Aerial shooting, untried in the area, could be considered in specific areas, including the margins of sugar cane farms. Fencing, including electric fencing, is probably only cost effective around small ecologically significant areas or for some instances of endangered species protection, but may be useful to direct feral pigs to areas where they can be trapped. Biological control, while feasible, is not likely

to be available in the near future. Although individual techniques used alone are thus unlikely to be effective, a carefully selected combination of techniques can usually be found to work with coordinated trapping being the central method. While trapping may be the most efficient technique, it is readily used by growers because they can receive \$75 for a 45 kg pig delivered to the commercial chiller operator.

#### Implementation

Group Action. The most effective control strategy for the region is to carry out simultaneous control programs against pigs inside the margins of the conservation area and on adjacent properties such as sugar cane and tropical fruit farms during the dry season. Priority should be given to areas where pigs are having significant impacts both within and outside the conservation area during the late dry season when pig numbers are likely to be at their lowest during the year and many are searching for food outside the WHA. A coordinated approach, using funds that would otherwise be spent separately by control authorities, Cane Boards, and farmers during this period could have several benefits for both the WHA and adjoining landholders. These include a closer working relationship and recognition of the pig problem by all major interest groups, with legislation if necessary, to enforce compliance by non-cooperative and disinterested landholders. More coordinated control between various landholders, land management and conservation agencies, and where practical, commercial harvesters of feral pigs, could also minimize costs, possibly provide benefits to some landholders with low or negative cash flows, provide a means for disease surveillance, and result in more cost-effective control compared to the current, often spasmodic, ad hoc efforts undertaken.

Special control programs may also have to be undertaken against pigs deeper within the WHA where they are known to be having a negative impact on WHA values. Such programs should be based on a priority ranking system, and if sustained control is required, should be given a guarantee of continual financial support.

Monitoring and Evaluation. Measurements of impact and indices of pig density before and after control programs are necessary to help determine threshold densities and evaluate whether the control programs are achieving their goals or not. If the goals are not being achieved, improved strategies and community involvement will be necessary. Monitoring and evaluation can also indicate the best techniques to support, help promulgate research results, such as new trap designs or baits (for example, bananas) and provide more motivation and direction to control efforts. It may also indicate whether further research is required, such as on the intrinsic rate of increase of pigs after different levels of population control, including the effects of environmental factors on this rate. These include delays in the onset of the wet season or a poor fruiting year in the rainforests. Such information, along with that on the relationship between effort expended on control and the resulting densities obtained can be used to evaluate different methods and strategies to maintain sustained control or eradication in different areas.

#### What is the Future?

The final question is "where to now?" It can be more of the same—which would be a shame, because we have learned enough from Australia's past pest animal management to do much better.

The approach to pest animal management developed by BRS, and summarized in this paper, can help to deliver a better knowledge-based way of managing this nationally significant problem. The approach also is applicable to other land management problems including weeds and dryland salination.

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# ECOLOGICAL CHALLENGES TO CONTROLLING WILD RABBITS IN AUSTRALIA USING VIRALLY-VECTORED IMMUNOCONTRACEPTION

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**ABSTRACT:** The European wild rabbit in Australia threatens the sustainability of agriculture and conservation of native flora and fauna. Improved means of reducing these impacts are sought including effort to develop virally vectored immunocontraception (VVIC). VVIC for the wild rabbit involves complex interactions between the rabbit, myxoma virus and insect vectors of the virus. Development of the method includes not only reproductive molecular biology and genetics and manipulation of virus genetics, but also many problems in reproductive biology, ecology and population dynamics of the rabbit in diverse environments. Furthermore, epidemiology of enzootic myxomatosis, and behavior and population dynamics of several vector species of mosquito and flea must be considered. Some of these ecological problems are described with a brief description of the approach to experimental analysis.

**KEY WORDS:** vertebrate pest control, biological control, immunocontraception, *Oryctolagus cuniculus*, myxoma virus, insect vectors, ecology, models

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## INTRODUCTION

Virally vectored immunocontraception (VVIC) is a new theoretical concept that is aimed at managing the abundance of often inaccessible wild animal populations by interfering with their fertility and fecundity (Tyndale-Biscoe 1994b). Currently an attempt is being made to develop the concept for managing three introduced vertebrate pests of Australia, the European wild rabbit (*Oryctolagus cuniculus*), the European red fox (*Vulpes vulpes*), and the house mouse (*Mus domesticus*) (Tyndale-Biscoe 1994a). VVIC, as applied to the European wild rabbit in Australia, involves interactions among the rabbit, the myxoma virus that infects rabbits, and several species of insects that are vectors of myxoma virus. Some ecological problems are envisaged in attempting to develop this concept. This paper describes those challenges and the approach taken in attempting to assess their relevance and magnitude. Before discussing those problems, the author briefly describes aspects of the problem and ecology of the wild rabbit in Australia, its pathogenic myxoma virus, and the main insect vectors of myxoma virus.

## THE EUROPEAN WILD RABBIT IN AUSTRALIA

The European wild rabbit was introduced successfully to Geelong near Melbourne in 1859 for sport hunting. It spread rapidly and occupied its present range, the southern two-thirds of the continent, within about 50 years (Stodart and Parer 1988). This country is vast and much of it is arid or semi-arid, sparsely settled, and remote from urban infrastructure. The rabbit occupies most environments within that range, from sub-alpine humid to sub-tropical and temperate humid to lowland arid. Habitats occupied range from woodland to grassland and sandy dune. Mediterranean climates are its stronghold, but it also abounds in arid regions of erratic unpredictable rainfall, and it has a tendency to be limited by predominant summer rainfall.

Over most of that range the rabbit can increase seasonally to very high densities which have a severe impact on the native vegetation and fauna, and cause

significant losses to agricultural production and sustainability (Williams et al. 1995). Historically, the density of rabbits and their impact was extreme over most of the distribution, but the introduction of the myxoma virus in 1950 diminished the problem significantly for the more mesic coastal regions. Nevertheless, the rabbit problem remains extreme in the inland semi-arid and arid regions (Williams et al. 1995). There myxomatosis occurs irregularly and infrequently because of the inadequate and variable abundance of mosquito and flea vectors, and the long interval between episodes of rabbit breeding (Cooke 1984). In the mesic and more intensively settled areas the rabbit is managed by control programs that employ mainly poisoning, warren-ripping by tractor, and toxic fumigation of warrens (Williams and Moore 1995). In the arid and semi-arid regions little active control is undertaken. Rabbit populations undergo irregular cycles of "boom and bust" driven largely by weather and occasional myxomatosis epizootics (Williams et al. 1995). Since October 1995, rabbit calicivirus disease (RCD) has caused very high mortality of rabbits in some parts of the arid and semi-arid interior; its long-term role is not known yet (B. D. Cooke, pers. comm.).

## MYXOMATOSIS IN AUSTRALIA

Myxoma is a South American virus that seems to be specific to Leporids (Fenner and Ratcliffe 1965). In Australia, myxoma virus spread throughout the rabbit distribution within two years of its introduction in 1950, myxomatosis killing more than 99% of the infected rabbits and decimating local populations (Fenner and Ratcliffe 1965). Within two years attenuated myxoma strains emerged and death rates declined to slightly lower levels. Attenuation of the virus enabled the rabbits to develop a degree of genetic resistance to the virus. The virus and rabbit co-evolved to an accommodation of viral virulence and host resistance whereby most virus strains in the field were assessed to be of moderate virulence and most populations of rabbits had some degree of resistance, with wide variation between regional



populations (Fenner and Ratcliffe 1965). Later work has shown that recently most field viral strains are highly virulent, but the increased resistance of the rabbits (Parer et al. 1994) results in only moderate, but nevertheless very significant, levels of mortality (Parer et al. 1985). Thus, myxomatosis still exerts a strong controlling influence on rabbits in mesic regions.

#### VECTORS OF MYXOMATOSIS IN AUSTRALIA

Initially the main vectors transmitting myxomatosis among rabbits were two native species of mosquito, although many other species of biting invertebrates played a minor role in its spread (Fenner and Ratcliffe 1965). The dependence of the mosquitoes on rather high rainfall limited the extent and frequency of transmission of the disease. This prompted the search for a more reliable vector and led to the subsequent introduction of the European rabbit flea in 1969 (Sobey and Conolly 1971). This vector seems to have reduced rabbit numbers significantly in mesic coastal regions but not in arid areas. The European rabbit flea cannot persist where rainfall averages less than about 200 mm per year and where dry conditions may deter rabbits from breeding for several years (Cooke 1984). This species of flea desiccates readily (Cooke 1990a) and its breeding cycle depends on that of the rabbit, specifically the female rabbit's reproductive hormones, nesting behavior and the presence of nestling rabbits for food for larval fleas (Mead-Briggs 1964).

In order to provide a vector of myxomatosis in arid regions, another flea vector of myxomatosis, the Spanish rabbit flea (*Xenopsylla cunicularis* Smit), was released in the interior in 1993. This species is adapted to arid conditions and does not depend on rabbits breeding for its own reproduction (Cooke 1990b). Drought followed its introduction, limiting the opportunity for spread of the flea with dispersing young rabbits and for transmission of myxomatosis among the susceptible young. The recent spread of RCD among rabbits in the arid region also might impede the spread of this vector. Therefore, the likely future role of the Spanish rabbit flea as a vector of myxomatosis and RCD remains to be assessed.

#### THE CONCEPT OF VIRALLY VECTORED IMMUNOCONTRACEPTION (VVIC)

Because the wild rabbit remains a serious pest of agriculture and continues to devastate flora, fauna and landscape, further control methods and improved strategies are sought to integrate with the biological and conventional control methods and strategies applied currently (Williams et al. 1995). Now it is being attempted to exploit further the penetration of rabbit populations by myxoma virus, and to render infertile those rabbits that survive myxomatosis.

The concept of immunological suppression of fertility arose during the 1980s in research on humans and in related clinical research (Robinson and Holland 1995). Research on animal vaccines developed several attenuated recombinant viruses that delivered reproductive antigens via inoculation or bait but did not replicate in the host species (Kerr and Jackson 1995). Also in the 1980s, other research aimed at manipulating the genetic

constitution of myxoma virus in order to modify the severity of myxomatosis in the European wild rabbit.

Late in the decade the three concepts, immunological suppression of fertility, viral delivery of genetic information, and contagious spread of the genetic information through widely dispersed and inaccessible pest populations, were combined. Research in Australia began to develop virally vectored immunocontraception (VVIC) for the European wild rabbit, the European red fox and subsequently the house mouse (Tyndale-Biscoe 1994a).

The concept of VVIC involves: 1) identification of one or more reproductive proteins that are essential to the processes of fertilization, e.g., proteins on the surface of the sperm or ova, or proteins essential for embryo implantation; 2) identifying the gene that codes for the proteins and cloning them; 3) inserting the cloned genes into an appropriate intergenic site of a suitable infectious virus, together with any necessary cloned promoter genes; 4) infection of the host by the modified virus and initiation in the host of an immune (antibody) response to the virus and to the reproductive proteins (antigens) encoded in the infecting virus and produced during viral replication; and 5) attachment of the circulating antibodies to the specific reproductive proteins of the host, as well as to the reproductive proteins of viral origin, so that the normal processes of reproduction, fertilization or implantation, whichever was targeted, can no longer function. Theoretically, the infected host can no longer breed.

Thus, the theoretical concept of VVIC seems a very attractive potential technique for reducing rabbit abundance and impact over extensive areas of Australia (Tyndale-Biscoe 1994b; Holland and Jackson 1994). It seems to have advantages over hormonal and chemical methods of manipulating fertility which currently tend to be limited and localized in effectiveness (Bomford 1990). A potential advantage might be the retention of hormonal integrity and any social behavior that suppresses reproduction of conspecifics (Bomford 1990; Tyndale-Biscoe 1994b). However, the life history and mating system of the pest species must be suitable for fertility control or undesired outcomes may result (Caughley, Pech and Grice 1992).

Several potential variations of the concept can be chosen to match the problem and reduce any risks associated with the solution. These include bait delivery of encapsulated reproductive antigens, or use of recombinant bacteria which may be non-infectious or contagious. For example, the intent for the fox has been modified to bait delivery in the first instance (Bradley 1994).

The main potential advantages of this family of concepts are: 1) humane control of pest species; reduced fecundity may result in fewer individuals to suffer control action, drought or other diseases; 2) a capability of affecting individuals remotely and over extensive inaccessible areas; 3) cheap control of highly fecund pests; 4) species specificity and no non-target impact; and 5) non-polluting methodology.

The attractiveness of these potential advantages should not eclipse our perception of the difficulties involved in

developing the concept to reality. There are many challenges in the fields of reproductive molecular biology, immunology, molecular virology, epidemiology and ecology. Questions of social and ethical concern (Tyndale-Biscoe 1995) will not be addressed here.

#### CONSTRAINTS ON THE FORM OF VVIC

Biological constraints in anatomy, physiology, biochemistry, and immunology of the pest species, and genetics of the viral agent will dictate what is possible in VVIC. These functional traits will influence the initiation of an immune response, and its intensity and maintenance, either to self or non-self reproductive antigens, and whether VVIC can function via males, females or both.

Social and ethical issues will impinge on what is acceptable or not in VVIC, and what the design of the infertility agent should aim for, and how it is applied. Clearly VVIC must affect only the species intended, not any non-target species. This requirement will limit the choice of antigens to those that are either specific to the pest species, or induce an immune response only in the pest species. Other species-specifying strategies include the host-range of the virus carrying the sterility agent, and the specificity of any insect vectors that deliver the virus to the host pest species. Another social-ethical issue is the humaneness of the infection caused by the chosen viral agent and the humaneness of the immune response to the reproductive antigen. The form of the VVIC agent will influence the nature and difficulty of the ecological problems that must be overcome also. The choice of myxoma virus for VVIC in the European wild rabbit in Australia clarifies some of these issues (Holland and Jackson 1994; Kerr and Jackson 1995) but many remain uncertain.

#### THE NATURE OF THE INFERTILITY CAUSED BY MYXOMA VECTORED IMMUNOCONTRACEPTION (MVIC)

It will not be known whether males and females or either can be rendered infertile until antigens have been selected, inserted into the myxoma virus, and shown to induce infertility successfully in wild rabbits. MVIC could focus on causing dysfunction in a number of ways, such as preventing fertilization or implantation, although fertilization is preferred on the grounds of humaneness. While MVIC targets fertilization, infertility of the female is all that is required, and this might be achieved through viral presentation of the antigens of either ovum or sperm to females. Presentation of sperm antigens to female rabbits may be advantageous if males also react to them. If we assume random mating, and the probability of a mating female being infertile is  $p$ , and the probability of infertility of a mating male is  $q$ , then the probability of a mating being fertile is:  $(1 - p)(1 - q) = 1 - p - q + pq$  and the probability of a mating being infertile is:  $1 - (1 - p - q + pq) = p + q - pq$ . However, it is possible that the testes of rabbits may be protected immunologically (viz. Holland and Jackson 1994), either partially or wholly. If males cannot be rendered infertile and immunocontraception can be effected only through females, then  $q = 0$ , and the probability of an infertile mating is less, being only  $p$ . This demonstrates a

potential advantage of using sperm antigens for MVIC, if possible, either alone or in addition to ovum antigens.

Individuals may vary in their susceptibility to VVIC, possibly because of variation in recognition of the reproductive antigens or epitopes, or in the intensity of the immune response induced. The variation could be as extreme as some individuals failing to react while others become completely infertile. Such variation is fertile ground for natural selection against those which react to the antigen presented. If such variation in response to the final construct is evident it may be necessary to use strategies that counter such selection before it is deployed in the field.

It is also possible that infertility may be incomplete within individuals. The number of litters per year or the number of young per litter may simply reduce. In that case, individual variation is likely and natural selection may apply here also. The consequences for population control may differ if individual productivity declined instead of ceasing.

A variation on the theme of incomplete infertility is the possibility of a limited duration of infertility, temporary infertility. Immunity to myxomatosis persists for the lifetime of the recovered individual (Fenner et al. 1953), but it is not known if the response to the reproductive antigen would persist similarly. The persistence of immunity to myxomatosis suggests that there would be little chance that further inoculations of virus by insect vectors would reactivate or boost the infertility. Experimental inoculation of laboratory rabbits supports this inference (Kerr and Jackson 1995).

#### THE EUROPEAN WILD RABBIT AS A CANDIDATE FOR VVIC

The form of VVIC chosen will depend also on aspects of the biology of the rabbit. Even for a species as intensively studied as the wild rabbit, some aspects of rabbit biology that are crucial for VVIC are not known and will need to be investigated. It is also very pertinent that a widespread species, like the wild rabbit in Australia, varies markedly in population dynamics over the various regions and habitats (Gilbert et al. 1987). Undoubtedly, biology will vary in concert with the population dynamics.

One of the most important issues for MVIC for the wild rabbit is whether the dynamics of rabbit populations would compensate for the failure of some rabbits to breed, or would compensate for the intended decreased density of rabbits. Such compensation could nullify the intended benefits of MVIC or determine that greater reductions in fertility must be achieved for population reduction. Several aspects to this general question of compensation are considered below.

##### The Mating System of the Rabbit

The social aspects of mating will influence whether rabbit populations may compensate for infertility and affect the required level of penetration of the sterility agent into rabbit populations. Also, knowledge of the mating system of the wild rabbit is essential for conceptual or mathematical models of proposed systems of MVIC. The probability that a male rabbit mating with

a female at oestrus is sterile depends on the male having been infected with the sterilizing virus. That probability increases with age; young males would be more likely to be fertile. Domestic rabbits are induced ovulators; the act of mating initiates ovulation in about 10 hours (Asdell 1965). However, this may not be so for wild rabbits (viz. Myers and Poole 1962). The question of induced ovulation is pertinent to MVIC because it may determine whether only one or several males may fertilize ova at a female's oestrus, and thereby affect the probability that the mating is sterile. It is not known how many males mate with a female rabbit at oestrus, nor whether only one or more of these males fertilize the ova shed in one ovulation. Also, it is not known whether older males leave more progeny than younger ones, or whether any social dominance dissociated from age determines procreative success (viz. Daly 1981).

#### The Responses of Rabbit Populations to Infertility

It is not known how female rabbits respond to the presence of females that do not breed. The responses may vary, depending on the social status of the fertile and infertile females. The issue is whether the fertile females leave more or fewer progeny because of the presence of the infertile females. Such fecundity responses could result from variation in the proportion of the fertile females that breed, the number of litters they produce in a season, and the number of young in the litters. It is also possible that the fertile females might respond in this way, not for social reasons, but because of reproductive reaction to the altered population density of rabbits and the consequences for available resources such as quality or abundance of food and warren space.

Similarly, the progeny born to the fertile females may survive differently because of the altered population density of adults and young rabbits, and the different levels of available resources of food and warren space. Any such effects are likely to flow on to differences in growth rates, time to maturity, proportion surviving to maturity and the age at which they breed. Earlier maturity may mean that, in extended growing seasons, some young might breed in the season of their birth, with profound implications for population growth rates. These responses of females and progeny to infertility in rabbit populations are not known but are needed to predict the outcome of VVIC.

#### **MYXOMATOSIS AS A VEHICLE FOR VVIC OF WILD RABBITS IN AUSTRALIA**

Myxomatosis kills a proportion of the susceptible rabbits that become infected, the proportion depending on the virulence of the strain of myxoma and other factors inherent in the rabbits such as genetic resistance and the sire effect (Sobey and Conolly 1986; Williams and Moore 1991; Parer et al. 1995). The intent for MVIC is that those rabbits that survive the infection will remain infertile (Tyndale-Biscoe 1994b). Therefore, the choice of strain would influence the proportion of rabbits that the infection kills or renders infertile. Humaneness indicates that highly attenuated strains are preferred, whereas the impact of rabbits indicates that highly virulent strains should be chosen. However, other factors impinge on the choice of myxoma strain. The recombinant MVIC virus

may incur a competitive disadvantage relative to the myxoma strains present in the field. Therefore, the transmissibility of the MVIC virus may need to be maximized as far as possible, perhaps specifically for the particular region and its population of rabbits. Transmissibility depends on the rate of viral replication in the skin of the rabbit, and this varies with viral virulence (Fenner and Ratcliffe 1965). The European rabbit flea transmits the more virulent strains faster than attenuated ones (Mead-Briggs and Vaughan 1975), but we do not know the relative rates for other modes of transmission. Nevertheless, it is unlikely that highly attenuated myxoma strains would be a viable option for MVIC. At present there seems to be no alternative to experimental comparison of strains, at least initially, to derive information on which to choose suitable strains for MVIC.

Another element of uncertainty in the use of MVIC results from the very recent entry of RCD into wild rabbit populations in Australia. Myxomatosis appears to be co-existing with RCD in field populations (B. D. Cooke, pers. comm.). Nevertheless, if RCD persists in field populations, as it has in Spain (Blanco and Villafuerte 1994, cited in Cooke 1995), we can expect some realignment of the epidemiology of myxomatosis with the altered dynamics of the rabbit populations and perhaps also the vector flea populations. The implications for MVIC will be complex.

#### **INSECT VECTORS OF MYXOMATOSIS AS TRANSMITTERS OF MVIC AMONG WILD RABBITS IN AUSTRALIA**

Mosquitoes are erratic vectors of myxomatosis, whereas fleas are more regular in abundance and proximity to rabbits. Consequently, fleas are more likely to be targeted as the vectors for MVIC. Transmission of myxomatosis by mosquitoes tends to be fast and short-lived, whereas flea-borne epizootics tend to trickle through rabbit populations. Mosquitoes, being irruptive, may dominate the transmission of myxomatosis in some years, probably wetter years, and perhaps in regions rich in water bodies suitable for breeding of the appropriate species of mosquitoes. While mosquitoes and fleas probably differ in their transmission characteristics, different strains of myxoma may be favored according to the relative proportions of myxoma transmission by these vector species. Thereby different strains may be favored in different times and places, and in some years the MVIC may be favored or disadvantaged depending on the transmission characteristics of the chosen strains. It may prove advantageous to use several different strains of myxoma for MVIC that are transmitted best by the different types of vector.

The dependence of the reproduction of the European rabbit flea on the breeding cycle of the rabbit poses the question of whether fleas would remain abundant enough to transmit the MVIC. That is, would a prevalence of infertile females cause flea numbers to decline to some equilibrium level too low for adequate transmission of myxoma virus? The density of European rabbit fleas needed to sustain an epizootic of myxomatosis is not known; however, it can be anticipated that the minimum required density would vary with a multitude of field

conditions. Experimentation and measurement are needed. While the breeding of the Spanish flea does not depend similarly on rabbit reproduction, the role of this vector in transmitting myxomatosis in Australian wild rabbit populations remains to be determined. The role of the Spanish flea in viral transmission is a very important factor, for mortality caused by myxomatosis and RCD in the arid and semi-arid interior where the problem of rabbit impact is severe and in urgent need of solution, and for its potential role in transmitting MVIC. This role will not be elucidated for some time because the Spanish flea is still establishing there in the adverse conditions of low rabbit numbers caused by prolonged drought and the initial impact of RCD.

#### THE NEED FOR EXPERIMENTATION AND MATHEMATICAL MODELING

While so many factors might impinge on the effect of VVIC, and the interactions within them are so complex, mathematical modeling must be relied upon to synthesize likely outcomes and assess the relative importance of the various factors and interactions (e.g., Caughley et al. 1992; Barlow 1994). However, it is important that real interactions are recognized and that realistic values be used in such mathematical models. Primary observation through experimentation is needed to recognize or test those interactions and to obtain those realistic values.

#### ANALYSIS OF ECOLOGICAL PROBLEMS IN MVIC FOR THE EUROPEAN WILD RABBIT

##### Rabbit

The mating system of wild rabbits is being examined in a group of rabbits held in large enclosures. The progression of breeding is being examined closely and litters are checked for maternity by behavior, pregnancy and lactation, and for paternity by analysis of DNA. Preliminary results indicate that the males which are socially dominant in the enclosures may sire the majority of the litters, but by no means all. Most litters are sired by one male; the frequency of multiple paternity within litters is less than 10% (L. A. Hinds, pers. comm.). These preliminary results are seen as consistent with effective MVIC.

The responses of wild rabbit populations to infertility are being examined in two very large field experiments on either side of Australia in two different climatic regions. In these experiments female rabbits are sterilized at random by surgical ligation of fallopian tubules in proportions of 0% or 40% or 60% or 80% of all females. The dynamics of the 24 separate rabbit populations are monitored and recruits are sterilized annually. Progressive effects are expected over the three years of the trials, but some patterns are evident in the first year's results (Williams and Twigg in press).

The fertile female rabbits did not seem to respond to the presence of infertile rabbits; young rabbits were produced in proportion to the level of sterility imposed on the populations. Consequently, in the first year, no social responses influenced reproductive productivity, and any ecological consequences of the presence of fewer progeny did not affect the breeding of the fertile females. In the first year the numbers and survival in the adult stratum of the population did not respond to the presence of fewer

young rabbits, although flow-on effects are possible in later years. However, survival of the progeny varied with the level of sterility in the population and its productivity. Survival was greater where fewer young were produced because of imposed sterility. That is, the survival of the young partially compensated for sterility. Under the experimental conditions compensatory survival seemed to nullify the effects of sterility to levels between 60% and 80% of females. Although sterility may have more effect in later years when the numbers of adults might decline, these preliminary results suggest that the wild rabbit has some resilience to MVIC because of its production of more young than the resources of the habitat can support in most years (Williams and Twigg in press).

##### Myxoma Virus as a Carrier

These field studies examine also the prevalence of myxomatosis in the rabbit populations by measuring serum antibodies to myxoma virus. Active cases of the disease are sampled for analysis of the genetic type (strain) of virus by assessing restriction fragment length polymorphisms (RFLPs) of DNA (P. J. Kerr, pers. comm.). Seven such strains of myxoma virus have been identified from the study sites. Two of these appear to persist in the area while others apparently arrive and do not persist.

Very high proportions of the rabbit populations are exposed each year to myxomatosis, and most rabbits are immune by mid-autumn. This suggests that the myxoma virus has the potential to transmit immunocontraceptive antigens to most rabbits in these regions. However, these observations also indicate that it may be a very difficult task for the genetically modified myxoma virus to compete with the field strains already present.

The possibility of introducing an identifiable strain of myxoma virus into wild rabbit populations in competition with the naturally occurring field strains is being tested in another field trial (A. J. Robinson and J. C. Merchant, pers. comm.). One of the seven identified field strains has been introduced actively by inoculating trapped rabbits in four areas where this strain has not been found. The rabbit populations are being monitored very closely, and rabbits observed to be infected with myxomatosis are caught and the virus is sampled and identified.

This trial is still in progress, but current results suggest that the introduced identifiable field strain has spread locally on sites where other field strains have infected rabbits. There is no clear outcome on competition because there have been few cases of the introduced strain and a field strain infecting rabbits simultaneously in the same warren. The observations on transmission of the introduced strains and field strains will be applied to spatial competitive models of MVIC. Studies already planned might identify strains with greater transmissibility than this introduced strain, but it will be necessary for the MVIC virus to contain additional genetic material, and the transmissibility of the genetically modified virus will need to be assessed in containment.

##### European Rabbit Flea as a Vector

The field studies of the responses of rabbit populations to sterility imposed by surgery include

analysis of the abundance of the European rabbit flea. Practiced calibrated observers count or visually assess the numbers of fleas on each trapped rabbit without knowledge of the sterility treatment assigned to the sites. The effects of the sterility treatments of the female rabbits on the vector flea populations will be analyzed only after the field assessments have ceased.

#### Modeling MVIC

Mathematical models that will comprise the MVIC model are being developed. These will be modified as field studies progress and realistic data become available. A spatial model of spread of competing strains of myxoma virus (R. Pech and G. Hood, pers comm.) indicates that sterilizing strains of myxoma virus seem to be at a competitive disadvantage to equivalent non-sterilizing strains and eventually die out. The sterilizing virus reduces the rate of recruitment of young rabbits susceptible to myxomatosis, and thereby it deletes opportunities for transmission and persistence. However, the probability of persistence of the sterilizing strain increases with increasing distance of transmission between rabbit hosts. The probabilities of persistence of the sterilizing and non-sterilizing virus strains tend to equalize when the average distance of transmission of virus equals the average dispersal distance of the rabbits. This outcome suggests that an MVIC may persist longer and affect more rabbits if transmitted by potentially long-distance vectors such as mosquitoes. Transmission by fleas may enable MVIC to be used tactically in localized situations. Myxoma strains with differing transmission characteristics may be needed for areas that differ in prevalences of mosquito or flea transmission of myxomatosis. Thus, the mathematical models under development generate useful questions about how MVIC might function.

#### CONCLUSION

Virally vectored immunocontraception of the European wild rabbit in Australia, using myxoma virus to carry the sterilizing agent, involves very complex ecological interactions of virus, flea and rabbit. Experimental modeling of MVIC in field populations of rabbits, aided by mathematical modeling, seems to be progressing successfully in assessing the feasibility of developing the concept as an additional tool for managing the abundance and impact of this profoundly destructive pest.

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# EDUCATION AND TRAINING INTEGRAL PART TO 1080 POSSUM CONTROL IN NEW ZEALAND

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**ABSTRACT:** New Zealand currently has large scale possum and rabbit operations being carried out on about 10% of its land area. Education and training are integral to possum control in New Zealand because of the heavy reliance that the control agencies in New Zealand place on toxic baiting with 1080 (sodium monofluoroacetate). Education of the general public is treated as a high priority since without their approval many of the operations would not be carried out. It is equally important that school children are advised on what toxic baits look like and why pest control operations are required. Training of pest control staff is also considered important as it is vital that all staff are well trained in the latest technology and at the same time can answer inquiries with the latest results of research.

**KEY WORDS:** vertebrate pest control, training, public education, pest management, poisons, control methods, 1080, sodium monofluoroacetate, *Trichosurus vulpecula*, possum, *Oryctolagus cuniculus*

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## INTRODUCTION

Education and training are integral to possum control in New Zealand because of the heavy reliance that the control agencies in New Zealand place on toxic baiting with 1080 (sodium monofluoroacetate). Currently in New Zealand the main animal species being controlled are the possum (*Trichosurus vulpecula*), the European rabbit (*Oryctolagus cuniculus*) several species of feral deer, and mustelids including ferrets and stoats.

The possum is the major vertebrate pest in New Zealand. Possums act as vectors in the spread of bovine tuberculosis (*M. bovis*), and cause serious damage to indigenous forests and native birdlife.

Currently 1.25 million hectares of New Zealand are under continued maintenance operations for bovine tuberculosis possum control. In this financial year another 0.6 million hectares will be treated with initial control operations. Most of these maintenance operations and about 50% of the initial operations will be carried out with 1080 bait of various types applied by hand. About 0.3 million hectares will be aerially treated with either 1080 cereal pellets or diced carrot in various application rates from 4 to 6 kg per hectare for pellets or 8 to 14 kg per hectare for carrots. The toxic loading of 1080 bait varies between 0.08 to 0.15%. Lower sowing rates are used with higher toxic loadings.

In the case of protection of indigenous forests, the Department of Conservation currently carries out possum control on over 1 million hectares of forest. This large scale animal control for bovine tuberculosis and the protection of indigenous forests costs New Zealand about \$50 million per year. While some of the area is controlled by hunters with traps and other toxins such as cyanide, brodifacoum, cholecalciferol, phosphorus and pindone, the main toxin used is 1080.

This toxin is the most environmentally acceptable and cost effective toxin on the market today. New Zealand uses over 4 metric tons of the toxin each year for pest control. While the main use is for possum control, it is also used for rabbits and on feral deer in areas where they are known to have bovine tuberculosis.

A special committee, the National Possum Control Agency (NPCA), was set up in 1993 as an ad hoc coordinating body involving representatives of all agencies involved in possum control. The agency concerns itself with control programs and areas of training, public relations and consultation. The agency was also involved in the standardization of publicity material used to inform the public on the use of toxins in pest control.

The Ministry of Health, which under various Acts authorize all aerial poison operations and any operation that involves public land, has established guidelines for medical officers of health (MOH) in issuing permits for control operations. Part of those permit guidelines made it a requirement for agencies to hold education programs at all schools within 10 kms of areas to be treated with 1080.

With the wide reliance on the use of 1080, all agencies involved in its use have formulated a policy of coordination between agencies, and more importantly have embarked on a wide education and training program for all people involved in its use. This program is aimed at two areas: 1) educating the general public and the owners and neighbors of properties that are to be treated with 1080; and 2) training all staff using the toxin in the field to be as proficient as possible and keep up to date with new knowledge in possum control and toxin research.

## EDUCATION

Education is a vital component in generating and maintaining public support for pest management programs. The general public are often against the use of toxins to control animal pests. This is brought about by the general perception that the use of pesticides is not good for the environment. Opposition may also come from people with hidden agendas that do not want to see pesticides like 1080 used because of their effect on game species, such as feral deer and pigs. These people seldom admit this is the reason they do not want poison used and instead use other arguments. Other people believe that the use of the unemployed would be a good way to control animal pests, and at the same time ease the



unemployment figures. Little do they realize the extent of the problem or the type of terrain involved.

In the education of the general public it is important that the information provided is technically correct and based on the latest research. It must allow people to decide for themselves how significant the issues are, and allow them to assess how well the risk is being managed by the agencies by balancing both the adverse and beneficial effects.

It is vital that the true extent of the adverse impact of possums on agriculture and the environment are understood by the general public. Generally, it is initially found that the public do not have a good appreciation of the problem. The public perception of the risks and issues associated with wild animal control programs is critical to the success of those operations. The public concerns drive politics that drive the laws and regulations.

New Zealand has seen public pressure force an inquiry by the Parliamentary Commissioner for the Environment, which resulted in a 196-page report "Possum Management in New Zealand." That report covered the use of 1080 and noted that, "The public disquiet at large scale poison operations is understandable. There is a risk using 1080. However the risk to the environment and to public health is low and in some areas there is at present no alternative to aerial control operations using 1080. Public disquiet will be dispelled only if adequate information is supplied by the agencies and every attempt is made to evaluate control options including aerial use of 1080. Careful planning with the assistance of all affected parties can help to achieve public support and develop appropriate strategies for managing possums." (Parliamentary Commissioner for the Environment 1994)

The NPCA has, with the agency's assistance, developed a wide range of publicity material aimed at addressing public concerns. This includes:

1. *1080 Questions and Answers*—answers the most commonly asked questions on 1080.
2. *Fact Sheet Package*—aimed at rural and semi-urban landholders, supplied on disk and hard copy.
3. *The Possum Busters are Coming*—for parents and care givers of pre-schoolers. (1080 Health and Safety)
4. *1080 is Not Kid's Stuff*—resource material for use in primary schools.
5. *Possum Control in Native Forests*—possum control for conservation purposes written for the general public.
6. *1080 A Review of the Science*—suited for people with a science background.
7. *Possum Control and the Use of 1080 in New Zealand*—written for the general public.
8. Possum Buster stickers and magnets—for use in schools.
9. *Model Permit Conditions for Use of 1080*—contains model permit conditions on use of 1080 for the guidance of MOH issuing permits for possum control operations.
10. A video on health and safety and awareness in possum control—for use in schools and for the general public at meetings.

11. *A Plague of Possums*—a video aimed at senior secondary science curricula dealing with science and ecology of the possum problem.
12. Various posters—such as conservation and possum control, as well as specific posters on the bovine tuberculosis problem and on 1080 for use in schools and public places.

Various agencies have also produced stickers, flyers, puzzles, and games that relate to possum control, along with numerous small publications on understanding the problem and how the farming community and the general public can assist in possum control in various ways. All of the above have, in many instances, helped the public to understand why this particular toxin is used.

We still have problems from some people over the use of 1080 on their land, though we now take the attitude that if a specific landholder does not want 1080 used on his property then he may request any other control method he likes or carry out the control himself. But in doing so, they must sign a heads of agreement or a contract to reduce possum numbers to a specific level. If they achieve that, they will receive a payment equal to the cost of the 1080 operation minus the cost of monitoring the result. All of the above effort appears to have achieved a generally better public acceptance to the use of 1080. Often school children, after they have been visited by the agencies, have a better understanding of the risks of 1080 and the precautions that need to be taken with domestic pets. They, in turn, inform their parents of the risks. Standard full training packages for the agencies to use in schools are being developed at the present. These will include mounted pest animals, samples of traps, poison warning signs, nontoxic samples of all baits, and other equipment used in possum control.

## TRAINING

Training in pest control in New Zealand is also on the increase, with the realization from the agencies that staff need to be well trained and well informed. Staff must be able to use toxins safely and at the same time answer any questions on the use of toxins in the correct manner.

Research work on 1080 as well as other toxins is ongoing and the results of this research need to be relayed to the field staff at regular intervals to ensure they are well informed. This is done both by regular publications on the research findings, plus several technology seminars held each year throughout New Zealand to update key staff with any new advancements in control technology.

Both the Animal Health Board and the Department of Conservation have issued protocols that are regularly updated. Also in preparation is a series of Vertebrate Pest Control Manuals covering:

Vol 1. Toxins and Poisons: This covers statutory requirements for use of toxins and poisons; properties and uses; toxins to use on different animals; and health, safety, storage and transport.

Vol 2. Planning an Operation: This covers statutory requirements, contents of an operation plan, formal consents and approvals, notification and consultation, and contracts.



Vol 3. Conducting an Operation: This covers selection of the method of initial control, maintenance control and aerial control using 1080, and ground control methods and monitoring.

A full training package is also being developed with the Local Government Industry Training Organization to cover the whole range of pest management. This package will be designed in modules and can be studied by anyone. The assessment of this training will be carried out by on the job competency, and passes in any modules will be credited to the person passing the training.

Other training carried out includes specific courses of two to three days duration on subjects including aerial poisoning, monitoring, or maintenance methods of control, where course participants are actually involved in carrying out operations. Specific courses on management, health and safety, public relations, and other subjects are regularly carried out by the various agencies to further ensure that staff are competent to handle the general public in a professional manner.

As we are the biggest user of 1080 in the world, and are reliant on the use of this toxin, it behooves us to explain its use to all the public in New Zealand. One way of doing this is to ask a person, "If we must use a toxin to control vertebrate pests, then what sort of toxin should we use?" Is it one that has the following attributes?

1. A toxin that occurs naturally in plants in the environment.
2. A toxin that breaks down readily in the environment.

3. A toxin that does not cause residue problems.
4. A toxin that is humane in its action on most vertebrate pests.
5. A toxin that is cost effective in its use.
6. A toxin that mixes readily in a variety of bait.

There is only one toxin that fills that role and that is 1080—hence the reason we use it. The public perception of the use of toxins to control vertebrate pests is fragile in that one action which causes an accident will undo much of the good work done over the years to develop an acceptance of its use. It is, therefore, vital that control agencies continue to cement progress to allow the use of 1080.

We, as a nation, need 1080 to control the vertebrate pest problems we have, and money spent in education and training is a wise investment for the future of New Zealand's economy and environment. 1080 is a good toxin. The reason it has been restricted in some areas is that not enough effort has been made to explain its use, or because of its effects on other native vertebrate animals.

A lot of other toxins used in the world are not as humane, cause residue problems, and are far more expensive. Hence, many of them are not registered in New Zealand for wide use in agriculture. If they are registered, it is only for use in bait stations where bait application can be carefully monitored.

# MOLE CONTROL—A HISTORICAL PERSPECTIVE

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**ABSTRACT:** Various methods and approaches, including chemical and physical repellents, flooding, burrow fumigants, poison baits, vibrating devices and exclusion, have been explored for reducing mole problems. In addition to these, habitat management through reducing the moles food supply has received considerable attention, but environmental concerns and the lack of consistent results have tempered this approach. Over the years, trapping remains the best and most useful method of mole control. The pros and cons of some of the methods are discussed, along with some historical perspectives. The emphasis is placed on the Broad-footed mole, *Scapanus latimanus*, of California.

**KEYWORDS:** mole, *Scapanus latimanus*, mole control, poison bait, burrow fumigants, repellents, traps, trapping, exclusion

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## INTRODUCTION

Moles are essentially a subterranean living animal belonging to the order Insectivora. Their diet consists principally of insects, earthworms, and other invertebrates. Depending on the species, some may consume up to about 20% vegetable matter. They are capable of causing some damage to crops and ornamentals, but they are most detrimental in turfed areas where their unsightly mounds continue to plague those attempting to establish and maintain turf on golf courses, sport playing fields, cemeteries, parks, and a variety of other landscaped areas.

This paper discusses mole control, past and present, with emphasis on the Broad-footed mole, *Scapanus latimanus*, which is the most widely distributed and common mole pest in California (Figure 1). While there have been some changes through the years in the methods used and their importance in reducing the problems moles cause, the single most useful control method, trapping, has changed very little over the past 100 years. Each of the major management methods or approaches are discussed separately.

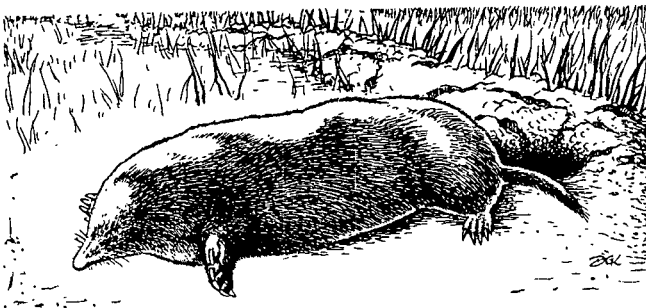


Figure 1. The Broad-footed mole, *Scapanus latimanus*, the most widely distributed mole in California.

## CONTROLLING MOLE FOOD RESOURCES

The restriction of available food is often an approach to vertebrate pest management. Since moles thrive largely on diets made up of invertebrates such as earthworms and grubs, then one useful approach is to limit their invertebrate food resources. The most practical method of lowering the invertebrate population is through the use of pesticides, principally insecticides. This approach to mole management has been practiced in the past and was most frequently conducted for the protection of turf. Anecdotal or subjective evidence varies—from reported success, to those who claim it had no negative effect on the mole population. Both of these observations are probably true, and reasons for this seem readily apparent, although supportive evidence by way of field evaluations is lacking.

Different soils support different invertebrates and at varying population levels. Yet, for the most part, we know little about what species of invertebrates are present and how numerous they are in any given soil area; nor do we know what invertebrates are critical to the mole's survival. We know that some mole species do feed on some vegetation, hence a dramatic reduction in invertebrates may be compensated for, in part, by a greater plant intake. While the application of selected insecticides, and even some fungicides, may control some invertebrate species, other species may survive in adequate numbers so that the mole's invertebrate food supply is not critically affected. The penetration of the insecticide into the soil and its persistence will also influence its ability to reduce invertebrates over time. If this control approach is selected, use only pesticides recommended for turf situations and apply at recommended rates.

Even if the application(s) of an insecticide are effective in significantly reducing the mole's food resources, it still may take some time for moles to die out or move to an area where food resources have not been limited. Reduced food resources may actually temporarily result in an increased search for food and this, in turn, may result in more tunneling damage to turf, at least for a time. Trapping as a supplement to this control approach is always advisable.

While modifying mole habitat to reduce food resources might seem in line with touted IPM approaches, the use of insecticides for this purpose is, at best, a most inefficient use of pesticides, especially when the results, relative to mole control, are so variable and unpredictable. Although the practice is legal, some believe this borders on pesticide misuse. In view of the present environmental concern over pesticides, their use, as a roundabout method to manage moles, is an approach which some find difficult to support, especially since many of the invertebrates killed (i.e., earthworms) are in no way harmful. With due considerations, this approach to mole control is, at present, infrequently recommended here in California unless there are compelling reasons and no suitable or practical control alternatives for the situation.

## REPELLENTS

A number of chemical substances have been registered and/or used in the past for mole control. Few, however, have demonstrated any effectiveness, and most lacked any scientific basis for potential repelling efficacy. Paradichlorobenzene "PDB" and naphthalene are often mentioned in the literature for mole control. Various home remedies such as lye, kerosene soaked rags, castor oil, and castor bean pumice represent some of the other substances that have been recommended in the past. Currently Mole-Med™ and Scoot Mole™ are the only two chemical mole repellents that the author is aware of that are being sold. Both materials are said to be derived from castor beans. Castor bean products have not been particularly effective in the past, and only time will tell if these new products are effective and live up to their claims.

The mole's feeding and subsurface activity patterns help lend credence to the effectiveness of various odoriferous or potentially objectionable substances as repellents, in spite of the fact that they do not work. Those convinced of their effectiveness and who tout their use are nearly always individuals with relatively small gardens. The reasons for this are simple, moles are a relatively solitary animals except for when breeding and rearing young, and they have large complex tunnel systems which may extend for several hundred lineal feet. Moles may work one portion of their tunnel system for a few days and then move on some distance away to another portion of the system, which may be in the neighbor's yard. Hence, the application of some obnoxious substance just prior to or immediately following the mole's shift in its feeding location will be credited to the effect of the repellent. When the mole returns a week or two later, the gardener is convinced it is a new mole.

Many nonchemical repellent items, placed in the mole's tunnels, have also been suggested as home remedies. These include ground or broken pieces of glass, used razor blades, sections of barbed wire, or thorned rose bush canes. Some of these are actually more hazardous to the gardeners themselves than to the moles. When moles run into the unfamiliar foreign object in their tunnels, they may simply circumvent the object by blocking those tunnels off with soil and then proceed to dig new tunnels, just as they do with a poorly set trap.

There is no convincing evidence that these sharp, potentially harmful items cause any mortality or that they resulted in the mole leaving the immediate area.

Planting a row of *Euphorbia lathyris*, sometimes referred to as the mole plant or gopher purge, as a garden perimeter barrier to moles is suggested in many garden publications, but these, too, are ineffective. Because of their general lack of effectiveness, repellents of any type play an insignificant role in mole control.

## BURROW FUMIGANTS

A wide variety of fumigants have been explored or registered for moles, including such materials as calcium cyanide, carbon bisulfide, methyl bromide, carbon tetrachloride, sulfur dioxide, ethylene dibromide, aluminum phosphide, and gas cartridges. Most have not proven all that effective—for several reasons. Moles have the ability to quickly plug their tunnels with soil, thereby blocking off toxic gasses before lethal levels have been reached. The applied fumigant may also escape to the surface through the complex of shallow subsurface feeding tunnels. Where the moles are well established and have been in place for some time, the burrow system may be so extensive that the normally recommended dose of fumigant may be inadequate. The soil texture may be such that too much of the fumigant is diffused into the soil or escapes from the system and the lethal threshold is never achieved or is not sustained for an adequate period of time.

Burrow fumigants, such as gas cartridges currently available to gardeners, have their best chance of working if used on moles which have just invaded an area, as their burrow systems will be less extensive. Be sure to apply a cartridge into the main tunnel and not into the shallow feeding tunnels. A cartridge should be placed in two or more locations of what is believed to be the burrow system of one mole. Some smoke escaping to the surface will provide some assurance that the gas has penetrated the entire burrow system. If smoke is not visible, placement of additional cartridges may be indicated. Professionals in mole control have found that results are enhanced by attaching a hose to the exhaust of a small gas engine, using the exhaust pressure to rapidly force the toxic smoke from the cartridge through the mole's burrow system. Rapidly forcing the toxic gas through the burrow system may overcome the mole before it has a chance to plug off the toxic gas. Turning on the sprinkler to wet the soil surface of the garden or turf prior to the application will aid in retaining the toxic gas in the burrow system. If new mole activity appears two or three days following the initial application, then repeat the treatment procedure. Several applications may be needed; persistence is the key to success.

The effectiveness of gas cartridges is so limited that the author rarely recommends them for commercial growers or for large landscaped or turf areas. As a possible alternative to trapping, they are offered to the homeowner who finds fumigants such as the gas or smoke cartridges much easier to use. Currently aluminum phosphide, a restricted use pesticide, is available and is used by some professionals in the midwest and east for mole control. Reported success is variable, depending on the site and soil conditions. Here, in the far west, results

with aluminum phosphide for mole control have been poor.

#### POISON BAITS

A number of mole baits have been marketed in the past, but few were even moderately effective—for two major reasons. First, the principle diet of moles consists of insects, earthworms, and other invertebrates; this makes the formulation of an effective bait difficult, especially if you are trying to prepare a bait which can be marketed and can meet the requirements for a reasonable shelf-life. Second, finding that ideal single feeding toxicant which is essentially odorless and tasteless and to which moles are highly susceptible, is a significant challenge. These two factors, plus the fact that our mole species are difficult to maintain in confinement, make the evaluation of experimental bait formulations, as well as suitable toxicants, very difficult to adequately test when conducting bait development research under controlled conditions.

The desire for an effective mole bait led to a considerable number of trial- and error-type studies with perishable and nonperishable toxic baits. Perishable baits made of fresh earthworms were generally considered best by the professionals in mole control, although some used freshly ground meat. The fresh baits were treated with a prescribed amount of strychnine (sulfate or alkaloid), thallium sulfate, or 1080 (sodium fluoroacetate). The treated baits were applied to the burrows shortly following preparation—before they began to deteriorate. Such baits were not generally used by home gardeners, as some toxicants, such as 1080, were not available to the public. Of these freshly prepared baits, 1080 treated earthworms gave, by far, the best results. None of these baits could be formulated today because of pesticide registration restrictions.

The commercial baits which did appear on the market were generally formulated with a variety of ingredients, including grains, raisins, peanuts, hemp seed, and dried meat. These usually contained arsenic, strychnine, or thallium sulfate. In recent years, zinc phosphide has been added to this list. In some states an anticoagulant rodenticide, chlorophacinone, was also registered for mole control. Of all the limited number of commercial mole baits, thallium sulfate treated peanuts seems to have gained the greatest use. As was the case with both perishable and nonperishable baits, they were placed into each burrow system in two, and preferably more, locations. The main tunnels were located by probing, and the bait applied through the enlarged probe hole. Unfortunately, none of the commercially available mole baits were all that effective and, for various reasons, most have disappeared from the market. In recent years, the use of a mole bait is rarely suggested for their control.

#### TRAPPING

Trapping is by far the most applicable and dependable method of mole control available. Trapping, to be successful, requires a good knowledge of the moles burrowing and food habits and how they respond to foreign objects placed in their paths. It is labor intensive and, therefore, relatively expensive if a trapper is hired on an hourly basis and contracted by the job. An

experienced professional mole trapper, however, can trap many more moles than the novice. Over time, with practice and experience, most anyone can become a proficient trapper.

The development of mole traps in North America has a traceable history of at least 150 years. The local blacksmith made the first examples about that long ago. These were large, cumbersome devices but, judging by their designs, it is obvious that the makers were familiar with the mole's habits as they had figured out the basic principles required of an effective trap. Around 1885, the first few kinds of commercially produced mole traps began to appear on the market, but by the 1900s there was a proliferation of mole traps representing many unique designs. A search through the trap patents issued around that time is both an interesting and enlightening undertaking and reflects the rapid advances being made during that period of the industrial revolution. Intrigued by trap designs and their trapping mechanisms, the author has included a few drawings of some of these early traps to provide some historical perspective into traps and mole trapping (Figure 2).

The best mole traps are distinctly different from effective pocket gopher traps. The most effective traps are designed so that no part of it obstructs the mole's tunnel, and it is triggered by a pan that lies horizontally on compressed soil and out of the animal's path. The trap is activated by soil heaved upward against the pan as the mole reestablishes its tunnel. The three best and most popular mole traps were all patented around 1900 and have changed very little over the years. These are the scissor-type Out O' Sight Mole Trap, the harpoon- or spear-type Victor Mole Trap, and the choker loop-type Nash Mole Trap (Figure 3). All have horizontal pans and have stood the test of time. In California, the Out O' Sight and Victor mole traps are the two most frequently used. Of these two, the Out O' Sight is considered the most effective by professional mole trappers. The Nash Mole trap is about equally effective, but this trap is not readily available in this state as it is rarely stocked by hardware stores.

Traps normally are sold with instructions for use which provide details on how and where to set the traps. It is important to understand mole burrowing habits and how the tunnel system is constructed. Moles produce very shallow tunnels that ridge up the soil or turf, providing an easily visible indication of their presence. These are thought to be mostly feeding tunnels and the same tunnel may not be used by the mole on a regular basis. For this reason, setting traps in these very shallow tunnels does not produce results as often as does setting the trap in the deeper, much more frequently used tunnels. Most experienced trappers prefer to set traps in these deeper tunnels as the trapping success is superior, with more moles caught per trap set. In order to set traps in the deeper tunnels, which are generally from about 8 to 12 inches below ground, they must first be located. To find these tunnels requires the use of a steel probe which is inserted at 3 to 4 inch intervals across an area between the fresh mole mounds, the assumption being that there is probably an underground tunnel that connects these two mounds. This is where experience is most critical in the ability to quickly locate the deeper tunnels.

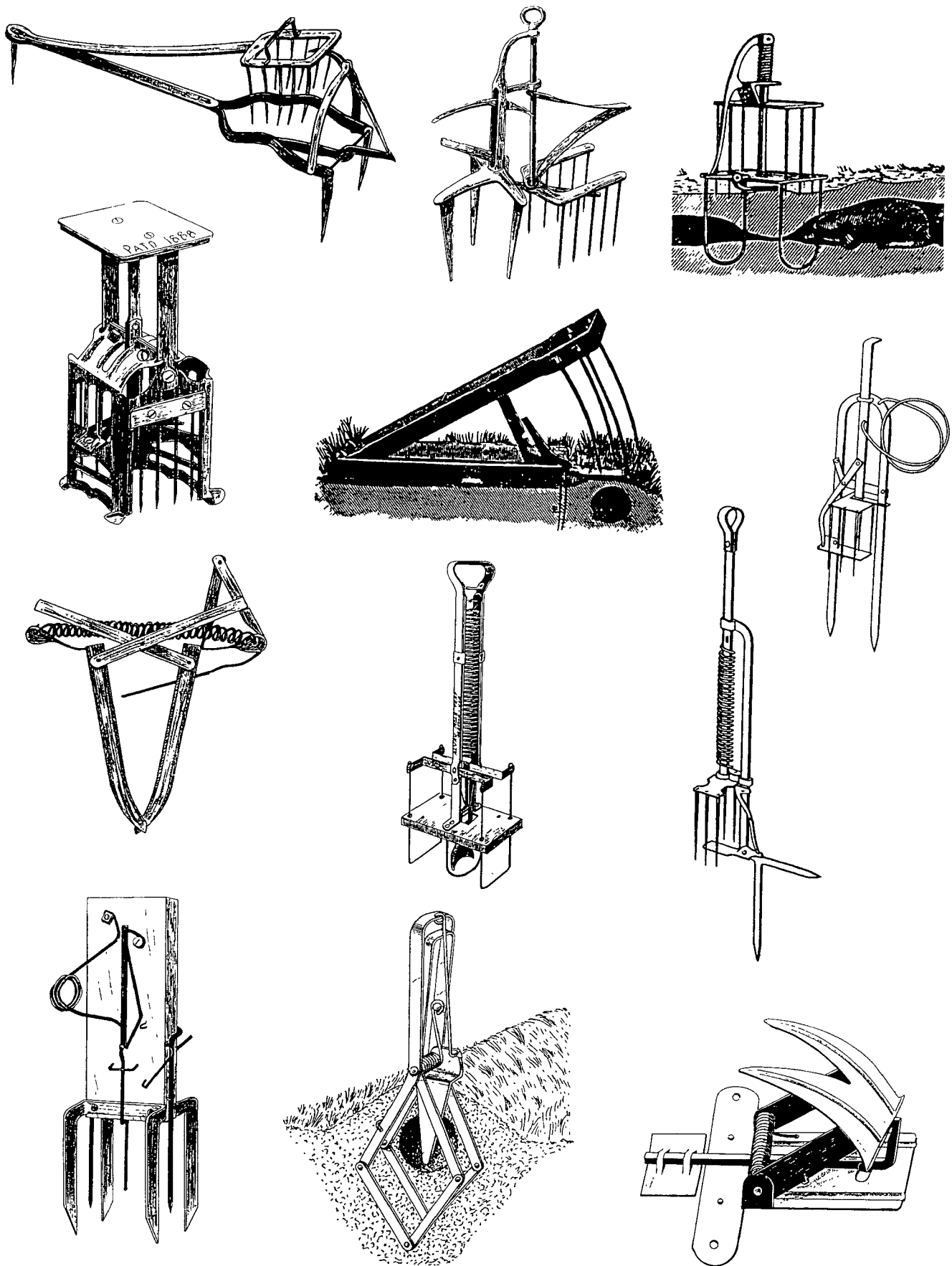


Figure 2. Illustrations of some of the mole traps dating from about 1860 to 1970. (First row, L to R) Hand forged mole trap, unidentified commercial trap, Mabbett's mole trap. (Second row, L to R) Van Wormer, Daffodil, Side-spring. (Third row, L to R) Chandler, Alvau, Wherry. (Fourth row, L to R) Wyman's, Mole-choke, Taylor's Sure Kill.

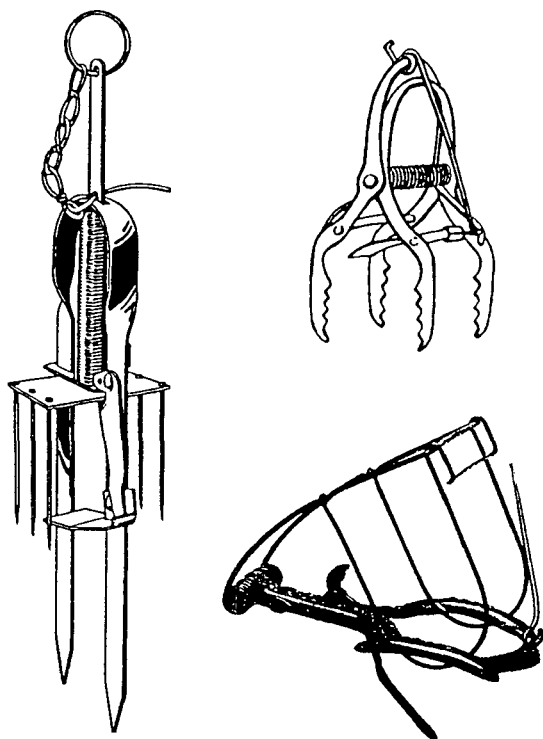


Figure 3. Three of the most popular mole traps in current use; Victor mole trap (left), Out O' Sight mole trap (top right), Nash mole trap (bottom right).

As the steel probe enters a tunnel, a difference in soil friction on the probe will be noticeable. A well designed probe with a slightly enlarged tip will greatly aid in locating the tunnels. Once the deeper, frequently used, main tunnel is found, a shovel or spade is used to dig a hole down to the tunnel. The hole should be no larger than is necessary to provide room for the trap. The soil where the trap is set needs to be sufficiently loose and free of rocks so that the trap will function properly. The exposed tunnel hole is back filled with about three inches of fine soil, just enough to cover the exposed tunnel. This backfilled soil is tamped slightly and the set trap is pushed into place so that the pan rests on the compacted soil. No part of the trap should obstruct the tunnel. As the mole proceeds to push through the slightly compacted soil plug in its path to reestablish the tunnel, it will cause an upward pressure on the pan and the mole is caught.

#### VIBRATING DEVICES

For 50 years or more, small windmill devices that produce a clippity clop sound have been sold to home gardeners for mole control. Such windmills, with their wind activated hammers, are said to produce a vibration which is transferred from the windmill's head, downward through the support post, into the soil. The soil vibrations are advertised as having the capability of

repelling moles from the area. The fact that moles can apparently detect unfamiliar ground vibrations and will normally scamper back to their underground nest when detecting an approaching source of vibration, adds some credence to this control approach. This sensitivity to vibrations is confirmed by radio tagged moles, monitored from above ground. However, this little bit of mole behavior is misleading, as moles readily become accustomed to these vibrations and soon learn to live with them. The habituation is readily apparent by noting that moles have learned to live alongside busy railroads where, each time a train passes, the ground vibrates for distances of several hundred feet from the tracks. The same is true for roadways used by heavy trucks, and major airport runways, where both moles and pocket gophers seem to thrive unaffected. There is no evidence that any of these marketed mole windmills live up to their advertised claims.

In recent years battery powered electric vibrator devices have appeared on the market and are advertised to resolve mole and/or pocket gopher problems. Some incorporate and promote sound or magnetic fields along with the vibration to assist in convincing gardeners that they have truly entered the technological age of pest control. Until such devices are proven effective, buyer beware!

#### FLOODING

Flooding a burrow system to drown or force the mole above ground, where it can be dispatched, is often tried. This approach has the greatest chance of succeeding if the property is being invaded by moles for the first time. Flooding success is greatest if a couple of five gallon plastic buckets are filled with water so that the burrow system can be flooded with a copious amount of water. The amount of water that can be delivered from a bucket will greatly exceed that which will come from a garden hose and has a greater chance of overwhelming the mole's tunnel system. Where moles are already well established, their systems are extensive. In this case, flooding them out with a hose rarely produces the desired result. Where water conservation is critical, this method of mole control is very wasteful of that resource, particularly in view of its lack of effect.

#### EXCLUSION

Some gardeners have resorted to planting bulbs which are sensitive to mole disruption or heaving in wire mesh baskets, such as those used to prevent pocket gopher damage. The bottom of raised flower or vegetable beds can be lined with 1/4 or 1/2 inch wire mesh to exclude both moles and pocket gophers.

Underground wire mesh barriers have also been explored. A two foot deep, six inch wide trench is dug, in which is placed 36 inch wide hardware cloth with a 1/4 or 1/2 inch mesh. Before placing the hardware cloth perpendicularly in the trench, the bottom six inches are bent outward at a 90° angle. Six inches will also be left protruding above ground. Rarely can this effort be justified; it is expensive and, although it may have a temporary effect, it is not a lasting solution since moles are very capable of digging deeper than 24 inches. Such

a below ground barrier will only slow their movements for a time and sooner or later the barrier will be breached.

#### PREDATORS

Avian predators, such as red-tailed hawks and barn owls, occasionally take moles, as do some mammalian predators such as fox, coyotes, and badgers; however, such predation, has little if any negative effect on mole populations. Their nearly exclusive subterranean habits provide moles with an environment relatively safe from predators. Domestic dogs and cats that are good hunters sometimes catch moles in home gardens. Every mole taken by your pet means one less you may have to trap, but you cannot depend on dogs or cats by themselves to keep your garden free of moles.

#### ACKNOWLEDGMENT

I wish to thank Ron Munro for permitting me to use some of his drawings to illustrate early mole trap developments.

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# DEALING WITH WILD PIG DEPREDATION IN CALIFORNIA: THE STRATEGIC PLAN

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## INTRODUCTION

The *Wild Pig Management Plan* is required by Fish and Game Code Section 4651. It is intended to be a strategic plan for dealing with wild pigs for the five-year period 1995-2000. The plan is a dynamic document that will be reviewed and updated at least every five years.

As prescribed by law, the plan contains information related to the status and trend of wild pig populations, and describes management units established by the Department to address regional needs and opportunities. Those needs include alleviating damage to property, protecting sensitive natural resources, and providing recreational hunting where feasible. Opportunities include using the demand for recreational hunting of wild pigs as a practical and cost-effective means of controlling wild pigs and their impact on property and natural resources. In addition, there are opportunities for cooperation between public agencies, conservation organizations, and private landowners that use incentives to manage wild pigs in conjunction with primary land use objectives.

The plan invites participation from the public and incorporates the results of surveys and applied research to achieve stated objectives. The plan has seven objectives as follows:

- 1) Study the distribution and density of wild pigs in California.
- 2) Reduce wild pig depredation on private land.
- 3) Increase hunting opportunities.
- 4) Determine the impact of wild pigs on native communities and agricultural areas.
- 5) Provide public information.
- 6) Monitor disease, both endemic and exotic, in the wild pig population.
- 7) Investigate the economic impact of wild pigs.

This paper will only concentrate on that aspect of the plan that deals with reducing wild pig depredation on private land.

## BACKGROUND AND HISTORICAL PERSPECTIVE

Pigs (*Sus scrofa*) are not native to North America. Their history in California dates back to the mid-1700s, when they were introduced by European settlers as livestock. Historical journals indicate that domesticated pigs were allowed to forage in oak woodland areas to take advantage of acorn crops. As a result of this practice, some pigs escaped, and this created wild, free-ranging feral populations. Additional pigs escaped to the wild as California was explored and developed through the 1800s and early 1900s. In the early 1920s, European wild boars were imported into Monterey County by a landowner in Carmel Valley under a domesticated game breeder's permit. Some animals escaped and dispersed into central coastal areas where they bred with feral domestic pigs.

Wild pigs occurred in relatively low numbers in 10 to 15 counties until the mid-1960s. Since then, wild pigs have increased in numbers and expanded their range, primarily in coastal counties from Humboldt to Santa Barbara. Recent surveys indicate that wild pigs occur in at least 45 counties (see Figure 1).

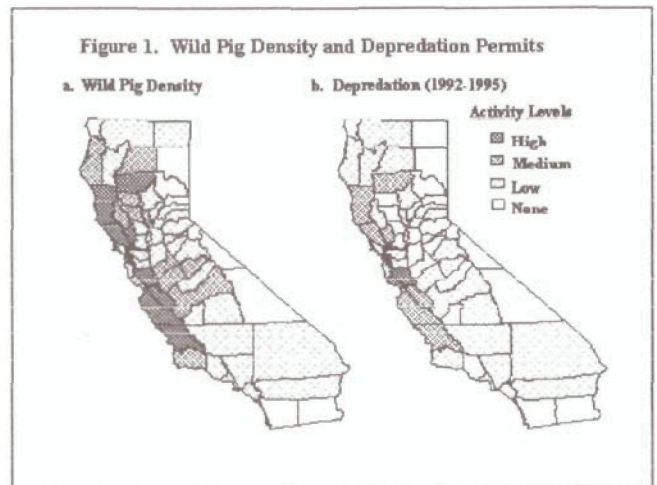


Figure 1. Wild pig density and depredation permits.

Wild pigs have expanded their range by dispersing when rainfall patterns provide good forage conditions. In addition, considerable evidence suggests that humans illegally captured wild pigs, transported them to previously unoccupied areas, and released them primarily for hunting purposes. One result is the presence of some European wild boar characteristics in virtually all wild pigs in the state.

In 1957, wild pigs were classified as game mammals by the Legislature. The intent was, in part, to recognize the valued status of the European wild boar for hunting purposes. However, the fact that: 1) pigs are not native to California; 2) they are very productive; 3) they can cause serious damage to property; and 4) they disrupt native plant and animal communities, distinguishes them from other game mammals. In addition, the history of owners allowing pigs to range freely, and the practical problems in determining the legal status of pigs captured on private lands, complicate enforcement efforts.

In 1992, the FGC §4650 through §4657 was amended to require hunters to possess wild pig license tags to hunt wild pigs. When a wild pig is taken, hunters are required to place a portion of the tag on the wild pig carcass and complete and return the report end portion of the tag to the Department. This law allows the Department to



obtain wild pig harvest information and provides funding to manage wild pigs.

The dual role of the wild pig as an exotic species and a game mammal presents a challenge to the Department. The plan provides methods to take advantage of the demand for recreational hunting to minimize conflicts associated with wild pigs damaging property and disrupting native plant and animal communities where feasible. It also recognizes the need to provide practical means of controlling wild pigs where property and natural resources are affected, including alternatives where recreational hunting is not feasible.

## REDUCING WILD PIG DEPREDATION ON PRIVATE LAND

### Background

Before 1957, wild pigs could be killed by any means and in any number. In 1957, the legislature designated the wild pig as a game mammal.

As with other game mammals, provisions were made to provide relief to landholders experiencing damage from wild pigs by means of a depredation permit system. Figure 2 illustrates the types and incidence of different types of depredation damage as noted by depredation permit requests from 1992 through 1995.

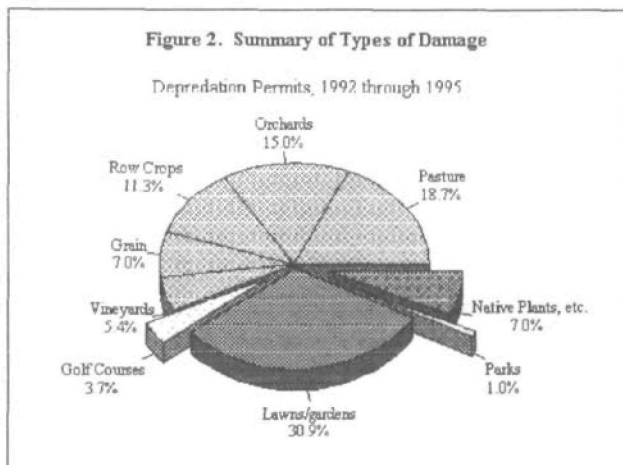


Figure 2. Summary of types of damage.

During the six-year period from 1985 through 1990, the Department issued an average of 68 permits per year to kill an average annual removal of 474 wild pigs that were causing damage, pursuant to FGC §4181 (see Table 1). Though the data are incomplete, it is estimated that an average of about 15 depredating wild pigs per year were killed during that period. This low reported take probably reflects a poor return rate of successful depredation tags.

During the three-year period from 1991 through 1995, the Department issued an average of about 112 permits per year to kill an average of over 515 wild pigs that were causing damage. Though the data are incomplete due to missing permit copies and tags, returns suggest that

an average of at least 127 depredating wild pigs per year were actually killed during that period (see Table 1).

The reported removal of approximately 127 reported wild pigs per year from an estimated annual statewide harvest of 30,000 wild pigs represents approximately 0.4%. This percentage is probably a low estimate, reflecting a low depredation reporting rate. However, these figures do suggest that hunting is currently the major mechanism that is controlling the wild pig population in California.

Figure 1 shows the counties where depredation permits have been requested during 1992-1995 and compares the relative number of requests. Figure 3 demonstrates the counties which have requested the most depredation permits for the period 1992-1995.

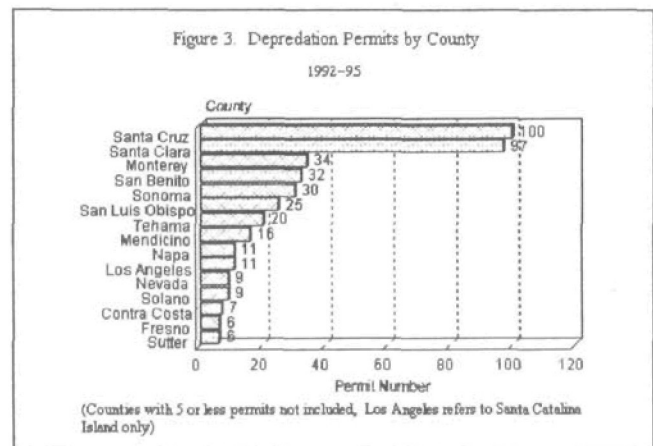


Figure 3. Depredation permits by county, 1992-1995.

### Proposed Programs

**Proposal 1. Review and amend laws, regulations, and Department procedures to facilitate depredation control.** When property is, or is in danger of, being damaged or destroyed, depredation permits to kill certain mammals, including wild pigs, shall be issued by the Department (FGC, §4181). Section 4181.1 allows a wild pig caught in the act of inflicting injury, molesting or killing livestock to be taken immediately by the owner if the taking is reported no later than the next working day. The wild pig carcass is to be made available to the Department, or there is provision for the landholder to have alternate means to dispose of the carcass.

California Code of Regulations (CCR), Title 14, Section 401, subsection (f) allows for alternate disposal methods for wild pig carcasses. Subsection (p) allows hunters to assist landholders with the removal of depredating wild pigs.

There is some concern that current laws and regulations that apply to depredation control do not allow all landholders to efficiently control depredating wild pigs. The definition of wild pig damage and means for carcass disposal are two major areas of controversy. The wanton waste law (FGC, Section 4304) includes the

Table 1. Average number of permits, average authorized take, and average actual take per year.

Region	1985-1990			1991-1995		
	Permits	Auth. Take	Actual Take	Permits	Auth. Take	Actual Take
No. California	3.3	16.2	0.2	6.8	19.0+ *	1.8
No. Sierra	2.8	14.7+	1.0	6.8	22.8+	3.0
Central Coast	55.0	412.8+	13.8	91.0	422.2+	116.8
So. Sierra	1.7	8.7	0.2	3.0	12.6	1.2
So. California	5.0	21.7+	0.2	4.8	38.4+	4.2
State Total	67.8	474.1+	15.4	112.4	515.0+	127.0

\*On some permits the actual number allowed was unspecified, therefore a + after a number indicates a minimum estimate.

provision that "... no person shall at any time leave through carelessness or neglect any game mammal which is in his possession, or any portion of the flesh thereof usually eaten by humans, to go needlessly to waste." Many members of the public comment that the Department's depredation process is cumbersome and not responsive enough to the needs of landholders experiencing wild pig problems.

The Department continually reviews and amends laws and regulations related to wild pig management. For the 1994-95 hunting season, the regulations were amended to allow more wild pigs to be harvested by hunters. In the seven counties with the highest densities of wild pigs, the bag and possession limit was raised to two per day, four in possession. In the balance of the state, the possession limit was raised to two. This change was initiated as a result of the Commission's new wild pig policy where one of the aims is to use hunting to keep wild pig populations at levels that minimize depredation problems.

The detailed proposals to amend existing regulations and Departmental procedures pertaining to wild pig depredation are being prepared. The preparation of these proposals are a high priority of the wild pig management plan. Items being considered include:

- 1) providing additional, more practical options for carcass disposal. The main concern is that carcass disposal requirements do not interfere with effective wild pig control. Particular areas of discussion will include the possibility of:
  - a) leaving carcasses on site without concern for wanton waste when warranted; and
  - b) allowing landholders to use wild pig carcasses of depredating wild pigs;
- 2) reviewing Department procedures to ensure that there are clear and objective criteria for issuing depredation permits;
- 3) exploring the concept that the mere presence of wild pigs constitutes a threat of wild pig damage;
- 4) examining the possibility of arranging MOU's with appropriate county agencies for "Wild Pig Control Zones" in areas where depredation control procedures that use hunting or depredation permits are found to be ineffective; and

- 5) taking steps to ensure all Department employees consistently interpret and implement depredation permit procedures and regulations.

In situations where the current regulations or procedures are found to be inadequate, alternatives will be proposed to the Fish and Game Commission for consideration.

*Proposal 2. Depredation Hunting.* Wild pigs should probably be viewed as a permanent part of the California landscape. Total eradication is not a realistic goal, and wild pig control will be a continuing annual activity. In many cases, the least expensive and most effective control method to annually reduce wild pig numbers to an acceptable level is provided by hunters at no cost to landholders. This is not always the case, and may not be the preferred solution for wild pig depredation problems in all areas.

Many landholders currently use hunters to provide wild pig control. Commonly, this is accomplished by using family friends who hunt, hunters who request hunting access, or by allowing hunting for a fee. With an estimated harvest of at least 30,000 wild pigs annually, it is suspected that hunting currently provides an adequate level of control on many properties throughout the state.

The Department has a large database of hunters that can assist private property owners experiencing wild pig problems. Private landholders may call the Department and receive a randomly drawn list of licensed hunters who they would contact. This program is intended to be a tightly-controlled program, using responsible hunters, as follows:

- 1) the landholder interviews and selects hunters;
- 2) the number of hunters is determined by the property owner;
- 3) the property owner has the ability to limit any aspect of the hunting. Such restrictions could include limiting the method of take (i.e., shotguns or archery only), restricting daily hunter numbers, setting hunting times (i.e., mornings only), choosing to allow the use of dogs, requiring walk-in only, or restricting vehicle use to roads only; and
- 4) the landholder may deny access at any time to

any hunter who does not behave responsibly or does not follow the conditions established by the landholder.

With a program like this, landholders would likely use a small group of hunters that they know and trust. They would use the same hunters year after year to keep wild pig numbers at a tolerable level.

Legal liability of using hunting is often stated to be a concern of landholders. Section 846 of the Civil Code expressly relieves landholders of any liability for a recreational purpose (including hunting) on their property if a hunter requests permission to hunt on that land and the permission is given. This section does not limit the liability if there is a malicious failure on the part of the landholder to warn against a dangerous condition, if the hunter pays an access fee, or if the landholder expressly invites the hunter onto the premises.

*Proposal 3. Use of multi-property or area hunting to alleviate depredation.* In many locations, especially where high value crops are grown on relatively small acreage, two general situations frequently complicate efforts to achieve effective control. The wild pigs usually do not live on the property, but only enter now and then to cause damage, and there is often a high enough density of residences to prevent the legal use of firearms for control.

Smaller areas with more intensive agriculture are often surrounded by larger, less intensively managed properties. Small property owners can often experience damage from wild pigs that either: 1) move from small property to small property, causing damage everywhere they go; or 2) live on surrounding large properties where they generally are not a serious problem. Other than with the use of exclusion fencing, these situations make effective control particularly difficult. In the former case, even when each individual owner attempts control, small property size and easy movement of wild pigs across boundaries make most methods of control impractical or illegal; and because food in the form of crops is readily available, trapping is usually unproductive. In the latter case, the same difficulties apply with the added complication that the larger properties often do not perceive the need to undertake any control. For safety reasons, it is illegal to discharge a firearm within 150 yards of any occupied dwelling or any building or barn used in connection with such a dwelling.

If wild pigs learn to come onto a property and feed only at night, control can be even more difficult. Control using hunting is illegal at night, while control under depredation permits only allows for control to be undertaken on the property where the damage occurs.

The basic problem is the situation where wild pigs are doing damage by feeding on one property, but generally living on another property or properties. In this situation, one solution would be to get all the landholders in an area to agree to give, to a small group of carefully chosen hunters, written permission for access to each property. When damage occurs, this would allow hunters to put immediate pressure on the wild pigs regardless of where they went because hunters could follow them across property boundaries. Because it is a hunting situation, it would reduce: 1) the need to wait for significant damage

to occur, as for depredation permits; 2) the need to obtain depredation permits and the unavoidable loss of time this entails; and 3) the difficulties involved with carcass disposal. With this method, there would most likely be very little wild pig damage because statistics show that where hunting pressure is continual, there are usually very few wild pigs.

The steps proposed to initiate the program are as follows:

- 1) The Department and the County Agriculture Commissioners would meet with local landholders to explain the proposed program and to obtain agreement from a number of adjacent landholders to allow hunter access.
- 2) The current Department list of wild pig hunters would be used to provide property owners with a list of hunters who meet their specific requirements.
- 3) The property owners, as a group, would interview and select hunters, or hunter parties, that they felt met their needs and were responsible.
- 4) Hunters would be oriented to discuss safety, special landholder conditions, hunting area boundaries, any special "off limits" areas within the hunting area, and the need for the hunters to be considerate and responsible.

The Department needs to clearly convey to property owners that they:

- 1) interview and select hunters;
- 2) decide on the number of hunters given permission, though the Department might give advice if this is desired;
- 3) limit hunting times, hunting days, party sizes, vehicle use, or methods of take (i.e., whether dogs may be used, or requiring that only shotguns or bows and arrows be allowed); and
- 4) have the right to cancel any hunter's permission if they decide the hunter is not responsible or does not follow the conditions laid down by them.

With a program like this, a group of landholders would end up with a small group of hunters that they knew and trusted. These same hunters could either be called on to hunt regularly, and significantly reduce property damage.

## CONCLUSION

A number of points need to be stressed when considering damage caused by wild pigs. First, wild pig depredation is a long term problem. The wild pig is intelligent, mobile, and has an exceptionally high breeding potential for a large mammal. This makes control difficult and eradication unlikely. Second, the Department places a high priority on minimizing depredation on private land. Third, the solutions presented here are not the only answers, but they are the ones that will be closely investigated during the next five years. Finally, landholders, agricultural agencies, and the Department need to continue to work together to find the best solutions to wild pig depredation problems in California.

# FEDERAL AND STATE FISH AND WILDLIFE REGULATIONS AND OTHER PERTINENT CALIFORNIA LAWS

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**ABSTRACT:** Working knowledge of Federal and State Fish and Wildlife regulations and other laws are critical for today's commercial applicator in the vertebrate pest control business. The everchanging focus on environmental protection, endangered species considerations, occupational health and safety, and animal rights have put vertebrate pest control operators in the precarious position of correctly interpreting the steady stream of laws and regulations passed by government. The consequences of failing to stay abreast of these changing regulations and correctly interpreting them can lead to very costly fines and possible imprisonment. Maintaining close contact with the many agencies that regulate the pest control industry and their enforcement personnel is essential to navigating and promoting a successful, long-term business in today's hostile, anti-business environment.

**KEY WORDS:** vertebrate pest, animal damage control, control methods

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## INTRODUCTION

The enactment, interpretation and enforcement of government regulations pertaining to all facets of business activity continue to grow and change at a prolific rate. Observed from the business person's perspective, federal laws, state regulations and local ordinances create a maze of obstacles that require careful negotiation, often with the potential for ruinous consequences.

Today's business decision makers are increasingly burdened with environmental and workplace regulatory compliance laws, none of which can be ignored. Large corporations retain full time legal consultants whose prime functions are to interpret regulations and provide advice to decision makers on how best to negotiate regulation pitfalls.

A large percentage of businesses, however, fall into the small business category with fewer than 50 employees and are just as responsible for interpreting and implementing laws and regulations, most without the help of a full-time staff devoted to this express purpose. Many small business operators, therefore, unknowingly work in violation of one or more of the thousands of laws that regulate business activity.

If you don't think this is the case, look at the quickly growing "regulation compliance" industry that provides updated federal and state mandated labor posters, "employee right to know" kits and other information for government mandated workplace programs.

The effect of broad based business regulations is only compounded by industry specific regulation. The pest control industry, in general, is a perfect example. This industry is made up of a diverse group of businesses, researchers and regulators who oversee the development, production and application of chemicals and devices targeted toward a wide range of pests every year.

No matter which branch of pest control you are in, the layers of regulation are thick. The manufacturing branch faces very stiff opposition from federal and state Environmental Protection Agencies (EPA) to register new or existing products. Researchers testing the toxicity and efficacy of chemicals for pest control are losing the use of live test animals due to misguided regulations resulting

from nonscientific-based public opposition. Pest control operators and applicators are subject to more stringent regulations requiring careful evaluation of operational business procedures and sale of products to avoid potential fines and possible imprisonment.

The vertebrate pest and animal damage control branch incorporate even more regulation. This branch of pest control operates in areas that are regulated by the United States Fish and Wildlife Service (USFWS), United States Department of Agriculture (USDA-APHIS/ADC), United States Forest Service (USFS), Bureau of Land Management (BLM), United States Army Corps of Engineers (USACE), State Departments of Fish and Wildlife, State Departments of Agriculture and the Humane Society.

The regulations governing vertebrate pest control operations are numerous, complex and almost overwhelming. Due to the number of government agencies involved in regulating the pest control industry, each agency must be contacted to request information and regulations. Following is a basic, "must-have" reference list of sources necessary for any vertebrate pest control business:

1. *California Employer's Guide. A Handbook of Employment Laws and Regulations*, contact Summers Press, Inc., (800) 743-6491.
2. *California Animal Laws Handbook*, contact State Humane Association of California, (408) 647-8897.
3. *Vertebrate Pest Control Handbook*, contact California Department of Food and Agriculture, (916) 654-0768.
4. *Prevention and Control of Wildlife Damage*, contact University of Nebraska Cooperative Extension, (402) 472-2188.

A useful way to approach the subject of pertinent laws is to discuss site specific jobs where the preeminent regulations will determine your mode of operation.

The market share of each branch of pest control directly drives the amount of funding and effort that is put into research, product development and training.

The market share in the vertebrate pest control industry is small in comparison to that of the other branches of the pest control industry. In turn, the capital outlay required for vertebrate pest research, product development, label registration and end user products are high compared to the market profit potential. In a business climate where market force economics and government regulations frequently collide, it is easy to see the circumstances that will dictate corporate direction. Without a doubt, the direction for the best profit with least amount of regulation and overhead will be pursued. Unlike the other branches of pest control where manufacturers are developing competing types of control products for individual pests, the vertebrate pest control industry is suffering from a lack of competitive development in broad range of products.

Vertebrate pest control operators in California are feeling the effects of this problem directly. For example, the manufacturer of Avitrol has not renewed their label registration in the state of California because CalEPA does not recognize FedEPA reregistering data. The manufacturer looking at the bottom line will immediately see that spending more money on concurrent efficacy data to satisfy a hostile government agency is not worth the profit potential. In a market niche where it is tough to make a decent profit to keep research going on current products, let alone new products, the choice to bypass the California market is easy to see. The continuing loss of acute toxicants for vertebrate pest control is a trend that may not stay in California.

In this disturbing age of overblown environmental activism, too many key legislators are caving in to non-scientific rhetoric and passing very dangerous legislation which ties the hands of researchers and the pest control industry to maintain a healthy living environment for us all.

## BUSINESS PRACTICES

The safest approach for working in a heavily regulated industry with a duplicity of government overseers is to stay focused on business and marketing practices so that you can also stay focused on the regulations that govern your field of operations.

Survival of a business specializing in vertebrate pest control requires that the operator become highly focused in terms of species, application and operational techniques, relative to market niche and market share. A focused business approach is one way to stay on top and in tune with the regulations and maintain personal contact with key regulators.

A focused approach also creates the necessity that a company take time to develop specialized operating skills and application tools for capturing market niches with the profit potential required to support the business. Focusing mandates a high priority for creative time toward developing field applications.

The downside of a highly focused approach toward conducting business is that the company must be willing to sacrifice sales outside the focus area. Focusing always requires sacrifice (loss of work to competitors). Over the long haul, the focused approach pays off for any business when combined with an equally focused marketing strategy built from sound advertising tactics.

Obviously, a focused approach requires patience, tenacity, faith, and a willingness to expand skill levels. Slow, steady growth stimulates a healthy, long-term, stable base of operation from which a company will preempt weak competitors and become a dominant player in the marketplace. History points out, however, that the financially successful company tends to branch out, lose focus, and eventually weaken its grip on the substantive markets, products or service that brought initial success.

The emphasis on business practices in relation to laws and regulations force a company to focus its energy toward improving business standards and discovering new market niches.

## FIELD APPLICATION

The following examples will illustrate some of the interaction that is required to conduct vertebrate pest control operations in the State of California.

Fresno County, located in the San Joaquin Valley of Central California, has one of the highest concentrations of endangered species of any county in the U.S. It is also one of the most intensely farmed counties in the U.S.; consequently, it is monitored closely by several government agencies. Knowledge of the written regulations and personal contact with agents that interpret and enforce the regulations is very important.

In some instances, a gopher control job using the fumigant aluminum phosphide (Fumitoxin) becomes complex because of the overlapping range of multiple endangered species. The San Joaquin Kit Fox (*Vulpes macrotis*) and the Blunt Nosed Leopard Lizard (*Gambelia silus*) have overlapping ranges. In essence, you should know if either of these species is on or within one mile of your treatment site. Regardless of what the special agents tell you, they are not responsible if your Fumitoxin application violates any of the regulations.

The use of Fumitoxin for gopher control is a good example for discussion. The label states, "Please consult Local, State, and Federal Game Authorities to ensure that endangered species do not inhabit the area proposed for treatment." "Use of this product in the above areas is prohibited without first contacting and obtaining permission from the Endangered Species Specialist in the regional office of the U.S. Fish and Wildlife Service (USFWS) nearest you."

First, the USFWS Endangered Species Specialist in Sacramento is contacted and notified that Fumitoxin is being considered for gopher control in an almond orchard. The Endangered Species Specialist will request further information which will include a copy of the label, site map, area map, list of applicators, resumes of the applicators, training procedures for the applicators, and explicit details of how applicators will determine whether a burrow is a gopher burrow or that of a kit fox or blunt-nosed leopard lizard.

After this information is submitted, your application to use Fumitoxin is considered by a USFWS committee. If you are approved, then you are required to notify local USFWS agents, California Department of Fish and Game, FedEPA, and CalEPA if any unexpected wildlife mortality results from your use of Fumitoxin. They will determine if there are any known burrow sites of endangered species within one mile of the treatment area.

If there are known burrow sites within one mile of the proposed treatment area, you may not use Fumitoxin at that site. If the California Department of Fish and Game (CDFG) approves the use of the Fumitoxin, you will then contact the County Agricultural Commissioner's office to ensure that you are registered in the county to apply restricted use materials and, specifically, that you have a restricted use materials permit with aluminum phosphide plainly listed.

Then you must obtain a written recommendation from a Pest Control Advisor (PCA) and then submit a Notice of Intent (NOI) to the county more than 24 hours before treatment time.

At the end of the month you are required to submit a Monthly Summary Pesticide Use Report to the county informing them of how many applications and the amount of Fumitoxin that was applied during the month in their county.

Next, show up at the job site on time, on the correct day, with a clean truck and all the safety gear as required by the label. Above all, do not deviate from any of the label restrictions.

If one or more of the regulatory agents wants you to do something that is more restrictive than what the label calls for, give it careful consideration.

Feral cats (*Felis domesticus*) are vertebrate pests that cause problems for food packing or processing plants, for example. Feral cat control can create a number of problems for the pest control operator if coordination with the local Humane Society (HS) is not done properly.

That is where the California Animal Laws Handbook will come in handy. Know ahead of time what you can and cannot do with feral cats. Then contact your local Humane Society office, explain the situation, and ask their advice on where to take the cats after they have been live trapped. Be careful and thoughtful with the manner in which you transport the cats. Avoid keeping them overnight. If you must overnight them, make sure they have food and water and are in an approved holding cage.

The pest control operator that scoffs at the California Animal Laws will have "eternal cat nightmares," if feral cats are not handled with delicate diplomacy within the limits of the law. The same holds true of any wildlife that has been live trapped and will be transported to a holding center.

Let us discuss an issue where knowledge of the California Animal Laws and the Migratory Bird Treaty Act will help you avoid stressful confrontations. A customer from an exclusive lake front housing project calls to complain about the ducks and geese eating the high dollar landscape and leaving little piles of poop everywhere, which in turn are being tracked inside by the kids and pets. If your government agencies were not so restrictive to private enterprise, you might be able to use alpha chlorolose. Since alpha chlorolose is not labeled and registered for use by private enterprise you are going to test the first rule of free market economics, which is, "Will the customer pay enough for me to risk my business to capture and remove a few waterfowl?" This job may be one of those that you sacrifice to your competitors. If you cannot resist the work, commit only to a carefully worded, signed contract.

Now the fun begins. Contact the local USFWS to see if a depredation permit can be obtained. A permit is usually very hard to obtain the first time around. The USFWS usually recommends calling USDA-APHIS/ADC to have them do the control work (they get to use alpha chlorolose).

Generally, the folks at USDA-APHIS/ADC are busy on more important calls and will not be able to help (they know what a hassle it will be). The USFWS also likes to have cultural practices employed in cases like this before agreeing to issuing a depredation permit. You call the home owners association to recommend they implement a no feeding policy and ban residents from releasing domestic waterfowl. They agree to the recommendation, but acknowledge that the problem still exists and they want all the domestic waterfowl removed. You notify the USFWS that you will not be trapping native (wild) waterfowl and outline your plan, which they will most likely approve. You then call the local CDFG office to keep them informed and to find a rescue shelter for the domestic waterfowl.

Make personal contact with the folks at the rescue shelter to make sure that your live trapping and methods of transportation and handling will meet their expectations. Make sure that their expectations are sanctioned by the Humane Society. For example, domestic or native waterfowl must not be exposed to wind or hot sun during transportation. Once you have established your transportation procedure, check it out again with someone from the local Humane Society. If not, you run the risk of discovering that a group from the HS is waiting at the destination site to inspect the condition of the ducks. This is not a pleasant experience, nor is the resulting bad press if you have mishandled the birds in any way.

Waterfowl present a challenging problem in situations where netting is used to exclude them from fish farm raceways or from toxic containment basins. The use of netting as an exclusion barrier is a viable control technique, but occasionally waterfowl or shore birds become entangled in the netting. Some birds die of exhaustion attempting to free themselves. Some species during seasonal migration are so driven by thirst and a need to rest that they die of exhaustion on top of the netting without becoming entangled. At locations where this is known to occur, a trained rescue team, that is on alert, can prevent these accidental deaths.

The Migratory Bird Treaty Act (MBTA) does not expressly prescribe methods for preventing "accidental take." The USFWS uses their interpretation of the MBTA to "encourage" businesses to modify their operations to reduce or prevent hazards to wildlife. There is provision for a \$10,000 fine per bird and imprisonment for those individuals or companies with flagrant violations. Some states also have laws or local ordinances requiring that some type of physical barrier be present to exclude waterfowl and shorebirds.

The latest development toward excluding birds from containment basins is the use of four-inch diameter, black, HDPE plastic balls, floating on the surface of the liquid. These Bird Balls™ camouflage the liquid and become an impenetrable barrier for birds that may try to

land. The Migratory Bird Treaty Act is clear about what can and cannot be done regarding species covered in the Act. Always contact the local USFWS and CDFG office to discuss any work you want to do with waterfowl. Be persistent until you find someone that is interested in what it is you want to do.

The regulations regarding the control of bats in the State of California are unclear. There are no pesticides registered for use in the control of bats. Exclusion is the professional option and works very well on bats. Schedule work before young are born or after they are able to fly. The California Department of Health Vector Control staff can help you with the timing. Harassing or entrapping the bats during the exclusion process may be interpreted as a violation of the California Animal Laws.

Cliff swallows are protected by the Migratory Bird Treaty Act and, therefore, require special consideration before any work is done that may be regarded as a violation of the Act. Removal of their mud nests, for example, is permitted as long as there are no eggs or young in the nest. Removal of completed nests late into

the nesting season is a touchy situation and should be avoided. Nest removal should be started well before the swallows return from their wintering grounds. Exclusion of prime nesting areas is the only effective method for long term control.

The local USFWS office should be contacted at the beginning of each swallow nesting season to determine the current interpretation of the Migratory Bird Treaty Act regarding the removal of swallow nests.

#### CONCLUSION

The best advice for any vertebrate pest control operator is to develop contacts in the various agencies that regulate your work. Seek their interpretation of the regulations so that you will be covered by the government regulators nearest to your work site. This approach will help you to avoid driving to a job site thinking you are covered by the Federal laws only to discover that a local mandate has a different spin on interpreting your guidelines.



# DEVELOPING WILDLIFE MANAGEMENT INTO A SUCCESSFUL BUSINESS

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**ABSTRACT:** Wildlife management has been developed into a successful business. The company was set up after the principal shareholder was made redundant after over 30 years in the wildlife management field. The company has been successful, as it diversified into a consultancy and supply company, and targeted a wide range of animal species and equipment.

**KEY WORDS:** wildlife management, vertebrate pest control, rodenticide, pest control operators, pest management, materials and equipment, toxicant formulation

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## INTRODUCTION

I have spent the last eight years developing a company known as Pest Management Services, Ltd., in New Zealand into a highly successful wildlife management business. I had spent most of my life involved in wildlife management in New Zealand—starting as a young person at 20 years of age in a business that I thought would last me until I retired. I worked my way up in seniority in the organization to become, in 1970, the Senior Field Advisor of the Agricultural Pest Destruction Council on vertebrate pest matters. This was ad hoc to a government agency and I intended to remain until I attained the age of 65 years. Little did I know, due to changes in government policy, that in 1988 it would be decided to close the so-called organization down and pay off all staff. Therefore, in late 1989 I was a 53 year old wildlife specialist without a job and all I really knew was pest control.

I will admit today that I had visions of retirement and wondered what I could do. Just prior to the closure of the organization, I had gained qualifications as a pest control technician in domestic pest control, and I knew I could survive in that area.

Thanks to the support given to me by my family and friends I decided that since I had over the years supplied information and advice to a large number of staff in the industry and had also trained a large number of them in pest control, there could be at least a part-time business for me as a wildlife consultant.

I, therefore, spent quite a large percentage of my redundancy check purchasing the organization's office equipment which included computers, a slide and photo library, and other allied equipment, such as map cabinets and a library of reference books.

Over a number of years prior to this I had also been computerizing all my research publications for reference material which makes available over 8,000 computerized papers for quick reference. In the six months prior to the closure of the Agricultural Pest Destruction Council they assisted most staff in obtaining other jobs and also backed me with letters to other organizations suggesting that I would be available as a consultant.

Once the organization closed down, I shifted all my equipment to my home and started as a consultant, while at the same time carrying out limited domestic pest control. It was obvious from the start that while there

was work as a consultant in New Zealand, it would not be a full-time occupation; and, due to the nature of consultancy work, I would only be required when there was a problem.

As a result, I spent some time evaluating what was the best direction to take in our business. It was apparent that for the business to succeed I would need to balance hours and dollars over a full year and to do this I needed to diversify. From the beginning I offered free advice over the phone to anyone who had a pest problem and advised many people on a variety of matters, which I still do to this day. Many of the senior people in pest control still contact me for advice or to bounce ideas off me—all of which is done confidentially. Some of these people have given my name as a reference if they are applying for a position, and they often seek my advice on whether they should apply for a job. Although the advice is given free, in terms of public relations it does in the long term bring in orders and therefore dollars.

Within two days of becoming redundant, I obtained a consultancy position that paid me more for a three-day week than I was being paid for my previous full-time position. During the first year I also looked at what was available in pest control toxins in New Zealand and, realizing there was a need for new toxins, I sorted registration of Pindone for rabbit control on two types of cereal pellets and investigated a number of other toxins for a variety of pests. A number of these we have since registered for use in New Zealand.

I also decided there was a need for a one-stop pest shop that could supply a wide variety of pest control tools to help control the wide variety of pests that affect New Zealand agriculture and horticulture. I started approaching a variety of companies both in New Zealand and overseas to see if I could handle their products. We started to handle spotlight equipment, traps, and bait stations for rodents and possums. In the case of possum bait stations, we worked with companies to develop bait stations that would be suitable for use in the field.

From the beginning, we also realized that much of the equipment being sold in New Zealand was supplied with very little information on how to use it correctly. We, therefore, started to supply small information pamphlets on the equipment we sold, how to use it correctly, where to place it, and how to maintain and bait traps correctly.



We also introduced a comprehensive catalog of products, and we readily send a catalog to anyone who requests it. Over the last seven years we have developed the business into a company that has a turnover in excess of six figures in U.S. dollars, and our extensive product range now spans 21 pages of A4 paper.

Consultancy work still earns the company in excess of NZ\$90,000 per year from a variety of clients, including various agencies which include local and regional government, private companies, and private individuals. We employ three people in the company and, while I still carry out a variety of consultancy work, my wife handles the accounts and the other staff member is employed as a consultant who handles advertising, orders, and assists me in consultancy work. We are also involved in assisting with the writing of training material on pest control both for agricultural and domestic pest control. Often we are asked to edit assorted training material produced by health and safety organizations and general publicity information.

To operate solely as a consultant in New Zealand with a population of only 3.5 million people could only be a part-time position, but the inclusion of a sales division combined with a company that readily looks for niche markets has meant that we have a full-time business. The ability to service a variety of pests also ensures that we do not get periods of the year where business slacks off, thus ensuring regular sales. If the problem is not possums, it can be rabbits, birds, rodents, insects or other pests—for which we can supply advice or products to control the problem. This, combined with a low operating expense through working from home, ensures that we can keep prices down, remain competitive, and still make a profit. Other companies with high overheads cannot compete with us and we can retain a high percentage of the market by having lower overheads and, therefore, lower prices.

We as a company continue to evaluate the market in pest control technology and seek other equipment that may sell readily in the marketplace. We also treat all of our customers in a way that they feel important—remembering them at Christmas by sending out presents like diaries, and continuing to produce a quarterly newsletter on pest control that is distributed at no charge to our customers and colleagues.

As a company, we believe that retaining customers is important to the extent that we always send customers a letter thanking them for their order or, even if they only request a catalog, thanking them for the interest they have shown. We also treat every customer as if they are the most important and always aim to send out their orders the day they are received.

We target our products by advertising in home garden, horticulture, pest control and agriculture magazines. In most cases, we include in our advertisements a tear out strip for requesting information. This area alone supplies us with regular orders.

I have found over the years that to succeed in this business you need to keep a reasonably high profile and, as such, I belong to a variety of organizations that relate to pest control. These include the New Zealand Pest Control Association as a Council member, president of the New Zealand Institute of Pest Destruction Officers, member of the National Pest Control Association of USA,

member of Animal Damage Control USA, and a number of other organizations—all of which keep me up to date with new technology and meeting other people in similar types of business. This Vertebrate Pest Conference is an example of this, as over the years attending this conference, meeting contacts, and gaining friends has been of great assistance to me, especially if I strike a problem I need to seek advice on. I also regularly write for magazines on pest control advice and, as stated earlier, we always give free advice. I am also prepared to speak to various groups like grape growers, adult learning clubs, bird breeding clubs, zoological gardens, and other groups interested in specific areas of pest control.

We no longer carry out commercial pest control, as the business has become too cut-throat in New Zealand. However, we do accept specialist jobs, especially control of birds like sea gulls on refuse areas and bird problems in shopping malls and similar places; or we will consider jobs that other people will not consider. Because of this, we have a public liability insurance in excess of \$1 million—this is important, as is professional liability insurance, if you are giving people advice.

When we are approached by customers requiring pest control, we recommend reputable companies or, if they wish to carry out the task themselves, we give advice and supply the material to carry out that task.

We are currently at the stage in our business where we must decide where we are heading in the future. We can stay as we are and continue to seek new products to keep up our share of the marketplace—ensuring at the same time that we can supply the latest in pest control technology to our customers—or we can take the next step and become larger. We get all of our bait made under contract at present. The next logical step is to possibly manufacture our own bait. We could also start up a pest control company and actively seek work in the pest control field.

We are in the process of exporting to Australia and we currently import products from the United States, Australia, Taiwan, China, Italy, Spain, England and other countries. We are currently the agent in New Zealand for B&G and Bell Laboratories of USA, as well as the agent for Vector, Fly City and other fly traps, and the agent for Fenn Traps England, Chemical Enterprises of Australia, and numerous other overseas agencies. We are always looking at new products and different lines that will fit into our business.

## IF YOU ARE CONSIDERING WILDLIFE MANAGEMENT AS A BUSINESS

Spend some time evaluating what area of wildlife management you are best suited for. Then, if you think you have the expertise that is saleable, you need to decide in which areas you will specialize.

### Consulting

When consulting and advising people on their problems, remember that if you cannot solve their problems, you are not likely to secure further work. Furthermore, as a consultant, do not specialize in only one species unless you are sure there is enough work over the year. Specializing in a number of pests spreads the

work over a larger period of the year. If you intend to carry out specialized research, then make sure there is enough work to keep you employed. You also need to set a realistic hourly rate that customers will pay. We have found in New Zealand that customers do not want to pay more than NZ\$50 to NZ\$60 per hour for advice.

As a consultant with a number of clients, it is important that you treat each of your clients confidentially. I find that there are some requests from clients that you cannot act upon as it may affect other clients you already work for. I was once requested to prepare a report on a situation that would have placed me in court as an expert witness against one of my regular customers. In that case, I did not accept the job. On the other hand, you may carry out a task for one customer that in the future is a good basis of a report for another customer. This is particularly so if you are preparing a report on options to, for example, control birds in a shopping center.

#### Specialized Pest Control

When carrying out specialized pest control work, you will be in direct competition with existing pest control companies. Again, you need to specialize in a variety of pests to keep you employed over the entire year. There is good money in this business if you specialize and present detailed reports and costings and act in a business like manner.

#### Handling Products

When considering handling products, you will need one or two key lines that preferably no one else has. This could be a bait or toxin that you have registered; however, that is initially expensive to do. Or, it may be a specialist bait station, trap or repellent that you can market. If you are working with another company developing a product or getting it manufactured by them, make sure you have secrecy agreements signed and take steps to ensure they cannot market your ideas. This is where it pays to have a good lawyer. If you are involved in product registration, then you need to form a close working relationship with the people in charge of registrations and with the research groups carrying out research in areas in which you are involved. Remember, however, that they have procedures they must follow and you cannot use friendships to gain an unfair advantage.

#### Starting a Business

When starting a business on your own, you need advice from a reputable lawyer and accountant to ensure that you set the company up correctly. In fact, it may

pay to take a small business course so you understand what is involved. Many small businesses collapse through lack of understanding or over expenditure of money in the early stages. Ensure from the start that you invest in a small accounting package to make your work easier when sending out accounts. Also, always be mindful of the tax that you must pay each year, and make allowances to ensure you have that money at tax time—otherwise the penalties for late payment increase your financial problems.

#### Working from Home

Unless you are a self-motivated person, do not work from home. It is easy to not do a full day's work because it is a nice day to do something else—like go fishing or golfing. Additionally, working from home can involve you in work seven days a week and you never seem to leave the office. It is important to allocate an area for an office that is quite separate from the house to ensure the division between the office and your home. I work from home, but I can leave the office, turn on the security and retire to the house.

If you do set up in business, it is advisable that you register your company name so no one else can use it. In the early stages of business we had people trying to use a name similar to ours and we had to get lawyers to stop them. It is a good idea to produce a business card with your photo on it. People will find it easier to put a name to a photo in the future, and it is even helpful when you are in a meeting with a number of other people.

Prepare letterhead and envelopes that have your company name on them—this is good advertising. We also have personalized license plates on our company cars—PESTM and NOPEST—again, good advertising.

Be prepared to advertise your company and your business and join various groups like the Chamber of Commerce, Standards Association, and other organizations that allow you to meet business people. It is surprising how much business you gain. Also be prepared to give good free advice, it repays you over time and often attracts extra business.

Developing wildlife management into a successful business can be a rewarding venture. It is hard work, but is challenging and worthwhile. I personally would never go back to working for someone else full time. Being your own boss is excellent, and you can say no if you choose to. You will make mistakes, but as long as you learn from those mistakes then there is no real problem.

If I can give anyone any further advice, please contact me at anytime.

# AN OVERVIEW OF ANIMAL DAMAGE CONTROL (ADC) ASSISTANCE TO THE VERTEBRATE PEST MANAGEMENT INDUSTRY

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**ABSTRACT:** The Animal Damage Control (ADC) program has had a long history dating back to 1885. ADC was officially established in 1931 under the United States Department of Agriculture. In 1939, the program was moved to the United States Department of Interior's Fish and Wildlife Service. In 1996, ADC was transferred back to the USDA and placed under the Animal and Plant Health Inspection Service. The mission of the Animal Damage Control program is to provide federal leadership in managing problems caused by wildlife. Current program assistance includes: a) technical assistance in wildlife management; b) conducting research and development activities related to wildlife damage control; c) providing a source for a variety of animal damage control tools; d) development and transfer of scientific and technical information on wildlife damage issues; e) helping obtain migratory bird depredation permits; f) providing training sessions on wildlife damage management issues; and g) registering and maintaining chemical products for wildlife management.

**KEY WORDS:** animal damage control, vertebrate pest management, federal animal damage control program.

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I appreciate the opportunity to provide you with an overview of the different types of assistance that we provide to the vertebrate pest management industry. The Animal Damage Control (ADC) program has a long history of involvement and service in this area. In fact, the Federal Government's involvement in wildlife damage control efforts first occurred back in 1885 when the U.S. Department of Agriculture's Branch of Economic Ornithology sent questionnaires to farmers about damage caused by birds. The very next year, the Commissioner of Agriculture stated that this division's primary responsibility would be to educate farmers about birds and mammals affecting their interests. Efforts to educate farmers included conducting studies and training sessions which demonstrated how to use different wildlife damage control techniques. This was the early beginnings of what is now the ADC program. While our program has evolved considerably over the years, and we now provide a variety of other types of services and assistance to the public, conducting research and providing training sessions still continues to be a integral part of basic services that we provide.

Examples of some of the assistance that ADC provides includes:

- Providing technical assistance to wildlife management professionals as well as the general public.
- Conducting research and developing new, innovative wildlife damage control methods.
- Providing a source for a variety of control tools used by the wildlife damage management community.
- Developing and transferring scientific and technical information on wildlife damage issues.
- Helping the public obtain migratory bird depredation permits from the U.S. Fish and Wildlife Service (FWS), where warranted.
- Providing training sessions on wildlife damage management issues to pest control operators and others on the vertebrate pest management industry.

- Registering and maintaining chemical products, many of which benefit private businesses.

I will talk in more detail about the different types of assistance a little later on, but before I get into that, I would like to give you some very brief background information on the ADC program.

ADC officially began in 1931 with the passage of the Animal Damage Control Act. This authorized ADC to control wildlife to protect agricultural resources, forestry products, and public health and safety. Further legislative authority was provided by the Rural Development, Agriculture, and Related Agencies Appropriated Act of 1988 which authorized ADC, except for urban rodent control, to conduct activities and enter into cooperative agreements to control nuisance animals and birds, and those that are reservoirs of zoonotic diseases.

Initially, ADC was placed under the Department of Agriculture where it stayed from 1931 until 1939. A government reorganization in 1939 placed the program under the Department of the Interior's Fish and Wildlife Service, where it remained until 1986. At that time, ADC was transferred back to USDA and placed under the Animal and Plant Health Inspection Service, or APHIS.

The mission of the Animal Damage Control program is to provide Federal leadership in managing problems caused by wildlife. We attempt to accomplish this with about 1,050 Federal employees, along with approximately 270 State or County cooperative employees. Our headquarter offices consist of the Deputy Administrator's office located in Washington, D.C., and the Operational Support Staff located in Riverdale, Maryland, about 12 miles away. We have two regional offices; one located in Lakewood, Colorado, a suburb of Denver; and the other one in Brentwood, Tennessee, a suburb of Nashville. States under the responsibility of the Eastern Regional Office include Minnesota down to Louisiana and everything east of there including Puerto Rico and the

Virgin Islands. States under the Western Regional Office include North Dakota down to Texas, and everything west of there including Alaska, Hawaii, and Guam. Another important part of the ADC program is the Denver Wildlife Research Center which, as you heard yesterday, is in the process of completing and relocating their entire research facilities to the foothills campus of Colorado State University in Fort Collins. Also included within ADC, located in Idaho, is the Pocatello Supply Depot (PSD) which manufactures and sell a variety of toxicants, fumigants, and other products used in wildlife damage management.

ADC assistance to the vertebrate pest control industry first began about 1930 with the establishment of the U.S. Biological Survey Bait Mixing Station in McCammon, Idaho. In 1933, this facility began operation in Pocatello, Idaho and soon after, became known as the PSD. The purpose of the PSD is to manufacture and sell specialized wildlife damage management materials that are not readily available from commercial sources. These products include things such as gas cartridge fumigants used for burrowing rodents or predator control, grain baits for the control of specific birds or rodents, and M-44 products for predator control. In fact, these three items account for 80% of the total sales at the depot. Gas cartridges and grain baits are commonly provided to distribution centers such as Agway or Caldwell Supply, which in turn, provide these products to farm stores and other agricultural outlets. Other products available from the PSD include the electronic guard (a siren and strobe frightening device to scare coyote away from sheep); a variety of animal attractants, gopher probes, and pan tension devices for foothold traps. As the manufacturing entity of ADC, the PSD plays a key role in transforming materials from research into readily available products.

Over the past decade, and particularly since the 1988 revisions of the Federal Insecticide, Rodenticide, and Fungicide Act, ADC has invested an enormous amount of money to maintain and reregister its vertebrate pesticides. Presently, ADC maintains about 35 separate pesticide registrations. Most of these products are needed in such low quantities or at such infrequent intervals that commercial sources have shown little or no interest in providing them because they could not generate a profit. Nearly all of these are considered low volume, minor use vertebrate pesticides. Although these products are considered minor-use and low volume, they are still extremely important in specific cases where damage is occurring and a registered, effective product is needed. The information gathered by Denver Wildlife Research Center and other APHIS personnel to support these registrations is also provided to other State and Federal organizations, or private-sector companies, at no cost, in an effort to help others register their products.

One way I believe that ADC also assists the vertebrate pest management industry is by referring pest control operators (PCOs), nuisance wildlife control operators, and others who deal with wildlife nuisance and damage problems to the homeowners, or farmers and ranchers needing assistance. Many of our State ADC programs maintain a listing of individuals in the private sector who are available for hire, and these people are often referred to the public upon request. This is especially true in

many of our State programs in the Eastern United States where they may only have one or two ADC employees to cover the entire State and, as a result, are often restricted to conducting primarily a technical assistance program. This relationship benefits both of us. ADC benefits because we are able to provide the public with someone to directly resolve the wildlife conflict, and I believe the PCOs and nuisance wildlife control operators receive a direct financial benefit because of our referrals.

Another important service that ADC provides to the public is helping obtain migratory bird depredation permits from the FWS where warranted. In situations where migratory birds are causing damage or creating a nuisance, and lethal control is warranted to resolve the problem or supplement ongoing nonlethal techniques, a migratory bird depredation permit is needed to take the birds. However, the FWS will not issue a depredation permit unless ADC personnel have first determined that it is necessary.

By serving in this capacity, I believe that ADC provides a valuable service allowing many migratory bird depredation conflicts to be resolved, where otherwise a permit might not have been recommended and provided.

But probably, by far, the biggest service that ADC provides to the vertebrate pest management industry is through the development and transfer of scientific and technical information. For example, ADC was a co-sponsor of the Prevention and Control of Wildlife Damage handbook which was recently revised. This handbook is a comprehensive reference of North American vertebrate species and contains control information on over 80 different birds, mammals, reptiles, and amphibians. It also contains information on pesticides, equipment, dealers, etc. In addition to being a co-sponsor of the handbook, ADC personnel helped co-edit, fund, and write a number of the chapters in the handbook. As evidenced by this meeting, ADC is also extremely active presenting papers at conferences such as the Vertebrate Pest Conference, Great Plains Wildlife Damage Control Conference, Eastern Wildlife Damage Management Conference, Wildlife Society Meetings, and others. At this conference, ADC employees are giving 15 technical papers, and other ADC employees are serving as chairpersons for many of the sessions.

ADC has also developed a number of fact sheets and informational brochures over the past five years on a variety of subjects dealing with wildlife damage control issues which are made available to the vertebrate pest management industry of other members of the public upon request. This information covers a broad range of topics such as how to deal with urban wildlife problems, fish-eating birds at aquaculture facilities, livestock predation, or wildlife problems at airports. We have an ADC exhibit in the lobby this week that contains most of the informational material that we have produced.

Dick Curnow did a good job yesterday morning giving an overview of the Denver Wildlife Research Center. I would just like to emphasize that DWRC is the only research facility in the world devoted exclusively to the study of wildlife damage control and has been the primary source of effective, nonlethal control methods during the past few years. Examples of some of the products that have been developed or tested through

DWRC recently include the electronic guard, methyl anthranilate, improved break-away snares, and approval from the Food and Drug Administration (FDA) to use the tranquilizers alpha-chloralose and propiopromazine. As mentioned yesterday, alpha-chloralose is a chemical immobilizing agent that is now being used by ADC, and in some situations, to humanely address urban waterfowl problems. Propiopromazine is also a tranquilizer which was recently approved by FDA for ADC use. This has the greatest potential for use as a tranquilizer tab for foothold traps, but it can be used on almost any type of capture device. The purpose is to reduce or prevent injury to the captured animal. Present research efforts directed towards immunocontraception, habitat management, and new repellents may also soon show promise as new methods available to the vertebrate pest management industry. DWRC also maintains a scientific library of numerous publications and research papers on a number of vertebrate pest issues which is made available to others upon request. Tomorrow afternoon, Diana Dwyer, with DWRC, will present a paper on library research through the internet. I would encourage all of you to attend that presentation, if possible, to get a better understanding of the different types of assistance the library has available, and the many functions that it provides.

Another way that ADC helps transfer technical and scientific information is through training sessions. Last year, ADC personnel conducted approximately 950 training or instructional sessions demonstrating the proper techniques for various wildlife damage control methods. Groups included in these training sessions were County Extension Agents, farmers, ranchers, homeowners, PCOs, nuisance wildlife control operators, and others.

ADC personnel in Indiana also help co-sponsor and host the Purdue Pest Control Conference in Indiana on an annual basis. This is a week-long conference involving pest control operators from across the United States. The purpose of the conference is to promote new ideas and technologies and provide a forum for exchange of information. ADC personnel in that State also help train PCOs and other individuals who are interested in becoming certified applicators in various vertebrate categories. They do this on behalf of the State Chemistry Office in Indiana, which is the State regulatory authority. After becoming a certified applicator, many States require recertification every two or three years, and Indiana ADC

personnel also offer recertification training so certified applicators can maintain their licenses.

In addition, some ADC biologists teach wildlife damage management courses at different colleges or universities including the University of Georgia, Mississippi State University, and the University of Vermont. Since 1981, DWRC has hosted students from the Managing Wildlife and Human Conflicts course in the Department of Fishery and Wildlife Biology at Colorado State University. This course was originally under the title "Vertebrate Pest Management." ADC also helps provide financial support for the wildlife damage management curriculum at Utah State University.

As you might have realized, a lot of the assistance that we provide, and some of the newer methods that have been developed, have been in cooperation with others in the vertebrate pest management industry. A good example of this is the new break-away snares which were recently made available through the DWRC. The initial snare was obtained from a private individual, and DWRC tested and further improved the break-away concept on the snare. Methyl anthranilate, the chemical repellent now available under the brand name "ReJeX-It" is labeled for use in standing water, turf areas, and golf courses as a repellent for geese and other birds. This product was the direct result of a cooperative effort between DWRC and PMC Specialties Group, a private sector company.

These are just a few of the examples of the types of assistance that ADC provides to the vertebrate pest management industry, but I hope that it has given you a broader overview of the many different services that we make available. ADC has been involved in wildlife damage control for a long time but, in my opinion, we have made the most progress developing new methods during the past five years. I think one of the main reasons for this success is because of a cooperative effort between ADC and the vertebrate pest management industry. I think such cooperation is not only important, but critical to the entire vertebrate pest management field. I see such cooperation continuing well into the future as both the range and extent of wildlife damage problems continue to grow.

Again, I appreciate the opportunity to be here. Please stop by our exhibit if you have not already, and pick up some of the information that we make available. Thank you.

# THE PERSISTENCE AND SECONDARY POISONING RISKS OF SODIUM MONOFLUOROACETATE (1080), BRODIFACOU, AND CHOLECALCIFEROL IN POSSUMS

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**ABSTRACT:** To determine the risk of secondary poisoning for animals preying on sub-lethally poisoned brushtail possums, captive possums were treated with near-lethal doses of sodium monofluoroacetate (1080) or brodifacoum, and toxicant concentrations in blood and tissue were monitored over time. Sodium monofluoroacetate was rapidly eliminated from the blood (within three days). Brodifacoum was retained in the liver and, to a lesser extent, the muscle of possums for eight months after dosing. To determine the potential risk for animals scavenging on the carcasses of possums poisoned with cholecalciferol, cats were fed poisoned carcasses for six days. No changes in behavior, appetite, or body weight were observed. Serum calcium concentrations increased slightly, but remained within the normal range for cats.

**KEY WORDS:** vertebrate pest control, secondary poisoning, sodium monofluoroacetate, brodifacoum, cholecalciferol

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## INTRODUCTION

Sodium monofluoroacetate (1080) has been used for vertebrate pest control in New Zealand since 1954. It is currently used most frequently in aerially sown baits and in baits in bait stations for the control of the Australian brushtail possum (*Trichosurus vulpecula*) (Livingstone 1994). The use of 1080 has been largely restricted to authorized wildlife management staff within the Department of Conservation and licensed operators within regional councils. In recent years, community groups, farmers and hunters have become more involved in possum control, and alternatives to 1080 that can be used without special permits have been sought. This need has led to the registration of brodifacoum (Talon®) in 1991 and cholecalciferol (CAMPAIGN®) in 1995, and these two poisons are now playing an increasingly significant role in possum control.

An important consideration when using any vertebrate pesticide is the risk of secondary poisoning. Secondary poisoning can be in two forms: from non-target animals scavenging poisoned possum carcasses, or from animals preying on live possums that have the pesticide in their tissues but have not received a lethal dose. Humans also occasionally harvest possums for food.

Dogs are particularly susceptible to secondary poisoning with 1080 (Eason et al. 1994a). Analyses of 1080 concentrations in rabbit carcasses have shown that there is a substantial decrease in 1080 in muscle, liver, and kidney during the first three weeks after death (Gooneratne et al. 1994). However, recent analyses of residue in possum carcasses after a control operation have shown that 1080 can persist in tissues in amounts that would be lethal to dogs for at least two to three months (Meinken, pers. comm.), even though the carcasses had substantially decomposed over this period. As for 1080, the secondary poisoning risks from brodifacoum-contaminated carcasses are well known (Eason and Spurr

1995), and toxic amounts of brodifacoum may be retained in a carcass.

The existence of an effective antidote to brodifacoum in the form of vitamin K1 means that dogs that have eaten carcasses containing brodifacoum residues can usually be saved. Unfortunately, there are no consistently effective antidotes for 1080 poisoning.

In contrast, studies of dogs fed rats poisoned with cholecalciferol suggest that the risk of secondary poisoning with this pesticide is low (Marshall 1984). However, these data may not be directly applicable to possums, since higher concentrations of cholecalciferol are used in possum baits (0.8%) compared with rat baits (0.075%) which may lead to higher residue levels in the possum carcasses.

In this paper persistence data is reported which may be used to assess the magnitude and duration of the risks of secondary poisoning of animals preying on live possums which have been sub-lethally dosed with 1080 or brodifacoum. In addition, preliminary tissue residue results are reported in possums, and feeding study data from cats fed possums that have been poisoned with cholecalciferol.

## METHODS

### Determining the Persistence of Sub-lethal Doses of Brodifacoum and 1080

A stock solution of brodifacoum was obtained from ICI Crop Care, Richmond, New Zealand and 1080 powder from Animal Control Products, Wanganui, New Zealand. Groups of six possums (three male and three female) were orally dosed with 0.1 mg/kg (2 ml/kg of a 0.05 mg/ml solution) of either brodifacoum in propylene glycol or 1080 in distilled water. The animals were allowed free access to food and water before dosing. These doses were equivalent to a possum eating 10-20 g of Talon® cereal baits containing 20 ppm brodifacoum,

or approximately 0.5 g of cereal bait containing 1080 at 0.08%. Earlier studies have demonstrated that 100 to 200 g of Talon® bait or 5 to 10 g of 1080 bait would be sufficient to kill most possums (Eason et al. 1994a). A series of blood samples were taken from the jugular vein of each possum before and after dosing. Samples were taken at 0.5, 1, 1.5, 2, 3, 4, 8, 12, 24, 48, and 96 hr after dosing with 1080, and at 4, 8, 24, and 48 hr and 7, 14, 21, 28, and 35 days after administration of brodifacoum.

Previous studies in laboratory animals and sheep demonstrated that concentrations of 1080 in blood exceed those in tissue (Eason et al. 1994b). Thus, tissue samples were not taken for 1080 analysis, since concentrations in the blood provide a worst-case persistence profile. By contrast, experiments in rats and sheep have shown that higher concentrations of brodifacoum in tissues (particularly the liver) exceed blood concentrations (Laas et al. 1985). Hence, a further 32 possums were randomly divided into groups of four animals each (two male and two female). One group was killed before dosing and the other seven groups at 2, 7, 14, 35, 64, 126 or 256 days after dosing with brodifacoum at 0.1 mg/kg. Muscle tissue and liver samples were collected at post-mortem.

All plasma and tissues were stored at -20°C for later analysis. Brodifacoum was analyzed by high-performance chromatography with fluorescence detection using published methods of determining the compound in blood (Kelice and Murphy 1989) and animal tissues (Hunter 1983). A gas-chromatography technique with electron capture detection was used to measure the dichloroaniline derivative of 1080 (Eason et al. 1994b).

#### The Persistence of Cholecalciferol in Possums

A stock solution of cholecalciferol was obtained from AgrEvo, Pennants Hill, Sydney, Australia. Thirteen possums were randomly divided into two groups and orally dosed with 20 mg/kg (2 ml/kg of a 10 mg/ml solution) of cholecalciferol diluted in corn oil. A dose of 20 mg/kg cholecalciferol would be equivalent to a possum eating approximately 10 g of cereal bait containing cholecalciferol (0.8%) which would be a lethal or near-lethal dose for most animals. Serial blood samples were taken from three cholecalciferol-treated animals immediately before and at 3, 6, 9, 12, 17, 23, and 29 days after dosing. At 3 and 29 days after dosing, the remaining ten possums were killed and samples of heart, kidney, liver, abdominal fat, and femoral muscle tissues were collected.

In order to gain biological activity, cholecalciferol (Vitamin D<sub>3</sub>) must undergo metabolic conversion to 25-hydroxy vitamin D (25OHD), a major active metabolite (Keiver et al. 1988). Concentrations of 25OHD were measured in possums after exposure to cholecalciferol as an indication of vitamin D status. A radioimmunoassay (Amersham International Ltd, Amersham, UK) based on competition between unlabelled and tritium-labelled 25OHD for binding to the 25-hydroxy vitamin D binding protein from rickettic rat serum was used to determine 25OHD concentrations. As with the 1080 and brodifacoum experiment, all possums were allowed free access to food and water before and after dosing, and plasma and tissue samples were stored at -20°C before analysis.

#### Secondary Poisoning Feeding Studies

Twelve feral cats were exclusively fed whole cholecalciferol-poisoned possum carcasses for five days. Appetite and body weight were monitored daily, and blood samples were taken for serum calcium measurements at regular intervals.

### **RESULTS**

#### Determining the Persistence of Sub-lethal Doses of Brodifacoum and 1080

No differences were detected between the results from male and female possums, so the data were combined. Sodium monofluoroacetate was rapidly absorbed into the blood and remained at peak concentrations (i.e., >1 µg/ml) for 0.5 to 8 hr after dosing. By 24 hr after dosing, plasma concentrations had decreased to 0.025 µg/ml. Trace amounts (0.006 µg/ml) were detected at 48 hr after dosing. No 1080 could be detected in the blood 96 hr after dosing (Figure 1). By contrast, peak plasma concentrations (i.e., >1 µg/ml) of brodifacoum occurred in possums between 24 and 48 hr after dosing, and trace amounts could still be detected in the blood of some possums 21-28 days after dosing (Figure 2).

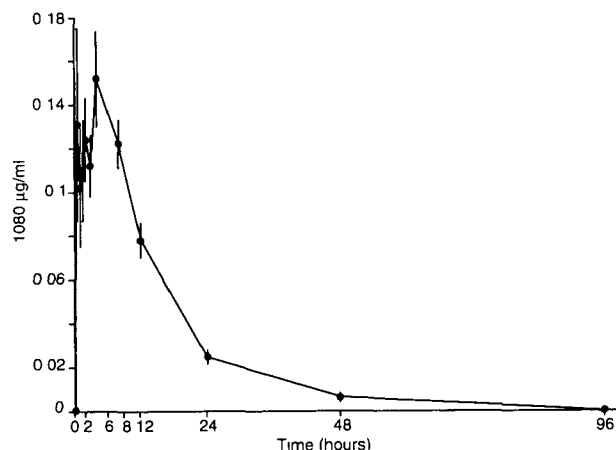


Figure 1. Concentrations of 1080 (µg/ml ± SE) in possum plasma after oral administration of 0.1 mg/kg.

Persistence of brodifacoum in the liver and muscle differed markedly from persistence in the blood. Measurable concentrations were found in the liver 254 days after dosing. Considerably lower concentrations were also found in the muscle tissue (Table 1).

#### The Persistence of Cholecalciferol in Possums

Concentrations of 25OHD in plasma increased from a mean of 39.6 ng/ml before dosing to a mean of 949 ng/ml six days after exposure, and subsequently declined to approximately 600 ng/ml by 29 days post-dosing (Figure 3).

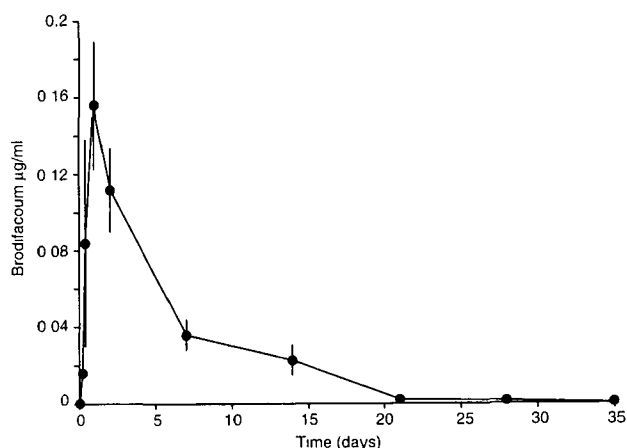


Figure 2. Concentration of brodifacoum ( $\mu\text{g/ml} \pm \text{SE}$ ) in possum plasma after oral administration of 0.1 mg/kg.

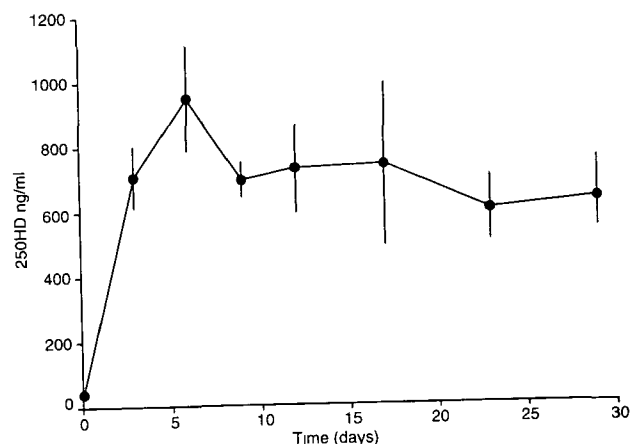


Figure 3. Concentrations ( $\mu\text{g/ml} \pm \text{SE}$ ) of 25-hydroxyvitamin D (25OHD) in possum plasma after oral administration of 20 mg/kg cholecalciferol.

Table 1. Mean brodifacoum concentrations in possum muscle, liver, and plasma after oral administration of 0.1 mg/kg to each group (n=4).

Time in days after dosing	Concentration ( $\mu\text{g/g}$ or $\mu\text{g/ml} \pm \text{SE}$ )		
	Liver	Muscle	Plasma
2	0.177 (0.011)	0.016 (0.001)	0.118 (0.021)
7	0.119 (0.009)	0.011 (0.007)	0.034 (0.009)
14	0.100 (0.032)	0.011 (0.000)	0.004 (0.003)
35	0.095 (0.023)	0.010 (0.002)	0.002 (0.002)
63	0.109 (0.024)	0.008 (0.001)	0.000 (0.00)
126	0.075 (0.029)	0.009 (0.002)	0.000 (0.00)
254	0.085 (0.009)	0.007 (0.002)	0.000 (0.00)

Concentrations of 25OHD in heart, kidney, liver, and fat ranged from 40 to 60 ng/g 3 days after dosing, and appeared to decrease in all tissues with the exception of fat during the following 4-week period (Figure 4). As with the 1080 and brodifacoum studies, sample size was not adequate to detect any sex difference so the data from both sexes were combined.

#### Secondary Poisoning Feeding Studies

Each of the 12 cats ate approximately 1 kg of possum carcasses containing residues of cholecalciferol over the five-day period. At the end of five days mean serum calcium concentrations were slightly elevated compared to pre-treatment levels, but remained close to the normal range for cats (2.0–2.7 mmol/L). Calcium concentrations

declined to baseline levels by 12 days post-dosing (Table 2). Appetite and body weight of the cats were not affected (Figure 5).

#### DISCUSSION

After oral administration of sub-lethal amounts of 1080 to possums, 1080 was rapidly absorbed and subsequently eliminated from the plasma. These results in possums are consistent with our early results in livestock (Eason et al. 1994b) and rabbits (Gooneratne et al. 1995), and studies in mice which show rapid elimination of 1080 (Sykes et al. 1987).

For livestock suspected of near or sub-lethal exposure to 1080, it has been suggested that an adequate margin of safety (for avoiding residues in food) would be achieved



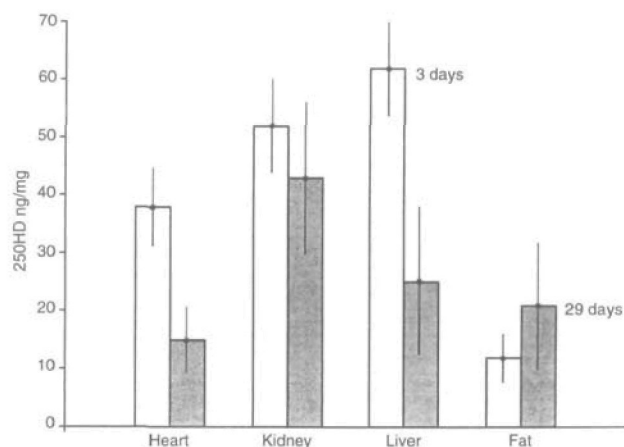


Figure 4. Concentrations ( $\mu\text{g/ml} \pm \text{SE}$ ) of 25-hydroxyvitamin D (250HD) in possum tissue 3 ( $n=7$ ) and 29 days ( $n=3$ ) after oral administration of 20 mg/kg cholecalciferol.

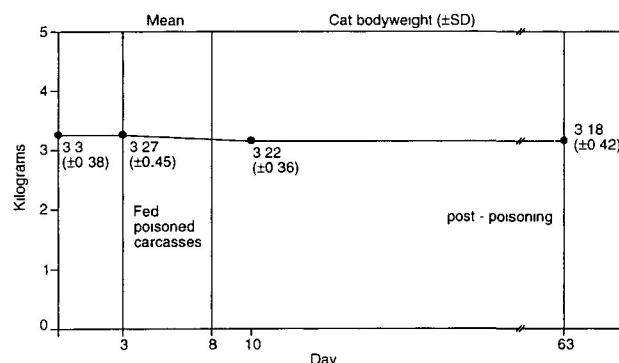


Figure 5. Mean bodyweight ( $\text{kg} \pm \text{SD}$ ) in cats before, during, and after feeding on the carcasses of cholecalciferol-poisoned possums.

Table 2. Mean serum  $\text{Ca}^{++}$  ( $\pm \text{SE}$ ) concentrations in cats.

Pre-treatment	After 5 Days	1 Week Later	7 Weeks Later
2.54 (0.06)	2.75 (0.10)	2.72 (0.07)	2.64 (0.03)

by imposing a minimum withholding period of five days. Should a death in a flock or herd be attributed to 1080, the withholding period should be doubled to ten days for the surviving stock and the livestock removed to a 1080-free pasture (Rammell 1993). The results would indicate that a similar safety margin of at least ten days after baits have been removed or decomposed would be appropriate for possum to ensure that residues are not present in meat harvested for human consumption. It is apparent that there is a contrast between the persistence in living animals which have received a sub-lethal dose of 1080 versus the persistence of 1080 in carcasses.

This is not the case with brodifacoum, where persistence in possums is probable in both lethally and sub-lethally poisoned animals. This remarkable persistence highlights the potential secondary and tertiary risks associated with brodifacoum when used for possum control. For example, feral pigs will scavenge possum carcasses and it is apparent from this study that possums dying up to eight months or more after being exposed to brodifacoum may contain residues that could be transferred to pigs. As feral pigs are hunted as a food source in New Zealand, there is at least a theoretical risk of tertiary poisoning of humans long after the use of brodifacoum has been discontinued in a particular area. A sensible precaution would be to recommend that the livers from all game be discarded, since much higher concentrations occur in the liver than in muscle or blood. Even if residues in most animals never reached levels

capable of causing serious harm to meat-eaters, the presence of brodifacoum in any meat could be a concern to the public. The presence of brodifacoum in possum carcasses is also likely to pose a hazard to predators such as harrier hawks, as well as farm dogs.

The preliminary results with cholecalciferol indicated that elevated concentrations of 250HD were present in possum carcasses, and that they were likely to persist for several weeks in animals that had received sub-lethal doses. In comparison to other examples in the literature, the clearance of elevated 250HD in poisoned possums appeared to be quite slow. This is perhaps not surprising since it has been shown in other animals that clearance of 250HD is dose dependent (Keiver et al. 1988), and possums in the present study received extremely high near-lethal doses. For example, the plasma elimination half lives of 250HD were 15 to 36 days in humans when vitamin D status was normal, but increased to 25 to 68 days in humans and cows experiencing vitamin D toxicosis (Keiver et al. 1988).

The feeding study of cats appeared to confirm earlier work with dogs (Marshall 1984) which indicated that the risk of secondary poisoning with cholecalciferol is low. This is despite the presence of elevated concentrations of 250HD in possum carcasses. Research in rats has demonstrated that 250HD is active when administered orally (Rambeck et al. 1990), but is partially degraded in the intestinal tract (Frolick and Deluca 1971). Hence, some degradation of 250HD in possum meat by cats

during digestion probably protects them. Further studies are planned with dogs to confirm the findings with cats, since it is believed that the data suggests a low risk, but not no risk, of secondary poisoning.

Even in the absence of this additional data, it is apparent that the risks of secondary poisoning with cholecalciferol are low when compared with brodifacoum or 1080. Dogs and cats only need to eat a very small portion of a possum carcass poisoned with 1080 to receive a lethal dose, and pets or farm dogs could not feed exclusively on possum carcasses containing 1080 for brodifacoum for 5 days without becoming ill or dying. Nevertheless, all pets and farm dogs should be discouraged from eating animals that have been poisoned with cholecalciferol, even if the risk of secondary poisoning is perceived to be low, based on currently available evidence.

#### ACKNOWLEDGEMENT

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## RODENTS AND COVER CROPS—A REVIEW

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**ABSTRACT:** Inter-row plantings of herbaceous cover crops has become a widely accepted practice by orchard and vineyard managers. Cover crops, used as part of a production management system, are not considered a cash crop and are therefore selected by individual growers for various reasons. Little is written regarding the relationship of cover crop management and the impact on rodent populations. This paper reviews the recent literature and examines how cover crop species and cultivar selection along with management procedures may be influential in limiting rodent populations and their damage to cropping systems.

**KEY WORDS:** vertebrate pests, cover crop, field rodents

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### INTRODUCTION

From a managerial perspective cover crops offer a number of benefits to an orchard or vineyard manager. Cover crop species selection may include the planting of annual and/or perennial legumes and grasses or the management of established forbs. Species and cultivars are often selected based on the individual manager's cultivation practices. In tilled situations cover crops may include: bell beans (*Vicia faba*), field peas (*Pisum sativum*), vetch (*Vicia* spp.), clovers (*Trifolium* spp.), fescues (*Festuca* spp.), barley (*Hordeum vulgare*), and oats (*Avena sativa*). Under a non-till scenario a grower may choose clovers (*Trifolium* spp.), fescues (*Festuca* spp.), Blando brome (*Bromus mollis*), perennial ryegrass (*Lolium perenne*), bur clovers (*Medicago* spp.), trefoils (*Lotus* spp.), orchard grass (*Dactylis glomerata*), wildrye (*Elymus* spp.) and others. McGourty (1994) provides a thorough overview of cultivar selections and management for northern California. The inclusion of these plantings into an otherwise sterile production environment increases biological diversity thereby promoting cultural and pest management options.

Cover crops are recognized for providing beneficial aspects to soil fertility, stability and compaction (Nicholson and Richmond 1984; McGourty 1994). Likewise, they often serve as a nursery crop for beneficial organisms that otherwise would have to immigrate from adjacent sites. Proper cover crop selection can: 1) reduce the number of ice nucleating bacteria responsible for frost damage to crops; 2) reduce the costs of petro-chemical inputs into a production system; and 3) serve to manage plant vigor by adding a measured degree of competition into a production system (G. McGourty, pers. comm., Plant Science Advisor, UCCE, Mendocino County).

Though widely used in orchard and vineyard cropping systems, little is known about the impacts of cover crop selection and rodent populations or how cover crops

should be managed in order to minimize rodent damage. This paper reviews the current literature and provides some recommendations from a managerial perspective.

### THE INFLUENCE OF COVER CROP MANAGEMENT ON RODENTS

#### Pocket Gophers (*Geomyidae*)

Pocket gopher feeding impacts on agronomic crops are well documented (Fitch 1949; Foster and Stubbendieck 1980; Luce et al. 1981; Case 1989) and widely recognized by managers. Growers are acutely aware of the potential negative impacts from uncontrolled pocket gopher populations. However, the benefits realized from the inclusion of cover crops into their management systems far exceeds the potential threat of pocket gopher feeding damage.

Anecdotal information exists from individuals who have been experimenting with cover crop selections and rotations. Norton (pers. comm., UCCE Farm Advisor, Merced County) suggests that the use of clovers in apple and peach orchards has resulted in elevated pocket gopher populations precluding the continued use of this perennial cover crop. Bugg (pers. comm., Pest Management Specialist, UCD) has observed relatively high numbers of pocket gophers in perennial clovers as compared to systems using perennial grasses. These generalizations are pervasive among a number of people who have observed pocket gopher/cover crop interactions. Formal evaluations of pocket gopher response to cover crop selection is lacking. Managers are left to their own intuitive approaches to manage cover crop selections and pocket gopher population controls.

Loeb (1990) and Giusti (unpubl. data) reported that irrigation in alfalfa can increase pocket gopher fecundity by extending the breeding season and increasing litter frequency and sizes. Case (1989) provides a strategy to minimize pocket gopher damage to alfalfa. He suggests using cultivars with a fibrous root system rather than a

tap root to minimize feeding damage on overall field productivity. He argues fibrous cultivars can sustain higher levels of gopher feeding. From a managerial perspective, since cover crops are not managed as a cash crop, production is unimportant; therefore, the lower yields of fibrous cultivars are not a factor. It could be argued that a plant with a fibrous root system, could potentially lower carrying capacity for pocket gophers, provide beneficial soil and crop amendments, yet still be capable of tolerating high levels of pocket gopher damage.

Since the presence of pocket gophers is often first noticed through the detection of mounds it is important to select a cover crop that does not obscure a manager's ability to view burrowing activity. Short statured grasses would make visible detection relatively simple when compared to a dense, mat-forming cover crop such as a perennial legume. This scenario provides a cover crop of relatively low density and canopy height for burrow detection, and avoids fleshy rooted plants conducive to increased pocket gopher fecundity. Sheep fescue (*F. ovina* cul. *covar*) and hard fescue (*F. ovina* var. *duriuscula* cul. *durar*) are examples of low growing (3" to 6" canopy heights), fibrous species appropriate for this situation.

#### Management Implications

Since pocket gophers have the ability to cause catastrophic losses to perennial crops one should be extremely cautious when trying to manage cover crops as the only means of reducing pocket gopher populations. Pragmatic approaches to a cropping system should include the use of cover crops in combination with time-tested methods of pocket gopher controls. Cover crop selection and management should: 1) be viewed as a cultural approach to population manipulation not control; 2) ground covers should be selected on the basis of canopy height in order to allow early detection of mounds and burrowing activities; and 3) legumes should be viewed as having the greatest potential of causing increases in pocket gopher populations.

#### Voles (*Microtus*)

Unlike pocket gophers, the damage and presence of voles is readily visible. Giusti (1985) provides a review of the relationship of voles and herbaceous cover. It is well documented that voles respond positively to the onset of winter precipitation in California and the subsequent emergence of green forage. Throughout northern California where vineyard and orchard crops are often grown in close proximity to oak woodlands, the presence of voles in adjacent fields is common. The potential threat from voles immigrating into a vineyard or orchard from an adjacent grassy field is a likely scenario between the months November through March. Cover crops that provide adequate cover and food should be viewed as being attractive to voles. In addition, cover crops that are allowed to come into contact with the production commodity should be viewed as being at risk of damage from vole feeding.

Nicholson and Richmond (1984) discuss the relative abundance between native bunch grasses, legumes and their relative palatability to *Microtus pennsylvanicus* and *M. pinetorum*. They recognize that forage selection may

have more of an effect on a surface-dwelling species, *M. pennsylvanicus*, than on a fossorial species like *M. pinetorum*. Throughout California the dominant species is *M. californicus*. This species should be considered a surface-dwelling type similar to *M. pennsylvanicus*. In their paper, Nicholson and Richmond (1984) discuss the importance of "heavy grass cover ... dense vegetation, low light penetration and high moisture levels" as beneficial to increasing vole populations. These criteria should also be viewed equally important when dealing with the California species. They conclude that, "vulnerability for this small prey species (from predation) can be increased by selecting orchard ground-covers with an erect, bunch-type growth habit that does not mat or lodge." This statement should be considered accurate for any cropping systems having potential vole damage in California.

Thompson (1965) evaluated the palatability of 30 plant species to voles. Generally, he demonstrated that legumes were the most preferred followed by grasses of European origin. He further determined that native grasses and sedges were of intermediate preference while boreal and bog plants were least favored. Rhodes et al. (1983) found similar preferences with legumes being the most attractive forage to voles. In his work he further demonstrated that crown vetch (*Coronilla varia*) and creeping myrtle (*Vinca minor*) were highly unacceptable. Though these particular species may not be suitable for cropping systems in the west it does point to the need for further investigative types of selections.

Coley et al. (1995) suggest that certain endophytic fungi associated with fescue may play a role in reducing vole fecundity. The impacts of endophytes on domestic animals is well documented (Fribourg and others 1991). However, as pointed out by Coley, the focus has been on trying to eliminate endophytic fungi from grazing systems while ignoring the potential benefits they could provide to both invertebrate and vertebrate pest control. He suggests endophytic-positive ( $E^+$ ) grasses could provide a potential mechanism for reducing rodent populations in specific sites. If further tests prove this hypothesis accurate, this could provide an environmentally safe alternative to conventional field rodent control techniques, particularly in regions having to deal with associated threatened and endangered species. Growers now have the ability to select  $E^+$  or  $E^-$  grasses when planting pastures. From a managerial perspective  $E^+$  grasses should be evaluated as part of a cover crop regime to determine their potential to reduce herbivore populations.

Edge et al. (1995) demonstrated a 50% reduction in gray-tailed voles (*M. canicaudus*) after mowing and haying in perennial alfalfa fields. They reported that populations declined due to mortality and an increase in dispersal. They warned of the species ability to rapidly repopulate an area and that mowing by itself should be viewed as having only limited and short-term impacts. Their paper demonstrates the importance of habitat disruption in managing vole populations.

#### Management Implications

Past control efforts for voles have concentrated on application of toxic baits in combination with complete removal of suitable habitat and forage. The work

described herein provides some managerial perspectives on cover crop management that may serve to constrain vole populations without having to completely remove all associated vegetation. Ground-cover selection based on the presence or absence of endophytic fungi, native grasses that tend to grow in an erect fashion, and prudent mowing and clean farming techniques directly beneath vines or trees could provide the necessary criteria to minimize vole damage while maintaining maximum cover crop benefits.

#### Ground Squirrels (*Spermophilus*)

The relationships between cover crop management and subsequent influence on ground squirrels is poorly understood. As a group, ground squirrels are widely recognized as having the ability to achieve very high populations levels in suitable habitats. The Belding ground squirrel (*S. beldingi*) is a serious pest in irrigated alfalfa fields of northeastern California. The California ground squirrel (*S. beechyi*) is widely considered a major pest of many orchard crops in the Central Valley under a variety of management systems. Current practices rely on the application of toxic baits and fumigants in combination with cultural manipulations to minimize squirrel damage.

From a managerial point of view, it could be inferred that E<sup>+</sup> endophytic plants would have similar impacts on ground squirrels similar to other herbivores, but this has not been tested. It could also be inferred that short-statured grasses may be less conducive to ground squirrel populations than perennial legumes, but similarly this too has not been evaluated. Simply said, very little quantitative evaluations have taken place regarding the response of ground squirrels to cover crop selection and management.

Cable and Timm (1987) demonstrated how manipulation of grass through deferred grazing had significant impacts on black-tailed prairie dogs (*Cynomys ludovicianus*). They showed deferred grazing reduced reinfestation of prairie dog sites following population reduction through vegetation manipulations. Their work suggests that some species of ground squirrels may be susceptible to vegetation manipulations.

#### Management Implications

Damage by ground squirrels may be exacerbated by fields with squirrels next to a highly attractive crop. Because of the squirrel's ability to feed at great distances from its burrow, it may be difficult to minimize damage in any particular field utilizing cover crops if an adjacent field is providing optimum forage and cover. This said, it would be prudent to select a cover crop that has the least potential for attracting ground squirrels. Such crops may include native grasses including: California brome (*Bromus carinatus*), Blue wildrye (*Elymus glaucus*) and Meadow barley (*H. brachyantherum*). Annual grasses, as well as other species that require minimum irrigation requirements, provide minimal forage and cover qualities should also be evaluated to better identify

important managerial procedures. Mowing, baiting, fumigation and habitat manipulations should all be considered as a means of reducing squirrel populations and should not be eliminated in light of the general lack of knowledge regarding cover crop management and these species.

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# THE TEXAS ORAL RABIES VACCINATION PROJECT AND THE EXPERIMENTAL USE OF RABORAL V-RG RABIES VACCINE IN THE SOUTH TEXAS COYOTE RABIES EPIZOOTIC

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Beginning in October 1988, Texas experienced the onset of an expanding epizootic of canine rabies in South Texas. That epizootic now involves 21 counties, with 678 laboratory confirmed cases as of February 1996. Approximately 50% of those cases have occurred in coyotes and most of the remainder in domestic dogs. Seventy-six "spill over" cases have been reported in seven other species, both wild and domestic. Since 1991, over 2,000 people in South Texas have received post exposure rabies treatment due to potential exposure to a rabid animal and two human deaths have been attributed to this virus strain. The Texas Department of Health (TDH) is the lead agency in the development of an experimental program designed to explore use of an oral rabies vaccine, Raboral V-RG, produced by Rhone-Merieux, Inc. in Athens, Georgia. The Oral Rabies Vaccination Program (ORVP) is an innovative cooperative project involving the TDH; Texas Animal Damage Control; U.S. Department of Agriculture (USDA); Texas A&M University-College Station; Texas A&M University-Kingsville; Centers for Disease Control and Prevention, Denver Wildlife Research Center; USDA Predator Research Center at Logan, Utah; Texas National Guard, U.S. Army; Canadian Ministry of Natural Resources; and Rhone-Merieux, Inc.

The objective of the first year of the program was to determine the feasibility of using Raboral V-RG oral rabies vaccine, delivered in a bait to coyotes, as a method of controlling the northward expansion of the South Texas rabies epizootic. Field application of the vaccine was with vaccine/bait combinations containing 2 milliliters of Raboral V-RG vaccine at a minimum field dosage of 107.4 virus particles in a plastic container (a sachet) enclosed in a hollow extruded bait. The long term program strategy is to be conducted over the next four to five years, and has the goal of pushing the epizootic southward and eliminating it from Texas.

The program was first conducted in February 1995 and resulted in the deployment of 830,000 doses of oral rabies vaccine over 15,000 acres of South Texas. The 1995 program was successful not only in the logistical accomplishment, but post-drop surveillance programs demonstrated a dramatic reduction in rabies in the

targeted area. Evaluation of the program to date has been based on three parameters: 1) epidemiologic evidence of containment of the virus in its present location; 2) identification of marking agents that determine uptake of the bait in coyotes from the baited area; and 3) evidence of change in the immune status in a representative sample of the coyote population in the baited area. The program has shown significant success in all three of these areas. The expansion of the rabies outbreak not only has been halted but, with the exception of an isolated area in Atascosa County, cases of canine rabies have ceased to be reported in the primary 40-mile wide baited zone. Evidence of bait uptake has exceeded expectations with 68% of one- to three-year old animals having eaten an average of 2.6 baits each. Studies indicating the immune status of coyotes from the baited area revealed evidence of immune response in 49% of the coyotes eating baits. Therefore, by all measures of success, the program has met or exceeded expectations. The success of the first year was a prelude to a larger, and hopefully more successful, 1996 program.

In the short time period of 31 days, beginning on January 4, the participants of the 1996 program aerially distributed more than 2.5 million doses of vaccine over 41,679 square miles of Texas. This has been the world's largest single application of an oral rabies vaccine and involved 276 separate flights of three "Twin Otter" aircraft provided through an agreement with the Ontario Ministry of Natural Resources. The 1996 program was flown from four airports and resulted in a total flight distance equaling more than four trips around the world. This accomplishment was due, in large part, to a unique spirit of cooperation from all agencies and individuals participating.

The successful completion of this program will have a significant long term impact on public health programs in the United States. Not only does this program represent the best approach for obvious human health reasons, but it will also save health care dollars, is a nonlethal solution to a wildlife disease problem, and will yield information that may provide answers to future wildlife disease and management questions.

# ZOONOTIC DISEASES OF CARNIVORES AND OCCUPATIONAL SAFETY ISSUES FOR PREDATOR CONTROL EMPLOYEES

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**ABSTRACT:** The paper highlights some important zoonotic infections of carnivores in North America. The etiologic agents, routes of transmission, reservoirs, and methods for prevention are emphasized. Occupational safety issues for people working in predator control are discussed.

**KEY WORDS:** diseases, predators, public health, safety, wildlife management, zoonoses

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## INTRODUCTION

Carnivores are an integral component of the ecosystem and in many ways enhance people's lives. Unfortunately, encroachment on wilderness environments has led to potentially dangerous encounters between wildlife and humans. Pet overpopulation has produced unwanted feral domestic dogs and cats in both urban and rural areas. In some instances, livestock and endangered species have suffered devastating losses due to predation by carnivores. As a result, predator control has become an important component of vertebrate pest control and wildlife management.

In addition to the inherent danger from injuries due to attacks, carnivores further represent a health threat because they may harbor diseases transmissible to humans. Acha and Szyfres defined zoonoses as communicable diseases shared by humans and other vertebrate animals (1987). Historically, some of the most deadly diseases known to humans have been zoonoses. For example, rabies has tormented humankind since antiquity and ultimately inspired the pioneering research that led to vaccine development (Steele and Fernandez 1991). Today we are seeing the emergence of newly recognized pathogens and the re-emergence of infectious diseases once thought to be successfully controlled (Morse 1990, Institute of Medicine 1992). In a recent report from the Centers for Disease Control and Prevention (1994a), approximately one-third of the emerging infections mentioned were zoonoses.

## BACTERIAL INFECTIONS

The most common bacterial infections transmitted by carnivores to humans are due to wound infections, usually by direct inoculation of the bacteria via a bite or scratch. Bite wounds from felids are ten times more likely to cause infection in comparison with dog bites (California Department of Health Services 1992). Pasteurellosis, caused by *Pasteurella multocida*, represents 90% of the isolates from victims hospitalized with infected bites (Anderson 1992). Pasteurellosis in humans is characterized by moderate to severe cellulitis with swelling and pain. Other agents that may cause wound infections include hemolytic *Streptococcus*, *Bacteroides*, *Fusobacterium*, *Staphylococcus aureus*, and *Capnocytophaga* (CDC Group DF-2) (Benenson 1995). In addition, tetanus, caused by *Clostridium tetani*, is a

life-threatening illness that may be contracted through wounds caused by animal bites or scratches.

Cat scratch disease is another infection acquired by the bite or scratch of an infected animal, usually a domestic cat. Initially, the area at the bite or scratch develops a red papular lesion. The disease progresses to a subacute regional lymphadenopathy. The causative agent, *Bartonella* (formerly *Rochalimaea*) *henselae*, has only recently been described (Regnery et al. 1992, Dolan et al. 1993, Zangwill et al. 1993). *B. henselae* has also been found in the cat flea, *Ctenocephalides felis*, by polymerase chain reaction testing (Koehler et al. 1994); however, the role of fleas in the transmission cycle of *B. henselae* is unclear.

Wild and domestic carnivores have played an increasingly important role in the transmission of plague to humans. Plague is caused by *Yersinia pestis*, a bacteria maintained in nature by a sylvatic cycle involving wild rodents and their fleas in the western United States. There are three clinical forms of plague in humans: bubonic, septicemic, and pneumonic. The initial symptoms are fever, chills, and headache two to six days following exposure to the bacteria. The fatality rate is high without prompt diagnosis and treatment. The most frequent route of transmission of *Y. pestis* to humans is via the bite of an infective flea. Alternatively, humans can contract the illness by direct contact with the secretions of an infected animal or person.

In recent years, almost all human cases of the most lethal form of the disease, pneumonic plague, have been linked to domestic cats (Centers for Disease Control and Prevention 1994b). Both wild and domestic cats may develop symptomatic plague infection, including abscesses or buboes and pneumonia. The secretions (e.g., pus, respiratory secretions) are highly contagious to humans, particularly if inhaled. In contrast, canids do not usually develop clinical illness following plague infection; thus, they are less important in the transmission of the disease to humans. Other carnivores that may be infected include badgers, raccoons, skunks, bears, and opossums. Serologic titers have been demonstrated in many species of carnivores, making them useful sentinels for plague surveillance (Barnes 1982, Clover et al. 1989, Smith 1994, Chomel et al. 1994).

Tularemia, caused by *Francisella tularensis*, may also be harbored by carnivores and transmitted by bites,

scratches, or direct contact with infected tissues; however, carnivores are rarely involved in transmission to humans.

Leptospirosis is an important zoonotic infection worldwide. The disease is caused by a spirochete, *Leptospira interrogans*. The spectrum of illness ranges from no symptoms in some people to severe illness in others. The illness usually begins with fever, chills, and headache, and may progress to vomiting, jaundice, anemia, and a rash. Leptospirosis may cause damage to the kidneys, liver, brain, lungs, or heart, but it is not usually fatal. Wild and domestic animals are the reservoirs, including many species of carnivores (badgers, foxes, skunks, opossums, domestic dogs). Wild rodents are well-adapted to the bacteria and represent the most important reservoirs in nature. *L. interrogans* is shed in urine and may contaminate water and moist environments. Transmission to humans occurs by direct contact of the skin (especially if cut or abraded) or mucous membranes with the urine of infected animals. Less commonly, the route of transmission is by ingestion or inhalation of contaminated water or aerosols, respectively.

Enteric infections of carnivores are another important group of zoonoses. These bacteria cause a mild to severe

illness in humans, but may be life-threatening in the very young, very old, and immunosuppressed individuals. *Salmonella* spp. and *Campylobacter jejuni* are examples of bacteria frequently isolated from mammals, birds, and reptiles (Altekruse and Hunt 1994). These bacteria are classically known for causing outbreaks of food poisoning. However, they can also be transmitted directly to humans by ingestion of fecal material or via objects contaminated by feces.

#### VIRAL INFECTIONS

There are surprisingly few documented viral diseases of carnivores transmissible to humans. However, rabies, perhaps the most important zoonotic infection ever, falls into this group. Rabies virus belongs in the family Lyssavirus. Symptoms in humans include a sense of apprehension, headache, fever, and unexplained sensations, usually at the site of the bite. The disease may progress to more severe neurologic disorders. Rabies infection is invariably fatal. There is no specific treatment, but pre- and post exposure prophylaxis is available (Centers for Disease Control and Prevention 1991). Table 1 summarizes risk categories and pre-exposure immunization regimens.

Table 1. Rabies pre-exposure immunization criteria.\*

Risk Category	Nature of Risk	Typical Population	Pre-Exposure Regimen
Continuous	Virus present continuously often in high concentrations aerosol, mucous membrane, bite, or nonbite exposure possible. Specific exposures may go unrecognized.	Rabies research lab workers. Rabies biologics production workers.	Primary pre-exposure immunization course. Serology every 6 months. Booster immunization when titer falls below acceptable level.
Frequent	Exposure usually episodic with source recognized, but exposure may also be unrecognized. Aerosol/mucous membrane, bite or nonbite exposure.	Rabies diagnostic lab workers, spelunkers, veterinarians, animal control, wildlife workers, travelers to epizootic rabies areas for >30 days.	Primary pre-exposure immunization course. Serology every 2 years.
Infrequent, but greater than population-at-large	Exposure nearly always episodic with source recognized. Mucous membrane, bite, or non-bite exposure.	Veterinarians, animal control, wildlife workers in low rabies endemic areas. Travelers to foreign epizootic areas, veterinary students.	Primary pre-exposure immunization course. No routine booster immunization or serology.
Rare (population-at-large)	Exposure rare and episodic, mucous membrane or bite with source recognized.	U.S. population-at-large including individuals in rabies epizootic areas.	No pre-exposure immunization necessary.

\*Adapted from Guidelines for the treatment, investigation, and control of animal bites, 1992, California Department of Health Services, Sacramento, California.



In the United States, wild animals account for over 90% of all rabid animals identified and most of these are carnivores (Krebs et al. 1995). In areas where canine rabies is not yet controlled, dogs represent the majority of rabid animals. The reservoir of rabies varies by antigenic variant and geographical area. The predominant vectors of rabies in developed portions of North America are raccoons (East Coast), arctic and red foxes (Alaska to New York), skunks (Canada to central U.S. to Mexico), gray foxes (western Texas, southeastern Arizona), and dogs and coyotes (southern Texas). Bats are reservoirs throughout North America. Although these species are the primary reservoirs, virtually all mammals are susceptible to rabies in varying degrees and, therefore, pose a health threat to humans.

In 1994, there were 8,224 cases of rabies in animals and 6 cases in humans reported to the Centers for Disease Control and Prevention in the United States (Krebs et al. 1995). Because of ongoing epizootics of rabies on the East Coast in raccoons and in southern Texas involving dogs and coyotes, rabies has become one of the targeted re-emerging infectious diseases (Krebs et al. 1995, Clark et al. 1995).

The rabies virus is shed in the saliva of infected animals and it is usually transmitted by bites. Scratches or contamination of wounds, abrasions, or mucous membranes with saliva or nervous system tissue of an infected animal and airborne transmission (very rare) are other documented routes of transmission. Rabies often causes abnormal behavior in animals and it should be suspected in any wild animal showing a lack of fear of humans, activity during the day (if normally nocturnal), or aggression and unprovoked attacks. Other signs of rabies in animals include weakness, paralysis, and increased excitability.

## FUNGAL INFECTIONS

Several zoonotic fungal infections are found in carnivores. Young animals are particularly susceptible. These infections may be transmitted to people by direct contact with the infected animal or via fomites such as soil. Dermatophytosis or "ringworm" is a very common fungal infection caused by members of the genera *Microsporum* or *Trichophyton*. In humans, infection generally results in a self-limiting dermatitis characterized by reddish, flat, spreading, ring-like lesions. These fungi may or may not cause visible lesions on an infected animal. Sporotrichosis is a more serious, but rare, fungal infection caused by *Sporothrix schenckii*. Soil and decaying vegetation are the reservoirs. People and animals, especially felids, become infected by introduction of the organism into wounds caused by thorns, splinters, or other trauma (Reed et al. 1993).

## PARASITIC INFECTIONS

Parasitic infections represent the largest group of zoonoses transmitted by carnivores, especially in tropical and subtropical regions. However, many are not transmitted directly; often these parasites require an intermediate host or maturation in the environment to complete their life cycle.

Several important protozoal diseases are carried by carnivores. Felid species of the genera *Felis* and *Lynx*

are the definitive hosts of *Toxoplasma gondii*, one of the most widespread parasites in the world. In most people, the disease is asymptomatic. However, when women are infected early in pregnancy the fetus may suffer congenital infection causing congenital defects or fetal death. There may be a recrudescence of a subclinical infection in people who are immunosuppressed resulting in a severe, often fatal, infection of the nervous system. Infected felids shed oocysts in their feces, but these are not infective to humans and other intermediate hosts until they sporulate in the environment; sporulation may be as short as one day in favorable environmental conditions. The life cycle of *T. gondii* is very complex, but it is usually transmitted to humans by ingestion of sporulated oocysts from cat feces in the environment, ingestion of raw or undercooked meat of an infected intermediate host, or transplacentally (Acha et al. 1987).

Two other common protozoa, *Giardia* spp. and *Cryptosporidium* spp., are also transmitted by the fecal-oral route and may be found in many mammal species, including domestic and wild carnivores. These parasites may contaminate the environment, especially water. Infected humans may be asymptomatic or suffer from a severe diarrheal illness, particularly if they are immunosuppressed.

Larva migrans is a class of syndromes caused by parasites in the order Nematoda, primarily *Toxocara* spp. (carried by canids and felids) and *Baylisascaris* spp. (carried by raccoons, bears, skunks, fishers, martens, and badgers) (Glickman and Schantz 1981). The larvae of these parasites may migrate aberrantly in the organs and tissues of infected humans. The infection is usually inapparent or mild, but sometimes symptoms persist for many years causing lesions in the liver, kidneys, lungs, brain, and eye (visceral larva migrans) or skin (cutaneous larva migrans). Children are more commonly infected, probably because of poor hygiene and a tendency to eat dirt. The signs are more severe if large numbers of eggs are ingested. The adult worm is found in the intestine of the infected carnivore, especially in lactating mothers and their young. Eggs are shed in the feces and require maturation in the environment where they may survive for extended periods of time.

Echinococcus infections are caused by a group of tapeworms (Order Cestoda) harbored by carnivores. Echinococcosis or hydatid disease is a very serious illness of humans. The parasite causes a highly invasive, slow-growing cyst to form in the internal organs, especially the liver. The cysts may spread throughout the body like malignant cancer. There is no specific treatment and the disease is frequently fatal.

Two species of the tapeworm occur in the United States, *Echinococcus granulosus* and *E. multilocularis*. The adult tapeworm lives in the intestine of the carnivore and eggs are shed in the feces. The eggs are infective at the time of shedding and may have prolonged survival in the environment. The life cycle of *E. granulosus* primarily involves a domestic dog (definitive host) and sheep or other ruminants (intermediate host) cycle; thus people working in the sheep industry, slaughterhouse workers, and veterinarians are at highest risk.

*E. granulosus* is found in the western United States and Alaska, Central America, and Canada. The parasite

can be eliminated from domestic dogs with treatment and by denying them access to infected meat. *E. multilocularis* is maintained in nature primarily by arctic foxes (definitive host) and microtine rodents (intermediate host). Domestic dogs and cats, wolves, and coyotes may also carry the parasite. *E. multilocularis* is currently found in the tundra zone including Alaska, south central Canada, and the north central United States and it appears to be spreading (Hildreth et al. 1991). The practice of illegal translocation of foxes from tapeworm-endemic areas for release in fox-chasing enclosures has become of great concern because of the potential for introduction of this parasite into tapeworm-free areas (Lee et al. 1993).

#### ECTOPARASITES AND ZOONOTIC INFECTIONS

There are numerous species of ectoparasites that infest carnivores and potentially carry infectious diseases. Examples of tick-borne infections that may be harbored by carnivores include Lyme disease, tularemia, Q fever, Rocky Mountain Spotted Fever, and Endemic Relapsing Fever. As previously discussed, fleas transmit plague. Phlebotomine flies vector visceral leishmaniasis, a serious human illness for which canids are the reservoir. Scabies is caused by the mite, *Sarcoptes* spp., and may cause a superficial dermatitis characterized by a skin rash with intense itching. Ectoparasites may be transferred directly from an infested carnivore to a person handling the animal. Alternatively, carnivores may transport ectoparasites to human environments. Ectoparasites will usually leave a host that has died and immediately seek a new, nearby host, which may or may not be of the same species. Appropriate use of insecticides when handling carnivores or working in their environments is important to prevent transmission of vector-borne diseases.

#### PREVENTION STRATEGIES AND OCCUPATIONAL SAFETY ISSUES

Awareness of the diseases potentially carried by the species of carnivores that employees are exposed to is cornerstone to an occupational safety program. Education about zoonoses should be incorporated into regular training programs related to occupational safety. In addition, special precautions should be followed when working with carnivores including: 1) wearing protective clothing including gloves (rubber and leather), coveralls, boots, goggles, and respiratory protection when applicable; and 2) practicing good personal hygiene such as thorough hand washing and abstinence from eating, drinking, and smoking while working with potentially infectious animals or with contaminated objects or environments. Employers may want to collect and store (at 20°C) a baseline serum sample from employees, preferably drawn before activities placing the worker at risk are initiated. Any employee who is injured by a carnivore or develops a febrile illness or skin condition should seek medical attention immediately and inform the attending physician of the potential occupational risk of a zoonotic infection (Weinberg 1991, Anderson 1992, Communicable Disease Report 1992). Employees whose duties include direct contact with carnivores should have a tetanus immunization and strongly consider receiving rabies pre-exposure prophylaxis (Table 1).

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# INVESTIGATIONS AND MANAGEMENT OF EPIZOOTIC PLAGUE AT ICE HOUSE RESERVOIR, ELDORADO NATIONAL FOREST, CALIFORNIA, 1994 AND 1995

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**ABSTRACT:** The occurrence of plague (*Yersinia pestis*) at Ice House Reservoir in 1994 and 1995 was characteristic of widespread epizootics in high use recreational areas of California. Staff of the Vector-Borne Disease Section investigated these epizootics and found dense populations of plague susceptible California ground squirrels (*Spermophilus beecheyi*) with high numbers of fleas, primarily *Dipodomys montanus*, the most important plague vector. This combination indicated a high risk of plague exposure to campground users. A non-fatal human case of plague, contracted at Mountain Camp II, was reported after the initial epizootic investigation. The patient's exposure occurred prior to the reporting of the epizootic die-off among the California ground squirrels. The plague investigation included direct observations, animal trapping, and laboratory testing of rodent carcasses, sera, and fleas. Plague management and prevention included flea control with 2% Diazinon dust and rodent population reduction using 1% zinc phosphide treated grain. Evaluation of the 1994 applications indicated a successful reduction of rodents and fleas. However, the need for an ongoing management program was emphasized in 1995 when the plague epizootic continued. Intrusion of plague infected rodents and their fleas necessitated a 1995 treatment in the four campgrounds involved.

**KEY WORDS:** disease management, plague, epizootic, control, flea, California ground squirrel, diazinon, zinc phosphide, California, USA

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## INTRODUCTION

In California, involvement of native wild rodents in the ecology of plague began shortly after the 1900 introduction of the plague bacterium (*Yersinia pestis*) into San Francisco. The first reported incidence of infections in California ground squirrels (*Spermophilus beecheyi*) occurred in 1903 (Lien-Teh 1926). In 1908 the bacterium was isolated from this squirrel (McCoy 1908). Ground squirrel epizootics occurred throughout the San Francisco Bay area during the early part of the 20th century, even though disease eradication by shooting ground squirrels had been attempted (Murray 1964). Since the outbreak in Los Angeles in 1924, involving both commensal rats and California ground squirrels, human cases have been associated with sylvatic rodents only. The California ground squirrel continues to be the most important rodent in plague epidemiology in California (Nelson 1980). The Vector-Borne Disease Section of the California Department of Health Services (CDHS) is charged under the California Health and Safety Code to provide surveillance, investigations, and control of plague in the state. Plague activity in California during the 1990s has recently been described by Smith (1994, 1996).

Investigations of California ground squirrel and chipmunk (*Tamias quadrimaculatus*) related plague epizootics at four campgrounds at Ice House Reservoir during the 1994 and 1995 plague seasons are described and documented in this paper. It is often difficult to document the full extent of plague epizootics due to insufficient resources. Once direct evidence of plague at a site is established from a carcass, flea pool, or series of antibody titers, sampling is normally reduced. In an effort to obtain more data, a broad range of human and epizootic plague management and prevention activities were carried out by the Vector-Borne Disease Section and

other cooperating agencies at Ice House Reservoir. The epizootics were well documented by extensive observations of rodent activity or abandonment, and by laboratory confirmatory testing of samples from trapped rodents and their ectoparasites (fleas).

For consistency and comparative value, only laboratory test results of flea pools and sera collected from ground squirrels pretreatment (before an insecticide application) are reported. Not included in the data are: three plague positive squirrel serologies from the Ice House Campground, taken during the only post treatment bleeding in both years; two positive chipmunk serologies from 1995; and three negative chipmunk flea pools from 1995. The exact role of chipmunks in the epizootics could not be determined because of the few samples collected.

## SITE DESCRIPTION

Ice House Reservoir is approximately three miles long and one mile wide. It is located at an elevation of approximately 5,500 feet in El Dorado County, California. The area is administered under the jurisdiction of the Pacific Ranger District in the Eldorado National Forest, United States Department of Agriculture, Forest Service (USFS). The landscape is typical habitat at this elevation on the west slope of the Sierra Nevada Mountains, showing evidence of glaciation and having abundant granite outcrops and boulders. The area is montane forest; predominately ponderosa pine (*Pinus ponderosa*), sugar pine (*P. lambertiana*), white fir (*Abies concolor*), with ground cover of snow brush (*Ceanothus cordulatus*), and greenleaf manzanita (*Arctostaphylos patula*).

The investigation involved four primary sites at the reservoir:

### 1. Mountain Camp II

An exclusive 26-acre private camp located on USFS land about midpoint on the north side of the reservoir. The camp is situated on a hillside, with conifers providing heavy shade. Approximately 110 campers and 45 staff utilize three main buildings for cooking, eating, medical supervision and showering. Sleeping facilities at the site are primitive. Staff and campers used tents on the ground or on elevated platforms for housing.

### 2. Strawberry Point Campground

A 10-unit campground owned and operated by the USFS, adjacent to the reservoir on 32 acres. This widely spaced campground is adjacent to site 1. The campsites are located in open forest and are surrounded by dense brush and large boulders.

### 3. Northwind Campground

A 10-unit campground owned and operated by the USFS covering approximately 37 acres. The campground, located on a rocky ridge, is about 0.5 mile west of sites 1 and 2. The widely spaced campsites overlook the reservoir and are surrounded by dense brush.

### 4. Ice House Campground

An 83-unit campground of about 50 acres owned by USFS and operated by a concessionaire. The campground is located on the western end of the reservoir approximately 1.5 miles west of sites 1 and 2, and includes picnic and boat launching facilities. Ice House Campground has two major loops about 0.5 mile apart; one is located on an open forest ridge, and the second is located in dense forest near the reservoir.

## INVESTIGATION AND CONTROL, 1994

The first indication of an epizootic in progress began with observations of two dead chipmunks at Mountain Camp II in July. One long-eared chipmunk carcass was collected by camp staff and submitted for plague testing to the CDHS, Microbial Diseases Laboratory (MDL). The animal was bacteriologically plague positive, prompting an on-site evaluation by the Vector-Borne Disease Section and the El Dorado County Environmental

Health Department. The following observations were made at Mountain Camp II, Strawberry Point Campground, and Northwind Campground:

1. An extremely high concentration of California ground squirrels populated the sites.
2. Campers were living and sleeping in close proximity to rodents and rodent burrows.
3. Rodents had direct access to camper living areas.
4. There appeared to be an absence of long-eared chipmunks in areas of dense cover.

Overall, there was direct evidence of plague in the area, with a high risk of human exposure to vector fleas. The California ground squirrel flea (*Diagnosis montanus*) is the primary plague vector in California (Barnes 1982). Recommendations were made to close Mountain Camp II at the end of the camping session (two days away) and to immediately close the two nearby USFS campgrounds (Strawberry Point and Northwind). Staff and campers at Mountain Camp II were provided informational handouts about plague. Parents, when picking up their children, were instructed to contact a physician if plague compatible symptoms appeared. Recommendations were made to control fleas before reopening the camp and campgrounds. Management of Mountain Camp II and the USFS accepted the recommendations and voluntarily closed the areas to public use.

Animals were trapped, anesthetized, combed for fleas and bled to establish the flea index and incidence of animal plague at each site. Trap success at Mountain Camp II was 54% in one hour of mid-morning trapping. Trap shyness and aversion were not observed at this or the other three campgrounds sampled. Flea indices on California ground squirrels preapplication and post insecticide application were 10.7 and 0.5, respectively (Table 1). During the 1994 epizootic, 14 of 56 (25.0%) California ground squirrels sampled showed antibody titers to plague, range 1:32 to 1:8192. Strawberry Point had the highest percentage of positive squirrels, 62.5% (Table 2). Additional evidence obtained at the sites included isolations of the plague bacteria from one of two flea pools from Mountain Camp II, and from one of two flea pools tested from Strawberry Point. These plague positive findings confirmed an extensive epizootic.

Table 1. Pre- and post-insecticide application flea indices<sup>1</sup> at four sites in 1994 and 1995, Ice House Reservoir, Eldorado National Forest, California.

Campground	1994		1995	
	Pretreatment	Post Treatment	Pretreatment	Post Treatment
Mountain Camp II	10.3	0.6	--	--
Strawberry Point	9.0	0.1	7.5	0.4
Northwind	12.7	0.7	7.7	0.0
Ice House	11.0	0.3	2.2	0.1
Overall <sup>2</sup>	10.7	0.5	5.2	0.2

<sup>1</sup> Average number of fleas per animal.

<sup>2</sup> Total number of animals/total number of fleas.

Table 2. Number of serological plague positive California ground squirrels and the number tested during the 1994 and 1995 plague epizootic, Ice House Reservoir, Eldorado National Forest, California.

Campground	1994		1995	
	Positive/Tested	Percent	Positive/Tested	Percent
Mountain Camp	5/21	23.8	1/6	16.7
Strawberry Point	5/8	62.5	5/6	83.3
Northwind	2/12	16.7	1/11	9.1
Ice House	2/15	13.3	4/14	28.6
Overall	14/56	25.0	11/37	29.7

Cooperators, under supervision, began flea control immediately after the camping areas were vacated. Flea reduction was accomplished by hand and bait-dust station application of 2% Diazinon dust, Gold Crest 2D, EPA Reg. No. 1037-43-432 under SLN Reg. No. CA-800157. Diazinon 2D is the only product registered for flea control in California campgrounds and is to be used only under supervision of the California Department of Health Services. The insecticide was applied one time to burrows using B&G 1152-A DUST-R hand operated plunger dust dispensers. Approximately three ounces of the product was applied to each burrow located within 30 yards of the targeted campground areas. One bait-dust station was placed at each campsite and, if needed, between campsites to cover the target area. Bait was a four ounce solid bait block made of oats lightly coated with peanut butter and impregnated with wax. The bait block was wired into the center of each station. Approximately six ounces of the insecticide were spooned into each end of the 4" x 18" PVC pipe bait-dust station. Bait stations were checked for five to seven consecutive days and dust or bait was replenished as necessary. Eight hundred seventy-five pounds of insecticide (Table 3) were applied in all four campgrounds to achieve a 96% reduction in the overall flea index.

Table 3. Pounds of 2% Diazinon dust applied by hand duster and bait stations at four sites during the 1994 and 1995 epizootics, Ice House Reservoir, Eldorado National Forest, California.

Campground	1994	1995
Mountain Camp II	275	not treated <sup>1</sup>
Strawberry Point	70	25
Northwind	130	45
Ice House	400	140
Overall	875	210

<sup>1</sup>Mountain Camp II closed for the season, to be treated before opening.

After successful flea control, the camping areas were allowed to reopen. During the application, six California ground squirrel carcasses were found, none fresh. Although a positive carcass is an absolute indicator of bacterial activity, only one California ground squirrel was suitable for testing and it was plague negative. The animal was also reported as a possible road kill. A total of eight carcasses were collected in 1994.

One day after the post-treatment evaluation at Mountain Camp II, El Dorado County Environmental Health notified the Vector-Borne Disease Section that a 10 year old male resident of Menlo Park, San Mateo County, was a suspect human plague case. Approximately one week after returning home from a week stay at Mountain Camp II (June 19-25), the boy developed headache and malaise, followed by temperatures of 103 to 104°F., and generalized adenopathy with very tender right inguinal swelling (0.8" node). The pain was such that the patient was unwilling to move that leg. At his first emergency room visit (July 13), he was started on Keflex and switched to cefuroxime when he did not improve. The boy improved but relapsed when treatment was discontinued. On July 25, the boy was started on tetracycline after a history of camping was given and plague was considered. He responded well to the tetracycline and fully recovered. El Dorado County Environmental Health obtained a list of all previous campers and contacted their families to identify other possible illnesses and to provide information on plague. Children and their families were often difficult to contact, many having traveled to Europe and various areas in the United States. Several children were identified with fevers consistent with viral infections, but none had symptoms consistent with plague. By this time, epizootic plague had been identified and actions had been taken to reduce risks of plague transmission (or, as it turned out, to reduce risks of further transmission). Patient serum was submitted to CDHS and forwarded to the Center for Disease Control and Prevention (CDC), Fort Collins, Colorado, where a plague titer of 1:512 was reported (California Morbidity, November 1995). San Mateo County Health, El Dorado County Environmental Health, and CDHS completed a CDC case report follow-up.

After the report from CDC, the investigation expanded to include Ice House Campground at the west end of the reservoir and additional campgrounds in the Crystal Basin Recreation Area. Ice House Campground was trapped and animals sampled to establish flea indices and test for evidence of plague. Trap success at this campground was 75% for 20 traps in a one hour period. Thirteen percent of the animals tested were plague positive (Table 2). Campers were notified, the campground closed, and flea control was initiated, as previously described. Campgrounds outside of Ice House Reservoir but within Crystal Basin (20 mile radius) were visually inspected for epizootic plague activity. Campground hosts were alerted to the importance of plague in recreational areas, asked to display plague warning posters, and to report dead rodents. Indications of plague were not found in the other campgrounds.

Rodent control, coupled with flea control, can be used in a plague management program to reduce the number of disease-bearing hosts, as well as providing some relief from damage caused by rodent burrowing and gnawing. Evidence of rodent damage at Ice House Reservoir included structural damage to roads and buildings, and electrical damage to vehicles. Over \$1,000 was paid for electrical repairs to CDHS vehicles. The overall costs or revenue loss attributed to the rodents and the plague epizootic was not assessed. The USFS agreed that it was necessary to reduce ground squirrel populations and provide an ongoing management program. All cooperators agreed that an application of zinc phosphide to all four sites was the appropriate control method, even though its effectiveness on ground squirrels had been reported to be mediocre and inconsistent, ranging from poor to fair (Marsh 1994). Based on bait acceptance during flea control and observed feeding habits of the "campground peanut population," bait shyness with zinc phosphide treated grain was not anticipated. Low risk of secondary poisonings is well documented (Matschke 1992; Ramey 1994). Use of zinc phosphide treated grain appeared ideal under the circumstances observed during the investigations. The El Dorado County Department of Agriculture formulated and provided the 1% zinc phosphide treated grain, Calif. Reg. No. 10965-50014-ZA and EPA SLN No. CA 890026. They also provided safety and application training.

Seven hundred pounds of prebait were applied to evaluate bait acceptance and consumption. This amount was determined to be excessive. Two days later, 270 pounds of zinc bait were selectively scattered near rodent burrows (Table 4). Twenty-four hours after the application, eight observers walked the campgrounds for a five-hour period to evaluate bait acceptance, observe squirrel mortality, collect any carcasses, and check for non-target mortality. Bait acceptance was excellent, and only two live squirrels were observed—one in Ice House campground and one in Northwind campground. Pretreatment road counts of ground squirrels averaged 32 sightings in a 10 minute period in a portion of Ice House campground (campsites 17-27), while no squirrels were spotted post treatment. Three California ground squirrel carcasses were collected on the surface during the evaluation. One deer mouse (*Peromyscus maniculatus*) carcass, a potential carrier of plague and hantavirus, was

also found. No other mortality was observed. Following the post treatment observations, a work crew closed all rodent burrows in the treatment area with shovels to contain any remaining fleas and allow for monitoring reuse of burrows. One week after the application, two observers spotted two ground squirrels in Ice House Campground, and one in Northwind Campground, over a two hour period.

Table 4. Pounds of 1% zinc phosphide selectively scattered near burrows during the 1994 and 1995 epizootics, Ice House Reservoir, Eldorado National Forest, California.

Campground	1994	1995
Mountain Camp II	30	25
Strawberry Point	15	50
Northwind	30	75
Ice House	195	250
Overall	270	400

#### INVESTIGATION AND CONTROL, 1995

Plague surveillance in the same four sites at Ice House Reservoir during July 1995 detected 30% serological positive California ground squirrels (Table 2). Additionally, two of nine chipmunks (23%) trapped from Ice House Campground were also seropositive. Only one other chipmunk was collected during the 1994 and 1995 investigations, and was seronegative. The wide range of antibody titers (1:32 to 1:2048) among ground squirrels indicated a continuation of the epizootic. During this surveillance, 37 California ground squirrels were captured per two hours of trapping and the overall flea index on squirrels averaged 5.2 fleas per animal (Table 1). The sites were again treated with Diazinon 2D, as previously described, to reduce the risk of plague transmission by fleas. Two hundred ten pounds of insecticide dust (Table 3) were used in the campgrounds for burrow dusting and in bait stations, 25% of that used in 1994. The insecticide application reduced the overall ground squirrel flea index by 96%. Flea control operations were not undertaken at Mountain Camp II at this time. The camp remained open for three days before closing for the season. Management was notified that the camp would remain closed until flea control operations were completed. The management of Mountain Camp II agreed to additional precautionary measures: 1) to notify current and past campers of plague conditions; 2) to distribute literature to all staff, campers and their parents concerning plague symptoms and the need to seek prompt medical attention should symptoms appear; 3) to post the camp with plague warning posters; 4) to provide DHS with addresses and phone numbers of all campers; and 5) to provide assistance in future plague control activities. In the fall, all three USFS campgrounds were temporarily closed and all four camping areas were treated with zinc phosphide grain. The amount used was about 1.5 times that used in 1994 (Table 4). In order to reach ground squirrels in the fringe habitat, the rodenticide target area

was expanded to include squirrel activity sites over 100 yards from campsites. Seventy traps collected 51 animals one day before the zinc phosphide application, and 70

traps at the same locations collected five animals 48 hours after the application (Table 5). Post treatment trapping success indicated a 90% reduction of the ground squirrel.

Table 5. Numbers of trap/captures of California ground squirrels before and after an application of zinc phosphide treated grain at Ice House Campground in 1995, Eldorado National Forest, California.

Campground	Before		After	
	No. Captures/Trap	Percent	No. Captures/Trap	Percent
Strawberry Point	12/15	80	0/15	0
Northwind	11/15	73	2/15	13
Ice House	28/40	70	3/40	8
Overall	51/70	73	5/70	7

## DISCUSSION

Comparing epizootic activity between 1994 and 1995 (Table 6), surveillance data suggests that the epizootic intensity was less in 1995. The primary indicator of the 1994 control success was that no additional human cases occurred in an amplified epizootic, even though the areas were reopened about a week after initial closures. The Geometric Mean Positive Titer (GMPT), an indicator of titer level, declined from 362 to 165 between 1994 and 1995. A 2.2 fold decline in GMPT is indicative of a decline in plague activity (Harrison 1995). Four additional indicators of the decline of plague activity observed between 1994 and 1995 were: 1) lowered animal populations as observed by trap success (56/hour reduced to 19/hour); 2) lower flea index (10.5 reduced to 5.2); 3) negative flea pools in 1995; and 4) the absence of carcasses in 1995. Although the 1995 epizootic showed decreased intensity, it was clear that the 1994 efforts did not prevent the occurrence of plague in 1995. The authors speculate that a population void developed in the preferred campground habitat due to the zinc phosphide application. Squirrels from the fringe habitat reoccupied the camping areas, introducing the epizootic back into the campgrounds. Staff estimated that about one-half of the squirrel burrows in the Ice House Campground had been reoccupied in 1995.

Plague is spread within a rodent population by an interchange of fleas within nesting or burrow sites, by direct contact between rodents, and through cannibalism following mortality. When a rodent dies within a burrow, a new inhabitant is likely to occupy the burrow. Non-resident rodents seeking a new home often enter any available burrow system. Surviving infected fleas residing in burrow systems may infect new hosts entering those systems (flea-host transmission). Invading hosts already infected with plague may enter systems and be fed upon by non-infected fleas, which in turn become infected (host-flea transmission). Both factors allow for a continuation of a plague epizootic in a rodent population.

A high density of susceptible rodent hosts amplifies the potential for increased plague epizootic activity. Control

of plague in dense populations of amplifying hosts, such as California ground squirrels, is difficult. Initial control efforts may reduce the number of fleas and lessen the risk of transmission to humans in the immediate area, however, the epizootic may continue among rodents, especially outside of the control area. As disease activity continues, higher numbers of fleas become infective and additional control efforts may become necessary. The continuation of an epizootic and the problems of plague control in a dense ground squirrel population are well documented at Ice House Reservoir.

## CONCLUSION

Human cases of plague will continue to occur in association with epizootics among susceptible rodent species in high use recreational areas in California. Because of the sporadic occurrence of cases and the rarity of physicians having to diagnose or treat patients, cases may not be initially recognized and treatment may often be delayed or inappropriate. Removing the campers from the vicinity of a known epizootic eliminates the immediate threat or human disease. Therefore, the closures of Mountain Camp II, Strawberry Point, Northwind, and Ice House Campgrounds were prudent and in the best interest of campers and workers at these sites. However, there is economic incentive to reopen the area as soon as possible, requiring prompt risk reduction through vector suppression. Expanding investigations into adjacent areas, as was done at Ice House, is necessary to define the areas of concern and protect the public health.

Bait and trap shyness of California ground squirrels, as reported in agricultural environments, is not a problem in campgrounds where squirrels are accustomed to people and a variety of man-made foods. This was clearly shown in animal trapping and in flea and rodent control at Ice House Reservoir. Two percent Diazinon dust applied by hand in burrows and in bait stations for five to seven days was shown to be effective in reducing the fleas on California ground squirrels. Following flea control, rodent management should be considered to maintain animals at levels below thresholds of damage or



Table 6. Indicators of reduced epizootic plague activity between 1994 and 1995, from all areas, Ice House Reservoir, Eldorado National Forest, California.

Antibody Titer	Number of Positives		Additional Indicators	Numbers Found	
	1994	1995		1994	1995
1:32	4	1	Human case	1	0
1:64	2	2			
1:128	1	5	Carcasses found	8	0
1:256	0	1			
1:512	1	0	Carcasses pos/number tested	1/2	0/0
1:1024	0	1			
1:2048	3	1	Flea pools pos/number tested	2/8	0/6
1:4096	1	0			
1:8192	2	0			
GMPT <sup>1</sup>	362	165			

<sup>1</sup>GMPT - Geometric Mean Positive Titer

disease transmission. When label instructions on both prebaiting and application are followed, the use of zinc phosphide treated grain can be an effective rodent management tool. Rodent control with zinc phosphide at Ice House Reservoir demonstrated that the majority of the target animals die underground and non-target mortality may not be a problem.

Overall success of a plague and rodent management program cannot be measured in terms of the success of a single season. One must measure the success and failure of the components of an ongoing program, and monitor the information carefully to eventually obtain the desired program goals.

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# POPULATION DENSITIES AND DISEASE SURVEYS OF WILD PIGS IN THE COAST RANGES OF CENTRAL AND NORTHERN CALIFORNIA

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**ABSTRACT:** In 1994 and 1995, 233 different wild pigs were captured during population research at seven research sites focused primarily in the coastal regions of central and northern California. Mark-resight data and information on wild pig movements were used to assess wild pig population densities at those sites. Population densities ranged from 1.01 wild pigs/km<sup>2</sup> in Mendocino County in 1994 to 3.32 wild pigs/km<sup>2</sup> in Santa Clara County in 1995. Comparisons of population densities between years at three research sites suggested that wild pig populations increased in 1995 in response to favorable forage conditions after the wet fall and winter of 1994-95. Serum samples collected from 462 wild pigs at 28 different sites were screened for exposure to brucellosis and pseudorabies. Preliminary results were that seropositive results for brucellosis were noted at only three sites, whereas no animals were confirmed seropositive for pseudorabies. Although analyses of these two diseases are continuing, test results for trichinellosis, toxoplasmosis, and sylvatic plague reinforce previous warnings to hunters and consumers that sanitary handling and cooking of wild swine meat are warranted.

**KEY WORDS:** feral pigs, *Sus scrofa*, mark-recapture, population estimation, home range, diseases, experimental design, wildlife management

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## INTRODUCTION

Wild pigs (*Sus scrofa*) are an introduced mammal in the United States where they presently occur in at least 20 states including California (Mayer and Brisbin 1991). Populations of wild pigs were first established in California around 1770 with the arrival of the Spanish (many domestic pigs that were released to forage in the oak woodlands around the early Spanish settlements became feral; Barrett and Pine 1980). Subsequent to their initial establishment, wild pigs have increased in number and expanded their range through both natural dispersal and numerous additional introductions by humans. Currently, wild pigs occur in at least 45 of 58 counties in California (Waithman 1995).

Although accurate estimates of population sizes are difficult to obtain, Clark et al. (1983) used annual hunter take survey information to estimate that there were approximately 80,000 wild pigs in California in 1983. However, little is known about the present number of pigs in California because of their high reproductive output (mature females can produce more than 10 piglets/year; Barrett 1978) and the resulting high rate of population growth. Also, pig populations fluctuate in response to changing environmental conditions because of weather-related variation in forage quantity and water availability (Schauss et al. 1990; Sterner 1990). Drought conditions may have severely limited pig numbers in the period from 1987 to 1991. More recently, substantial rainfall during the fall and winter of 1992-93 and 1994-95 has created substantial scope for the expansion of wild pig

populations due to the improved availability of forage and water.

In California, wild pigs are valued by hunters and private ranch lease hunt operations as an important big game species (Tietje and Barrett 1993). For example, from 1990 to 1993 approximately 30,000 wild pigs were taken annually by hunters from private lands and through paid recreation programs (Waithman 1995). However, other constituencies consider wild pigs pests because their rooting behavior can damage agricultural fields and natural areas (Kotanen 1995; Tietje and Barrett 1993). Related to these issues, wild pigs are often the focus of ecological studies and/or eradication efforts (Hone 1995; Katahira et al. 1993; Schauss et al. 1990; Sterner 1990; Baber and Coblenz 1986).

The disease status of wild pigs is another important consideration in their management because wild pig populations may serve as reservoirs of infection for domestic pig herds and/or humans. For example, wild pigs have been implicated as the source of infection of economically important diseases such as pseudorabies virus (PRV) in domestic pig herds. In California, disease surveys have documented serologic evidence of brucellosis and PRV in wild pigs in Monterey, Santa Clara, Tehama, and San Luis Obispo counties, and from San Clemente and Catalina Islands (Timm et al. 1994; Drew et al. 1992; Clark et al. 1983). From a human health perspective, the potential for exposure to zoonotic disease in those people with direct or indirect exposure to wild pigs is also of concern. Hunters and trappers may

receive intensive exposure to diseases in infected tissues and body fluids when field dressing wild pig carcasses. For example swine brucellosis can cause severe acute and chronic disease in humans, and hunters may be exposed when dressing wild pig carcasses and consuming meat from infected feral pigs (Bigler et al. 1977). Also, humans can contract trichinellosis, toxoplasmosis or sylvatic plague from consuming poorly cooked meat or by direct or indirect contact with wild pigs.

Wild pigs have been managed as a big game mammal in California since 1957. Associated with increasing human conflicts with expanding wild pig populations in the 1980s, management strategies for wild pigs are evolving by legislative mandate. Current wild pig management objectives are to maximize recreational opportunities for sportsmen while simultaneously reducing human conflicts with wild pigs through depredation programs (Waithman 1995). Effective management of wild pig populations depends on access to reliable information on their distribution and density throughout California. In 1994, a research group of biologists and veterinarians at the University of California, Davis undertook a study aimed at assessing population densities and disease status of wild pigs in California. The primary objective of the study was to develop techniques and methodologies useful for assessing current and future densities of wild pig populations. This information will be used by the California Department of Fish and Game (CDF&G) to develop and revise management strategies for wild pigs. In addition to conducting population research, wild pig populations were sampled and examined for the seroprevalence of selected zoonotic agents. The disease research is directed at updating and adding to the current knowledge on the distribution and prevalence of diseases such as brucellosis and PRV in wild pig populations. Information on zoonotic agents will

be used to assess the potential for disease transmission from wild pigs to domestic livestock and humans. In this paper, research protocols are detailed and the results briefly summarized of the population and disease research for 1994 and 1995.

## STUDY SITES

Information on wild pig habitat associations and the relative densities of wild pig populations (e.g., hunter killed pig tag return data) was used to select areas for research. Permanent pig range in California includes oak woodland/thickets, oak woodland/grasslands, chaparral, and chaparral/grasslands around reliable water sources. Within these habitat types in northern California, data from hunter killed pig tags indicate that high density pig populations occur primarily in Tehama, Mendocino, and Sonoma counties. Less dense wild pig populations occur in Lake, Colusa and Napa counties. In central California, high density pig populations are focused in Santa Clara, San Benito, Monterey, and San Luis Obispo counties, less dense populations are focused in Santa Cruz, Stanislaus and Santa Barbara counties. In 1994, research was conducted at two sites in Sonoma county, and one site each in Mendocino, and Monterey counties (Table 1). Research was conducted in 1995 at one study site each in San Luis Obispo, Monterey, Santa Clara, Sonoma, Mendocino, and Colusa counties (Table 1). To assess potential changes in wild pig population sizes associated with variation in weather conditions between 1994 and 1995 (precipitation was low in 1994 and high in 1995), in 1995 the population studies were repeated at three of the four sites studied in 1994 (Table 1). In the disease survey research, wild pig serum samples were obtained from several additional sites described in the disease methodology section.

Table 1. U.C. Davis wild pig project population and disease research sites in California in 1994 and 1995.

Site Name	County	Trapping Period	Description
Lake Sonoma Park	Sonoma	May-June 1994	Army Corps of Engineers Reservoir
Bradford Ranch	Mendocino	June-July 1994	Private cattle ranch
Austin Creek SRA	Sonoma	August 1994	California State Park
Rancho San Carlos	Monterey	September-October 1994	Private ranch/land partnership
Chimney Rock Ranch	San Luis Obispo	May-June 1995	Private cattle ranch
Rancho San Carlos	Monterey	June 1995	Private ranch/land partnership
Henry Coe State Park	Santa Clara	July 1995	California State Park
Austin Creek SRA	Sonoma	August 1995	California State Park
Bradford Ranch	Mendocino	August-September 1995	Private cattle ranch
Salt Lake Ranch	Colusa	September 1995	Private cattle ranch

## POPULATION RESEARCH STUDY DESIGN AND METHODS

Early in the project the feasibility, cost, and practicality of several different techniques for estimating wild pig population sizes and densities were reviewed. Based on this review, an experimental design was selected using mark-resight techniques to estimate local population sizes, which, in association with data on wild pig movements, could be used to estimate population densities.

The basic procedure in a mark-recapture study is to capture a number of animals from a population over a short time, mark and then release them, and recapture individuals to check for marks. Information on the proportion of marked animals in the second sample of recaptured individuals can be used to calculate population sizes. The mark-recapture technique is most effective when the initial sample and the sample of recaptured individuals are relatively unbiased with respect to the sex and age structure of the population being sampled. Also, the sample of recaptured animals should be unbiased relative to the original sample of marked animals. Previous studies of wild pigs suggest that adult male and possibly adult females are difficult to recapture (Baber and Coblenz 1986; Schauss et al. 1990). Because of this, automatically triggered camera systems were used to "recapture" pigs by resighting them in order to minimize biases associated with retrapping animals. Mark-resight techniques may be used for open or closed population situations. The wild pig research was designed to approximate a closed population model by resampling with camera systems within one month of the original marking period. Techniques used to estimate population sizes from resight data are detailed below.

### Wild Pig Trapping

Modified panel traps were used to trap wild pigs (trap design described by Sweitzer et al., unpublished manuscript). At each study area an attempt was made to operate a minimum of three traps. Traps were geographically arranged to minimize overlap in trapping areas with respect to wild pig movements. Two factors that are known to influence wild pig trapping success are the selection of sites with recent pig activity and prebaiting of both the potential trap site and the trap itself (Choquenot et al. 1993; Saunders et al. 1993). Suitable trap sites were identified by surveying for evidence of recent wild pig activity (rooting, trails, wallows, and feces). Trap sites were prebaited with a mixture of fermented corn and meat scraps covered by an inverted 19 liter bucket weighted with a rock to secure it in place. Several small, uncovered bait piles were placed along transects at approximately 10 m intervals in the direction of areas of potential pig travel (along animal trails or drainages). Pre-bait stations were checked regularly until pig activity was detected on two to three successive nights, whereupon a trap was established.

Partial traps were initially set up to familiarize pigs with consuming bait in an enclosed area. After pigs consumed bait in the partial traps, complete traps were set up and baited. When pigs had fed inside complete traps for at least one night, traps were set for captures. Because wild pigs can overheat and die when exposed to

warm ambient temperatures (Baber and Coblenz 1986), traps were set at dusk and then checked and processing begun on animals one to two hours before dawn or late at night. Wild pigs were immobilized for processing using a combination of Telazol (3.3 mg/kg) and xylazine (1.65 mg/kg) as described by Sweitzer et al., unpublished manuscript).

### Wild Pig Processing Protocol

Immobilized pigs were removed from traps and hobbled with nylon straps for processing. Samples and data collected during processing included: 1) 20 to 60 cc of blood by jugular venipuncture; 2) dental formulas for aging with Matschke's (1967) tooth eruption schedule; 3) chest circumference and mid-dorsal body length (base of the skull to the top of the tail); 4) body weight ( $\pm 1$  kg); and 5) a sample of ectoparasites (five minute timed search).

All captured pigs were ear-tagged to facilitate identification in camera station photographs. Numbered yellow, orange, red, and white Allflex tags were attached to the ears of adult females, subadult females, adult males, and subadult males, respectively. California Department of Fish and Game tags were placed in the right ears of all animals. Two "ID photos" of individual pigs (one each from the left and right side of pigs) were taken to assist in identifying animals in the camera station photos.

### Resight Techniques and Analyses

Pigs were resighted using photographs from Trailmaster camera systems (TM1500 Active Infrared Trail Monitors with TM35-1 Camera Kits, Goodson & Associates Inc., Lenexa, Kansas). In 1994, a minimum of one camera station per successful trap was used to resight wild pigs at each site. In 1995, two camera stations were used per successful trap to resight animals. Resight operations were conducted within one month of the trapping period at a site. Camera stations were located in areas with pig activity in the vicinity of trap sites (camera stations were generally not placed directly at trap sites). Suitable sites for camera stations were located, prebaited, and monitored for pig activity until trapping terminated, after which camera stations were constructed. The Trailmaster camera systems consisted of a 35 mm fully automatic camera with flash, and an active infrared trail monitor (transmitter and receiver). The Trailmaster system uses the obstruction of an infrared beam of light passing between a transmitter and a receiver to trigger a camera and photograph the animal(s) passing through the beam. The date and time of exposure are automatically recorded on each photograph. At camera stations, the transmitter and receivers were mounted on trees or 0.9 m fence posts approximately 5 to 6 m apart. The two units were mounted so that the light beam between the transmitter and receiver was 35 to 40 cm above ground level. Cameras (linked to the receiver by a cable), were mounted either above the receiving unit or they were offset such that both the receiver and transmitter were visible in the cameras field of view. Uncovered bait piles were placed along the light beam path and two bucket covered bait piles were placed on either side of the light beam.

Trailmaster camera systems can be programmed to take photographs during selected periods of the day. At all sites except Rancho San Carlos, wild pig activity was primarily nocturnal. Thus, camera stations were programmed to take photographs from dusk until dawn at all sites except Rancho San Carlos. At the Rancho San Carlos site wild pigs were more diurnal, camera stations were programmed to take photographs throughout the day. All camera stations were programmed for 5 to 10 minute time delays between photographs in order to obtain multiple photos of wild pig groups consuming bait. Camera stations were monitored and rebaited until at least two 36 exposure rolls of film were used. In general, a minimum of four nights was needed to obtain  $\geq 72$  photographs. On several occasions, however, camera stations were damaged by wild pigs or other animals. Damaged camera stations were either prematurely removed or repaired and operated for longer time periods.

Camera station photographs were examined for marked and unmarked wild pigs using an 8X pocket magnifier. Only one sighting of an individual was counted at a camera station each day. Multiple photographs of pigs visiting camera stations usually allowed for individual identification of tagged animals from ear tag colors and ID photographs. In cases where tagged animals to the individual could not be identified, sightings were scored as "unknown tagged." Photographs in which the ears of pigs were not visible prior to analyses were excluded.

A review of the literature on mark-recapture and mark-resight computer models was conducted to select the most appropriate model for analyzing the wild pig data. Program NOREMARK uses the Lincoln-Peterson model for closed populations to estimate population sizes from mark-resight data (White 1994). Neal et al. (1993) provide an evaluation of this computer model using data on mountain sheep (*Ovis canadensis canadensis*). Program NOREMARK offers four different estimators of population abundance and the Bowden estimator was used to analyze the resight data as suggested by White (pers. comm.).

#### Home Ranges and Density Estimates

Estimated population sizes were converted into densities by using home range data to estimate areas sampled by traps. Information on the home ranges of wild pigs was obtained from literature sources and from 18 wild pigs that were radiocollared during the research. Criteria used for selecting home range data from outside literature sources included: 1) home range data generated from radiocollared pigs; 2) home range information restricted primarily to summer-fall time periods (corresponding to the trapping period); and 3) home range data was for wild pigs from mainland or island systems in California.

Wild pigs that were radiocollared in the study were located a maximum of twice a day to approximate independence of positions. To minimize the influence of bait on wild pig movements, radiotracking was not conducted until after trapping and resight operations had ceased at the research sites. Wild pig locations were determined from visual observations or foom triangulation on compass bearings taken from known positions. A

Trimble Basic Plus geographical positioning system was used to determine map locations of both visual pig observations and positions used for triangulation. Triangulation was done on 7.5 minute USGS topographical maps. Estimates of the minimum convex polygon (MCP) home ranges of wild pigs were determined using a computer software program (RANGES IV, Kenward 1990).

Excluding data from wild pigs at Rancho San Carlos (see below and Table 2), the MCP home ranges from the wild pigs that were radiocollared were very similar to the home ranges of wild pigs from other studies (Table 2). Thus, an overall mean wild pig home range was computed to estimate the area sampled by traps at the research sites (Table 2). However, wild pigs at Rancho San Carlos (RSC) had oversized home ranges relative to animals tracked at other research sites (Table 2). This was potentially because the RSC wild pigs exhibited more Eurasian wild boar characteristics than wild pigs at other sites (RSC was the site for the original introductions of Eurasian wild boars into California in 1925). Because the home ranges of RSC wild pigs were larger than at the other sites, the mean home range size was used for the eight pigs radiocollared at that site for estimating areas sampled by traps there (Table 2).

When the minimum convex polygon home ranges of wild pigs was plotted over their initial capture locations, visual analyses indicated that pigs were often captured near the edges of their ranges. This suggested that baited traps attracted wild pigs from distances of around one home range diameter. Assuming that wild pig home ranges were approximately circular (verified by MCP home ranges), it was estimated that the area sampled by a pig trap was equal to the area of a circle with radius equal to the diameter of an average wild pig home range. Thus, the area sampled by a trap was estimated by the equation  $A = \pi d^2$ , where  $d$  is equal to the diameter of the average wild pig home range. The total area sampled by traps at each research site was determined by calculating the area enclosed by the circles around traps minus areas of overlap.

#### DISEASE INVESTIGATION METHODS

Serum samples were collected opportunistically from 462 wild pigs from December 1993 to October 1995. Blood samples were stored on ice and centrifuged for serum separation within 24 hours of collection. After separation, serum samples were frozen or stored on ice until they could be transported to the University of California, Davis (UC Davis) for storage (samples were stored at  $-80^{\circ}\text{C}$  until analyzed). Serologic testing was conducted by the California Veterinary Diagnostic Laboratory System (CVDLS) in Davis and Fresno, California. Serology for trichinellosis, toxoplasmosis, and plague for 69 animals sampled during 1994 was performed in the laboratory of Dr. Bruno Chomel at the UC Davis. Laboratory examination of the samples collected in 1995 for trichinellosis, toxoplasmosis, and sylvatic plague have not been completed.

Specimens were screened for evidence of exposure to *Brucella* sp. using the buffered acid plate agglutination (BAPA) test, the CARD test, or both, and were interpreted as either positive or negative. The rivanol test

Table 2. Home range estimates (km<sup>2</sup>) for wild pigs in the coastal regions and islands of California. Mean wild pig home range *without* Rancho San Carlos wild boars = 2.44 (SD = 1.65, N = 31). Mean home range for Rancho San Carlos wild boars = 7.35 (SD = 4.10, N = 8).

Research Site	N	Home Range Size (km <sup>2</sup> )	Source
Lake Sonoma Recreation Area, Sonoma County	2	1.97 $\pm$ 0.13	This study, 1994
The Bradford Ranch, Mendocino County	1	2.86	This study, 1994
Austin Creek SRA, Sonoma County	3	3.33 $\pm$ 2.23	This study, 1994
Rancho San Carlos, Monterey County	8	7.35 $\pm$ 4.10	This study, 1994
Henry Coe State Park, Monterey County	4	1.72 $\pm$ 0.71	This study, 1994
Almaden Quicksilver Park, Santa Clara County	5	2.33 $\pm$ 1.82	Schauss, 1988
Grant Park - Mt. Hamilton, Santa Clara County	3	3.11 $\pm$ 0.95	Schauss, 1980
Calaveras & San Antonio Reservoir, Santa Clara & Alameda Counties	2	2.35 $\pm$ 0.35	Schauss, 1992
Santa Cruz Island, Santa Barbara County	10	2.49 $\pm$ 1.98	Sterner, 1990
Dye Creek Ranch, Tehama County	1	1.47	Grover, 1983

was used to confirm the results of positive tests. A specimen was considered suspect if either or both of the BAPA or Card tests were positive and seropositive only if the rivanol titer was greater than or equal to 1:25. The enzyme linked immunosorbent assay (ELISA) and/or latex agglutination (LA) tests were used to screen for exposure to PRV. Confirmation was by serum virus neutralization test (SVN). Statistical analyses were performed using Epi-info version 6. Due to small sample sizes and missing cell values, the Fishers' exact test was used to determine significant differences between groups and sampling sites.

#### POPULATION RESEARCH RESULTS

In 1994 and 1995 a total of 233 wild pigs were captured during research on wild pig populations at seven different sites (three of the seven sites were visited in both years). Trailmaster camera stations were effective for resighting wild pigs; a total of 3,192 photographs of wild pigs was obtained from 53 different camera stations for population size analyses. Resulting mark-resight data and MCP home range data were used to estimate population sizes and densities at each of the study sites.

##### Lake Sonoma

Lake Sonoma was the first site for research in 1994. Six wild pigs were captured in one successful trap with no recaptures over 10 trap nights (trap success = 0.6 pigs/trap night). Three of the six animals captured were radiocollared (Table 2). Two pigs were collared for estimating home range sizes and a third was collared because of a potentially lethal injury sustained upon capture (broken nasal bones). The injured pig was closely monitored via radiotelemetry and recovered. Three camera stations were used to resight pigs. Photos of wild pigs were obtained at two of the three sites. However,

because of limited success resighting pigs at the Lake Sonoma camera stations, observations of wild pigs noted during research activities were used to augment resight data. Using these data, the estimated population size for the 9.73 km<sup>2</sup> area trapped was 12 wild pigs for a density of 1.2 pigs/km<sup>2</sup> (95% C.I. range of 0.6 to 2.6 pigs/km<sup>2</sup>).

##### Bradford Ranch

Research was conducted at the Bradford Ranch in both 1994 and 1995. In 1994 eight wild pigs were captured in three modified panel traps and dogs and dart rifles were used to capture an additional two pigs. One animal was radiocollared here in 1994 (Table 2). Including recaptures, 14 wild pigs were captured over 16 trap nights at the Bradford Ranch in 1994 (Trap success = 0.88 pig/trap night). Three camera stations were used in resight efforts in 1994. Mark-resight data indicated that the estimated population size within the approximately 13.81 km<sup>2</sup> area trapped was 14 pigs for a density of 1.0 pigs/km<sup>2</sup> (95% C.I. range of 0.9 to 1.3 wild pigs/km<sup>2</sup>). In 1995, 10 different wild pigs were captured in two traps at the Bradford Ranch. No animals were recaptured and the trap success over nine trap nights was 1.1 pigs/trap night. Five camera stations were used for mark-resight efforts in 1995. The estimated population size for the 14.53 km<sup>2</sup> area trapped was 17 wild pigs for a density of 1.2 pigs/km<sup>2</sup> (95% C.I. range of 1.0 to 1.3 wild pigs/km<sup>2</sup>). One of the ten animals captured in 1994 was recaptured in 1995 and three others were observed at camera stations. Although the same number of animals was captured in both years, the estimated density of increased by approximately 16% from 1994 to 1995.

##### Salt Lake Ranch

Research was conducted at the Salt Lake Ranch in 1995 (Table 1). Twenty-two different wild pigs in three

traps at the site were captured. Including recaptures, 25 pigs were captured over 10 trap nights (trap success = 2.5 pigs/trap night). Four camera stations were used for mark-efforts. The estimated population size for the 24.81 km<sup>2</sup> area trapped was 44 wild pigs for a density of 1.8 pigs/km<sup>2</sup> (95% C.I. range of 1.5 to 2.2 wild pigs/km<sup>2</sup>).

#### Austin Creek State Recreation Area

Research was conducted at Austin Creek SRA in both 1994 and 1995 (Table 1). In 1994, 15 wild pigs were captured in three traps. Including recaptures, a total of 24 pigs were captured over 17 trap nights (trap success = 1.4 pigs/night) and three pigs were radiocollared to estimate home ranges (Table 2). Three camera stations were used for mark-resight efforts in 1994. The estimated population size within the 21.58 km<sup>2</sup> area trapped was 29 pigs for a density of 1.3 pigs/km<sup>2</sup> (95% confidence interval range of 1.0 to 1.7 pigs/km<sup>2</sup>).

In 1995, twenty-four wild pigs were captured in three traps at Austin Creek SRA. Including recaptures, 35 pigs were captured over 16 trap nights (trap success = 2.2 pigs/trap night). Six camera stations were used for mark-resight efforts in 1995. The estimated population size for the 21.58 km<sup>2</sup> area trapped was 45 wild pigs for a density of 2.1 pigs/km<sup>2</sup> (95% C.I. range of 1.8 to 2.5 wild pigs/km<sup>2</sup>). Of the 15 wild pigs captured at this site in 1994, three were recaptured and a fourth was noted at camera stations in 1995. More wild pigs were captured at the site in 1995 than in 1994. Most importantly, however, the estimated population density increased by approximately 56% from 1994 to 1995.

#### Henry Coe State Park

Research was conducted at Henry Coe State Park in 1995 (Table 1). Fifty-five different wild pigs were captured in five traps at the site. Including recaptures, 81 pigs were captured over 20 trap nights (trap success = 4.1 pigs/trap night). Four wild pigs were radiocollared at Henry Coe State Park and their mean home range was  $1.72 \pm 0.71$  km<sup>2</sup> (Table 2). Ten camera stations were used for mark-resight efforts. The estimated population size for the 29.19 km<sup>2</sup> area trapped was 97 wild pigs for a density of 3.3 pigs/km<sup>2</sup> (95% C.I. range of 2.8 to 3.9 wild pigs/km<sup>2</sup>).

#### Rancho San Carlos

Research was conducted at Rancho San Carlos (RSC) in both 1994 and 1995. In 1994, 54 wild pigs were captured in six traps. Including recaptures, 122 pigs were captured during 30 trap nights (trap success = 4.1 pigs/night). Eight pigs were radiocollared at the site. Seven camera stations were used for mark-resight efforts. The estimated population size within the 54.50 km<sup>2</sup> area trapped was 67 pigs for a density of 1.2 pigs/km<sup>2</sup> (95% C.I. range of 1.1 to 1.4 pigs/km<sup>2</sup>).

In 1995, 28 different wild pigs were captured in six traps at the site. Including recaptures, 36 pigs were captured over 21 trap nights (trap success = 1.7 pigs/trap night). Nine camera stations were used for mark-resight efforts. The estimated population size for the 64.9 km<sup>2</sup> area trapped was 112 wild pigs for a density of 1.7 pigs/km<sup>2</sup> (95% C.I. range of 1.2 to 2.4 wild pigs/km<sup>2</sup>). Fewer pigs were captured at the site in 1995 than in 1994.

Also, although many of the pigs that were marked in 1994 in 1995 were observed, none of the 1994 animals were recaptured. Although the 95% confidence intervals were wide for 1995, the estimated density increased by approximately 41% from 1994 to 1995.

#### Chimney Rock Ranch

Research was conducted at the Chimney Rock Ranch in 1995 (Table 1). Eleven pigs were captured in two successful traps at the site over seven trap nights (trap success = 1.6 pigs/trap night). Four camera stations were used for mark-resight efforts. The estimated population size for the 19.46 km<sup>2</sup> area trapped was 37 wild pigs for an estimated density of 1.90 pigs/km<sup>2</sup> (95% C.I. range of 0.87 to 4.16 wild pigs/km<sup>2</sup>).

### DISEASE INVESTIGATION RESULTS

Blood samples from 69 animals sampled in 1994 were screened for exposure to brucellosis, PRV, trichinellosis, sylvatic plague, and toxoplasmosis. Overall, two animals tested positive for trichinellosis at two different sites, five animals tested positive for plague (all at Rancho San Carlos), and eight animals tested positive for toxoplasmosis (one each at Lake Sonoma and Bradford Ranch and three each at Austin Creek and Rancho San Carlos). There were no differences in the seroprevalence of trichinellosis or toxoplasmosis among the different sex and age classes of wild pigs, or for pigs among study sites. For sylvatic plague, however, location and age group significantly affected seroprevalence results. Higher exposure to sylvatic plague was found at Rancho San Carlos in Monterey county compared to the other three research sites. In analyses with animals from all age categories included, the seroprevalence of sylvatic plague was marginally higher at Rancho San Carlos than at the other three research sites combined (Fisher exact 1-tailed p-value = 0.045). Because exposure to diseases may be a function of age (older animals have an increased duration of disease exposure), the data was partitioned and examined seroprevalence in adults only. For mature adults, the seroprevalence for sylvatic plague was higher at Rancho San Carlos than at the other three research sites combined (Fisher exact 1-tailed p-value 0.002).

Four hundred sixty-two samples collected at 28 different sites during 1994 and 1995 were screened for exposure to brucellosis and PRV. Fourteen wild pigs from three sites tested positive for brucellosis and no animals were confirmed positive for PRV. Additional analyses of these data will be presented elsewhere.

### DISCUSSION

#### Wild Pig Trapping

Success at trapping wild pigs was contingent on surveys for pig sign, pre-baiting at potential trap sites, and free-baiting traps prior to captures. Trap success at Lake Sonoma was low because of limited pre-baiting and poor initial trap design (Sweitzer et al., unpublished manuscript). With the standard surveying and baiting protocols, trapping success averaged a relatively high 2.4 pigs/trap night. In Santa Clara County, California, for example, Schauss et al. (1990) used box traps and noted an average trap success of 3.2 pigs/trap night during the summer months. Two different wild pig studies in



Australia reported trap successes of 1.0 and 2.0 pigs/trap night using square panel traps (Choquenot et al. 1993; Saunders et al. 1993). In general, it was possible to move to prebait, and capture and mark animals within three weeks.

#### Mark-Resight Techniques

Trailmaster camera stations were effective at resighting marked pigs for population estimation. Although some camera stations were placed along trails in areas with pig activity, sighting pigs when stations were pre-baited and set-up in the vicinity of pig wallows was most successful. Using two camera stations for each successful trap in order to enhance resight coverage and enhance the precision of population estimates is recommended. With prebaited camera station sites and 5 to 10 minute camera delays, it was possible to run through two 36 exposure rolls of film in less than seven days.

#### Wild Pig Populations

In the 1994 population research, wild pig densities were uniformly low across all four sites (mean density = 1.21 wild pigs/km<sup>2</sup>). Low population densities in 1994 may have been the combined result of low precipitation and poor acorn crops in the fall and winter of 1993-94. When landowners, hunters, and resource managers were questioned, for example, nearly all thought that pig populations had declined in 1994 because of these factors. By contrast, after near-record precipitation in the fall and winter of 1994-95, population densities were 16% to 56% higher at the three sites where population research was repeated. These results suggest that wild pig populations in central and northern California increased in response to the increased availability of forage after the wet fall and winter of 1994-95. How the availability of acorns in fall 1994 may have interacted with weather conditions to enhance the growth of the different populations has not been examined. For example, wild pig densities increased proportionally more at Austin Creek SRA than at Rancho San Carlos and the Bradford Ranch, potentially related to regional variation in acorn production in fall 1994. Hunting pressure may also affect wild pig population densities. In 1995, for example, wild pig densities were highest at Austin Creek SRA and Henry Coe State Park where hunting is not allowed. Preliminary comparisons of minimum population sizes from camera station sightings with the mark-resight estimates suggest that the computer program NOREMARK underestimated wild pig population sizes. This potential bias will be investigated further and other mark-recapture microcomputer programs will be investigated for their accuracy in predicting population sizes using camera station sighting data.

#### DISEASE INVESTIGATIONS

Preliminary results from the disease research suggest that wild pig populations have low prevalences of brucellosis and PRV. Serum samples collected from 462 wild pigs at 28 different sites were screened for exposure to brucellosis and PRV. Seropositive results for brucellosis were noted at only three sites, whereas no wild pigs were confirmed seropositive for PRV. Although few

wild pigs were seropositive for brucellosis, the infected herds were nonrandomly distributed and the seroprevalence in the infected herds was relatively high. Also, the disease results do not preclude the presence of PRV in areas not well sampled, and analyses of the brucellosis and PRV data are continuing. Seropositive test results for Trichinellosis (2.9%) and toxoplasmosis (11.6%) reinforce the previous warnings to hunters, butchers, and consumers that sanitary handling and thorough cooking of meat from feral swine are warranted.

The disease data on sylvatic plague from the four 1994 study sites were compatible with the known spatial distribution of the disease agent in California (Jay and Chomel 1994). The probability of exposure to plague appears to be greater in mature adults than in piglets and juveniles. As with other diseases, this is probably at least partly a function of the increased duration of exposure for adults. Clark et al. (1983) suggested that wild pigs may be a better sentinel species than coyotes or black bear for monitoring sylvatic plague, since hunting is conducted all year long. These assumptions require further testing through continued research on feral swine in California.

#### CONCLUSIONS AND FUTURE RESEARCH

In this paper, methods and preliminary results from two years of research were detailed on wild pig populations in California. Although the wild pig trapping and mark-resight techniques are effective at providing information on wild pig populations, the authors are working on a less labor intensive approach to estimate densities that may be more useful for management. Initial indications are that it is possible to individually identify unmarked pigs from camera station photographs. This is important because it may be possible to use automatic camera stations to gather population information on wild pigs without trapping and immobilizing the animals to mark them. Use of this camera station technique, however, will need to be validated using population estimates from more traditional mark-resight methodologies.

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# PRELIMINARY STUDY OF THE GENETICS OF RESISTANCE IN THE HOUSE MOUSE

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**ABSTRACT:** A wild house mouse (*Mus domesticus*) population originally trapped near Reading, Berkshire, United Kingdom, and maintained as a colony in the laboratory, was subjected to the discriminating feeding period of the warfarin resistance test, as used by Wallace and MacSwiney (1976) and derived from the work of Rowe and Redfern (1964). Eighty percent of this heterogeneous population survived the resistance test. A similar proportion of the population was found to survive the normally lethal dose of bromadiolone administered by oral gavage. The majority of this population of mice were classified as "warfarin-resistant" and "bromadiolone-resistant." The dose of 10mg.kg<sup>-1</sup> of bromadiolone administered by oral gavage appeared to give good discrimination between susceptible and resistant individuals. The results of breeding tests indicate a single dominant gene that confers both "warfarin-resistance" and "bromadiolone-resistance," with complete expression of the resistance genotype in both males and females. Individual mice were classified as to genotype by back-crossing to a homozygous-susceptible strain, and resistance-testing the F1 generation. Separate strains of homozygous-resistant and homozygous-susceptible house mice are now being established.

**KEY WORDS:** rodenticide resistance, warfarin, bromadiolone, house mouse

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## INTRODUCTION

House mice (*Mus domesticus*) (Marshall and Sage 1981) have a naturally low susceptibility to first generation anticoagulants. For example, the acute oral LD<sub>50</sub> is reported for warfarin to be 374 mg.kg<sup>-1</sup> (Hagan and Radomski 1953) and for diphacinone to be 250 to 300 mg.kg<sup>-1</sup> (Itoh et al. 1973).

Warfarin resistance in the house mouse was first described by Dodsworth (1961), although at that time it was not considered to be widespread. Rowe and Redfern (1964) acknowledged that some house mouse populations were extremely difficult to kill with warfarin and, therefore, investigated its toxicity to mice in the laboratory. The test animals were obtained from breeding pens which were stocked from 13 different localities where no previous warfarin treatment had been carried out. In the test, individually caged mice were offered an unrestricted amount of 250 ppm warfarin for a fixed number of days, weighing food consumption, and recording survival or mortality. Thirteen mice were tested over a 28-day feeding period resulting in complete mortality. However, of 53 mice tested over a 21-day feeding period, five animals survived. Rowe and Redfern (1965) suggested that these survivors are indicative of the probable presence of mice "resistant" to 250 ppm warfarin in any sizable mouse population.

Apart from the work of Rowe and Redfern (1964), which was concerned specifically with the toxicity of warfarin to house mice, there is no published laboratory test to identify anticoagulant-resistance in the house mouse. On the basis of the results of Rowe and Redfern (1964), Wallace and MacSwiney (1976) used a 21-day feeding period on a 250 ppm bait as a warfarin-resistance test to discriminate between warfarin-resistant and warfarin-susceptible individuals. In this way, they were able to demonstrate that warfarin resistance in the house mouse was controlled by a major resistance gene, which they designated "War;" whose expression was very variable and strongly influenced by modifiers (MacSwiney

and Wallace 1978).

This paper deals with a stock of wild house mice (*Mus domesticus*) trapped near Reading, Berkshire, United Kingdom (UK). The mice were initially shown to be resistant to warfarin by the 21-day warfarin feeding test (Rowe and Redfern 1964). Subsequently, it was found that the warfarin resistant stock were relatively resistant to bromadiolone, and a dose of bromadiolone was established that would distinguish between the susceptible and resistant phenotypes. This was then used to demonstrate single factor inheritance of the resistance.

## METHODS

Wild anticoagulant-resistant stock were derived from mice trapped from a warfarin-resistant infestation near Reading (Berkshire, UK), and subsequently maintained in population pens. The anticoagulant-susceptible stock were albino Swiss mice (CD-1) obtained from Charles River UK Ltd.

Except where stated, all animals were maintained on laboratory diet (PCD MOD [C] FG; Special Diet Services; Wiltham, Essex, UK). This diet contains a supplement of vitamin K<sub>3</sub> at 10 ppm.

Warfarin was obtained as a proprietary 250 ppm bait formulation. Bromadiolone was obtained as a proprietary 0.1% liquid concentrate and as a 0.23% liquid concentrate. The concentrations of warfarin and bromadiolone were verified by HPLC.

### Lethal Feeding-Period Test

Five male and five female wild mice were weighed, individually caged in stainless steel test cages with mesh floors, and maintained on ground laboratory diet in food bowls which were held in place by metal clips. Food consumption was measured daily for each mouse, taking spillage into account. The test animals were then presented with the 250 ppm warfarin diet for a no-choice feeding period of 21 days. Again food consumption was measured daily for each mouse, taking spillage into

account. The animals were then maintained on the ground laboratory diet for an observation period of 28 days. Throughout the experiment, the test animals were inspected for signs of toxicosis. At death, or at the end of the observation period, the animals were weighed again.

#### Intubation

Groups of animals were either received from Charles River UK Ltd., or removed from the population pen, and maintained in single sexed groups for an acclimatization period. They were then weighed, and dosed by gavage with the required concentration of bromadiolone at a rate of 1 ml per 100 g body weight; to achieve the highest dosage of 34.5 mg.kg<sup>-1</sup>, the 0.23% concentrate was dosed at a rate of 1.5 ml per 100 g body weight. Animals were not starved prior to dosing. They were then maintained in single sex groups for an observation period of 21 days. Throughout the experiment, the test animals were inspected for signs of toxicosis.

### RESULTS

#### Feeding Test With Warfarin

The results of the 21-day warfarin feeding test are presented in Table 1. Only two out of the ten animals died. They had consumed less than 30% of the warfarin formulation consumed by the survivors. The eight survivors showed no reduction in daily food consumption during the test, demonstrating a high level of resistance to warfarin. The contrast in the amount of active ingredient consumed by the survivors and those that died, suggests two distinct levels of susceptibility to the anticoagulant. The results indicate that 80% of the house mouse stock were warfarin-resistant and 20% were warfarin-susceptible.

Table 1. Wild house mice—mortality and warfarin dose consumed during 21-day no-choice feed on warfarin bait.

Sex	Mortality	Dose of warfarin consumed (mg.kg <sup>-1</sup> )	
		<u>Survived</u> mean (range)	<u>Died</u> mean (range)
Male	0/5	808 (657-1084)	-- --
Female	2/5	973 (842-1077)	195 (149-241)

#### Bromadiolone Toxicity By Gavage

The results of the initial bromadiolone gavage tests with the "Reading" house mice are presented in Table 2. Of the 30 mice that received a potentially lethal dose of bromadiolone, three animals died (10%). The proportion of animals that survived bromadiolone was comparable with the 80% of animals that survived the 21-day warfarin feeding test, suggesting a high level of cross-resistance between the two anticoagulants.

The results of the bromadiolone gavage tests with the anticoagulant-susceptible Swiss mice are presented in Table 3. A bromadiolone dose of 1.8 mg.kg<sup>-1</sup> body weight achieved incomplete mortality in both males and females. A dose of 0.9 mg.kg<sup>-1</sup> gave no mortality, and a dose of 3.6 mg.kg<sup>-1</sup> and above, gave complete mortality.

Table 2. Wild house mice—mortality following intubation with bromadiolone over a range of doses.

Dosed (mg.kg <sup>-1</sup> )	Sex	Mortality
2.9	male	1/3
2.9	female	0/3
5.8	male	1/3
5.8	female	1/3
11.5	male	0/3
11.5	female	0/3
34.5	male	0/6
34.5	female	0/6

Table 3. Anticoagulant-susceptible Swiss mice—mortality following intubation with bromadiolone.

Dosed (mg.kg <sup>-1</sup> )	Sex	Mortality
0.9	male	0/10
0.9	female	0/10
1.8	male	7/10
1.8	female	7/10
3.6	male	10/10
3.6	female	10/10
7.2	male	10/10
7.2	female	10/10

#### Breeding Experiments

The inheritance of the bromadiolone resistance was examined by setting up a series of breeding experiments in which the putative resistance gene is represented by *R*, and its allele for susceptibility is represented by *r*. The principal type of design employed was the Test-Cross, in which the wild mouse of unknown genotype (*RR*, *Rr* or *rr*) is crossed with a mouse of the anticoagulant-susceptible Swiss strain, which is of known genotype *rr*. In a Test-Cross, assuming unifactorial dominant inheritance, the expected proportions of resistant offspring of homozygous resistant (*RR*), heterozygous (*Rr*) and homozygous susceptible (*rr*) parents are 100%, 50%, and 0%, respectively. If the Test-Cross offspring were given a dose of bromadiolone that would selectively kill susceptible animals, then assuming a dominant gene, mortality for offspring of homozygous resistant (*RR*), heterozygous (*Rr*) and homozygous susceptible (*rr*) parent would be 0%, 50%, and 100%, respectively.

As a discriminating "Gavage Test" bromadiolone was administered at 10 mg.kg<sup>-1</sup> body weight, a dose between 5.7 and 10.1 times greater than published LD<sub>50</sub> values, and which would be lethal to susceptible Swiss mice (Table 3), but that was much less than the maximum dose survived by the putative "resistant" Campus Main Water Distribution System Upgrade - Phase I house mice (Table 2).

The results of Test-Crosses for 29 untreated wild mice are shown in Table 4. Significantly more females (10/14) than males (5/15) were homozygous resistant ( $\chi^2 = 5.32$ ; d.f. = 1;  $p = 0.02$ ), suggesting a sex-related effect on the fitness of the resistance genotype.

Mortality using the male Test-Cross offspring was 19.8% (39/197), slightly but not significantly greater than the 18.4% using the female Test-Cross offspring; 29/158 ( $0\chi^2 = 0.049$ ; d.f. = 1;  $p = 0.8-0.9$ ).

Mortality among the offspring of putative heterozygotes was 44% (68/153), slightly less than the theoretical 50% ( $\chi^2 = 1.67$ ; d.f. = 1;  $p = 0.1$  to 0.05). Litter size was substantially greater where the female parent was a Swiss mouse (mean litter size of 15.7; compared with 8.6 for wild females), presumably owing to the superior mothering ability of the domesticated strain.

If we define resistance as 100% survival, and susceptibility as 100% mortality in the Gavage Test, then the results are consistent with the hypothesis that the bromadiolone resistance is due to a single dominant autosomal gene. On this basis, assuming no selection within the population pen, the frequency of the resistance gene can be calculated to be 0.74, and the theoretical frequencies of the *RR*, *Rr*, and *rr* genotypes as 0.55, 0.38, and 0.07, respectively.

#### Development of Wild Homozygous Strains

The breeding nucleus of a putatively homozygous resistant strain of pure wild ancestry was formed from the eight mice (two males and six females) indicated by asterisk in Table 3. To date all 40 of their offspring have received and survived a Gavage Test.

The female mouse 94/16 (Table 3) was shown by the Test-Cross to be of the susceptible (*rr*) genotype. It was crossed with a wild heterozygote and the offspring were Test-Crossed. By this means, two homozygous susceptible (*rr*) offspring were identified, and were mated together to form the breeding nucleus of a bromadiolone-susceptible strain of pure wild ancestry. The Gavage Test has given complete mortality in all eight of their offspring tested to date.

#### DISCUSSION

Published  $LD_{50}$  values for bromadiolone are 0.99 mg.kg<sup>-1</sup> (Meehan 1978) and 1.75 mg.kg<sup>-1</sup> (Grand 1976). Other published bromadiolone toxicity data against the house mouse refer to no-choice feeding tests, where the animals are fed bromadiolone bait, normally containing 50 ppm of active ingredient for a pre-determined period of whole days. Since a mouse would normally consume between 10 to 20 mg.kg<sup>-1</sup> body weight of active ingredient per day, feeding on a 50 ppm formulation in a no-choice situation, this type of toxicity data is of little value in determining the toxicity of bromadiolone to a susceptible house mouse.

The bromadiolone toxicity data presented for anticoagulant-susceptible Swiss mice in Table 3 correspond well with the published acute oral  $LD_{50}$  value of 1.75 mg.kg<sup>-1</sup> (Grand 1976), and provide support for the Gavage Test, that dosing at 10 mg.kg<sup>-1</sup> is lethal to anticoagulant-susceptible mice.

Although the risk that the test misidentified a few animals cannot be excluded at this stage, the results of the breeding study strongly indicate a genetic basis for bromadiolone resistance in the wild "Reading" mice, which is consistent with a single dominant autosomal gene controlling the resistance phenotype.

There are numerous reports in the literature of house mice suspected to be resistance to the second generation anticoagulant bromadiolone, based on their survival of a 21-day feeding test on the field strength (50 ppm) formulation.

Rowe et al. (1981) investigated the efficacy of 50 ppm bromadiolone against groups of house mice in a pen environment with alternative food available, and in six field treatments. Survivors from both the pen and the field were subjected to either a 50 ppm or a 100 ppm bromadiolone formulation for a no-choice feeding period of 21 days. Ten individuals survived after consuming between 118 and 410 mg.kg<sup>-1</sup> body weight of bromadiolone.

MacNicoll and Gill (1987) considered 11 out of 30 wild house mice were resistant to bromadiolone following their survival of a 21-day feeding test on a 50 ppm bromadiolone formulation.

Lund (1984) investigated the effect of bromadiolone against the *Mus musculus* species of house mice trapped from Denmark and southern Sweden, using no-choice feeding tests of up to ten days duration, and formulation strengths of 50 ppm and 100 ppm. He reported mice surviving following consumption of up to 115.8 mg.kg<sup>-1</sup> body weight of bromadiolone, and considered that this was resistance of practical importance.

Unlike the major gene controlling warfarin-resistance in the house mouse (Wallace and MacSwiney 1976), the putative gene controlling bromadiolone resistance in the "Reading" mice would appear to be fully expressed in both males and females. This may be an artifact of the test doses chosen, since in resistance studies the expression of a gene always varies with the dose administered.

Rowe and Redfern (1967) in a study with LAC Grey mice, noted that male mice were more susceptible to warfarin than female mice. The incomplete dominance of the warfarin resistance gene, as reported by Wallace and MacSwiney (1976) may indicate that the 21-day feeding test on a 250 ppm warfarin bait was too severe to effectively separate resistant from susceptible male individuals. Although this discriminating feeding period distinguished resistant and susceptible female mice effectively, a number of male warfarin-resistant mice must have died as a result of the feeding test, and have been misclassified. The original toxicity data of Rowe and Redfern (1964) made no attempt to establish a resistance baseline, and gave no mention of the increased susceptibility of male mice, which they were to report in their later publication.

Although practical bromadiolone resistance occurs in field populations of house mice, the authors have as yet no evidence that the levels detected in the "Reading" stock are of significance. This will require further investigation.

Table 4. Genotype determination of wild house mice, by performing a Test Cross with an anticoagulant-susceptible mouse, and testing the litter with a Gavage Test (dosing bromadiolone at 10 mg.kg<sup>-1</sup> body weight).

Animal No.	Sex	Test Cross Litter		Mortality following Intubation of Bromadiolone at 10 mg.kg <sup>-1</sup>		Suspected Resistance Status of Wild Parent
		Males	Females	Males	Females	
93/1*	male	4	7	0/4	0/7	<i>RR</i>
93/2*	male	5	9	3/5	3/9	<i>Rr</i>
93/3*	female	6	4	0/6	0/4	<i>RR</i>
93/5*	female	3	7	0/3	0/7	<i>RR</i>
93/6*	female	11	0	0/11	0/0	<i>RR</i>
93/7*	female	7	2	0/7	0/2	<i>RR</i>
93/8*	female	1	9	0/1	0/9	<i>RR</i>
93/9*	female	1	7	0/1	0/7	<i>RR</i>
93/10	male	6	8	4/6	6/8	<i>Rr</i>
93/11*	male	6	6	0/6	0/6	<i>RR</i>
93/12	male	11	8	9/11	3/8	<i>Rr</i>
93/13	male	6	8	1/6	1/8	<i>Rr</i>
93/14	male	6	5	2/6	2/5	<i>Rr</i>
94/1	male	8	6	4/8	1/6	<i>Rr</i>
94/2	male	8	5	6/8	3/5	<i>Rr</i>
94/3	female	4	4	2/4	1/4	<i>Rr</i>
94/4	male	7	5	5/7	1/5	<i>Rr</i>
94/5	male	7	7	2/7	2/7	<i>Rr</i>
94/6	male	3	4	1/3	0/4	<i>Rr</i>
94/7	male	7	5	0/7	0/5	<i>RR</i>
94/8	male	5	10	0/5	0/10	<i>RR</i>
94/12	female	5	2	2/5	0/2	<i>Rr</i>
94/13	female	5	3	0/5	0/3	<i>RR</i>
94/15	female	4	3	0/4	0/3	<i>RR</i>
94/16	female	4	5	4/4	5/5	<i>rr</i>
94/17	male	6	8	0/6	0/8	<i>RR</i>
94/18	female	5	3	0/5	0/3	<i>RR</i>
94/20	female	4	5	0/4	0/5	<i>RR</i>
94/21	female	3	3	3/3	1/3	<i>Rr</i>

*RR* = homozygous resistant

*Rr* = heterozygous resistant

*rr* = homozygous susceptible

\*This was referred to earlier in text.

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## A PROFILE OF DEPREDATING MOUNTAIN LIONS

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**ABSTRACT:** Information regarding the demographics and physical condition of mountain lions (*Felis concolor*) killed during damage control efforts in Nevada was gathered and compared to sport harvested mountain lions. The average age of depredating male lions was 4.92 years of age compared to 4.95 years for sport harvested males. Depredating female lions were older than sport harvested females averaging 5.09 years compared to 4.44 years. Older age class mountain lions of both sexes were more likely to commit depredations than expected. Male lions were involved in depredations 45% more often than females. Domestic sheep comprise more than 90% of depredation events in Nevada.

**KEYWORDS:** animal damage control, wildlife management, mountain lion, puma, cougar, depredation, population characteristics

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### INTRODUCTION

In 1864, the Reese River Reveille, an Austin, Nevada, based newspaper recorded the first incident involving a conflict between the mountain lion and livestock. Since that first incident the control of depredating mountain lions has been a focus of debate between livestock producers, preservationists, mountain lion hunters and big game hunters. Mountain lion depredation management by the Nevada Animal Damage Control Program (ADC) was developed and has evolved with the participation from these stakeholders.

Mountain lion depredation management by the Nevada ADC Program has essentially moved through three phases since its inception in 1915. The first phase involved the focused attempt to control numbers of coyotes and the incidental take of mountain lions. From 1917 until 1949 this effort yielded an average of 3.1 lions per year and a total of 103 lions. In 1947, the ADC program began a second phase with a program to reduce lion numbers and hired a full time lion hunter to facilitate that objective. From 1950 when the project objective became operational until 1969, 1,821 lions were taken by ADC. The average kill per year during this phase was 91 lions. In the mid 1960s the mountain lion was classified by the State Board of Fish and Game Commissioners as a game animal. This classification, along with a national shift in sensitivity to environmental issues and predator management, fostered the implementation of the third phase of the mountain lion damage control program. The third phase, beginning in 1970, directed control efforts only to lions that were actively depredating. Since 1970, a total of 943 mountain lions have been taken on depredation complaints and averaging 37.7 per year.

Although many mountain lions have been taken during this third phase, the number of depredation complaints and livestock losses continue to rise and fall in synchrony with the lion population trends. The current program is effective at limiting mountain lion depredations once an event has occurred. This paper will explore some demographic characteristics of depredating lions in Nevada.

### METHODS

Each mountain lion killed by sport hunters or ADC Specialists since 1970 in Nevada has been validated by the Nevada Division of Wildlife. As part of the validation process State biologists collect data on the age, sex and physical condition of the dead lion. These data are stored in a statewide computer database. Mountain lion ages are determined by a physical evaluation of the tooth wear, staining, tooth eruption and the occurrence and degree of spotting on the pelage. These criteria were developed by Ashman during the 1970s and reported in Ashman et al. 1983.

The physical condition of mountain lions was determined by examination and interviews with the hunters. Nevada regulations require that a hunter only retain the head and hide for validation resulting in most carcasses remaining in the field. Hunters were queried about the general condition of the lion, generally rating the lion from starving to excellent. Hunters are asked about fat observed on the carcass and the estimated or actual body weight. The subjective evaluation of the hunter or examining biologist was scaled to a rating scale from one for a lion in starving condition to five for a lion rated as in excellent body condition. Female lions that had dependent kittens were reported, but not compared with the sport harvest take of females.

The actual weights recorded for lions taken by both sport hunters and mountain lions taken on depredations were collected. Only actual weights were compared in this analysis, however, no allowances were made for stomach contents.

Analysis was conducted on all age classes of mountain lions once the animal became independent of its mother. All lions that were aged older than 1.5 years were assumed to be independent. Basic descriptive statistics were developed to describe means, standard deviations and standard errors. Comparisons between sport harvested mountain lions and depredating mountain lions were computed using Chi square tests, two sample t-tests, one sample t-tests and ANOVA tests.



## RESULTS

Evaluations were made of 3,129 mountain lion mortality reports from mountain lions taken in Nevada from the period between 1970 and 1994. A total of 943 mortality reports resulted from the kill of mountain lions at depredation events. This sample included 772 mountain lions judged to be at least 1.5 years of age. A total of 2,051 mountain lions was harvested during the same period in Nevada's sport hunting program. Of these lions, 1,875 were judged to be at least 1.5 years of age.

A strong bias was expected to exist between the sexes of sport harvested mountain lions. Most sport hunters reportedly attempt to select large males for their trophy quality. The ratio of sport harvested males to females is 1.36:1. Mountain lions killed during depredation events are hunted based upon the fact that an event occurred without regard to the size or sex of the offending lion. The ratio of males to females from the ADC sample was 1.45:1 (Table 1). Anderson (1983) concluded that data do not exist to make a valid estimation of natural sex ratios. Subsequent modeling and research (Hemker 1984, Lindzey 1987, Logan 1983) indicate that male to female sex ratios should be less than 1:1. Both methods of a kill are significantly different from the projected proportions of males in the population. No significant difference between the type of kill and sex was detected.

Table 1. Sex ratios—lions older than 1.5 years.

	Males	Females	Ratios
ADC	456	315	1:45:1
Sport	1079	796	1:39:1
Modeled Population			0.95:1

Ages of male lions killed during the sport hunting program were compared with those males killed by ADC specialists. The average age of males killed by sport hunters was 4.95 years (n=1079) compared with 4.92 years (n=457) of age for ADC lions. This difference was not significant ( $p < 0.79$ ). The mean age of females killed during the sport hunting season was different ( $p < 0.0008$ ) than ADC killed females with a mean age of 4.44 years (n=796) compared with 5.09 years (n=316) of age, respectively (Table 2). Both male and female ADC mountain lions showed significant tendencies toward a bimodal age distribution. Male and female mountain lions from two years to six years of age showed age frequencies that are within expected values for a lion population. Male lions seven years of age and older were

Table 2. Age Samples.

Age	Male			Female		
	ADC	Sport	Modeled	ADC	Sport	Modeled
1-2	93	91	100	73	154	100
2-3	78	172	69	51	174	69
3-4	59	233	63	33	154	63
4-5	47	204	51	35	107	51
5-6	36	158	41	29	75	41
6-7	49	100	33	27	46	33
7-8	68	60	26	34	29	26
8-9	10	23	21	4	12	21
9-10	8	34	17	12	39	17
10+	8	4	12	17	6	12
Totals	456	1079	NA	315	796	NA
Average Age	4.92	4.95		5.09	4.44	

significantly ( $p < 0.004$ ) more common in the ADC kill than they should exist in a natural population. Female mountain lions seven years and older were also represented in the ADC kill at a greater frequency than they exist in a natural population ( $p < .047$ ).

Body condition can be evaluated by both weight and condition. Mountain lion body weight was determined from whole carcass weights taken from mountain lions shortly after death. The body conditions were subjectively rated for both sport harvested and ADC

killed mountain lions. The rating scale ranged from one to five, with a one being equivalent to a lion described as starving and a five describing excellent condition. Male weights were not significantly different between sport harvested and depredating mountain lions. Depredating males weighed 60.3 kg (n=49) compared to 63.0 kg (n=305) for sport harvested males. Female weights were significantly different ( $p < 0.0001$ ) between sport harvested and depredating animals. Depredation females weighed 39.7 kg (n=36) with sport harvested females weights averaging 45.0 kg (n=175). Body condition ratings for male lions were 3.9 for depredation and 4.1 for sport harvested cats. Females rated 3.8 for both classes of animal.

## DISCUSSION

Demographic and physical characteristics of mountain lions involved in a depredation do not appear to show any particular deviation from sport harvested lions, except older age class lions. Both classes of mountain lion kill differ from the expected representation of both sex and age classes in the population.

Male mountain lions are more likely to be involved in a depredation event compared to females. Male mountain lions that are in older age classes (seven+ years) are more likely to be involved in a complaint than they exist in the population.

Management practices that limit the number of old age class male lions in a population may decrease the number of depredation events in Nevada.

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# LEG INJURIES TO COYOTES CAPTURED IN STANDARD AND MODIFIED SOFT CATCH® TRAPS

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**ABSTRACT:** Leg injuries of coyotes (*Canis latrans*) captured in standard No. 3 Soft Catch traps were compared with those captured in the same trap type modified with two additional coil springs. One hundred thirteen coyotes were trapped in southern California in conjunction with livestock predator control operations, 53 in standard traps, and 60 in modified traps. Observed injuries were similar in both trap types. The most frequent injuries were edematous hemorrhages and small cutaneous lacerations. Injuries, such as joint luxations and bone fractures, were noted more frequently for coyotes trapped in standard Soft Catch traps.

**Key words:** *Canis latrans*, coyote, capture, injury, trap

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## INTRODUCTION

Foothold traps are commonly used to harvest coyotes for fur and as a depredation management tool. Opposition to the use of traps has increased in recent years due to public concern that foothold traps inflict unacceptable injuries to trapped animals. Recent research on padded traps has shown that the No. 3 Soft Catch<sup>1</sup> trap (Woodstream Corporation, Lititz, PA) can be used to successfully capture coyotes while producing only minor leg injuries (Olsen et al. 1986; Linhart et al. 1988; Linhart and Dasch 1992; Onderka et al. 1990; and Phillips and Mullis 1996). Other research has demonstrated that coyote traps with unpadded jaws typically cause more injury than padded models (Phillips et al. 1996). Despite the positive results with the Soft Catch trap, some field personnel with the U.S. Department of Agriculture's Animal Damage Control (ADC) Program have observed that the standard coil springs on the trap weaken after repeated use (M. Small, pers. comm. 1995). Reduced spring pressure may result in some coyotes escaping by pulling their foot from the trap, thereby reducing capture efficiency. To correct this problem, many Soft Catch traps used in California by ADC personnel have been equipped with two additional springs to increase the clamping force and closure speed of the trap.

The effect of this modification on leg injuries of trapped coyotes is undetermined. To make this determination, a study was conducted to compare coyote limb injuries associated with standard and modified Soft Catch traps used in coyote depredation control.

## METHODS

Coyotes were captured by two experienced trappers (ADC Specialists) in southern California from February to August 1995. The two trappers had more than 50 years of combined experience in capturing coyotes. Coyotes were captured as part of routine livestock depredation control activities with all traps checked daily. Each trapper was issued 72 new No. 3 Victor Soft Catch traps, 36 of which were modified with the addition of a "taos lightning" spring kit (J. C. Conner, Newcomerstown, OH). Modification included the addition of a double torsion spring made of music wire and a longer spring pin. The springs in the kit were smaller and weaker than the No. 1.75 springs on the standard Soft Catch trap. The addition of the spring kit allowed each trap lever to be powered by two coil springs instead of one. Clamping force of the traps (2.1 kg/cm<sup>2</sup> for the standard trap and 3.6 kg/cm<sup>2</sup> after modification) was measured by attaching a tension load cell to one jaw of the trap and recording the pressure exerted on the load cell when the jaw is within approximately 1.24 cm (0.5 inch) of closure. All traps were equipped with a center-mounted, 36-cm kinkless chain connected with an in-line shock spring and anchored to a stake. Each captured coyote was euthanized and the trapped leg removed near the elbow or knee joint. All legs were tagged showing the name of the trapper, date, and trap type. Legs were sealed in plastic bags and frozen until necropsies were performed.

Necropsies were conducted at the University of Wyoming's State Veterinary Laboratory. The pathologist (ESW) performed the necropsies without knowledge of the trap type associated with a particular leg. Leg injuries were identified and assigned numerical scores based on a Trauma Scale (modified from the Olsen Scale, Olsen et al. 1986) developed through the international standards process (Jotham and Phillips 1994). Limb injury scores were compared among trap types with the Kruskal-Wallis Test (Siegel 1956).

<sup>1</sup>Mention of commercial products is for identification and does not constitute endorsement by the authors or the federal government.

## RESULTS AND DISCUSSION

The authors examined 113 coyote legs; 53 from standard Soft Catch traps and 60 from modified Soft Catch traps. Some degree of edematous swelling or hemorrhage was observed in nearly all of the legs (96%) with no apparent difference among trap types (Table 1). Lacerations were noted in 83% of the legs from standard traps while only 73% of the coyotes captured in modified traps received cuts. The frequency of edematous swelling and laceration injuries was similar to the finding for coyotes captured in unpadded traps (Phillips et al. 1996).

A higher frequency of more serious injuries (those scoring 25 points or more) such as ligament severances, joint luxations, and bone fractures were associated with capture in the standard trap (Table 1). Fourteen joint luxations were noted in 53 legs (26%) taken from standard traps while only 4 (7%) were found in modified traps.

Five 100-point injuries were observed for coyotes captured in standard traps while none were noted for modified traps. These injuries included two major joint luxations, two compound fractures, and one major tendon severance.

Table 1. Frequency of limb injuries for coyotes captured in California from February to August 1995 with standard and modified No. 3 Victor Soft Catch traps.

Type of injury <sup>a</sup>	Points Scored	Occurrences by trap type			
		Standard (N = 53)		Modified (N = 60)	
		Number <sup>c</sup>	Percent	Number	Percent
Edematous swelling or hemorrhage <sup>b</sup>	5-15	51	96	57	95
Cutaneous laceration <2 cm	5	32	60	37	62
Cutaneous laceration >2 cm	10	12	23	7	12
Minor subcutaneous soft tissue maceration or erosion	10	3	6	1	2
Minor periosteal abrasion	10	12	23	15	25
Minor tendon severance or ligament severance	25	7	13	10	17
Major cutaneous laceration of foot pad	30	3	6	1	2
Joint luxation below carpus or tarsus	30	13	24	4	7
Major periosteal abrasion	30	0	0	1	2
Simple fracture at or below (distal to) carpus or tarsus	50	0	0	1	2
Amputation of 2 digits	50	1	2	0	0
Joint luxation above carpus or tarsus	100	1	2	0	0
Compound or comminuted fractures at or below carpus or tarsus	100	1	2	0	0
Major tendon or ligament severance	100	1	2	0	0

<sup>a</sup> Each injury category was considered separately and a coyote may be represented in more than one row. Total percent exceeds 100.

<sup>b</sup> Mild = 5 points, moderate = 10 points, and major = 15 points.

<sup>c</sup> Number of legs with this injury.

Median injury scores and the distribution of individual scores were similar for both trap types ( $\chi^2 = 0.01865$ , 1df,  $P = 0.8914$ ). Scores varied from 0 to 585 ( $\bar{x} = 43.5$ ) for the standard trap and from 0 to 110 ( $\bar{x} = 26.2$ ) for the modified trap. Coyotes captured in both standard and modified Soft Catch traps had relatively minor injuries compared to those noted in an earlier study of traps with unpadded jaws (Phillips et al. 1996). One possible explanation for the lower mean injury score associated with the modified trap is that the increased clamping force produced by the additional springs stabilized the trapped leg between the padded jaws. This reduced movement of the trapped leg may have reduced the likelihood of more injuries such as joint luxations and fractures.

In addition to reducing injuries to captured animals, the modifications to Soft Catch traps we studied may offer other advantages. Traps with increased spring pressure are more likely to function properly in moist or heavy soils thereby increasing capture efficiency. We recommend that trappers experiencing problems with coyotes springing traps without being caught or escaping from Soft Catch traps, consider modifying their traps with additional springs.

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# AGELAIUS BLACKBIRDS AND RICE IN URUGUAY AND THE SOUTHEASTERN UNITED STATES

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**ABSTRACT:** Throughout the world, wherever rice is grown, birds that damage the crop are attracted. The situations are particularly interesting in Uruguay and the southeastern United States where different species of blackbird have adapted to rice cultivation. In the two countries, rice production practices differ in several respects such as seeding rate, seedbed preparation, and insect control practices. Furthermore, although they are congeneric, the major rice pest species differ in important ways. For example, in Uruguay, *Agelaius ruficapillus* usually nests in the rice field, whereas *A. phoeniceus*, in the U.S., does so only rarely. Agronomic and ornithological aspects of these two blackbird-rice systems are discussed and implications for development of effective damage management strategies are evaluated.

**KEY WORDS:** *Agelaius*, blackbird, crop damage, rice, United States, Uruguay

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## INTRODUCTION

Rice is a major crop in many parts of the world, and virtually wherever it is grown, rice attracts depredating birds. Parakeets, waterfowl, blackbirds, finches, and numerous other species feed on cultivated rice. In North and South America, blackbirds of the genus *Agelaius* frequent fields, wetlands, and agricultural areas. Several of the nine species in this genus are responsible for crop depredations, and this study focuses on two species that regularly damage rice. This overview is not intended as an exhaustive comparative study, but is part of on-going investigations of bird damage to rice in Uruguay and in the United States. The objectives are to compare and contrast the blackbird rice depredation problem in the two countries and to relate species' life history traits to potential damage management strategies. Much of the information presented here was obtained in interviews with rice producers and researchers in each country as well as from relevant reports and publications (T.A.E.S. 1993; De Ambrosis and Blanco 1994; L.S.U. 1995). To conserve space, these three references are not cited throughout the text.

## RICE MANAGEMENT

### Seeding Rate

In the southeastern U.S., the recommended rice sprout density is 20 per square foot (215/m<sup>2</sup>). To achieve this density, rice fields are seeded at rates of 110 to 130 kg/ha. The actual seeding rate will vary with several factors, including rice variety, seeding method, and time of year. For example, drill-seeded rice fields generally require lower seeding rates (100 to 120 kg/ha) than do fields where seed is broadcast either dry or into water (120 to 165 kg/ha). Early planting requires higher seeding rates because unfavorably cool weather promotes water mold that reduces stand density. Fields that are planted earlier also are more prone to blackbird damage than are later fields (Wilson et al. 1989).

Typically, seeding rates in Uruguayan rice fields are much higher than in the U.S. Drill-seeded fields receive 150 to 200 kg/ha, whereas broadcast-seeded fields receive 200 to 250 kg/ha (Piriz 1992). All seeding is done onto dry seed beds. Recommended sprout density in Uruguay is 380 plants/m<sup>2</sup> which is about 80% greater than U.S. guidelines.

### Rice Variety

In Uruguay, the dominant rice cultivar for the past 25 years has been Bluebelle, a long-grain variety developed in Texas in the 1960s (Bollich et al. 1968). Another long-grain variety, El Paso 144, is now being planted in increasing acreages because of greater yield potential. These cultivars apparently do not vigorously produce tillers so the rate of seeding needs to be high. Other varieties developed for conditions in the U.S. tiller profusely so that as little as 60 kg/ha will produce adequate stands in drill-planted fields.

### Water Management

Rice is sown or drilled in dry seed beds in Uruguay, and the permanent flood is established six to seven weeks later. Producers rely on rain to stimulate germination, but seedling establishment is aided by periodically flushing irrigation water through the field if rain is insufficient. When a dry seedbed is used in the U.S., the field is flushed immediately after sowing and the permanent flood is usually established within three weeks. When rice is water-seeded, the field is usually drained within a day of planting so that seedlings can take root and begin to establish. The permanent flood is put on about three weeks later. To hasten seeding establishment in water-seeded fields, many U.S. producers presprout the seed by soaking it for 24 hours before planting. This technique is not practiced in Uruguay.

Uruguayan rice fields often contain numerous closely spaced levees for controlling water flow. The levees

follow the contour lines, and depending on the degree of slope, the levees may be separated by as little as 5 m. This is in contrast to U.S. rice fields which are usually leveled very precisely so that only a minimum number of widely spaced water control levees are needed.

#### Weed Management

Weeds are a serious problem for rice producers in both countries. Species in the genus *Echinochloa* infest fields in Uruguay, where the common name is "capin" and in the U.S. where the same weeds are commonly called "barnyard grass." In both countries, herbicides are applied to control these and other weed species. Timing of herbicide applications is crucial. In Uruguay, if the chemical is applied before the field is fully prepared with the levees constructed, the seeds that were below the surface will be brought up during the levee-building process and *Echinochloa* will soon festoon the levees. Water management is also important because when the permanent flood is delayed, weeds are able to become established. This situation often arises in Uruguay where fields are dry-seeded and permanent flooding occurs six to seven weeks after seeding. Post-emergent herbicide application may then be needed. Although red rice is a bane to many rice producers in the U.S., it is not a for producers in Uruguay.

#### Insecticides

A unique aspect of rice production in Uruguay is the absence of chemical insecticides. Even though insect pests occur in Uruguayan rice fields, their impact is minor, unlike in the U.S. where rice water weevil (*Lissorhoptrus oryzophilus*), rice stink bug (*Oebalus pugnax*), and other species seriously reduce productivity. To control damage by these pest species, U.S. rice producers apply a variety of chemicals including carbofuran and carbaryl. At least some rice growers in Uruguay believe that it is desirable to have blackbirds in their fields because of the amount of insects the birds eat. There are no data, however, that document the effects of bird predation on arthropod fauna in rice fields, either in Uruguay or in the U.S.

### **BIRD PEST SPECIES IN RICE**

#### Species of Concern

Although several depredating species occur in each country, the primary pest species in rice fields in Uruguay and in the U.S. are the rufous-capped blackbird, *Agelaius ruficapillus*, and the red-winged blackbird, *A. phoeniceus*, respectively. The adult male red-winged blackbird is slightly larger (22 cm overall length) than the rufous-capped (17 cm). Except for their respective head and wing markings, adult males of both species are mostly uniform black. Females of both species are somewhat smaller and brown overall.

#### Diet

During the breeding season, both species are largely insectivorous. Meanley (1971) found that insects comprised 59% of the diet of redwings in Arkansas rice fields during May to July. Similarly, animal matter dominated the stomach contents of blackbirds collected at Uruguayan rice fields in December and January (Figure

1). During other months, rice was the principal food item. Meanley (1971) also found that rice represented more than half of the diet among red-winged blackbirds in Arkansas during nonbreeding months. On the other hand, Wilson (1985) found that rice exceeded 50% of the diet of Louisiana red-winged blackbirds during September to November only. The rest of the year, weed seeds dominated the diet.

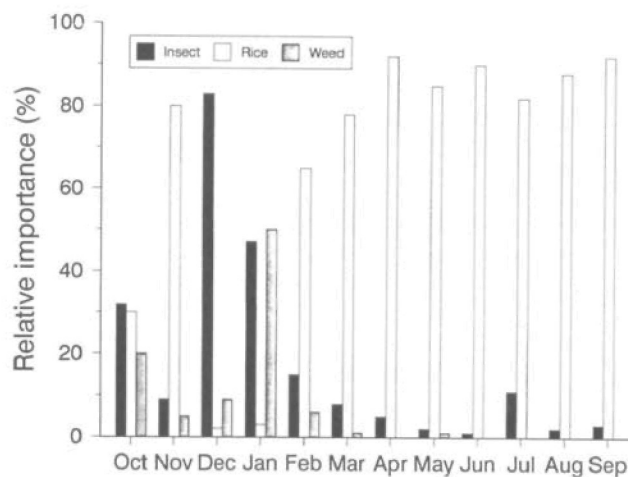


Figure 1. Relative amounts of insect matter, rice, and weed seeds in stomachs of rufous-capped blackbirds (sexes combined) collected monthly at Uruguayan rice fields during 1994 to 1995. Rice is planted during October and November, and harvest is primarily in March and April.

#### Reproduction

Both species are polygynous or promiscuous (Orians 1985), although mating habits of *A. ruficapillus* need to be more completely documented. In each species, average clutch size is three eggs. The female incubates and feeds the young while the male's role is primarily territorial defense.

There is a marked difference between species in nest site selection. In Uruguay, *A. ruficapillus* frequently nest in rice fields where the birds construct the nest in growing rice plants. In one 0.2 ha portion of a field, 27 nests were found, several of which had been preyed upon. Nesting also occurs in small trees and shrubs adjacent to rice fields (e.g., Bruggers et al. 1995), but the majority takes place in rice fields.

Conversely, *A. phoeniceus* seldom nests in rice fields. Rather, their nests are normally in emergent aquatic vegetation or in small trees and shrubs. In rice-growing areas, the nest site is often along a drainage canal or wood edge adjacent to a rice field (Meanley 1971).

#### Movements

In the U.S., many red-winged blackbirds migrate thousands of miles annually between wintering areas in the southeast and their breeding grounds in the northern Great Plains and Canada. It appears, however, that

migrants are present primarily during November to February, and local, nonmigratory birds are probably responsible for most damage in rice fields (Meanley 1971; Brugger and Dolbeer 1990).

Populations of rufous-capped blackbirds in Uruguay appear to move locally in search of feeding sites in the nonbreeding season, but as yet there is no indication of consistent migratory patterns. Intensive banding and telemetry studies are needed to document more adequately the local and long-range movements of this species relative to rice-growing practices.

## IMPLICATIONS FOR MANAGEMENT OF BLACKBIRD DAMAGE TO RICE

### Affecting Rice Field Carrying Capacity

Rice fields possess numerous resources essential for blackbirds, and rice field habitat can support large blackbird populations. The challenge then is to lower the carrying capacity of the rice field habitat for blackbirds. It is not feasible to eliminate blackbirds or blackbird damage to rice, but it may be possible to reduce the depredating blackbird population by lowering the carrying capacity of the rice field habitat.

The carrying capacity can best be affected by altering resource availability. Of the critical resources, it is impossible to restrict the amount of nesting habitat available as there is no way to reduce availability of the rice plants used by rufous-capped blackbirds. Similarly, there is no feasible means to reduce the availability of nesting habitat for red-winged blackbirds as it is pervasive throughout rice-growing areas in the southeastern U.S. Besides, numerous other species would probably be adversely impacted by any large-scale effort to alter habitat.

Arthropod abundance is an important factor for blackbirds during the breeding season. To reduce arthropod populations, pesticides would probably be necessary. Such applications could adversely affect beneficial species, however. Also, blackbirds may simply forage in adjacent areas if prey abundance is reduced in rice fields. It is unlikely that such measures would be economical, especially in Uruguay where rice producers do not currently need to control insect pests with insecticides.

Thus, to affect carrying capacity, lower the local blackbird population, and reduce damage, it will be necessary to focus on rice and weed seed, the birds' principal food items. Food resources for blackbirds are probably lowest just before the new crop of rice is planted. By that time of year, blackbird populations have, no doubt, largely depleted the rice and other seed reserves on the ground left from the previous growing season (Labisky and Brugger 1989). Therefore, it is appropriate to maintain the food resources at the lowest level possible by denying birds access to the newly planted rice seed. Such a reduction in carrying capacity at that time of year could translate to lower populations, and less damage, during both the seeding and ripening stages.

### Reducing Availability of Newly Seeded Rice

The high seeding rates (approximately 150 to 200 kg/ha) used by most Uruguayan rice producers ensure

that birds will have abundant rice seed available to eat for several weeks after planting. If the seeding rate could be reduced without jeopardizing the vigor of the rice crop, then food availability for blackbirds would be lowered. In Uruguay this could be accomplished by treating the seed with methiocarb, locally known as "Draza," prior to planting. Methiocarb is an effective blackbird repellent (Holler et al. 1982), and it should be possible to devise a cost-effective means to use it so that the seeding rate is lowered, blackbird depredation of seed is diminished, and adequate rice stands are produced.

For example, at a cost of \$16 to \$17 per 50 kg bag of seed, rice seed planted at a rate of 150 kg/ha will cost \$50/ha. If the seeding rate is reduced to 100 kg/ha, and if all of the seed is treated with Draza (\$30/kg) at a rate of 500 g/100 kg of rice seed (0.25% active ingredient because Draza contains 50% methiocarb), the planting will cost \$32 to \$34/ha for the seed plus \$15/ha for the Draza, giving a total cost of \$47 to \$49/ha. This is no more expensive than planting untreated seed at the rate of 150 kg/ha. A major advantage to the lower seeding rate, however, is that it greatly reduces the seed that is potentially available to the blackbirds at a time of the year when food availability is low. Furthermore, even the seed that is available will be unpalatable because of the Draza treatment.

This strategy can probably be refined to reduce costs further. For example, field studies in the U.S. showed that a methiocarb treatment rate of 0.125% effectively protects rice from blackbird depredation (Holler et al. 1982). This is one-half the rate proposed above, and if the Draza application rate is lowered, costs will be reduced accordingly, presumably without loss of effectiveness. Furthermore, pen studies with captive blackbirds have shown that treatment of half of the rice seed with 0.125% methiocarb is just as effective as treating all of the seed (Avery 1989). Thus, costs of Draza application can be reduced even further by treating only a portion of the seed and then mixing the treated seed with untreated seed prior to planting.

This strategy is currently unavailable to U.S. rice producers because methiocarb is not registered for use as a bird repellent. Other seed treatments that affect blackbird feeding behavior are available (Avery and Decker 1991) or are under development (Avery et al. 1994, 1995). It is, therefore, possible for U.S. rice producers to incorporate bird deterrent seed treatments into their blackbird management plans.

### Reducing Local Blackbird Populations

An alternative approach, currently being implemented in Louisiana and Texas, is to reduce roosting populations of mostly wintering birds by application of toxic bait at pre-roosting staging areas (Glahn and Wilson 1992). Such methods can reduce local roosting populations, but there has yet to be a link established showing that there is subsequent reduction of blackbird damage in rice fields. While the toxic baiting method of bird damage management continues to be pursued in the U.S., environmental concerns associated with rice production in Uruguay (Thresher 1995) are too great for lethal blackbird control to be considered an option at this time.



### Reducing Availability of Waste Rice

Rice spilled during harvesting is potentially an important food resource for the blackbird population. Actual quantification of the amount of waste rice seed during harvest and transportation from the field is underway in Uruguay. It is important to document the role that this source of food plays in the annual cycle of the blackbirds. It can then be determined how availability can be reduced through improvements in harvesting and transporting.

### Reducing Availability of Weed Seeds

When rice is in short supply, there are abundant weed seeds, principally *Echinocloa*, in and nearby the rice fields as alternative sources of food. Particularly in Uruguay, *Echinocloa* grows in dense stands along the levees and the borders of most rice fields. The weed problem is exacerbated in Uruguay because of the many closely spaced levees that wind through most fields. The numerous levees create additional substrate for weed growth which, in turn, offers many attractive opportunities for blackbirds. In addition to being a source of food, such stands of tall weedy vegetation provide blackbirds with protection from predators, shelter from high daytime temperatures, and roosting cover at night. By constructing levees in the rice field first and then applying herbicides, producers should be able to reduce abundance of *Echinocloa*.

### SUMMARY

There are many similarities in the blackbird-rice situations in the U.S. and Uruguay. The principal differences lie in the details of field preparation and seeding rates, and in the nest site selection of the primary depredating species, the rufous-capped and red-winged blackbirds. Uruguayan rice fields are dry-seeded and seeding rates are much higher than in the U.S. The seed is exposed to birds for about twice as long as in U.S. rice fields before the permanent flood is applied which creates a situation for higher bird populations to be supported for longer periods of time. Extensive levee systems permit growth of *Echinocloa* and other weeds that also contribute to supporting blackbird populations. Efficient use of methiocarb (Draza) will allow lower seeding rates and will protect seed from blackbird depredation thereby reducing food availability and populations at the site. Careful levee construction with appropriate timing of herbicide application can lead to more effective weed control and thus reduce food and cover resources available to blackbirds.

Prospects for effective management of blackbird damage in U.S. rice fields also depend on the ability to implement an integrated bird management strategy. Such an approach will probably include lethal control with toxic baiting, as well as repellent seed treatments and cultural practices (e.g., delayed planting).

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# DISACCHARIDE INTOLERANCE OF EUROPEAN STARLINGS

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**ABSTRACT:** The use of disaccharides to discourage bird depredation to agricultural crops has elicited some interest during the last few years. Data developed in these trials indicate that several avian species are intolerant to sucrose because of the lack of sucrase enzymes in their digestive systems. Based on this research it is hypothesized that progressively increasing rates and volumes of solutions would elicit consistent adverse stress reactions. Furthermore, that if birds were intolerant to sucrose, because of their co-evolutionary development with plants, then they should lack the ability to digest lactose. The data developed in these trials does not support either hypothesis. A maximum of 60% of the birds tested showed stress symptoms to 0.75 M sucrose (6.26 mg/Kg body wt.) and 1.00 M lactose solutions (9.15 mg/Kg body wt.) when the birds were subjected to 2 cc treatments. Less than 40% were stressed by the lower concentrations. No adverse reactions were noted with 1 cc concentrations of either solutions or rates. Treating fruit with sucrose did not appear to affect the results until 1.00 M (3.83 mg/Kg) sucrose solutions were applied. No adverse results were obtained with lactose treated fruit.

**KEY WORDS:** vertebrate pest control, birds, starlings, intolerance, disaccharide, sucrose, lactose

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## INTRODUCTION

The use of disaccharides to discourage bird depredation to agricultural crops has elicited some interest during the last few years (Martinez del Rio et al. 1988). Data suggest that the lack of specific digesting enzymes preclude the digestion of distinct disaccharides in avian species when their substrates are rare or absent from the diet. It has been suggested that the lack of sucrase enzymes precludes the use of sucrose as a useful energy source (Martinez del Rio and Stevens 1989).

From this, as well as other work, the concept of developing high sucrose fruit varieties, through genetic engineering, could be pursued if the threshold concentration of sucrose intolerance of targeted bird species could be established (Brugger and Nelms 1991; Brugger 1992; Brugger et al. 1993). The suggestion unfortunately ignores the data of Martinez del Rio and his colleagues (1988) as well as Stiles (1976), who demonstrated that sucrose intolerance is not uniform among avian species. Moreover, the development of high sucrose content fruit within the near future, with current genetic engineering strategies, does not appear to be forthcoming. An interim alternative, until the latter becomes possible, may be the development of a treatment strategy that incorporates disaccharides as an exterior coating to reduce depredation.

Data to develop such strategies, however, are lacking. Martinez del Rio and his colleagues (1988) found that European starlings (*Sturnus vulgaris*) and Red-winged blackbirds (*Agelaius phoeniceus*) immediately rejected 0.70 M solutions of sucrose, but total amounts of sucrose required to achieve these results were not determined. Brugger and Nelms (1991) found that plant cell agar containing 15% sucrose was sufficient to reduce consumption by American robins (*Turdus migratorius*) over a 60 min. time span but again did not record total amounts required to achieve these results. To address this deficiency a series of trials were conducted to determine the amount of sucrose required to cause physical

discomfort in starlings. It was hypothesized that the amount of sucrose needed to elicit discomfort could be determined by forced-feeding a test population, with whom prior symptoms had been shown, progressively increasing rates and volumes of solutions until 90% of the birds showed symptoms of stress.

With past research concentrating on sucrose and sucrase enzymes the potential aversion to lactose has been ignored. Lactose (4-O- $\beta$ -D-Galactopyranosyl-D-glucose; 4-[ $\beta$ -D-galactosido]-D-glucose) is a milk sugar to which many species of mammals, including some humans, are intolerant (Olson 1988). There is some reason to believe that this intolerance may extend to birds. Intolerance appears to be correlated with lactase enzymes deficiencies, and with mammals is often associated with the succession of breast feeding. If the absence of sucrose enzymes is a result of the co-evolutionary development between birds and plants, as suggested by Martinez del Rio and Stevens and accepted by others, then it can be hypothesized that lactase enzymes do not exist in any avian species. If lactase enzymes are absent, then avian species will exhibit signs of progressive discomfort to increasing concentration and rates of lactose.

To test these hypotheses a series of trials were conducted in which birds were subjected, through forced- or free-feeding to known quantities of either sucrose or lactose.

## MATERIALS AND METHODS

### Subjects

Approximately 200 European starlings were live-captured and maintained in a 6 m x 2 m x 12 m wire enclosed outdoor aviary at the Washington State University E.H. Stephen Research, Teaching and Extension Center in Pullman, Washington. Twice each day the birds were fed a prepared diet of banana mash (45% by weight), commercial pelletized bird meal (20% by weight), meal worms in corn meal (5% by weight)

mixed with water (30% by weight). Cooked, French-fried potatoes were served at two-day intervals as supplementary food. Fresh water was available ad lib. All sick and injured birds captured in the field were removed from the population during the two week acclimatization period. No mortality occurred in the population during the trials.

#### Test Materials and Methods

Pre-trial procedures, to develop treatment and observation strategies, were conducted with 25 birds randomly selected from the core population. All subjects were released into an adjacent aviary after the procedures were established to preclude inclusion as candidates in subsequent tests.

During each phase of the trial, five birds were captured from the core population, weighed, and placed in 60 cm x 90 cm x 120 cm wooden framed wire cages with papered drop pans below each cage and water 6 hr. prior to each treatment. In each trial four of the five birds were randomly selected and subjected to either sucrose or lactose gavage treatments or a no choice source of food. The fifth bird was designated as a control and its behavior monitored, for comparison, with the treated birds. Behavioral changes indicating stress were defined as ruffled feathers, increased water ingestion and defecation, lethargy and disorientation. Time of stress onset and termination (full recovery), in minutes after treatment, were recorded. Number of droppings were counted on each paper removed from the drop pans before and after each trial. Each treatment was replicated five times. Prior to the trials five birds were randomly drawn from the population to determine the total amount of liquid they could be force-fed without injury and the optimal amount of currants they would consume after five hours of deprivation.

Immediately before each trial 0.25 M, 0.50 M, 0.75 M, and 1.0 M sucrose (mol. wt. 342.30) and lactose (mol. wt. 209.24) solutions were prepared. Each subject was gavaged with either 1 cc or 2 cc sucrose or lactose solution or given access to 25 whole currants (ave. wt. 2.84 g) soaked in 1 cc of the prepared solutions for 5 min. Each trial was replicated five times and all birds were observed at ten minute intervals for 2.5 hr. post-treatment.

## **RESULTS**

### Pre-treatment

A little more than 2 cc was determined to be the optimal amount of liquid that could be injected, by gavage, into the average starling in the pre-treatment test sample.

A little more than 25 currants (2.84 g) were found to be sufficient to placate the subjects for 1 hr. after a 5 hr. food deprivation period. A 30 min. observation period, with 10 min. reassessments during the following 2.5 hr. was determined to be an adequate observation strategy.

### Sucrose by Gavage

A stepwise aversion to sucrose was not noted with increased dosage (Table 1). No consistent behavioral changes were observed between the controls and the birds within each dose rates. No adverse reactions were noted

with 1 cc gavage treatments (data not included). Less than 50% of the subjects showed any form of stress at the 0.25 M, 0.50 M and 1.00 M rates with the 2 cc treatments. At least a 75 M solution was required to effect a response in 60% of the test group. The onset of symptoms ranged from 3.5 to 15.0 min. and lasted from 4.0 to 16.0 min. The 1.0 M sucrose solution produced the quickest stress reaction (3 min.) and the longest duration (16 min.). Water ingestion and defecation rates were not significantly different among subjects and treatments. Treatment rates of 6 to 9 mg/kg were necessary to induce stress in 50% of the test population. No significant differences were noted between number of bird droppings pre- and post-treatment.

### Sucrose-treated Fruit

A stepwise progression in sucrose aversion with sucrose treated fruit was also absent. Only 20% of the test subjects showed any aversive signs to the 0.25 M treated currants. None of the subjects showed any aversion signs to the 0.50 M and 0.75 M treated material. All of the subjects in the 1.00 M treated current trials, however, appeared to be affected. Stress symptoms began approximately 16 min. after the birds fed on the treated samples. Signs of physical stress lasted about 11 min. The average amount of sucrose consumed was 3.83 mg/kg. Water was consumed an average of 1.4 times during the 30 min. observation period. No significant differences were noted between number of bird droppings pre- and post-treatment.

### Lactose by Gavage

Subjects in the lactose gavage test series did not exhibit stress symptoms consistent with treatment rates (Table 1). Again, no adverse reactions were noted with 1 cc treatments (data not included). Stress symptoms were evident in over 50% of the test group at the 1.00 M solution rate. The onset of stress began to appear approximately 6 to 13 min. post-treatment and lasted about 7 to 15 min. Water was rarely consumed during the 30 min. observation period post-treatment. Defecation frequencies did not increase. No significant differences were noted between number of bird droppings pre- and post-treatment.

### Lactose-treated Fruit

No signs of stress were observed in the birds of the lactose-treated food series (Table 1). Again, no significant differences were noted between number of bird droppings pre-and post-treatment.

## **DISCUSSION AND SUMMARY**

The data from these trials do not support the hypotheses that birds are intolerant to sucrose and lactose. No consistent step-wise progression of stress symptoms were noted the forced-feeding or free-feeding trials.

A maximum of 60% of the birds tested showed stress symptoms to 0.75 M sucrose (6.26 mg/Kg body wt) and 1.00 M lactose solutions (9.15 mg/Kg body wt) when the birds were subjected to 2 cc treatments (Table 1). Less than 40% were stressed by the lower concentrations. No adverse reactions were noted with 1 cc concentrations of either solutions or rates.

Table 1. Stress symptoms in European Starlings subjected to .25, .50, .75, and 1.0 M solutions of lactose and sucrose.

	Solution Rate (M)	Stress (% of sample)	Onset of Symptoms (min.)*	Total time of Stress (min.)	Wt./ Bird (g)	Treatment mg/kg.	Water intake (average)	Fruit consumed (No. of currents)
<b>Lactose</b> <i>Gavage</i>	0.25	40.00	13.50	7.50	77.20	2.22	0.20	
	0.50	20.00	6.00	11.00	74.00	4.63	0.00	
	0.75	40.00	8.00	15.50	81.80	6.28	0.00	
	1.00	60.00	11.67	9.67	74.80	9.15	0.00	
	Mean	40.00	9.79	10.92	76.95	5.57	0.05	
	Stdev	16.33	3.41	3.38	3.51	2.91	0.10	
<b>Sucrose</b> <i>Gavage</i>	0.25	20.00	15.00	10.00	79.00	2.17	0.60	
	0.50	0.00	0.00	0.00	82.60	4.14	0.00	
	0.75	60.00	12.33	4.33	82.00	6.26	0.20	
	1.00	40.00	3.50	16.00	77.00	8.94	0.20	
	Mean	30.00	7.71	7.58	80.15	5.38	0.25	
	Stdev	25.82	7.11	6.95	2.62	2.91	0.25	
<b>Lactose</b> <i>Fruit</i>	0.25	0.00	0.00	0.00	76.25	0.67	1.00	19.50
	0.50	0.00	0.00	0.00	85.50	1.24	1.00	24.25
	0.75	0.00	0.00	0.00	76.00	2.64	1.50	18.75
	1.00	0.00	0.00	0.00	82.75	3.27	2.25	17.00
	Mean	0.00	0.00	0.00	80.13	1.96	1.44	
	Stdev	0.00	0.00	0.00	4.75	1.20	0.59	3.10
<b>Sucrose</b> <i>Fruit</i>	0.25	20.00	15.00	11.00	75.00	0.87	1.00	16.40
	0.50	0.00	0.00	0.00	77.80	1.67	1.20	19.20
	0.75	0.00	0.00	0.00	81.60	2.61	0.60	23.80
	1.00	100.00	16.40	11.00	73.20	3.83	1.40	23.60
	Mean	30.00	7.85	5.50	76.90	2.25	1.05	
	Stdev	47.61	9.08	6.35	3.66	1.28	0.34	3.59

\*Time from treatment to first signs of physical stress.

Treating fruit with sucrose did not appear to affect the results until 1.00 M (3.83 mg/Kg) sucrose solutions were applied. As with the gavage treatments, no step-wise progression of stress symptoms were noted between control and increasing sucrose concentrations. No intolerance was noted in the lactose fruit treatments.

This leaves several unanswered questions. First, if this avian species lacks specific disaccharide digestive enzymes, as suggested by prior research, why did more of the test population not show signs of stress after forced-feeding or free-feeding on either of these disaccharides? Moreover, why were no consistent progressions in symptoms observed as dose rates were increased?

The results of these trials suggest that more research, using protracted feeding regimes with larger population sizes, are needed before any of the hypotheses presented can be accepted or rejected.

#### ACKNOWLEDGMENTS

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# USE OF THE MODIFIED AUSTRALIAN CROW TRAP FOR THE CONTROL OF DEPREDATING BIRDS IN SONOMA COUNTY

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**ABSTRACT:** The Modified Australian Crow (MAC) trap to control depredating birds can be a very humane, target species specific and effective bird control tool. Pertinent topics will include legal status, timing, and care of trapped birds. The following are also discussed: species identification, trap construction, and placement and humane euthanasia methods.

**KEY WORDS:** vertebrate pest control, bird control, live trapping

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## INTRODUCTION—SITUATION

Since the 1960s, Modified Australian Crow (MAC) traps have been used for the control of many depredating bird species on wine grapes in Sonoma County, California. These species include house sparrows (*Passer domesticus*), crowned sparrows (*Zonotrichia* spp.), house finches (*Carpodacus mexicanus*), starling (*Sturnus vulgaris*) and cedar waxwing (*Bombycilla cedrorum*).

The MAC trap has recently become the primary means of control for these problem bird species since a number of bird repellants and toxicants have lost their registrations for use. The loss of registrations for effective materials began in 1984 with the loss of the bird repellent Mesurol 75 WP. This was followed in 1989 with the loss of strychnine house finch treated grain bait and recently with the loss of AVITROL mixed grain bait in December of 1994. The MAC trap has thus become the primary means of control for our problem bird species (Figures 1 and 2).

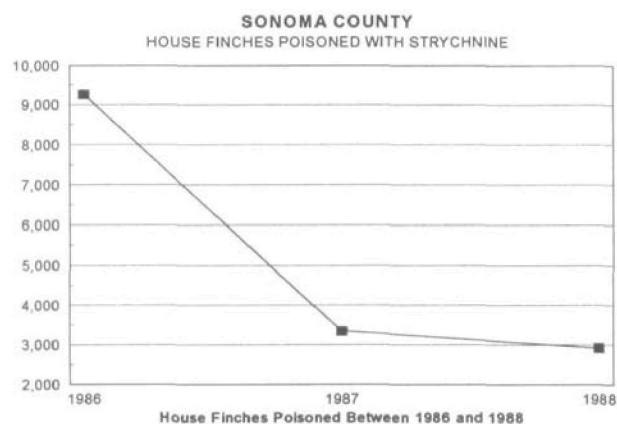


Figure 1. The number of house finches poisoned with strychnine in Sonoma County, CA from 1986 through 1988.

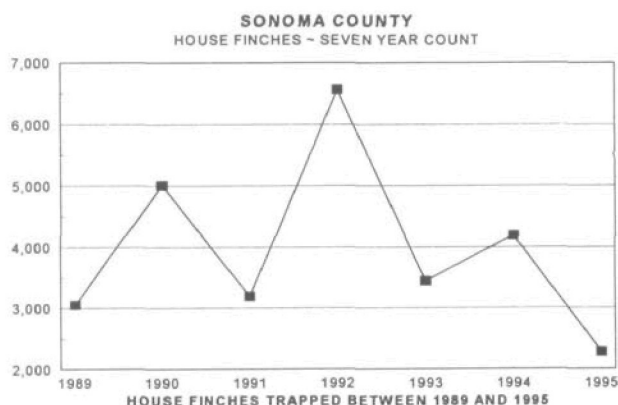


Figure 2. The number of house finches trapped in Sonoma County, CA from 1989 through 1995.

With the spread of wine grape acreage into the hills and small coastal valleys, house finches have become the most destructive bird species in Sonoma County. "Bird control in California is almost as old as the agriculture of the State itself. Yet the principal offending species for more than half a century, notably the house finch and horned lark, are today as abundant as ever" (Koehler 1962). Approximately 1100 acres (3.3%) of the 33,000 bearing acres of wine grapes are adversely affected.

In the problem bird affected areas within Sonoma County, an average of 0.5 tons per acre, or 11% of the total production, are damaged. The total dollar loss is approximately \$550,000 annually.

In addition to trapping, another means of crop protection is bird netting. This provides almost 100% crop protection. The cost of netting is about \$350/acre/year.

## LEGAL CONSTRAINTS

House finches, crowned sparrows and cedar waxwings are classified as migratory non-game birds according to the Code of Federal Regulations, Title 50.

House finches and crowned sparrows may be taken under the general supervision of the Commissioner of Agriculture. Cedar waxwings and ravens require a depredation permit from the U.S. Fish and Wildlife Service. Starlings and house sparrows may be taken by anyone without a permit when causing damage. Other applicable sections of the Fish and Game Code of California are 2000, 3005, 3511, 3513, 3800, 3801 and 3801.5.

#### NON-TARGET SPECIES HANDLING

During the use of the MAC trap, bird species identification and handling of non-target birds is very important. This trap is usually species specific for the house finch when equipped with the proper entrance opening and bait seeds. However, a few species will enter the trap when house finch numbers are low. The non-target species that most often enter these traps are: Oregon junco (*Junco oreganus*), white crowned sparrow (*Zonotrichia leucophrys*), golden crowned sparrow (*Zonotrichia atricapilla*) and the brown towhee (*Pipilo fuscus*). The predatory loggerhead shrike (*Lanius ludovicianus*) and American kestrel (*Falco sparverius*) have been known to enter through the 1-1/2 inch entry slot (Figure 3). All non-target species must be released immediately. If the same non-target birds continue to enter the trap it should be moved to a new location in the field. Predatory raptors can sometimes be repelled from the MAC traps by the use of a 7-foot pole with a small platform (4" x 6") on the top of the trap. This platform can be covered with a tactile repellent (Polybutelene). The raptors, usually sharp-shinned hawks (*Accipiter striatus*), Cooper's hawks (*Accipiter cooperii*) or American kestrels (*Falco sparverius*) will alight on the highest point on or near the trap. The tangle foot which is applied 1/4-inch thick on the platform will frighten the raptor by the feeling of entrapment when the bird's feet touch the tactile repellent. The affected bird will often move away from the trap never to return. Because of the possible hazard to small bird species, the platform must be removed from the trap as soon as the offending raptors have been frightened from the trap.

All non-target bird species that die in the trap must be reported on the bird take monthly summary (Figure 4).

#### MATERIALS AND METHODS

MAC trap design has been effective in catching starlings, blackbirds, house finches, house sparrows and white and golden crowned sparrows. This can be easily accomplished by changing the entrance opening for the starling and blackbird from 1-1/2 inches to 1-3/4 inches. With other modifications, this same trap can also be used to capture crows, magpies and ravens.

The basic design of this trap should not be altered. Minor modifications can be made so the trap will fit in the back of a pickup, etc. These traps can be built in panels to facilitate transportation and storage. See trap design and assembly instructions (Figure 3).

As illustrated by its use with house finches, the MAC trap placement and timing are very important for the control of depredating birds. By midsummer, juvenile house finches are gathering in loosely formed flocks. Trapping in Sonoma County should start during the last

week of June to the middle of July. In the case of wine grapes, the first softened fruit around 12° brix (sugar content) is a good indicator of when to place the trap.

House finch flocks tend to use tree rows and power lines to congregate. The trees provide shade and protection from raptors. House finches move in and out of the crop from these positions. The MAC trap should be placed in these areas of activity. A vineyard or orchard of 50 acres or more may have two or more flocks within its borders. In such situations, two or more traps may be necessary to quickly stop depredation. If a few birds are not caught within four to six days, the trap should be moved to a new location.

After the trap is constructed, adequate food, water and shade must be made available 24 hours per day. For humane reasons, as well as efficacy, the trap must be cared for as one would maintain a home aviary. The recommended bait mixture for house finches is, 1/3 rape and 2/3 canary grass seeds. A 6-foot by 1-1/2 inch V shaped trough should be suspended approximately 24 inches below the 1-1/2 inch entrance slot. The rape and canary seed should be placed in the trough to a depth of 1/2 to 3/4 inch. The trough should be cleaned out often to remove the seed hulls. Trapped birds have been found starving with 1 inch of grain hulls in the trough.

Clean, cool water is essential to the proper care and maintenance of a MAC trap. The water is best contained in a 1 gallon automatic poultry waterer. The waterer should be elevated off the floor of the cage and covered with a slant board about 14 inches square made of a rigid material. This board is best attached with wire to the cage wall about 6 inches above the waterer. The narrow trough around the waterer should be cleaned often and the water tank filled as necessary. The waterer should be placed in the shaded area.

Adequate shade is very important to the proper operation of the MAC trap. Shade material can be built into the trap during construction or added during trap setup. The shade material should be placed on the south and west exposures to provide the proper shadows within the trap during the hot daytime hours. Sun blocking materials can include shade cloth, tarps, plywood, etc.

Finally, humane disposal of target bird species must be practiced. The 1993 Report of the American Veterinary Medical Association (AVMA) Panel on Euthanasia provides two acceptable euthanasia (good death) methods.

1. Carbon dioxide is recommended in small laboratory animals as birds, cats and small dogs. The trapped house finches must be either caught with a small net and placed into a portable cage or driven into a small cage approximately 12" x 12" x 30" that can be affixed to the outside corner of the trap. A wire door should be built into the MAC trap for this purpose. A sliding door on the small cage can be used to safeguard against escape.

*Place a heavy gauge plastic bag, with dimensions of 38" x 60", over the small cage. The end of this plastic bag should be secured (plastic tie) around the hose from the compressed gas cylinder. Compressed CO<sub>2</sub> gas is preferable to dry ice. The inflow to an euthanasing chamber can be precisely regulated with*



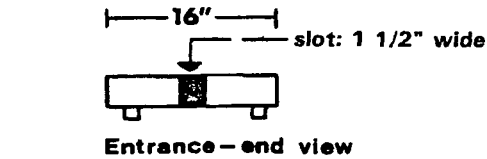
## TRAP DESIGNS

### MODIFIED AUSTRALIAN CROW TRAP

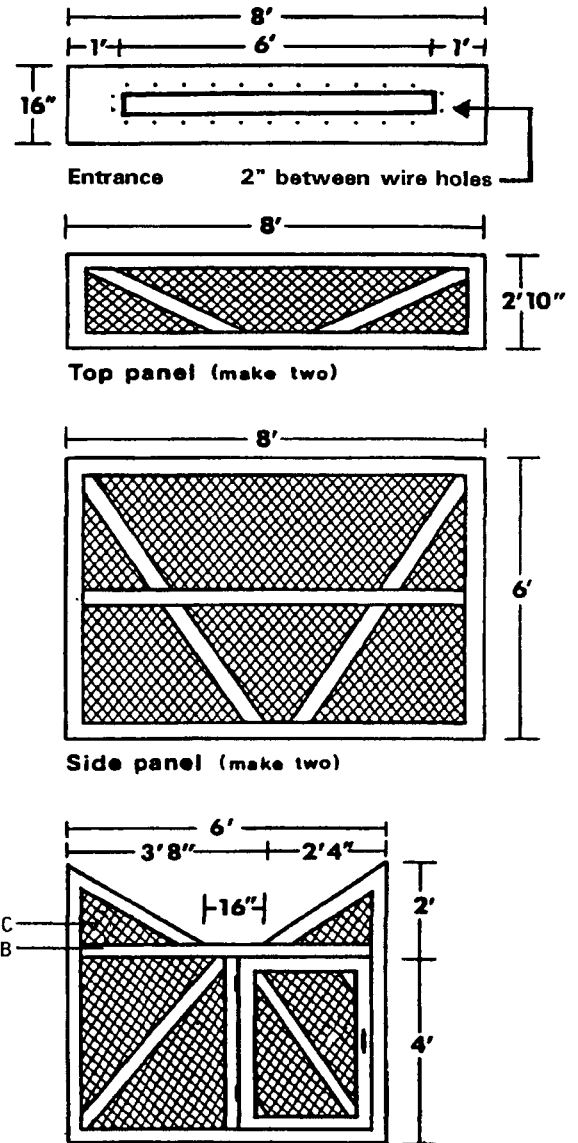
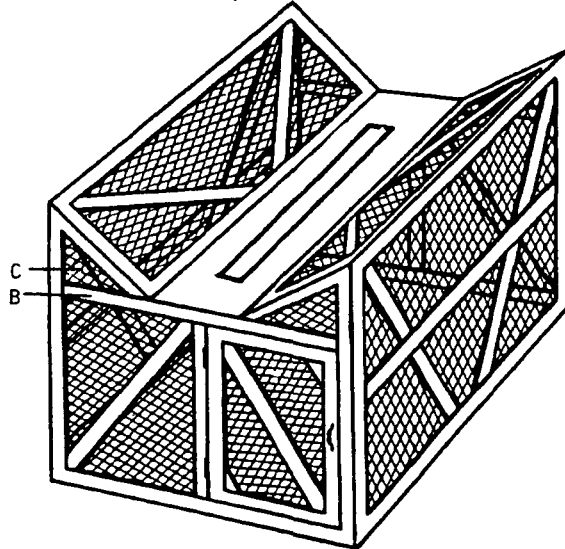
Modified Australian crow traps have been effective in catching starlings, blackbirds, house finches, house sparrows and white crowned sparrows. By changing the entrance, the same trap can be used to capture crows, magpies and ravens. The basic design of the trap should not be changed, however, minor modifications can be made such as making the trap so it will fit on a truck, trailer, etc.

### MATERIALS NEEDED FOR TRAP:

- 15 - 1 x 4s, 8' long
- 25 - 1 x 4s, 6' long
- 4 - 1 x 1s, 8' long
- 1 - ½" x 16" exterior plywood 8' long
- 2 - hinges
- 2 - pounds staples
- 80' length x 3' wide aviary wire ½" mesh
- 1 - roll heavy gauge baling wire.



**Assembled Trap**



### IMPORTANT ASSEMBLY INSTRUCTIONS:

Place end panels between side panels; otherwise, top panels will not fit properly.

- A. Rough cut redwood is good material. If pine or fir is used, be sure to use wood preservative.
- B. Reinforce this area with a 2" x 4" x 16" piece of wood. This gives a greater surface area for the entrance board to rest on.
- C. In this area, place a small door for removal of trapped birds.
- D. 8" pieces of heavy gauge baling wire are hung around 1 1/2" entrance slot. See entrance diagram.

Figure 3. Modified Australian crow trap design.

**COUNTY OF SONOMA - AGRICULTURAL COMMISSIONER - VERTEBRATE PEST MANAGEMENT**

Permittee \_\_\_\_\_ Authorization # \_\_\_\_\_ Expiration Date \_\_\_\_\_

LOCATION		SECTION	TOWNSHIP	RANGE	FIELD REPORT #	COMMODITY
ACRES AFFECTED	DAMAGE %	POTENTIAL CROP LOSS		BIRD SPECIES	# OF TRAPS	
PCO NAME , ADDRESS AND LICENSE #:						

**FIELD INSPECTION COMMENTS**

DATE:	BIOLOGIST:

**CONDITIONS**

1. None of the above migratory birds killed, or the parts thereof, or the plumage of such birds, shall be sold or removed from the area where killed; but that all such dead migratory birds shall be buried or otherwise destroyed within this area. The estimated number of such birds killed pursuant to the exercise of this authorization shall be submitted to the Agricultural Commissioner on a monthly basis, with the final monthly report submitted on or before January 5 of each year. These reports shall be in a form approved by the Commissioner.
2. No non-target birds shall be killed. Non-target birds shall be released alive.
3. Traps shall be partially covered to provide shade for trapped birds and adequate feed and water shall be made available 24 hours per day.
4. By the 7th day of each month, report the number of target birds trapped and killed and the number of non-target birds trapped and found dead by calling (707) 527-3852. Give your name, authorization number and bird count.
5. Affix the authorization tag, provided by the Agricultural Commissioner, to each trap used.
6. Deviation from these procedures may result in poor control and could result in the cancellation of your authorization.

I understand that this authorization does not relieve me from liability for any damage to persons or property caused by the use of these control methods. I waive any claim of liability or damages against the Sonoma County Department of Agriculture based on the issuance of this authorization. I further understand that this authorization may be revoked when used in violation of applicable laws, regulations and specific conditions of this authorization. I authorize inspection at all reasonable times by the Agricultural Commissioner of all areas under control or to be controlled.

PRINT NAME \_\_\_\_\_ SIGNATURE \_\_\_\_\_ TITLE \_\_\_\_\_ DATE \_\_\_\_\_

\_\_\_\_ By authority of the Code of Federal Regulations 50, 21.44, the Agricultural Commissioner of Sonoma County authorizes the permittee to control specified non-game migratory birds under the general supervision of the Commissioner in order to safeguard and prevent serious injury to specified agricultural or horticultural crops in Sonoma County under the conditions specified in this authorization.

\_\_\_\_ Application Denied.

BY \_\_\_\_\_ TITLE \_\_\_\_\_ DATE \_\_\_\_\_

Figure 4. Bird trapping statement of conditions and catch reporting form used in Sonoma County, CA.

*compressed CO<sub>2</sub>. The optimal flow rate appears to be a rate that will displace approximately 20% of the chamber volume per minute.*

**Advantages** of the use of CO<sub>2</sub> (as found in 1993 report of AVMA Panel on Euthanasia):

- The rapid depressant and anesthetic effects of CO<sub>2</sub> are well established.
- Carbon dioxide may be purchased in cylinders.
- Carbon dioxide is inexpensive, not flammable and non explosive and presents minimum hazard to personnel.

**Disadvantages** of the use of CO<sub>2</sub>:

- May be aesthetically displeasing to personnel.
- The time required for euthanasia may be substantially prolonged in immature animals.

2. Cervical dislocation is the second method which is a conditionally acceptable form of euthanasia. On the house finch, this method can be accomplished by placing the thumb and the index finger on either side of the neck at the base of the skull. Using the other hand quickly pull the base of the tail or hind limbs causing separation of the cervical vertebrae from the skull.

**Advantages** of cervical dislocation:

- Cervical dislocation is a technique that may induce immediate unconsciousness.
- Does not chemically contaminate tissues.
- It is rapidly accomplished.

**Disadvantage** of the use of cervical dislocation:

- May be aesthetically displeasing to personnel.

There are six specific trapping conditions required by the Sonoma County Agricultural Commissioner's Office (Figure 4).

## CONCLUSION

The use of the MAC trap can be an effective tool for the control of depredating house finches and crowned sparrows. Cedar waxwings have been trapped, however, there is a lack of the necessary replications to evaluate the efficacy. Palmer (1982) has reported that 10,000 waxwings were captured at a food processing plant. Adult house sparrows are difficult to trap in sufficient numbers to cause adequate population control. Starlings, especially juvenile starlings, can be trapped in great numbers. However, late summer and early fall starling congregation can overcome any positive effect of earlier trapping.

Winter and early spring house finch trapping, except to mitigate fruit tree disbudding, should be not done. Code of Federal Regulations Title 50—Wildlife and Fisheries, Section 21.44 states that: "such migratory birds shall be killed only when necessary to protect agricultural or horticultural crops from depredation."

## ACKNOWLEDGMENTS

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# OVERHEAD WIRES REDUCE ROOF-NESTING BY RING-BILLED GULLS AND HERRING GULLS

JERROLD L. BELANT, and SHERI K. ICKES, U.S. Department of Agriculture, Denver Wildlife Research Center, 6100 Columbus Avenue, Sandusky, Ohio 44870.

**ABSTRACT:** The authors evaluated the effectiveness of overhead wires in reducing roof-nesting by ring-billed gulls (*Larus delawarensis*) and herring gulls (*L. argentatus*) at a 7.2 ha food warehouse in Bedford Heights, Ohio during 1994-1995. In 1994, stainless steel wires (0.8 mm diameter) were attached generally in spoke-like configurations between 2.4 m upright metal poles spaced at 33.7 m intervals over the main portion of roof. The 6 to 14 wires radiating from each pole created a mean maximum spacing between wires of about 16 m. Nesting by ring-billed and herring gulls was reduced by 76% and 100% in 1994 and by 99% and 100% in 1995, respectively, compared to 1993 pretreatment levels (1,011 ring-billed gull nests and 98 herring gull nests). Ring-billed gulls that constructed nests after wire installation gained access to the roof where wires were not installed along the roof edge, where wires were broken, by hovering over wires and landing between them, or from structures such as air conditioners that were at or above the level of surrounding wires. Initial placement of overhead wires above roof structures and regular maintenance of broken wires is recommended to increase effectiveness. Mean maximum spacing of 16 m between wires was effective in excluding nesting by herring gulls; however, narrower spacing is necessary to exclude nesting by ring-billed gulls. Also, many of the ring-billed gulls displaced by wires from the warehouse in 1994 relocated to nest on an adjacent building without overhead wires. Thus, although overhead wires can be effective in reducing nesting by gulls on roofs and in other urban situations, management should be considered at a scale broader than specific problem sites as displacement of nesting gulls may cause relocation of the colonies to surrounding areas.

**KEY WORDS:** animal damage control, exclusion, gulls, *Larus* spp., overhead wires

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## INTRODUCTION

Populations of ring-billed gulls (*Larus delawarensis*) and herring gulls (*L. argentatus*) have increased throughout the Great Lakes region in recent years. For example, the nesting population of ring-billed gulls along the Canadian portion of the lower Great Lakes increased from about 56,000 pairs to 283,000 pairs between 1976 and 1990 (Blokpoel and Tessier 1992). Winter populations of ring-billed and herring gulls along the south shore of Lake Erie increased 21- and 6-fold, respectively, from the 1950s to the early 1980s (Dolbeer and Bernhardt 1986). Potential causes for these increases include protection of breeding colonies, the ability of gulls to exploit anthropogenic food sources, and a greater availability of human-made nesting habitat (e.g., roofs, dredge disposal islands) (Kadlec and Drury 1968; Blokpoel and Tessier 1984, 1992; Belant et al. 1993, 1995).

Although gulls have reportedly nested on roofs for about 100 years (Goethe 1960), dramatic increases in the use of roofs and other urban sites for nesting by gulls have occurred only in recent years (Monaghan 1979; Blokpoel and Tessier 1986; Dolbeer et al. 1990; Vermeer 1992). This prevalence of roof-nesting has caused an increase in gull/people conflicts. Gulls are frequently considered a nuisance and health hazard when nesting on roofs because they cause structural damage by obstructing drainage with feathers and debris, harass maintenance personnel, and defecate on nearby vehicles (Belant 1993). Gull nesting in urban areas near airports can also create hazards to aircraft (Dolbeer et al. 1993).

Several techniques are available to reduce roof-nesting by gulls including egg oiling, nest and egg removal, and various harassment or frightening devices (Christens and

Blokpoel 1991; Blokpoel and Tessier 1992). Use of overhead wires is another technique that has successfully reduced nesting, feeding, or loafing by gulls (Amling 1980; Blokpoel and Tessier 1984; McLaren et al. 1984; Dolbeer et al. 1988). Optimal spacing and configuration of overhead wires, however, has not been determined.

In response to large concentrations of nesting ring-billed and herring gulls, personnel of a large food warehouse in northern Ohio installed an overhead wire system in 1994 to reduce the prevalence of nesting on their roof. The objective was to evaluate the efficacy of this overhead wire system to reduce roof-nesting by ring-billed gulls and herring gulls.

## STUDY AREA

Riser Foods Warehouse (RFW), 21 km south of Lake Erie in an industrial area of Bedford Heights, Cuyahoga County, Ohio, has a 7.2 ha roof covered with gravel and small stones (<10 cm diameter). The roof contains numerous vents and other structures, including a large refrigeration unit that creates an area of open water  $\leq 80$  m<sup>2</sup> on Section 7 (Figure 1). Ring-billed and herring gulls have nested on RFW since at least 1990, when about 50 nests were observed (E. C. Cleary, U.S. Dept. Agric., pers. commun.). During 1993, 1,011 ring-billed gull and 98 herring gull nests were observed on RFW (Gabrey et al. 1993).

## METHODS

### Installation of overhead wires

Overhead wires were installed by RFW personnel during spring 1994. On the main roof (Sections 1 to 7), stainless steel wires (0.8 mm diameter) were installed

creating a series of spoke configurations (Figure 2). Wires typically were attached from the top of 2.4 m high metal poles spaced at 33.7 m ( $SD = 6.5$  m,  $\bar{n} = 22$ ) intervals to adjacent poles or the roof edge. Poles were anchored in automobile tires filled with cement. Usually 6 to 14 wires radiated from each pole. This arrangement of wires created openings 8.4 to 73.4 m<sup>2</sup> ( $41.8 \pm 19.2$  m<sup>2</sup> [ $\bar{x} \pm SD$ ],  $\bar{n} = 10$ ). Some wires were also attached to existing roof structures (e.g., vents, air conditioners). Wires along the roof edge were often attached horizontally and/or diagonally between adjacent poles, perpendicular to the roof. On the lower sections of roof (Sections 8 to 11), wire was attached primarily from eyebolts on the main roof to eyebolts on the lower roof. As with the main roof, some wires on lower roof sections were attached to pre-existing structures. Maintenance personnel replaced broken wires with stainless steel wire or monofilament line (1.1 mm diameter).

An X,Y coordinate system was used to document the location of each pole and wire installed on the roof. The area of each section of roof was also measured. The authors then calculated the total length of wire installed, length of wire (m) installed by section of roof, and length of wire (m)/m<sup>2</sup> of roof by section.

#### Nest Monitoring and Removal

During 1994, RFW was monitored for nests on April 19 and April 26, then weekly from May 13 to June 24. During each visit the number of nests, clutch size, and species using each nest was recorded. Also, on April 19, May 27, and June 17 the location of each nest was recorded to the nearest 0.1 m using an X,Y coordinate system before removing all eggs and nest material. In 1995 nest searches were conducted on RFW at three-week intervals from April 27 to August 2. Data were collected as during 1994 except that no nest and egg removals were conducted.

During July 1994, the X,Y coordinates were used to relocate each 1994 nest location. For each nest the authors determined the shortest distance to each wire ( $\bar{n} = 2-5$ ) which immediately bordered the nest location, and the height of wire at each of these points. The minimum and maximum distances were measured between wires that bordered the nest location, using the center of the nest location as a point on the line. The distance from the nest location to the nearest structure was also measured. The authors used Pearson correlation analyses (SAS Institute, Inc. 1988) to determine the association between the maximum number of ring-billed gull nest locations observed in 1994 and the length of wire (m)/m<sup>2</sup> of roof, the number of structures present, and the maximum number of ring-billed gulls nest locations recorded in 1993 by roof section.

#### RESULTS

Maintenance personnel installed 25 km of wire on RFW. Cost of materials, including poles, tires and cement for mounting poles, and wire was \$6,000 (Meuti, RFW, pers. commun.). Installation of the overhead wires required 16 person-weeks labor at a cost of \$15,000. Thus, total cost of the system was \$21,000 or about \$3,000/ha. Maintenance costs in 1994 and 1995 were minimal, associated with occasional replacement of wires.

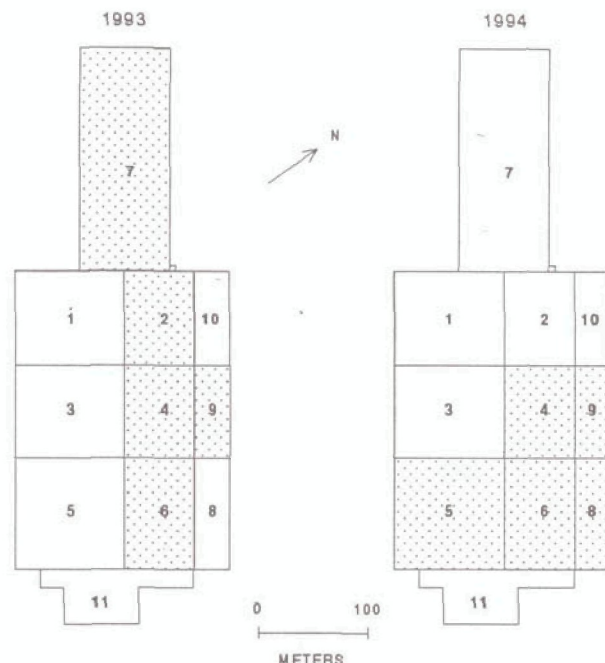


Figure 1. Location of nesting concentrations (stippled areas) of ring-billed gulls during 1993 (before overhead wire installation) and 1994 (after wire installation) by roof section, Riser Foods Warehouse, Bedford Heights, Ohio. Stippled roof sections contained  $\geq 90\%$  of nest locations in 1993 ( $\bar{n} = 1,477$ ) and 1994 ( $\bar{n} = 254$ ). Herring gull nests occurred primarily in Sections 2 to 4 during 1993; no herring gull nests were observed in 1994.

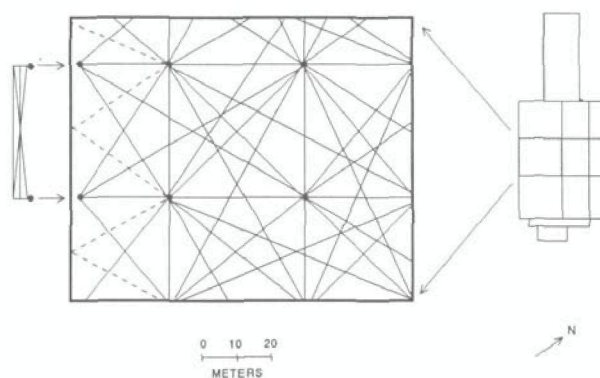


Fig. 2. Spoke configuration of overhead wires on Section 4 of roof of Riser Foods Warehouse, Bedford Heights, Ohio, 1994. Solid lines represent wires attached between adjacent poles; dashed lines are wires attached between a pole and the roof. Inset represents wires installed at the roof edge, perpendicular to the roof.

Compared to 1993 levels (1,011 ring-billed gull nests and 98 herring gull nests), nesting by ring-billed and herring gulls in 1994 was reduced by 76% and 100%, respectively. Nesting was further reduced in 1995 by 99% and 100% for ring-billed gulls and herring gulls, respectively.

In 1994, initiation of ring-billed gull nesting occurred in mid-April, with a maximum of 246 nests recorded on May 27 (Figure 3). Three nest and egg removals comprising 254 nests total were conducted. Most ring-billed gull nests (70%) occurred on Sections 5, 6, and 8 (Table 1). Ring-billed gulls that constructed nests after wire installation were observed accessing the roof where wires were not installed along the roof edge, where wires were broken, by hovering over wires and landing between them, or from structures such as air conditioners that were at or above the level of surrounding wires.

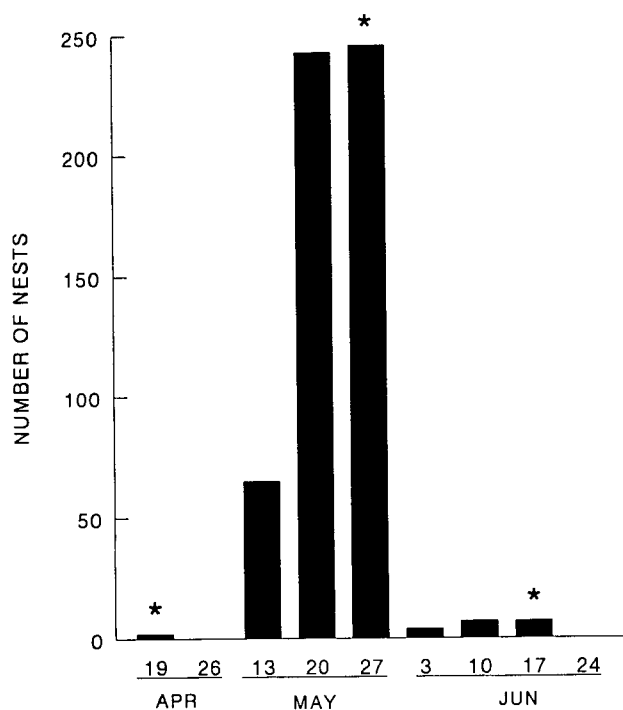


Figure 3. Number of ring-billed gull nests present after installation of overhead wires, Riser Foods Warehouse, Bedford Heights, Ohio, 1994. Asterisks indicate dates nests and eggs were removed.

Fourteen ring-billed gull nests were observed on Section 11 on May 31, 1995. Gulls likely entered this section of roof using several large structures with few adjacent wires. On June 21 only two ring-billed gull nests were present on this section. Maintenance personnel stated that additional overhead wires were installed on Section 11 on June 7 and that existing nests (about 14) had been removed. No additional ring-billed gull nests were observed during prior or subsequent searches.

There was no association ( $r = -0.23$ ,  $P = 0.49$ ,  $n = 11$ ) between the number of ring-billed gull nest locations

by roof section in 1994 and the number of nest locations by roof section in 1993 (Table 1). Also, the number of ring-billed gull nests by roof section in 1994 was not correlated with the number of structures present or the mean length of wire/m<sup>2</sup> by roof section ( $r = 0.13$  and  $0.09$ ,  $P = 0.69$  and  $0.78$ , respectively,  $n = 11$ ). The number of structures by section of roof ranged from 26-86. The length of wire/m<sup>2</sup> of roof also varied among sections (0.17-0.53 m/m<sup>2</sup>).

The mean minimum and maximum distances between wires surrounding ring-billed gull nest locations were 6.2 and 16.4 m, respectively, (Table 2). The mean distance from the nest location to adjacent wires was 3.8 m. Mean height of wires that encompassed nests was 2.2 m. Ring-billed gulls on average nested 0.4 m from roof structures.

## DISCUSSION

In this study, a mean maximum spacing between wires of about 16 m was effective in preventing nesting by herring gulls but not ring-billed gulls. In contrast to the spoke configuration of wires used in this study, most previous studies have evaluated parallel overhead wires. Parallel wires at 0.3 m to 2.5 m intervals were used to exclude ring-billed gulls from nesting and loafing areas (Blokpoel and Tessier 1983, 1988, 1992). Forsythe and Austin (1984) also reduced ring-billed gull use of a landfill using parallel overhead wires with 6 m spacing. McLaren et al. (1984) deterred ring-billed gulls and herring gulls from feeding sites with wire spacing of 6 m and 12 m, respectively. Amling (1980) effectively excluded gulls from reservoirs using parallel wires at 15 m intervals. Wires spaced at 3 m intervals over a landfill excluded herring and great black-backed (*L. marinus*) gulls but not laughing gulls (*L. atricilla*) (Dolbeer et al. 1988). Thus, it appears that herring gulls (and possibly other large gull species) can be excluded from nesting, loafing, or feeding areas with parallel overhead wires at  $\leq 16$ -m intervals whereas exclusion of ring-billed gulls would likely require wire spacing of  $\leq 6$  m. Additional research is required to determine optimal wire spacing and configuration necessary to exclude various gull species.

Height of wires above ground or roof level is probably less critical than the spacing interval used and is more dependent on the type of human activities at each site. In this study, wires were on average 2.2 m above the roof to provide access for maintenance personnel. In areas not used by people, Blokpoel and Tessier (1992) placed lines only 30 to 40 cm above ground to exclude ring-billed gulls. Dolbeer et al. (1988) evaluated lines placed 24 m above ground that reduced gull activity yet allowed large trucks to transport refuse underneath the wires.

To prevent gulls from using roof structures as access to roofs, overhead wires should be installed higher than any structures present on the area to be protected. Regular maintenance of broken wires is also recommended to maximize effectiveness. To prevent gulls from accessing the site laterally, wires perpendicular to the roof should be installed along the roof edge. Similarly, adjacent wires should be suspended at the same elevation to reduce lateral access. Dolbeer et al. (1988)

Table 1. Characteristics of overhead wire system, number of structures, and maximum number of ring-billed gull nest locations by roof section, Riser Foods Warehouse, Bedford Heights, Ohio, 1993 to 1995.

Roof Section	Section Area (m <sup>2</sup> )	Wire Length (m)	Wire Length/m <sup>2</sup>	Number of Structures	Maximum Number of Nests Observed In:		
					1993	1994	1995
1	8288	2273	0.27	49	17	0	0
2	8483	1405	0.17	49	528	1	0
3	7898	2512	0.32	72	0	12	0
4	5225	1722	0.33	46	157	29	0
5	9555	3041	0.32	83	49	79	0
6	6321	2456	0.39	74	144	62	0
7	16137	8525	0.53	77	400	6	0
8	2974	880	0.30	36	5	38	0
9	2471	598	0.24	26	97	27	0
10	2593	778	0.30	86	80	0	0
11	2336	862	0.37	60	0	0	14
Total	72281	25052	0.35	569	1477	254	14

Table 2. Characteristics of overhead wires and structures nearest to ring-billed gull nest locations ( $n = 253$ ), Riser Foods Warehouse, Bedford Heights, Ohio, 1994.

Parameter	Distance (m)	
	$\bar{x}$ (SD)	Range
Minimum distance between wires bordering nests <sup>a</sup>	6.2 (6.8)	0.0-24.1
Maximum distance between wires bordering nests <sup>a</sup>	16.4 (9.1)	2.4-40.2
Mean distance from next to bordering wire(s)	3.8 (1.2)	1.8-8.1
Mean height of wires bordering nests	2.2 (1.3)	0.0-2.3
Distance to nearest structure	0.4 (0.6)	0.0-3.8

<sup>a</sup>Measured using the center of the nest location as a point along the line.

speculated that variation in elevations of adjacent lines of  $\leq 1.5$  m may have allowed laughing gulls to penetrate overhead wires at a landfill. Differences in heights of adjacent wires in this study could have provided openings large enough for ring-billed gulls to fly through. Some gulls may also have gained access from the roof edge, as side wires perpendicular to the roof on some sections occasionally were attached only at the top of adjacent poles, rather than diagonally between them.

In a comparison of eight techniques used to control nuisance gulls, Blokpoel and Tessier (1992) ranked installation of overhead lines as third for overall effectiveness. Advantages of overhead wires included

high effectiveness in excluding gulls from nesting or loafing and a moderate level of permanence. Disadvantages included high initial cost and the need for specialized skills during installation. Permanent habitat alteration was suggested as the best method to reduce overall gull use of an area. Although modifications to roofs such as reducing the number of structures present or changing the roof substrate from gravel to tar or metal will likely reduce nesting (Belant 1993), the ability of gulls to nest on almost any substrate suggests that roof modifications alone will be only partially effective (Blokpoel and Tessier 1992) and that other methods, including overhead wires, should be considered.



In this study, many ( $\leq 470$  pairs) of the ring-billed gulls displaced by overhead wires at RFW in 1994 apparently relocated about 300 m to nest on an adjacent building without overhead wires (Dwyer et al. 1994). Gulls had not previously nested on this building. Blokpoel and Tessier (1983, 1988, 1992) also stated that ring-billed gulls displaced from nesting or loafing areas by overhead lines moved to nearby areas to loaf or recolonize.

Overhead wires are an effective technique for reducing nesting by gulls on roofs and in other urban situations. Management should be considered at a scale broader than specific problem sites, however, as displacement of nesting or nuisance gulls may cause relocation of the problem to surrounding areas.

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# NEST MATERIAL AS A DELIVERY METHOD FOR AVICIDES: PRELIMINARY TESTS WITH AFRICAN WEAVER FINCHES

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**ABSTRACT:** To evaluate the potential of using nesting material as a medium for avicide delivery, five organophosphates (Dasanit<sup>®</sup>, Volaton<sup>®</sup>, fenthion, parathion, and Cyanophos<sup>®</sup>) were tested on small groups of paired male-female quelea ( $n = 4$  to 9). Toxicants were presented to each pair of birds on five 13-cm strands of cotton string after a preliminary screening for male nest weaving behavior. Tested concentrations ranged from 100% technical grade to 0.003% compound diluted with acetone. Dasanit<sup>®</sup> was found to be the most effective candidate with some lethal effects noted at 0.012%. An optimal concentration for Dasanit<sup>®</sup> was estimated to be 0.80% based on combined male and female mortality (72%). This level was further evaluated in two aviary cage tests using 25 male-female quelea pairs during three-day exposure periods. A first replication yielded mortality ratios of 23:25 (92%) for males, but mortality ratios of only 1:24 (4%) for females. The second replication yielded mortality ratios of 24:25 (96%) for males and 11:25 (44%) for females. Females in the second group showed more weaving attempts than those in the first replication group, which could explain the pronounced mortality difference. Safety concerns about the use of toxicant-laden nesting material have not yet been evaluated in Africa. These concerns need to be addressed relative to the knowledge and literacy level of the local people applying the materials and to their awareness of methods of limiting pesticide exposures to the general public.

**KEY WORDS:** behavior, birds, nesting, toxicant application, avicides

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## INTRODUCTION

The African weaver finch, commonly known as the Sudan diach, black-faced diach, or quelea (*Quelea quelea*) has a total population estimated to be in excess of several billion (Crook and Ward 1968). These birds inhabit the dry region south of the Sahara Desert and their destruction to small grain cereal crops (rice, millet, wheat and sorghum) affects the economies of 25 African nations (Schafer et al. 1973; DeGrazio and Shumake 1982). When available, quelea tend to feed mainly on small grass seeds such as *Panicum*, *Echinochloa*, *Brachiaria*, or *Setaria* that grow extensively on the alluvial plains. However, when these wild grass seeds become unavailable during the early phases of the rainy seasons, the birds cause extreme and extensive damage to cultivated cereal grain crops (Ward 1965ab).

One of the most effective control methods for depredating quelea is aerial spraying of roosts or colonies with avicides (parathion, fenthion or Cyanophos<sup>®</sup>) within the first 20 to 30 minutes after sunset (Magor 1974; Meinzinger et al. 1989). Further, it has been recommended (Ward 1972) that the control operations should be carried out only on roost and nest sites within striking distance of vulnerable crops. The main objectives of this strategy are to reduce the cost of control and to reduce pollution hazards (Magor 1974).

Aerial spraying with avicides over quelea nesting and roost colonies has been thought to kill birds either via dermal absorption, inhalation, or oral routes (Meinzinger et al. 1989). The spraying operation is considered quite hazardous to the pilot of the aircraft and to associated ground crews since it must be conducted at dusk, under dark flying conditions, and when the birds are physically present in roost or nest sites. A safer, less costly, and

possibly equally effective method would involve the treatment of preferred nesting material with an avian-selective toxicant distributed by hand labor, by ground vehicles, or by aircraft over historical nesting sites prior to the breeding season. This approach to reductional control of local quelea populations could also have several other advantages over conventional aerial spraying: 1) increased safety due to less toxicant needed at lower concentrations; 2) reduced danger to pilots and ground crews; 3) lowered expenses associated with the purchase and maintenance of spray equipment; and 4) increased application potential in areas that could be treated at times during daylight hours when the birds are not physically present.

This study was conducted to evaluate the potential of using avicide-treated nesting material as a method for quelea control. Five organophosphates (Dasanit<sup>®</sup>, Volaton<sup>®</sup>, fenthion, parathion and Cyanophos<sup>®</sup>—see Appendix for chemical names) were evaluated as candidate treatments with individually caged male-female quelea pairs. (References to trade names do not imply endorsements of commercial products by the federal government.) One of the toxicants, Dasanit<sup>®</sup>, was further evaluated for efficacy with two groups of 25 male-female quelea pairs in an aviary cage.

## METHODS

Red-billed quelea were trapped in central Sudan, shipped by air to the Denver Wildlife Research Center, and held for 90 days under strict quarantine requirements in an indoor 2.4 x 4.8 x 2.1 m wire mesh aviary cage. Birds had free access to water, grit and a mixture of whole-grain sorghum, yellow millet, and Purina Game Bird Breeder Layena.

### Adaptation to Nest Material

Groups of 36 male and 36 female quelea were housed together in an indoor 2.5 x 2.4 x 2.2 m wire mesh aviary cage with mixed grain, water, grit, roosting branches (Russian olive), and nest materials (short lengths of cotton string and ribbon strips) constantly available. Throughout this 30-day adaptation period, a 12:12 light-to-dark cycle was maintained with room lights on at 0700 and off at 1900 MST. After adaptation, 18 male-female pairs were randomly selected and housed separately in 53 x 25 x 39 cm wire mesh cages for evaluations with avicide-treated nest material.

### Candidate Avicides

Five candidate organophosphate chemicals, previously registered as insecticides or avicides, were selected for assessment with male-female quelea pairs in individual cages. Parathion and fenthion were chosen because both have been used routinely for quelea roost and nest area application with aerial spray control operations for many years. Cyanophos<sup>®</sup> has also been tested experimentally with the aerial spray application method for control of quelea. The other two candidates, Dasanit<sup>®</sup> and Volaton<sup>®</sup>, are registered as insecticides and were selected for their high toxicity to finches and sparrows with relatively low toxicity to mammals.

### Avicide Assessments in Individual Cage Tests

After weaving behavior had been observed and recorded in each male-female quelea pair over a two to three week control period, the toxicant-treated material was prepared with five 13-cm strands of cotton string. This treated nest material was first introduced at full strength to 4 to 6 quelea pairs for a period of 2 hr of exposure. Bird pairs were observed repeatedly over the next 1-, 2-, 4-, and 24-hr periods and ten days post-exposure for signs of affectation (e.g., ataxia, tremors, etc.) and/or death. Serial dilutions of the toxicant concentration on the nest material were accomplished using acetone as the diluent at levels extending from 50.0% to 0.003%. Up to ten levels were evaluated for mortality effects for the candidate avicides. The avicide treatment that produced the highest number of deaths at levels below 3.23% was selected in terms of safety and cost considerations for further testing in a large aviary cage environment. For all candidate toxicants tested, closed circuit television (CCTV) observations were made to monitor and video record attempts toward male-female nest construction, passing of materials between the pairs, and total string contact time for individual quelea. Clean up of cages for toxic residues between each test consisted of using an ammonium hydroxide solution spray treatment followed by steam cleaning and water rinsing.

### Avicide Assessment in Colony Tests

Based on results from the individual cage tests, Dasanit<sup>®</sup> was selected as the candidate to receive colony tests at a concentration of 0.8% in acetone. Two replications of the colony test over an interval separated by four months were conducted. Both replications involved identical procedural sequences.

For each replicated test, 25 male and 25 female quelea were first housed together for two weeks of

adaptation to the aviary cage environment and to the nest material (13-cm strands of cotton string and ribbon). Daily CCTV observations and videotapes were made during this period to document normal weaving activity with untreated nest material. Treatment consisted of saturating 250 13-cm strands of string in a 0.8% Dasanit<sup>®</sup>/acetone solution and allowing 24 hr drying time under a fume hood in a separate room before offering the air-dried material to the 50 birds on the test day. Respiratory masks to filter and capture organic vapors were used in preparation of the materials to protect research personnel. Nest material was placed in a 26.6 x 16.5 x 5.1 cm glass holder and placed on a shelf 1.3 m above the aviary cage floor. A second day of treatment exposure consisted of offering 125 strands of the material (prepared 24 hr earlier) to the remaining survivor birds. The third day of treatment was a repetition of this procedure, but only 50 strands of freshly-treated nest material were made available to the surviving birds.

CCTV videotapes were made of quelea weaving attempts and any rejection or repellency to toxic nest material was noted. The times for quelea affectation due to toxicant contact were noted for the 2 hr period during which treated nest material was introduced on each test day. All surviving birds were held for two weeks post exposure with all treated material removed from the aviary after the third exposure day. The birds were observed during this interval for delayed mortality and for chronic toxicity effects.

## RESULTS

### Avicide Assessments in Individual Cage Tests

Several concentration levels were evaluated for mortality effects with Volaton<sup>®</sup>, Cyanophos<sup>®</sup>, and Dasanit<sup>®</sup>; whereas fenthion and parathion were only evaluated at 1 to 3 levels, none below 0.78%. For the latter two compounds (Table 1), male and female combined quelea mortality ratios never exceeded 3:12 (25%) even at the 100.0% concentration level. We observed no deaths with parathion.

For tests with paired quelea using Cyanophos<sup>®</sup> (Table 2), mortality ratios ranged from 0:8 to 5:8 (0.0 to 62.5%), with the 50% concentration level producing the highest number of combined male and female deaths. With Volaton<sup>®</sup> (Table 3), an even lower level of efficacy was noted. Only one male in five tested pairs apparently succumbed to the effects of this insecticide treatment at the 33.0% concentration level.

Lethal effects of Dasanit<sup>®</sup>, in contrast to the four other candidate avicides, were observed down to 0.012% concentration in acetone solution when applied to the string-nest material (Table 4). The highest level of male (8:9), female (5:9), and combined (13:18 or 72.2%) mortality was observed with this compound at the 0.787% wt/wt concentration. This level (approximately 0.8%) was subsequently chosen for further evaluations in the colony-aviary tests. Dasanit<sup>®</sup> produced some observable effects (uncoordinated perch stance) within 25 min after introduction to caged pairs at a 3.23% concentration level representing approximately 3.5 mg Dasanit<sup>®</sup> per strand of string. At the chosen level (0.8%), total Dasanit<sup>®</sup> available to male and female quelea in each cage was calculated to be 0.36 mg or .073 mg per strand of string.

Table 1. Acute toxicity test with individually caged male-female pairs of quelea and nest material treated with fenthion or parathion.

Concentration in Acetone (%)	Dilution Ratio	Mortality Ratios		
		Male	Female	Male + Female
Fenthion				
100.00	1:0	1:6	2:6	3:12
3.23	1:31	3:9	0:9	3:18
0.787	1:127	1:9	0:9	1:18
Parathion				
3.23	1:31	0:6	0:6	0:12

Table 2. Acute toxicity test with individually caged male-female pairs of quelea and nest material treated with Cyanophos\*.

Concentration in Acetone (%)	Dilution Ratio	Mortality Ratios		
		Male	Female	Male + Female
50.00	1:1	3:4	2:4	5:8
33.00	1:2	3:4	1:4	4:8
12.50	1:8	0:4	0:4	0:8
3.23	1:31	0:4	2:4	2:8
0.787	1:127	0:4	0:4	0:8
0.049	1:2,040	0:4	0:4	0:8

Table 3. Acute toxicity test with individually caged male-female pairs of quelea and nest material treated with Volaton\*.

Concentration in Acetone (%)	Dilution Ratio	Mortality Ratios		
		Male	Female	Male + Female
50.00	1:1	0:5	0:5	0:10
33.00	1:2	1:5	0:5	1:10
12.50	1:8	0:4	0:4	0:8
3.23	1:31	0:4	0:4	0:8
0.787	1:127	0:6	0:12	0:12
0.049	1:2,040	0:6	0:12	0:12
0.003	1:32,640	0:6	0:12	0:12

Table 4. Acute toxicity test with individually caged male-female pairs of quelea and nest material treated with Dasanit®.

Concentration in Acetone (%)	Dilution Ratio	Mortality Ratios		
		Male	Female	Male + Female
100.00	1:0	5:6	2:6	7:12
3.23	1:31	6:9	3:9	9:18
1.27	1:79	7:9	3:9	10:18
0.787	1:127	8:9	5:9	13:18
0.392	1:255	4:9	1:9	8:18
0.196	1:510	6:9	2:9	7:18
0.049	1:2,040	7:9	0:9	7:18
0.025	1:4,080	4:7	0:7	4:14
0.012	1:8,160	2:9	1:9	3:18
0.003	1:32,640	0:7	0:7	0:14

#### Avicide Assessments in Colony Tests

The first aviary test with 25 male-female quelea pairs indicated a predominance of male mortality; this was expected, as males were the primary nest builders in the laboratory cages as is the case in the wild. As shown in Table 5, a total of 24 males and only 1 female were killed by the nest material treatment (92% and 4%, respectively). Most of the deaths ( $n = 18$ ) resulted within 20 min after initial nest material contacts and weaving behavior by male birds on the first exposure day.

CCTV observations on this initial test day indicated that the male quelea were taking the introduced Dasanit®-treated nest material within 2 min after introduction. There appeared to be no detectable initial repellency at the 0.8% concentration. Within 10 min of introduction of the material, the male quelea appeared to be very active and excited with much wing fluttering and "tugs-of-war" over the string. Individual quelea took whole "bales" of string in their beaks to nest sites. These behaviors were commonly observed during the control-adaptation period as new untreated nest material was introduced each day. During the colony tests with Dasanit®, however, some birds appeared uncoordinated and unable to stay perched on the tree branches within 20 min of their initial contact with treated nest material. Within 30 to 50 min, several males fell from their nest site perches on the Russian olive tree branches to the floor of the aviary cage.

On the second test day, there was less vigorous-aggressive weaving behavior by the seven remaining males. However, this may have indicated either that the best nest weavers had been killed on the previous day, or that the Dasanit treatment produced repellency or aversion. During the final third day of exposure to freshly treated nest material by remaining birds (as observed with CCTV), three females contacted the string but only very briefly. Since only one of these females died, this may indicate that bill and/or foot contact for a

few seconds is necessary before a lethal dose is delivered to quelea via nest material. This was also an indication that Dasanit® vapor inhalation at the concentration and exposure interval used in the colony test was insufficient to produce any deaths or observable signs of toxicosis.

The second aviary test, conducted four months later in early February, produced similar results in male quelea (total of 24 deaths after three days of exposure), but a substantial increase in deaths of female quelea was observed (total of 11 deaths after three days of exposure). Whether the females in this second group were consistently more inclined to take nest material and to attempt to weave, or whether an increase in this weaving behavior was due to a seasonal effect, was not determined. With the indoor controlled lighting and heating regime, however, such seasonal effects were probably minimal.

CCTV observations of weaving behavior on the first exposure day of the second aviary test indicated again that several "tugs-of-war" over single strands of Dasanit®-treated string revealed no signs of initial repellency in the males. There was some head shaking and bill wiping behavior by a few males within 18 to 20 min after initial string contact. Within 30 min, males fell from their nest weaving sites to the floor of the aviary cage. A total of eight males were observed falling from the branches within the next 15 min interval post exposure.

On the second exposure day, with only one physically active male surviving, there was almost no weaving activity observed. Females were observed only tugging at the nest material already woven in place at nest sites on branches within the aviary cage. Some of the treated material may have been placed in the nest sites previously by males, but this could not be verified by CCTV observation. The third exposure day revealed only one female pecking at the string material, but she did not pick up any nest material in her bill.

Table 5. Cumulative daily and percentage total mortality in two groups of 25 male-female quelea pairs exposed for three days to 0.8% Dasanit<sup>®</sup> on nest material in colony tests.

Exposure Day	Male	Female	Total
Cumulative Mortality (Test 1)			
1	18	1	19
2	22	1	23
3	23	1	24
Total (%)	92	4	48
Cumulative Mortality (Test 2)			
1	24	8	32
2	24	9	33
3	24	11	35
Total (%)	96	44	70

## DISCUSSION

Feasibility of producing a high level of efficacy (92 to 96%) with an organophosphate insecticide (Dasanit<sup>®</sup>), using nest material as a delivery medium, was demonstrated under aviary conditions with captive male quelea. Although efficacy for the females was greatly lessened and was more variable (4 to 44%), the absence of males would undoubtedly lead to extreme reproductive failures during the breeding season. This is projected because males are the builders for almost all of the nests; and even if they became polygamous, females are not attracted to an individual male until he has constructed a viable nest, with pair-bonding then occurring after a short courtship period (Collias and Collias 1970). This reproductive failure, in turn, would lead to reduced crop losses by newly fledged birds in regions having historical quelea nesting sites within striking range.

For actual field application of this method, field efficacy data would, of course, be needed. If this method is verified as effective under field conditions, then nest material could be distributed by hand, from ground crews in vehicles, or from aircraft. For aerial application, automatic equipment has been developed (Schoenleber et al. 1973) to cut selected lengths and to distribute lure-toxicant treated twine for the control of certain insects. *Automatic preparation and handling could enhance safety* to applicators in terms of less dermal and inhalation exposure to the avicide. There would also be enhanced safety to the overall control operation as pilots and ground crews would no longer be limited to spray operations over the 20 to 30 min dusk period immediately following sunset (Meinzinger et al. 1989); this period provides for pilot visibility but reduces the number of quelea flushed from roost and nesting areas. Toxic nest material could be applied during those hours of daylight when birds are not in their nesting areas. Spray drift and bird-contact-

spray-droplet intercept angle would not be determining factors for efficacy as is the case with spray applications.

This nest material method for applying avicide would most likely be used in addition to, rather than replacing, the aerial spraying control method. New safety concerns would have to be addressed including: assessing the environmental fate of Dasanit<sup>®</sup>, scaling-up procedures with large amounts of avicide and distributed nest material, training of control applicators, warning communications to locals, and purchasing and maintaining protective safety equipment.

Dead and dying quelea have been recovered after toxic spray applications by locals in many African countries as a supplemental source of food (Jaeger and Elliot 1989). The residue levels in quelea killed by the toxic nest material method have not been determined, but they would probably be considerably lower than those generally found with the aerial spray method. Even though quelea meat harvest is routinely discouraged, many people will probably continue to partake of the cooked birds since the practice has been going on continually for decades. Cooking the collected birds in hot water probably quickly reduces the organophosphate residues to negligible levels. No documented severe sub-lethal toxicosis or deaths have been recorded in association with this practice (Jaeger and Elliot 1989).

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## APPENDIX

### Trade/Common Name — Chemical Name

Dasanit*	— <u>O</u> , <u>O</u> -diethyl <u>O</u> - <u>p</u> -(methylsulfinyl) phenylphosphorothioate
Volaton*	— <u>a</u> -[[diethoxyphosphinothioyl]oxy]imino]-benzeneacetonitrile
fenthion	— <u>O</u> , <u>O</u> -dimethyl <u>O</u> -[4-(methylthio)- <u>m</u> -tolyl] phosphorothioate
parathion	— <u>O</u> , <u>O</u> -diethyl <u>O</u> - <u>p</u> <u>6</u> -nitrophenyl phosphorothioate
Cyanophos*	— <u>O</u> , <u>O</u> -dimethyl <u>O</u> -[4 cyanophenyl] thionophosphate

# EFFECTS OF STAGE OF NUT DEVELOPMENT AND SIMULATED RAT DAMAGE ON MACADAMIA YIELDS

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**ABSTRACT:** Black rats (*Rattus rattus*) cause extensive damage in Hawaiian macadamia (*Macadamia integrifolia*) orchards. In a previous study, extensive and persistent snap trapping significantly reduced rat populations and depredations on developing macadamia nuts, but had little effect on subsequent yields of mature nuts. This suggested that macadamia trees may compensate for rat damage, and that commonly used indices based on rodent activity and proportion of nuts damaged may overestimate the impact of rodent depredations and exaggerate the effectiveness of control measures. To clarify the effects of rat feeding on developing macadamia nuts, two levels of damage at two times during nut development and evaluated yields of mature nuts were simulated. Both number of nuts per raceme ( $P = 0.0001$ ) and total weight of mature kernels per raceme ( $P = 0.0001$ ), but not mean weight per mature kernel ( $P = 0.90$ ), varied among treatments. Both number of nuts and total weight of kernels decreased ( $P < 0.05$ ) with increasing damage. Time during nut development that damage was simulated had no apparent effect ( $P > 0.05$ ) on yields. These results indicate that racemes did not compensate for damage by retaining other nuts on the same raceme that might otherwise have dropped prematurely. A variance component analysis was also conducted to determine how best to sample the orchard in a practical fashion while minimizing potential sources of bias and retaining sensitivity for distinguishing among treatment effects. All of the random variability in the number of nuts per raceme and total weight of nuts per raceme, and  $>93\%$  of the variability in mean weight per mature nut were due to variability between racemes on a tree. Thus, blocking was not needed to control for variability among the different areas in the orchard; sampling fewer trees and concentrating available resources on measuring more racemes per tree would have provided a more sensitive comparison of treatments. Focusing on entire branches or trees instead of racemes as experimental units might have provided a more realistic model for investigating compensatory mechanisms in macadamia trees.

**KEY WORDS:** animal damage control, compensatory growth, integrated pest management, *Macadamia integrifolia*, *Rattus rattus*

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## INTRODUCTION

Black rats (*Rattus rattus*) cause widespread damage in Hawaiian macadamia orchards (Tobin 1992). These arboreal rodents feed on macadamia nuts from the time kernels are small, fleshy unprotected fruits to when they are fully developed, high in energy-rich oils, and surrounded by shells and fibrous husks. Most damaged nuts are either pulled from the tree by rats or abscise prematurely and drop to the ground.

Many macadamia growers use toxic baits to control rat depredations in their orchards on the assumption that fewer rats result in less damage and, thus, higher yields. However, low levels of nut damage may have little or no impact on yield of mature nuts. A recent study (Tobin et al. 1993) indicated that although extensive and persistent snap trapping reduced rat populations and depredations on developing macadamia nuts, it had little effect on subsequent yields of mature nuts. Likewise, koa seedworm (*Cryptophlebia* spp.) feeding on developing macadamia nuts had little effect on premature nut drop until nut damage levels exceeded about 25% (Jones and Tome 1993).

These studies indicate that macadamia trees may compensate for low levels of damage. If so, the cost-effectiveness of rodent control programs may be

questionable in some situations. Commonly used indices based on rodent activity and proportion of nuts damaged may overestimate the impact of rodent depredations and exaggerate the effectiveness of control measures.

In 1994 a study was initiated to determine the effects of simulated rat damage on yields of mature nuts. The objective was to determine whether simulated rat damage to developing nuts results in reduced yields of mature macadamia nuts on the same raceme. The authors also investigated how best to sample in a macadamia orchard so that uncontrollable sources of variation were best addressed when conducting field studies.

## METHODS

The study was conducted during the 1994 crop season at the Kau Agribusiness, Inc. macadamia orchard in Keaau, Hawaii. The authors divided 310 fifteen-year-old macadamia trees of variety 344 into 62 blocks of 5 trees each and randomly assigned 5 treatments to the trees in each block. The same assigned treatment was applied to two 4-nut racemes on opposite sides of each tree. Half of the branches for each treatment faced the adjacent trees within the row, and half faced the nearest trees in the adjacent rows. Damage was simulated by removing one or two nuts from each raceme at 100 or 150 days after

anthesis (as estimated by G. Ueunten, Kau Agribusiness, Inc., pers. comm.). The authors also evaluated a control group from which no nuts were removed. For each treatment, an approximately equal number of nuts from the proximal, middle, and distal portions of racemes were removed. The racemes were bagged with plastic mesh to prevent injury by rats and to catch abscised nuts.

At 150, 200, and 230 days after peak anthesis, the authors collected, weighed and evaluated the maturity of nuts that had abscised and fallen into the bags. At 230 days after peak anthesis they also collected any remaining nuts attached to the racemes. The nuts were husked and weighed, allowed to air-dry in the laboratory for five to seven days to equalize their moisture content, and placed in a convection oven at 75°C for 72 hours to reduce moisture to 1.0-1.5% (M. Tsang, Univ. Hawaii at Hilo, pers. comm.). The authors then shelled the nuts, extracted and weighed the kernels, and floated each kernel in deionized water to determine whether its specific gravity was >1.0, an indication that the oil content was >72% and the nut was fully mature (Cavaletto 1980).

Randomized blocks ANOVAs were conducted using SAS PROC GLM (SAS Instit. 1988) to compare the effects of level (removed 0, 1, or 2 nuts) and timing (100 or 150 days after anthesis) of damage on the number of nuts, total weight of kernels, and mean weight per kernel harvested per raceme. The authors used Duncan's multiple range test with  $P < 0.05$  (Saville 1990) to separate treatment means.

Variance components were analyzed to identify which random effects in the randomized block ANOVA model

contributed most to the variance in the measured variables. SAS PROC VARCOMP (SAS Instit. 1988) were used to iteratively apply a restricted maximum likelihood method because variance components are constrained to be positive and the method separates the likelihood into a part containing fixed effects and a part containing random effects (Patterson and Thompson 1971).

## RESULTS

By 230 days post anthesis, all except 15 nuts on ten racemes had abscised. The authors harvested 1.8 to 3.6 mature nuts ( $F = 174, 4, 242 \text{ df}, P = 0.0001$ ) weighing 4.1-8.1 g ( $F = 103, 4, 242 \text{ df}, P = 0.0001$ ) per raceme (Table 1). Both the number of nuts and total weight of nuts were highest ( $P < 0.05$ ) for racemes with no simulated damage, and were higher ( $P < 0.05$ ) for racemes from which only one nut was removed than for racemes from which two nuts were removed. Timing of damage had no apparent effect on number of mature nuts or total weight of mature kernels harvested per raceme ( $P > 0.05$ ). Mean weight per mature kernel (2.2 g) did not vary among the treatments ( $F = 0.24, 4, 242 \text{ df}, P = 0.90$ ).

Nearly all of the random variability in the number of nuts per raceme, total weight of mature kernels per raceme, and mean weight per mature kernel was due to variability among racemes on a tree (Table 2). The other random effects in the design (blocks and block x treatment interaction) resulted in zero or negligible estimates of their variance components.

Table 1. Mean number of nuts per raceme, weight of kernels per raceme, and weight per kernel harvested from racemes with different levels of simulated rat damage in a macadamia orchard near Hilo, Hawaii, August to November 1994. Rat damage was simulated by removing 0, 1, or 2 nuts per raceme at 100 or 150 days after anthesis. Abscised nuts were collected at 150, 200, and 230 days after anthesis.

Days After Anthesis	Number of Nuts Removed	Number of Racemes	Yield <sup>a</sup>					
			Number of Nuts Per Raceme		Weight (g) of Kernels Per Raceme		Weight (g) Per Kernel	
			$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
--	0	122	3.6 <sup>A</sup>	0.07	8.1 <sup>A</sup>	0.21	2.2 <sup>A</sup>	0.04
100	1	119	2.7 <sup>B</sup>	0.05	5.9 <sup>B</sup>	0.15	2.2 <sup>A</sup>	0.04
150	1	119	2.7 <sup>B</sup>	0.06	6.1 <sup>B</sup>	0.19	2.2 <sup>A</sup>	0.04
100	2	120	1.9 <sup>C</sup>	0.04	4.1 <sup>C</sup>	0.11	2.2 <sup>A</sup>	0.04
150	2	112	1.8 <sup>C</sup>	0.05	4.1 <sup>C</sup>	0.12	2.2 <sup>A</sup>	0.04

<sup>a</sup>Means that share a common letter in each column do not differ ( $P > 0.05$ ) based on Duncan's multiple range test.



Table 2. Contribution of each random effect in the randomized block ANOVA model to the variance in the number of nuts, the total weight of nuts, and the weight per nut harvested in a macadamia orchard near Hilo, Hawaii, during August to November 1994. Treatments consisted of removing 0, 1, or 2 nuts from each of 2 racemes on each tree at 100 or 150 days after anthesis. Abscised nuts were collected at 150, 200, and 230 days after anthesis.

Variance Components	Variable		
	Number of Nuts Per Raceme	Weight (g) of Kernels Per Raceme	Weight (g) Per Kernel
Block	0.000	0.000	0.013
Block x treatment	0.000	0.000	0.002
Raceme	0.339	3.067	0.187

## DISCUSSION

Macadamia flowers and fruits abscise throughout the entire period of nut development, from anthesis through fruit maturity 28 to 30 weeks later (Sakai and Nagao 1984). A typical macadamia raceme produces 200 to 300 flowers, of which usually <1% develop to full nut maturity (Sakai and Nagao 1984). This high premature abscission is a major constraint on nut production (Nagao and Hirae 1992) and has been the focus of much research aimed at increasing fruit set and yields (Williams 1980; Nagao et al. 1982; Ueunten 1989; Nagao and Sakai 1990).

The bearing capacity of macadamia trees may be limited by the availability of nutrients and stored carbohydrates (Cormack and Bate 1976; Stephenson and Gallagher 1989; Stephenson et al. 1989a,b). Nagao et al. (1988) observed that macadamia trees had similar yields over the course of a four-year study despite differing flowering intensities; trees that initially had more flowers or immature nuts experienced higher premature abscission. Likewise, the authors' earlier work indicated that in some situations rat predation on developing nuts has no measurable effect on yields (Tobin et al. 1993). These studies imply that macadamia trees can compensate for some levels of damage.

Most studies of premature macadamia nut drop have focused on the early stages of nut development (e.g., Williams 1980; Nagao et al. 1988; Ueunten 1989; Nagao and Sakai 1990). However, rats may be most attracted to macadamia nuts during the latter half of the developmental process, when nuts accumulate high-energy fatty acids (Cavaletto 1980). A better understanding of the dynamics of premature nut drop during the latter half of the crop cycle would help determine the effects of rat damage, as well as of drought, insect damage, and disease.

The authors measured the effects on individual racemes of damage simulated at 100 days after anthesis (after the kernel has reached full size but just before the embryo begins to form and accumulate oil) and at 150 days after anthesis (when almost 50% of the dry nut weight is oil) (Cavaletto 1980). Yields (both number of nuts and total weight of kernels) decreased with increasing damage, indicating that racemes did not compensate for

damage by retaining other nuts on the same raceme that might otherwise have dropped prematurely. Timing of damage had no discernable effect on yields. The similar size of mature nuts in all groups indicates that trees did not compensate for damaged nuts by putting more resources into remaining undamaged nuts.

Macadamia trees translocate assimilates and other growth factors not only among nuts on a raceme, but also among racemes and branches (Ueunten 1989). This study investigated interactions only among nuts on individual racemes. Focusing on entire branches or trees as experimental units might have provided a more realistic model for investigating compensatory mechanisms in macadamia trees.

Macadamia fruit growth and abscission are complex, dynamic processes that are influenced by the variety, age, and condition of the tree. Varieties with extended flowering and nut drop may have enhanced opportunities to compensate for damage because resources that might otherwise have gone into damaged nuts can be assimilated by later developing nuts. The authors' previous study, that failed to detect a relationship between rat damage and macadamia yields (Tobin et al. 1993), was conducted mainly with variety 508, which in Hawaii flowers throughout most of the year. The current study utilized variety 344, which has a much more restricted flowering period and thus decreased opportunities for compensatory nut development. Age of tree also affects flowering; young trees flower over more restricted periods and thus may have diminished opportunities for compensatory growth. Further research would help clarify the effects of variety, flowering synchrony, and damage during the latter half of nut development on yields of mature nuts.

Investigations into responses of macadamia trees to nut damage pose logistical dilemmas about how best to sample an orchard in a practical fashion while minimizing potential sources of bias and retaining sensitivity for distinguishing among treatment effects. In this study, which utilized trees of uniform variety and age, almost all of the variability in yield was between racemes on the same tree. Neither the area of the orchard sampled (block) nor the application of the different treatments across the areas (block x treatment interaction) contributed any appreciable variability. This indicates

that blocking was not needed to control for variability among the different areas in the orchard. A completely randomized design for assigning treatments to the same number of trees would have increased the degrees of freedom, and thus the sensitivity, for comparing treatment effects. Likewise, sampling fewer trees and concentrating available resources on measuring more racemes per tree would also have provided a more sensitive comparison of treatments. A different experimental design might be more appropriate for examining yields in orchards with a greater diversity of tree varieties and ages or more varied orchard topography.

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# ECONOMIC EFFECTIVENESS, EFFICIENCY, AND SELECTIVITY OF FOX SQUIRREL TRAPPING IN PECAN GROVES

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**ABSTRACT:** Trapping is the most common damage management practice employed by pecan growers suffering fox squirrel (*Sciurus niger*) depredation. The author evaluated the economic effectiveness of foot-hold trapping for fox squirrels in native pecan groves from 1988 to 1991. Trapping significantly reduced squirrel damage the first and second year of treatment in all three study areas relative to the initial untreated year. This reduction was valued at \$38.63 to \$279.51/ha. In 1990 the author tested the relative efficiency and selectivity of five trap types. Number 110 body traps performed with the best combination of efficiency, selectivity, and cost of the trap types tested.

**KEY WORDS:** animal damage control, fox squirrel, pecan, *Sciurus niger*, trapping

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## INTRODUCTION

Fox squirrels are significant depredators of pecan production (Leppla 1980; Hall 1984), especially in native pecan groves (Huggins 1991). Foot-hold trapping is one of the most widely practiced damage management methods by pecan growers (Mullenax et al. 1984; Boyd 1988). This paper examines the economic effectiveness of this practice, and compares the efficiency and selectivity of five fox squirrel trap types.

## METHODS

### Economic Effectiveness

Native pecan groves on the Noble Foundation's Red River Demonstration and Research Farm (RRDRF) in Love County, Oklahoma were used to assess the economic impacts of foot-hold trapping for fox squirrels from 1988 to 1991. The RRDRF is beyond the western edge of the gray squirrel (*Sciurus carolinensis*) range. A pilot study was conducted in 1988 to establish pecan damage levels in a year in which hunting and other damage management methods were not implemented. Three, 4.3-ha (91- x 466-m) sampling areas (Areas 1-3) were established in the perimeter of groves adjacent to woodland. The methods of Huggins (1991) were used to estimate fox squirrel nut damage using ground plots. During the pilot study only, 10 rather than 15 trees were monitored and ground plots were established adjacent to each tree's trunk rather than midway between the trunk and outer canopy of the tree as in the remainder of the project.

In 1989, two additional Areas (4 and 5) were established for a total of five Areas monitored. In Areas 1 and 2, fox squirrel hunting was allowed from June 1 to December 31 and foot-hold trapping was conducted approximately five days per week from June 22 through December 8.

In 1990, no squirrel hunting was allowed in any Area and trapping was conducted in Areas 1, 2, and 4. Due to low relative trap efficiency during June and July 1989, trapping was not initiated until August 13 but continued seven days per week through December 13. All trap sets in both years were made with unbaited number 1 single long-spring foot-hold traps set on L-shaped wooden platforms nailed 1.2 to 1.8 m above ground. Twenty-five

traps were used in each area, with sets made on perimeter trees adjacent to woodland. Unsuccessful traps were periodically moved to other pecan trees within the same Area to increase effectiveness. All captured squirrels were killed.

In 1991, squirrel damage was again monitored in all Areas, but no squirrel damage management practices were implemented which provided the opportunity to observe any carryover effects from previous years' practices. All data were analyzed as a nested analysis of variance design (2 plots per tree, 10 or 15 trees per Area) and multiple comparisons were made with Duncan's multiple range test (SAS Institute, Inc. 1988).

### Trap Types

Trapping was conducted in the Griffith and Rutledge pecan groves comprising approximately 40 ha in Carter County, Oklahoma, from October 2 through December 20, 1990. Five trap methodologies were evaluated: 1) baited number 110 single-spring body traps, 2) baited 14- x 14- x 41-cm wire mesh cage traps, number 1 single long-spring foot-hold traps either 3) unbaited, 4) baited, or 5) unbaited and padded with Victor Soft Catch® number 1.5 replacement pads epoxied to the jaws. The padded traps were evaluated as an economical alternative to commercially available padded traps. Whole pecans were used as bait at all baited traps.

All traps were set on L-shaped wooden trapping boards nailed 1.2 to 1.8 m above ground to pecan tree trunks within 30 m of the grove-mixed timber habitat edge. Huggins and Gee (1995) found that cage trap sets made on trapping boards exhibited the best combination of efficiency and selectivity of the fox squirrel sets tested. A randomized block design with 25 blocks of 5 traps each (1 trap of each type) was used employing a total of 125 traps in the study. Five consecutive pecan trees within the 30-m zone along the edge of the grove formed a block, with 1 of the 5 trap types randomly assigned to individual trees. All trap sets were oriented on the trunk toward the woodland. Set traps were inspected a minimum of once per day, and all captured fox squirrels were killed. Means were evaluated using analysis of variance of a randomized block design and multiple comparisons were made using Duncan's multiple range

test (SAS Institute, Inc. 1988).

## RESULTS

### Economic Effectiveness

A total of 205 fox squirrels were removed by trapping (176) and hunters (29) from the combined 8.6 ha of Areas 1 and 2 in 1989. Trapping efficiency peaked in September (Figure 1) and averaged 3.71 squirrels per 100 trap days (TD). The overall trap efficiency of 0.71 fox squirrels per 100 TD in 1990 was fairly constant but greatly diminished relative to 1989. In 1990, only 46 squirrels were trapped in Areas 1 and 2 combined, with another 19 trapped in Area 4 for a total of 65 from the combined 12.9 ha of Areas 1, 2, and 4.

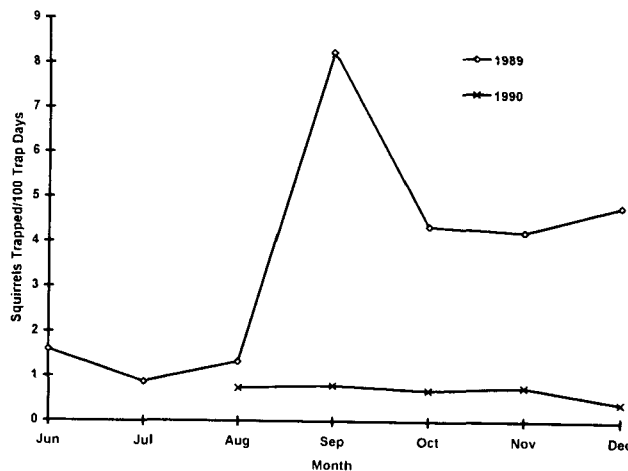


Figure 1. Fox squirrel trapping efficiency using unbaited number 1 single long-spring foothold traps set on L-shaped trapping boards in Love County, Oklahoma, native pecan groves.

Overall nontarget trapping rate was 0.74 and 0.30 per 100 TD in 1989 and 1990, respectively. Raccoons (*Procyon lotor*) and opossums (*Didelphis marsupialis*) together comprised 66% of the nontarget catches, but southern flying squirrels (*Glaucomys volans*), *Peromyscus* spp., eastern woodrats (*Neotoma floridana*), eastern bluebirds (*Sialia sialis*), barred owls (*Strix varia*), and blue jays (*Cyanocitta cristata*) were also caught. Approximately 37% of the nontarget captures were either killed by capture or were judged to have sustained serious enough injury that they had to be killed.

In untreated Areas, squirrel nut damage ranged from 13.3 to 425.5 kg/ha, a value of \$26.03-403.33/ha (Table 1). This damage exceeded harvested pecans in 5 of the 10 untreated Area-year combinations sampled. Within an Area, significant differences ( $P < 0.05$ ) were detected in fox squirrel damage levels between years for the trapped Areas 1, 2, and 4, but no differences were found among years in untreated Areas 3 and 5 (Table 2). Trapping significantly ( $P < 0.05$ ) reduced fox squirrel damage the first and second year of treatment relative to the initial untreated year in Areas 1, 2, and 4. A second year of trapping in Areas 1 and 2 reduced damage relative to the

first treatment year an average of 54%, but this difference was not significant ( $P > 0.05$ ). However, this reduction was important relative to the average damage increase of 51% in untreated Areas 3 and 5 over the same period. Damage levels rebounded 76% in 1991 in previously trapped Area 1. However, in previously trapped Areas 2 and 4, damage levels fell 17% and 24%, respectively, similar to the trend in the untreated Areas, which averaged 25% lower in 1991 than in 1990. The estimated savings due to trapping ranged from \$38.63 to \$279.51/ha (Table 3).

### Trap Types

A total of 86 fox squirrels and 20 nontarget animals were captured in the combined 5500 TD of the project. Nontarget catches were significantly ( $P = 0.008$ ) different among trap types. Fox squirrel catches were only weakly ( $P = 0.059$ ) different among trap types. Cage traps were the most efficient type, significantly more than foot-hold or padded foot-hold traps (Table 4). There were no significant differences in efficiency of padded versus unpadded or baited versus unbaited foot-hold traps. Cage and baited foot-hold traps caught more nontargets than the other three types. Baited foot-hold and padded foot-hold traps had the lowest and highest relative cost per trapped squirrel, respectively.

## DISCUSSION

The high number of squirrels removed from the study Areas in 1989 (23.8 squirrels/ha) apparently was a result of substantial immigration of immature (subadult and juvenile) squirrels from surrounding habitat into the relatively small, trapped Areas. Adult to immature ratios of trapped squirrels increased from 1:2.7 in August to 1:6.2 in September, and then dropped to 1:5 in October and 1:1.7 in November. Nixon et al. (1974) observed a similar influx of immature fox squirrels into heavily hunted woodlots in Ohio from early September through early November. This dispersal period was apparently much reduced in 1990, as the trapping ratio never increased above 1:3.

The damage levels and savings due to trapping are applicable to the perimeter portions of native pecan groves only. These edge habitats adjacent to woodland can be considered a fox squirrel "damage zone" extending into the grove approximately 90 m (Huggins 1995). Since native groves occur predominantly along riparian corridors, they generally have a large edge component.

In this study, trapping was limited to the pecan grove only, which limited the effectiveness of trapping prior to the initiation of damage. The effectiveness of trapping the adjacent woodland during other seasons should be evaluated.

Humaneness is one aspect of trap choice, though not specifically addressed in this study, which should be considered. Due to the large number of squirrels which must be dealt with in pecan management situations, translocation is not a practical option. Therefore, trapped squirrels will be killed. Under these conditions, killing traps are the most humane, for the squirrel is not held under stress, sometimes sustaining injury, prior to being killed by the trapper. Other factors which influence trap type choice include legality and ease of use.

Table 1. Estimated kilograms and dollar value per hectare of pecans damaged by fox squirrels from August to December in Love County, Oklahoma, native pecan groves.

Year	<u>kg/ha</u>					<u>\$/ha<sup>a</sup></u>				
	1 <sup>b</sup>	2	3	4	5	1	2	3	4	5
1988	110.3	425.5	40.3	--	--	104.54	403.33	38.24	--	--
1989	42.8	80.4	41.8	56.9	16.9	65.91	123.82	64.37	87.63	26.03
1990	12.1	52.6	67.3	17.3	22.3	30.73	133.60	170.94	43.94	56.64
1991	20.5	40.8	54.5	10.1	13.3	42.44	84.46	112.82	20.91	27.53

<sup>a</sup>Based on price received of \$0.94, \$1.54, \$2.54, and \$2.07/kg for in-shell pecans in 1988-1991, respectively.

<sup>b</sup>Study Areas: Areas 1 and 2 were squirrel hunted and trapped in 1989; Areas 1, 2, and 4 were squirrel trapped in 1990.

Table 2. Mean number of fox squirrel damaged pecans found in 1-m<sup>2</sup> ground plots from August to December in Love County, Oklahoma, native pecan groves.

Year	<u>Area<sup>a</sup></u>				
	1	2	3	4	5
1988	8.30A <sup>b</sup>	37.35A	3.25A	--	--
1989	2.58B	5.97B	3.62A	11.87A	7.47A
1990	0.75B	3.75B	5.92A	3.13B	10.28A
1991	1.32B	3.10B	4.38A	2.37B	6.20A

<sup>a</sup>Areas 1 and 2 were squirrel trapped and hunted in 1989; Areas 1, 2, and 4 were squirrel trapped in 1990.

<sup>b</sup>Means within a column followed by the same letter are not statistically different ( $P > 0.05$ , Duncan's multiple range test).

Table 3. Value of pecans saved due to fox squirrel trapping in three native pecan grove study areas in Love County, Oklahoma, 1989 to 1990.

Year	<u>Area 1</u>		<u>Area 2</u>		<u>Area 4</u>	
	\$/ha	CI <sup>a</sup>	\$/ha	CI	\$/ha	CI
1989	38.63	12.55- 64.71	279.51	150.38-408.64	--	--
1990	73.81	38.68-108.94	269.73	154.02-385.44	43.69	18.04-69.34

<sup>a</sup>Confidence intervals (95%) extrapolated as the same percentage of the mean as confidence intervals developed from 1-m<sup>2</sup> plot samples of fox squirrel nut damage.

Table 4. Mean number of fox squirrels and non-target wildlife and relative cost per squirrel caught in 44 trap days per set in various trap sets in native pecan groves in Carter County, Oklahoma, 1990.

Trap Type	Fox squirrels <sup>a</sup>	Nontargets	Relative cost <sup>b</sup>
Baited cage	0.92A	0.36A	16.39
No. 1 baited foot-hold	0.72AB	0.36A	4.17
No. 110 baited body	0.44AB	0.00B	4.55
No. 1 foot-hold	0.32B	0.08B	9.38
No. 1 padded foot-hold	0.20B	0.00B	18.20

<sup>a</sup>Means followed by the same letter within a column are not significantly different at  $P = 0.05$ , Duncan's multiple range test.

<sup>b</sup>Total cost of 25 traps/total squirrels caught in that type. Based on costs/trap of \$2.00 for body, \$3.00 for foot-hold, \$3.64 for padded foot-hold, and \$15.08 for cage traps.

Cage traps were highly efficient, but were not selective for fox squirrels and had a high relative cost. They also present the problem of dealing with a live, enclosed squirrel. Foot-hold traps were relatively inefficient, but selective. Baiting foot-hold traps did not significantly increase their efficiency, but significantly reduced their selectivity. Padding foot-hold traps did not eliminate leg injury to squirrels, and had minimal effect on efficiency and selectivity. Body traps had moderate efficiency, low relative cost, high selectivity, and were humane. Therefore, where legal, they appear to be the best type of trap of those tested. The tunnel trap, a kill trap not tested in this study, should be evaluated versus the number 110 body trap.

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# FIELD EFFICACY OF DIPHACINONE GRAIN BAITS USED TO CONTROL THE CALIFORNIA GROUND SQUIRREL

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**ABSTRACT:** Diphacinone treated oat groats were effective in reducing populations of California ground squirrels (*Spermophilus beecheyi*) by more than 84%. Two concentrations of active ingredient (0.005% and 0.01%) were compared, as well as two application methods: spot baiting and bait stations. Squirrel activity on test plots was assessed before and after bait applications using visual counts and active burrow counts. There was good correspondence between results of the two activity indices. There was no significant improvement in efficacy provided by the higher concentration of diphacinone. Bait consumption was much lower on bait station plots. Squirrel carcasses were found on treated areas at a rate of approximately one carcass per acre. Tissue residue analysis determined that residue loads were nearly identical regardless of the concentration of bait consumed or method of baiting.

**KEY WORDS:** vertebrate pest control, *Spermophilus beecheyi*, California ground squirrel, rodenticides, diphacinone, efficacy

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## INTRODUCTION

The California ground squirrel (*Spermophilus beecheyi*) is responsible for millions of dollars of damage annually to agriculture (Clark 1978). Since the cancellation of registrations for compound 1080 and strychnine for squirrel control, zinc phosphide and some of the anticoagulant compounds, such as diphacinone and chlorophacinone, have been the only baits available for squirrel control. The California Department of Food and Agriculture is seeking a Section 3 EPA registration of diphacinone treated grain bait for control of the California ground squirrel. These baits have been carried under 24(c) registrations previously. As part of the required data package field efficacy must be demonstrated, with a 70% level of control as the threshold.

This study was designed to evaluate the field efficacy of Rodent Bait Diphacinone Treated Grain, using two concentrations of active ingredient and two application methods. Degradation rates of baits placed in the field and residue loads in ground squirrel carcasses were also assessed.

## METHODS AND MATERIALS

### Study Site

The study was conducted on the San Joaquin Experimental Range, a 4,500 acre (1,790 ha) ranch located approximately 17 miles north of Fresno, California in the lower Sierra Nevada Foothills. Elevations range from 700 to 1700 feet above sea level. Winters are mild and moist and the summers hot and dry. Annual rainfall averages 19 inches. The vegetation is classified as the plant-oak woodland type, consisting of grassland, savannah, and dense stands of trees and brush (Duncan, et al. 1985). Most herbaceous plant species germinate with the fall rains, grow rapidly and set seed in the spring, drying out by mid-May (Larson, et al. 1985). This study was scheduled to present the bait at a time when the squirrel's diet is shifting from green forage to seeds, and when the young of the year are weaned and actively foraging.

Wildlife is abundant on the ranch. The open areas

support large, well established populations of *Spermophilus beecheyi*. Squirrels are distributed over the entire ranch, although densities are greatest in the large open meadows.

Seventeen census plots were established on the ranch in mid-May 1994. Census plots ranged from 1.4 to 3.3 acres in size. Census plot boundaries were marked with wire surveying stakes. Buffer zones of approximately 225 feet were marked around the perimeter of each census plot receiving test substance.

Using a randomization procedure, five plots were assigned to receive the 0.005% diphacinone bait applied by spot baiting, five plots to receive the 0.01% diphacinone bait applied by spot baiting, two plots were to be treated with the 0.005% bait in bait stations, and five plots served as untreated control plots. The two geographically closest untreated plots served as controls for the bait station plots.

### Activity Determination

Two activity indices were used: visual counts and active burrow counts.

The visual count method followed the guidelines established by Fagerstone (1983). Natural or artificial blinds which offered a view of most or all of the census plot were established near each census plot boundary.

Visual counts and active burrow counts were conducted before and after bait applications. On spot baited plots, mid-treatment visual censuses were conducted for three days, beginning seven to eight days after the first bait application. This census was conducted to assess baiting efficacy and help determine the appropriate time to begin the post-treatment censusing. Mid-treatment censusing on bait station plots was conducted for three days, starting 14 days after the initial application.

On spot baited plots, post-treatment visual censusing began 10 to 11 days after the first bait applications (bait applications were staggered, with half the plots being baited one day and half the next day). Post-treatment active burrow counts were conducted 14 to 15 days after

the first bait application. Post-treatment censusing on bait station plots began 22 days after the stations were first filled.

During each visual censusing period, three counts were made on each plot for three consecutive days during peak activity periods. At 15 minute intervals, a single slow scan of the plot was made using binoculars. All visible squirrels were counted. From the nine counts conducted over three days, the highest single count was used as the population estimate.

Closed burrow censuses were conducted immediately after the visual counting was completed. All squirrel burrows were closed on the census plots.

Active burrows were counted 48 hours ( $\pm 2.25$  hr) after being closed. Opened burrows were marked with wire surveying stakes to prevent double counting.

#### Bait Analysis

Baits were manufactured by Haco, Inc. of Madison, Wisconsin. The baits are a whole oat groat coated with diphacinone and an oil soluble blue dye. Representative samples of each product were analyzed at Genesis Laboratories in Fort Collins, Colorado to determine the concentration and homogeneity of the active ingredient. Samples were analyzed before the products were applied in the field.

Bait stability under field conditions was also studied. Approximately 200 g of each bait was placed in aluminum pie pans in the field. The pans were covered with 1/4" mesh hardware cloth and staked down to prevent disturbance by animals. The samples were placed on the first day bait was applied and retrieved after nine days exposure on the spot baited plots. A bait sample was also placed in a bait station, with the openings covered with wire mesh, for 22 days and then retrieved for analysis. Diphacinone concentrations in field samples were compared with samples taken from unopened sacks of bait under storage at the field site.

A high performance liquid chromatography (HPLC) method was used to determine the concentration of diphacinone in the baits. The method employs a reversed phase column, UV detection, and internal standard quantification.

#### Bait Application: Spot Baiting

Baiting began immediately following the closed burrow censusing. Bait was first applied on May 22, 1994. Plots were baited on a staggered schedule. Five plots received the first application on May 22. The other five plots were first baited on May 23. The final application was on May 29, 1994.

Bait was spread in the grass near active burrows at a rate of 1/3 cup (approximately 45 grams) per placement. Applications were repeated every second day until each plot had received four applications. Placements were replenished only as needed to maintain a continuous supply. The blue dye enabled applicators to readily estimate consumption in the field.

#### Bait Application: Bait Stations

Bait stations were constructed of 4 inch diameter white PVC pipe joined in a "T" shape. The bait stations were placed in the field four days before bait was applied.

Each station was placed in an inverted position, and fastened to a stake. This arrangement provides two entrances and visibility through both ends for squirrels. A cap covered the reservoir. Bait stations were filled on the first day with 7 cups of bait each, so each station contained about 900 grams or 2 pounds of bait. Stations were checked every third day and replenished as needed. Usually bait was added if it appeared that 50% or more of the initial quantity had been consumed. After June 4 (12 days), no more bait was applied to either plot. Stations with high activity were replenished by transferring bait from less active stations.

#### Baiting Efficacy

Baiting efficacy was calculated by the following formula if there was no decrease in the control plot population index during the period:

Efficacy =

$$\frac{\text{Pre-treatment Census} - \text{Post-treatment Census}}{\text{Pre-treatment Census}} \times 100$$

If the control plot population index declined during the treatment period, the following formula was used to adjust for the change:

Efficacy =

$$1 - \frac{\text{Post-treatment T-I}}{\text{Pre-treatment T-I}} \times \frac{\text{Pre-treatment C-I}}{\text{Post-treatment C-I}} \times 100$$

Analysis of variance was used to compare efficacy between and within test plots. T-tests were used to test for significant differences between treated and control plots, except in the case of the two bait station plots, which were simply compared to results on the two nearest control plots.

#### Carcass Searches

Census plots were cleared of carcasses before baiting began as part of the burrow closing procedure. Carcass searches were usually conducted once each day on each treated census plot and buffer zone during the baiting period.

Specimens of ground squirrels found on the surface were collected until a total of 8 to 10 animals had been recovered from each set of treatment plots. Ground squirrel carcasses were analyzed by a GS/MS method. Non-target mammal specimens were examined for signs of the test substance ingestion and symptoms of anticoagulant poisoning.

## RESULTS AND DISCUSSION

#### Plots Sizes, Bait Applications

Census plot areas ranged from 1.9 to 3.9 acres. With the addition of a 225' buffer zone to treated plots, the treated plot areas ranged from 11.5 to 18.4 acres.

Baiting rates ranged from 10.3 to 12.6 pound per acre on spot baited plots. The baiting rate was only 6.3 pounds per acre on the bait station plots (Table 1). The baiting rates for the bait station plots represent total consumption, whereas the figures for the spot baiting plots represent the amount of bait dispersed.



Table 1. Baiting rates on spot baited, bait station, and control plots. Census plots and buffer areas were treated. Spot baited plots were baited four times, every other day. Bait stations were refilled as needed every third day for 22 days. Control plots did not receive placebo bait.

Treatment	Pounds	Acres	Pounds/ Acre	DPN/acre (g)
<b>Spot Baited:</b>				
0.005 %	837.4	66.2	12.6	0.287
0.010 %	758.3	73.8	10.3	0.470
<b>Bait Stations:</b>				
0.005 %	205.7	32.9	6.3	0.143
<b>Control:</b>	None	12.1	None	None

The bait application pattern illustrated in Figure 1 corresponds well with field observations of bait consumption. Spot baited placements were readily consumed after the first and second applications, with most of the bait being gone within 24 hours. The consumption rate decreased sharply following the third application. It was estimated that roughly 50% of the third application was taken within 48 hours. Much of the fourth application remained uneaten.

### Efficacy

Efficacy was well above the EPA standard of 70% for both concentrations of bait and both application methods. Both activity indices found a greater than 90% decline in activity on spot baited plots (Table 2, Figures 2 and 3). Both baits reduced populations by over 90%. There was no significant difference between performance of the different bait concentrations. The bait exposure period was 10 to 11 days.

### APPLICATION PATTERNS SPOT BAITING

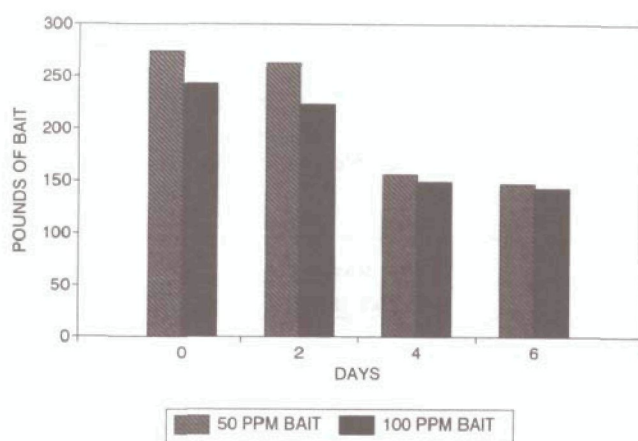


Figure 1. Spot baiting applications. Day 0 represents the initial application. Bait was replenished every other day to maintain a constant supply.

Evidence of squirrels was not seen using the bait stations until four to five days after the bait was first applied. Consumption then picked up. About one-half of the bait dispensed was retrieved when stations were collected following 22 days exposure.

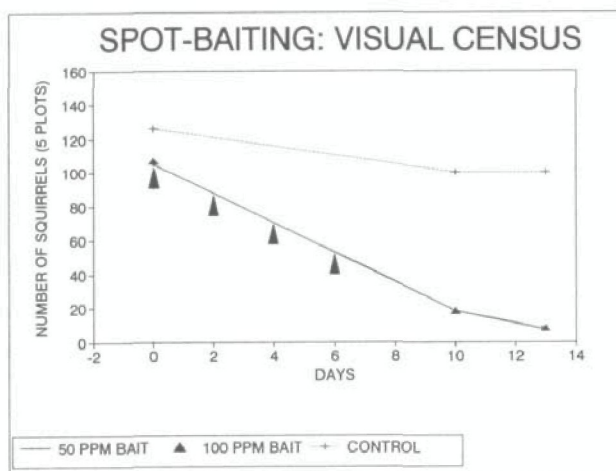


Figure 2. Results of visual activity counts on spot baited plots. Arrows indicate bait applications.

Tables 3 and 4 present the results of the activity counts on the bait station plots. The bait exposure period was 22 days. The efficacy was somewhat lower on bait station plots: 84.0 to 92.2% according to visual counts, and 81.8 to 87% according to active burrow counts. The lower efficacy is largely attributable to lower active

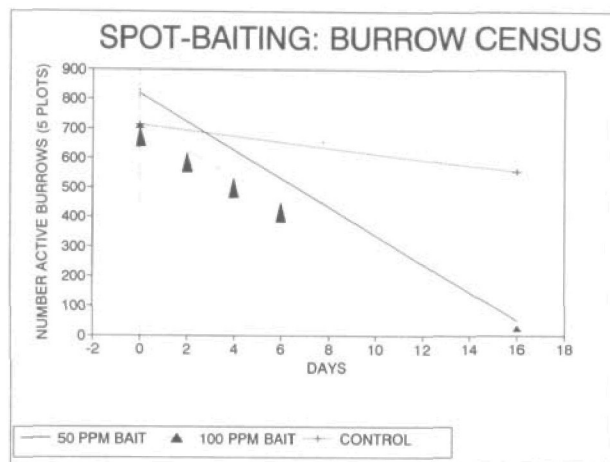


Figure 3. Results of active burrow counts on spot baited plots. Arrows indicate bait applications.

burrow counts on the control plots. As illustrated in Figure 4, visual activity counts increased on plots 11 and 14 during the bait station study, while active burrow counts (Figure 5) declined each time. This method may

not be suitable for using more than twice in a short time period.

#### Bait Degradation

Concentrations of diphacinone in baits placed in open locations (spot baited plots) declined by approximately 50% during the 9 day exposure period. Concentrations of diphacinone in bait retrieved from bait stations and bait stored in the original containers degraded by about 10% during 22 days (Table 5, Figure 6).

#### Carcasses

The number of squirrel carcasses found on treated plots was approximately 1 per acre, regardless of the bait concentration or application method (Table 6.) Mean total diphacinone in whole squirrel carcasses ranged from 0.45 to 0.48 milligrams. There appears to be no advantage in using the higher concentration of bait to reduce numbers of squirrel carcasses on the surface, as was suggested by previous studies (Clark 1978).

A total of 30 carcasses of eight other rodent species and lagomorphs were found on the spot baited plots (0.2/acre). A total of nine non-target carcasses of four rodent and lagomorph species were found on the two bait station plots (0.3/acre). Most non-targets had indications of bait ingestion. This design of bait station does not appear to provide any benefits in reducing non-target hazards compared to spot baiting.

No secondary poisoning cases were observed, although predators were common in the area. Vultures (*Cathartes aura*) were observed eviscerating squirrel carcasses found on the plots. This behavior has been noted before in vultures (Hazen and Poché, 1992) and in golden eagles (Record and Marsh, 1988).

Table 2. Results of visual activity and active burrow counts on spot baited plots. The highest number of squirrels seen during pre-treatment and post-treatment counts was used as the population estimate. The bait exposure period between censusing was 10 or 11 days. All burrows were closed on the census plots immediately after the three day visual census. Open burrows were counted 48 hours later.

	Number of Plots	Treatment (ppm DPN)	Pre-treatment	Post-treatment	Percent Change*
V I S U A L	5	50	105	7	-91.6
	5	100	107	8	-90.6
	5	Control	126	100	-20.6
B U R R O W	5	50	820	50	-92.2
	5	100	709	24	-95.7
	5	Control	713	555	-22.2

\*Analysis of variance showed both treatments differed significantly from the control plots ( $P=0.05\%$ ). T-tests found no significant differences between the bait concentrations ( $P=0.05\%$ ).

Table 3. Results of visual activity counts on bait station plots. The baiting period was 22 days. Of the five control plots used in the spot baiting study, the two closest to the bait station plots were used as controls. Mid-treatment counts were conducted 14 to 16 days after bait was applied.

Plot No.	Treatment (ppm a.i.)	Visual Activity Counts			Percent Change
		Pre- treatment	Mid- treatment	Post- treatment	
17	50	25	11	4	-84.0
18	50	14	4	1	-92.2
11	Control	28	20	36	+28.6
14	Control	27	24	22	-18.5

Table 4. Results of active burrow counts on bait station plots. The baiting period was 22 days. Of the five control plots used in the spot baiting study, the two closest to the bait station plots were used as controls here. Control plots were censused "mid-treatment" as part of the post-treatment census of spot baited plots.

Plot No.	Treatment (ppm a.i.)	Active Burrow Counts			Percent Change
		Pre- treatment	Mid- treatment	Post- treatment	
17	50	156	n/a	15	-81.8
18	50	131	n/a	9	-87.0
11	Control	158	113	49	n/a <sup>1</sup>
14	Control	157	129	83	-47.1

<sup>1</sup>Unable to complete activity count due to livestock on the plot.

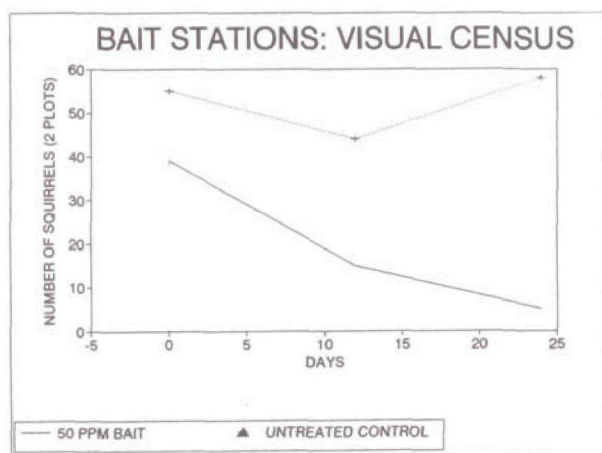


Figure 4. Results of visual activity counts on bait station plots.

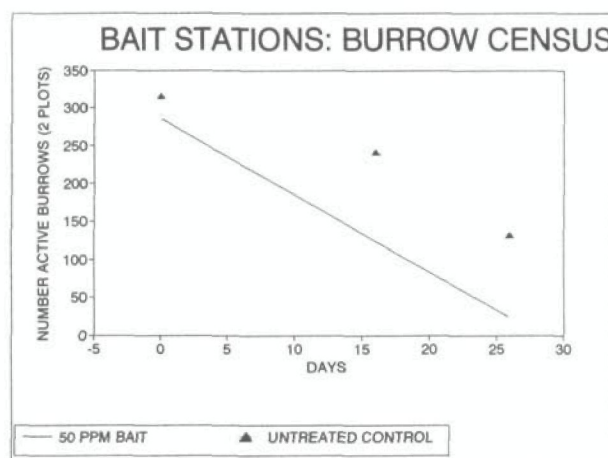


Figure 5. Results of active burrow counts on bait station plots. This method was used on the control plots three times, but only twice on treated plots. Note decline in index on control plots each time this method is repeated.

Table 5. Bait degradation rates. Baits were analyzed before and after application in the field. Samples from the initial application were retrieved from spot baited plots and from bait stations. These were compared with samples kept in storage at the field site. All values are ppm diphacinone.

Nominal	Initial	Spot Baiting <sup>1</sup>	Bait Station <sup>2</sup>	Storage
50.0	48.2	13.5	45.0	45.9
100.0	95.9	45.4	n/a	93.0

<sup>1</sup>Based on 9 days exposure in the field.

<sup>2</sup>Based on 17 days exposure in a bait station.

Table 6. Squirrel carcasses found above ground on treated plots. No carcasses of squirrels or other animals were found outside of the treated areas. Residues based on n = 8-10/treatment.

Treatment	<i>S. beecheyi</i> Carcasses	Carcasses/Acre	Mean DPN (ppm)	Mean Total DPN (mg)
Spot Baiting:				
50 ppm	76	1.1	1.4	0.48
100 ppm	67	0.9	1.4	0.46
Bait Stations:				
50 ppm	26	0.8	0.9	0.45

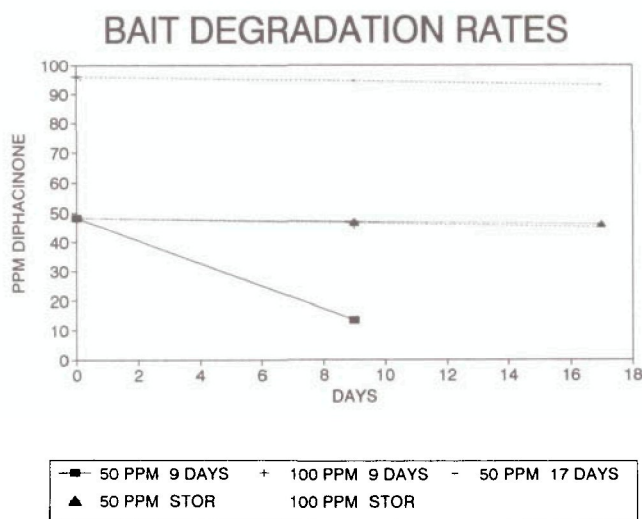


Figure 6. Bait degradation rates for baits retrieved from spot baited plots, bait stations, and bait stored in the original containers.

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# PALATABILITY OF RODENTICIDE BAITS IN RELATION TO THEIR EFFECTIVENESS AGAINST FARM POPULATIONS OF THE NORWAY RAT

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**ABSTRACT:** The palatability of 12 rodenticide baits, formulated to vary from poorly accepted to well accepted, was measured in laboratory choice tests against Wistar and wild-caught Norway rats. The baits, derived from six bait bases and two active ingredients, difenacoum and bromadiolone, were simultaneously tested in the field against 24 farm infestations (2/formulation) in order to investigate the relationship between palatability and efficacy. Bait acceptance in laboratory tests, with EPA meal as the challenge diet, varied from 7.0 to 50.6% for Wistar rats and 3.7 to 85.1% for wild rats. Changing the challenge diet to a ground-up laboratory animal food significantly increased the apparent palatability of three selected baits to Wistar rats, although the relative palatabilities between the formulations remained the same. Bait acceptance, as measured in the laboratory, was unrelated to the degree of control achieved in farm treatments. The presence or absence of alternative food and whether the baits were placed in containers or applied directly into rat burrows appeared more likely to determine the outcome and overwhelmed any influence due to bait palatability. The combined effect of container- and burrow-baiting reduced the rat populations by an average 96.8% with 16 of the 24 populations tested completely eradicated. The least palatable baits dispensed into burrow entrances controlled rats on all farms, including those with abundant food sources.

**KEY WORDS:** Norway rats, *Rattus norvegicus*, commensal rodents, baits, bait acceptance, efficacy, field tests, rodenticides, anticoagulants

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## INTRODUCTION

The optimum concentration of active ingredients in anticoagulant rodenticide baits is determined by their toxicity and the likelihood of the target animals ingesting a lethal dose in a reasonable time. The longer the time required to receive a lethal dose, the more important it is that the bait should be palatable, especially when alternative foods are available. Ideally, baits should be equally, or more, palatable than the usual food source. Conventionally, the palatability of poison baits is determined in the laboratory, either by testing whether the presence of the active ingredient significantly reduces the amount of bait consumed (Bentley 1958) or how successfully the test formulation will compete in a choice test against the rodents' normal diet (Palmateer 1979). For the latter test, the "normal" food will often be a laboratory-made unpoisoned bait which consists of ingredients that commensal rodents may consume in the wild. Formulations which show poor palatability in these tests are unlikely to go forward to field trials. There has been some controversy over the level of palatability which is considered acceptable (Miller 1974), particularly since the outcome of any treatment depends on a wide range of factors. Prior to this study, the palatability of a bait, although critical in the development of a rodenticide, has been of unknown practical importance in the field.

Without knowing the relationship between palatability in laboratory trials and effectiveness in the field, it is difficult to assess new formulations during the early stages of development. When resistance to the anticoagulant warfarin developed in Norway rats (*Rattus norvegicus*), more potent compounds with the same mode of action were introduced. It was soon realized that these new "second-generation" anticoagulants produced a

considerable overkill when tested against susceptible rats which ate far more than was necessary to kill them. The concept of "pulsed baiting" was introduced (Dubock 1979), which sought to limit the amount of bait a rat consumed and thus, incidentally, had environmental benefits by reducing any toxic residue in carcasses. Furthermore, as rats needed to eat less bait to get a lethal dose, palatability could be reduced, enabling the use of formulations which were less attractive to non-target wildlife. Thus, relatively unpalatable baits may be as efficacious as palatable baits with the same active ingredient, provided that the less palatable bait does not encourage individuals to completely avoid it.

In this study the authors sought to establish whether a link between the palatability of baits and treatment efficacy existed by measuring the palatability of 12 rodenticide baits to Norway rats in the laboratory and then testing each formulation in the field. The baits were formulated to give a range of palatabilities.

## METHODS

### Laboratory Trials

Six bait bases in combination with two anticoagulants, difenacoum (D) and bromadiolone (B), were tested, giving 12 formulations in total. The six bait bases were:

- 1) pinhead oatmeal and corn oil (PHCO)
- 2) pinhead oatmeal, corn oil and caster sugar (PHCOCS)
- 3) medium oatmeal (MO)
- 4) 1:1 mixture of maize (corn) meal and barley meal (MMBM)
- 5) cut wheat and corn oil (CWCO)
- 6) whole wheat (WW)



Corn oil and caster sugar were added, where appropriate, at 2.5% and 5% by weight, respectively. Each active ingredient was dissolved in 1:100 triethanolamine: polyethylene glycol 200 to make a liquid concentrate which was added to each bait base at 2.5% by weight. The final concentration of difenacoum or bromadiolone in each bait was 0.005%. Commercially available formulations replaced the cut wheat/corn oil/difenacoum (CWD) and whole wheat/bromadiolone (WWB) combinations. Two untreated challenge diets were used in the choice tests: EPA OPP rat and mouse challenge diet (EPA 1982) consisting of maize (corn) meal (65% by weight), ground rolled oat groats (25%), corn oil (5%) and sugar (5%) and, in a series of supplementary tests, three formulations were tested against a proprietary laboratory pelleted animal diet (GRK3 R20 diet, SDS Ltd., Witham, Essex, U.K.) which was ground into a fine powder.

The test baits were prepared three to four days before the test began, sealed in polythene bags and stored at room temperature. The cereal ingredients of the EPA meal were sieved and weighed at the same time, but were not mixed with the sugar and corn oil until the first day of the test period. As it has been reported that the palatability of EPA meal may vary from batch to batch (Johnson and Prescott 1994), the EPA tests were divided into ten replicates for laboratory rats and five for wild rats with each of the 12 bait formulations offered to a pair (one male, one female) of animals in each replicate. Similarly, for the supplementary tests, in which three baits, MMBMB, CWCOWB and PHCOWSB, were offered to laboratory rats with ground SDS as the challenge diet, each bait was offered to five pairs in each of two replicates. Each of the two commercial baits was bought from an agricultural supplier with sufficient quantity in one batch for all replicates.

Each test bait was offered to 20 laboratory (Wistar strain) and 10 wild-caught rats with equal numbers of each sex included. The laboratory rats were healthy adults ranging in weight from 204 to 294 g three days before the test period began. The wild rats were caught in live-traps baited with whole wheat on three farms from an area of southern England where most rats were thought to be susceptible to first-generation anticoagulants. Only healthy adults were brought to the laboratory where they were treated with an insecticide to kill ectoparasites and allowed to acclimatize to laboratory conditions for a minimum of three weeks. As expected, the body weights varied considerably when the animals were weighed three days before the tests began: males 210 to 503 g and females 129 to 422 g.

All rats were caged singly and the cages were arranged on the racks such that the sexes alternated vertically and horizontally. Water was available at all times. Two food pots were placed symmetrically at the front of each cage and filled with a ground laboratory diet one week before the test period (but after the acclimatization period for the wild rats); all other food was removed. During this pre-test period, the amount of laboratory diet eaten by each rat was recorded on four consecutive days to ensure that all rats were eating normally from the pots. On the first day of the test, clean pots were substituted and one was filled with about 50 g

of the challenge diet and the other with the same amount of the test bait. On each of the next three days, the amount of food eaten from each pot was recorded to the nearest 0.1 g and any remaining food was discarded. Clean pots were filled with fresh bait and replaced in the cage with the positions of the test and challenge diets interchanged to cancel the effect of place preferences. On the fifth day, the amount of food eaten was recorded and the rat was humanely killed. Post-mortem body weights were recorded.

The palatability (acceptance) of each formulation was calculated as the total amount of test bait eaten expressed as a percentage of the total amount of food consumed.

#### Field Trials

The infested farms used in this study were located in areas of southern England where the majority of rats were thought to be susceptible to warfarin (MacNicoll et al. these proceedings). Each formulation was tested twice on separate farms, giving a total of 24 field trials. The treatments were carried out over a 12-month period commencing in March 1994 with the test baits allocated in turn as the farms became available. Each farm was surveyed to assess the extent of the infestation by looking for rat signs such as runs, fresh droppings and active burrows. Farms were classified according to the type of stored food available to rats as: 1) no obvious food source identified; 2) cereals, such as wheat or barley; 3) commercial or farm-prepared animal feeds; and 4) maize silage (often burrowed into by rats especially where the clamps were lined with straw bales or railway sleepers). Wooden bait containers with metal lids were set out at least one week before the treatments began to enable rats to get used to them. On the first day of each treatment, 100 g of the test bait was placed into each container. Thereafter, all bait points were inspected each weekday, the remaining bait weighed and replenished sufficiently to maintain a surplus until the next inspection. However, during the first three trials most rats failed to take bait from the boxes. Container-baiting was, therefore, terminated after three weeks in these and all subsequent trials and the bait redistributed, if the infestation still persisted, to the entrances of active rat burrows. (No burrows were baited during the first three weeks of each trial.) When baiting burrows, the bait was laid as far into each burrow as possible and the entrance was lightly blocked with any suitable material. Such hole-baits could not be reliably inspected but the number of burrows baited was recorded on 11 farms. Hole-baiting was continued until all evidence of rat activity had gone, or for a maximum of three weeks.

The size of each rat population was assessed using a tracking plate method (Quy, Cowan and Swinney 1993) in the week before baiting began, then again after three weeks of container baiting, but before hole-baiting started. A final assessment was made in the week following the cessation of hole-baiting. In the analysis of results, any treatment in which the size of the population had increased between the pre-treatment census and the end of container baiting was considered to have 100% of the original population remaining alive. Weekly estimates of the size of the rat population present on each farm were obtained by linear interpolation between successive

census estimates. Dividing the average daily amount of bait consumed by these weekly estimates gave an estimate of the take by each rat. Additionally, a tracking plate was placed on one side of each bait container to detect visits by rats whether or not any bait had been taken; plates were inspected each time the bait was checked and scored as being marked or not.

In analyses relating bait take and efficacy to the palatability of the various baits, the data for palatability is the percentage bait acceptance obtained for each bait from the tests on Wistar rats rather than wild rats because the sample size of the former was greater. In all statistical tests percentages were transformed to arcsine square roots to stabilize variances. Untransformed means together with their standard errors are given in the text.

## RESULTS

### Laboratory Trials

The percentage bait acceptance for the test baits offered to Wistar rats varied from  $7.0 \pm 1.99\%$  (MOD) to  $50.6 \pm 5.38\%$  (PHCOCSB) ( $F_{11, 216} = 19.1$ ,  $P < 0.001$ , Figure 1). There was no difference in bait acceptance between the sexes ( $F < 1.0$ ). EPA meal was preferred to all baits (paired t-tests,  $P < 0.001$  –  $P < 0.01$ ) except for WWB and PHCOCSB where no preference was detected. The acceptance of each bromadiolone bait was greater than its equivalent difenacoum bait (t-tests,  $P = 0.05$  –  $P < 0.001$ ) except for cut wheat baits where there was no difference. The comparisons involving cut wheat and whole wheat bases should be treated with caution as, in each case, a commercial formulation was included which contained additional unspecified ingredients. Changing the challenge diet to ground SDS for three selected baits increased the measured palatability of the test baits: for MMBMB acceptance increased from  $13.2 \pm 2.33\%$  to  $26.1 \pm 3.25\%$  ( $F_{1, 36} = 18.1$ ,  $P < 0.001$ ), for CWCOB from  $31.9 \pm 3.21\%$  to  $62.0 \pm 4.16\%$  ( $F_{1, 36} = 47.3$ ,  $P < 0.001$ ) and for PHCOCSB from  $50.6 \pm 5.38\%$  to  $81.2 \pm 2.56\%$  ( $F_{1, 36} = 25.4$ ,  $P < 0.001$ ). However, there was a significant interaction between the sex of the rat and the type of challenge diet for MMBMB ( $P = 0.003$ ) and CWCOB ( $P = 0.011$ ). The acceptance of MMBMB by female Wistar rats with SDS as the challenge diet was greater ( $38.0 \pm 2.94\%$ ) than males ( $14.3 \pm 2.13\%$ ,  $t_{18} = 6.54$ ,  $P < 0.001$ ); similarly, the acceptance of CWCOB by females ( $76.0 \pm 2.49\%$ ) was greater than that by males ( $48.0 \pm 4.81\%$ ,  $t_{18} = 5.12$ ,  $P < 0.001$ ).

The percentage acceptance of the 12 test baits offered to the wild rats varied from  $3.7 \pm 1.65\%$  (MMBMD) to  $85.1 \pm 6.09\%$  (PHCOCSB) (Figure 1). Within each group there was considerable variation in acceptance of the same bait: for MOD, MMBMD, PHCOD, MOB, MMBMB and PHCOB the minimum percentage acceptance recorded was  $< 2.0\%$ , while a maximum acceptance  $> 98\%$  was recorded for WWD, PHCOCSB, CWD, MOB, PHCOB, PHCOCSB and WWB. The mean percentage acceptance for seven baits exceeded 50% (range 52.1 to 85.1%), but there was no significant difference between them ( $F_{6, 56} = 1.74$ ,  $P = 0.13$ ) and none related to the sex of the rat ( $F < 1.0$ ). The mean percentage acceptance of the other five baits (range from

3.7 to 43.3%) varied significantly ( $F_{4, 40} = 5.54$ ,  $P = 0.001$ ), and the mean acceptance by females consistently exceeded that of males ( $F_{1, 40} = 5.09$ ,  $P = 0.03$ ). In paired t-tests comparing each test bait with EPA meal, WWD and WWB ( $P < 0.05$ ) and PHCOCSB ( $P < 0.001$ ) were preferred to the challenge diet. EPA meal was preferred to both baits containing maize meal/barley meal ( $P < 0.001$ ). There was no preference shown with the other seven test baits. Statistical analysis (by t-tests) indicated that adding bromadiolone or difenacoum to the baits did not influence the preference of wild rats for the different bait bases.

Transformation of the values of bait acceptance to z-scores, and testing by analysis of variance, indicated that the relative palatability of the 12 baits was the same for both Wistar and wild rats. There was no significant interaction between the 12 baits and the two rat strains ( $P = 0.43$ ).

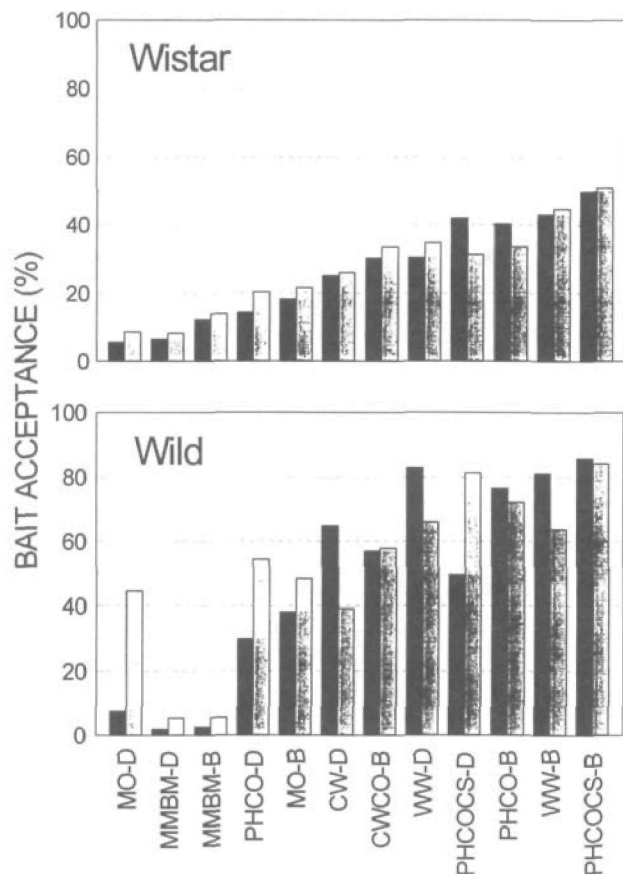


Figure 1. Choice tests using Norway rats between 12 rodenticide baits and EPA challenge diet: black bars, males; grey bars, females. MO, medium oatmeal; MMBM, maize meal/barley meal; CW, cut wheat with CO corn oil; WW, whole wheat; PH, pinhead oatmeal with CO corn oil CS caster sugar; D, difenacoum; B, bromadiolone.

### Field Trials

There was no correlation between percentage bait acceptance, as determined in the laboratory tests, and the estimated percentage reduction in the population during

the first three weeks of the treatment when the bait was laid in boxes (Pearson correlation coefficient  $r = -0.368$ ,  $df\ 22$ ,  $P = 0.08$ ). Excluding the four farms where there was no stored food,  $r$  increased to  $-0.430$  ( $P = 0.06$ ). The estimated mean size of the populations at the start of each treatment was  $49.0 \pm 9.2$  (range 10 to 215) rats. The estimated percentage reduction in the population following container baiting was  $37.1 \pm 7.1$ . The estimated mean take of bait during the first week of each treatment was  $2.5 \pm 51$  g rat/day (Figure 2), but varied from  $6.4 \pm 2.99$  g for four farms with no stored food,  $2.3 \pm 0.82$  g for eight cereal farms,  $1.8 \pm 0.58$  g for nine animal-feed farms, to 0.0 g for three farms with stores of maize silage. Within each farm type, there was no correlation (Spearman rank correlation test) between

the estimated mean daily take by each rat during the first week and the palatability of the bait. The estimated mean take during the second and third weeks of each treatment was  $1.6 \pm 0.6$  g (range 0 to 13.8 g) and  $1.6 \pm 0.56$  g (range 0 to 11.3 g) rat/day, respectively. After a further three weeks of hole-baiting, the populations were finally reduced by an estimated mean 96.8%, with 16/24 infestations completely eradicated (Figure 3). On the 11 farms where the number of hole-baits was recorded, there were in total 267 bait containers, of which 181 (67.8%) were "active" i.e., a take was recorded or rat footprints were found at least once on the adjacent tracking plate. The total number of holes baited was 300 (mean 1.66 holes/active bait box), but varied on individual farms from 0.5 to 6.0 holes/active bait box.

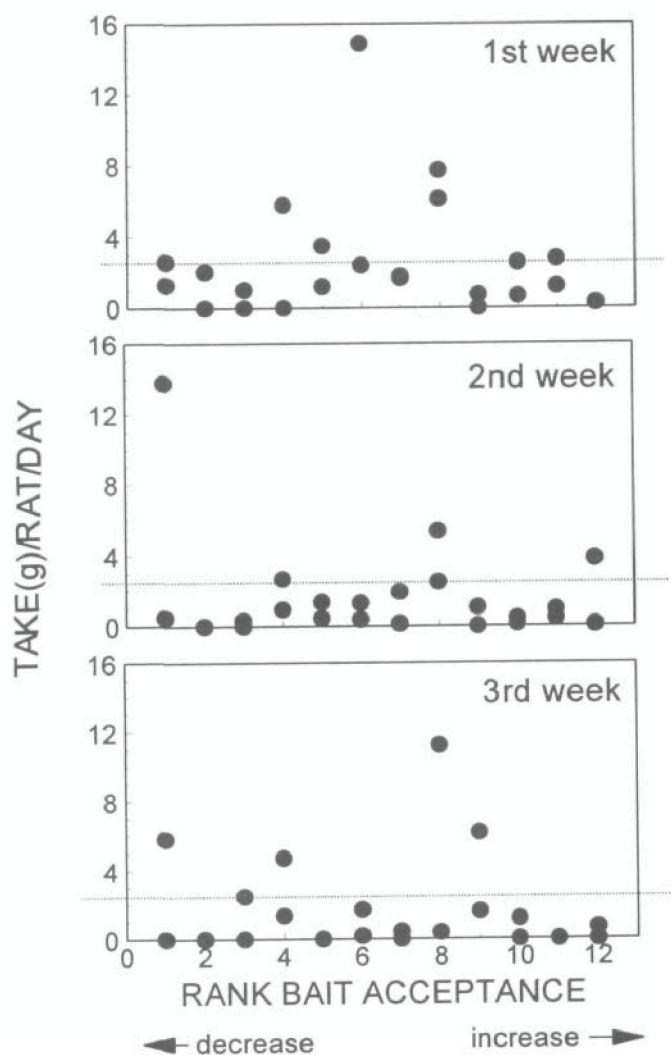


Figure 2. Estimated mean daily consumption by individual rats relative to bait acceptance (laboratory trials with Wistar rats). The dotted line represents the approximate amount of bait that a 250 g rat needs to eat each day for four consecutive days to ingest a LD50 dose of anticoagulant (Greaves and Cullen-Ayres 1988).

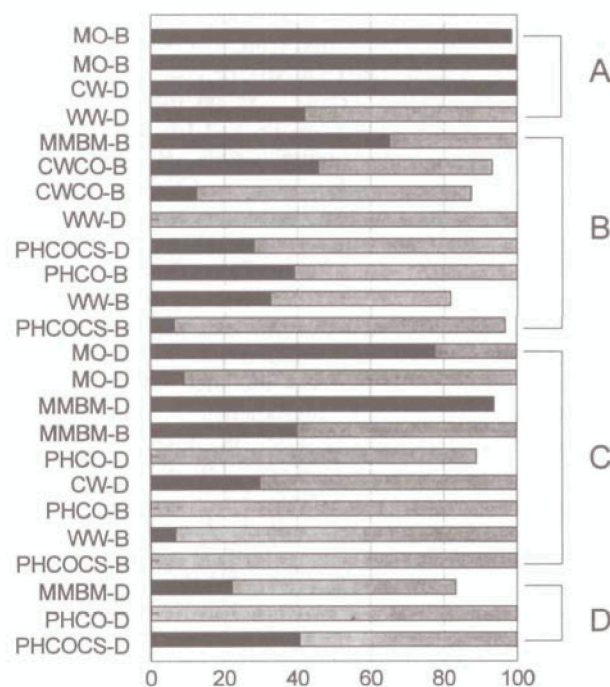


Figure 3. Percentage population reduction after three weeks of container-baiting (black shading) and a further three weeks of hole-baiting (grey shading). The treatments are grouped according to the alternative food available: (A) none; (B) cereals; (C) animal feedstuffs; and (D) maize silage. Within each group the baits are ranked from least to most palatable (top to bottom) according to the results of tests using Wistar rats. The key to the baits is the same as in Figure 1.

## DISCUSSION

In laboratory trials, a more variable response to the baits was observed with wild rats compared with the Wistar rats. This was to be expected, partly because of the difficulty in defining particular age/weight groups for wild-caught rats and the unpredictability of supply. Thus, variation due to age could not be measured. The strong preferences of some individuals for the test baits and total



rejection of EPA meal may have been related to previous experiences. The rats were trapped on farms where they had access to cereals and, thus, EPA meal may have been sufficiently unfamiliar in taste and texture to cause avoidance. In contrast, the laboratory trials showed that both maize meal/barley meal baits were apparently less acceptable to wild rats at only 4% bait acceptance, yet in the field an average reduction of 94% on four farms was achieved with those baits. Of course, the measured palatability of test baits may vary by changing the challenge diet or the strain of rat, but in these tests the relative palatabilities of the 12 baits remained more or less the same.

No relationship was found between the palatability of the baits tested and the degree of control obtained in the field. None of the 12 baits achieved less than an overall 81% reduction of an infestation despite the abundant supplies of alternative food on most farms. In containers, a medium oatmeal/difenacoum bait with an acceptance of 7% reduced a rat population by 78%, while a pinhead oatmeal/corn oil/caster sugar/bromadiolone bait with an acceptance of 51% gave no control at all. Both results were obtained on similar farms with supplies of animal feeds. In this study, the most important factor determining the outcome of a treatment appeared to be the bait application method, but only when there was alternative food available. Quy et al (1992, 1994) considered the impact of unprotected stored foods on the effectiveness of poison treatments and suggested that undermining the predictability of the rats' environment would encourage greater control because, presumably, the rats would be less wary about taking bait from containers in situations where there was constant change. In contrast, where there was little change but alternative food was limited, as on the four farms with no stored food, rats readily consumed baits from containers and any influence on the outcome due to bait palatability was lost. Thus baits, with an average acceptance of 24.5%, reduced infestations by 85.2% in three weeks (category A farms in Figure 3) and only one infestation required hole-baiting. Over the same period on the other farms (categories B, C, D), infestations were reduced by 24.2% with baits whose average acceptance was 27.4% and 19/20 required hole-baiting.

All of the field trials were carried out on farms where, to the best of the authors' knowledge, the majority of rats were susceptible to warfarin and, hence also to the more potent anticoagulants. Thus, the effects on efficacy of the poor palatability of some of the baits might have been offset by increased potency. With this relationship, there might be a fine line between treatment success and failure with difenacoum or bromadiolone. Palatability might, therefore, have more influence on treatment outcome for the less potent anticoagulants. It is quite likely that in conditions ideal for maximum treatment efficiency, many rats may be persuaded to eat apparently unpalatable baits, but such situations are not the norm and pest controllers should expect that their baits will compete with other foods for the rats' attention.

In this study, dispensing baits directly into rat burrows was the most effective means of control when abundant alternative food was present. This technique, although not new, may enable rats to be more easily

intercepted between their nest sites and their food supply, especially around maize silage clamps, where the distance between a nest and food can be very short. Substantial reductions in rat numbers were apparent after two weeks of hole-baiting on most farms even with the least palatable baits. There were, on average, more burrows baited than containers and, naturally, the distribution of hole-baits more closely matched the distribution of the rats. For each rat, a choice, in theory, could be made between the benefits of obtaining food with less expenditure of energy and less exposure to predators against the cost of a bait that was relatively unattractive. However, hole-baiting, as a practical technique, can be time-consuming and laborious, particularly when finding all the burrows in thick undergrowth and the bait takes are very difficult to monitor. Moreover, uneaten bait cannot easily be recovered at the end of a treatment and bait spilled as burrows are baited or bait kicked out by rats reopening a burrow may increase the risk to non-target animals.

In these trials against anticoagulant-susceptible rats, any influence that the palatability of the bait had on the outcome was too subtle to be measured. The availability of alternative food and the baiting technique used overwhelmed all other factors. This might not be true in trials to control anticoagulant-resistant rats, if the degree of resistance was sufficiently high such that significantly larger quantities of poison bait had to be consumed to provide a lethal dose.

#### ACKNOWLEDGMENTS

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# ZINC PHOSPHIDE RESIDUES IN VOLE: SCENARIOS SHOWING LOW RISKS TO DOMESTIC CATS AND DOGS

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**ABSTRACT:** Zinc phosphide ( $Zn_3P_2$ , CAS #1314-84-7) is an acute rodenticide having numerous agricultural applications. This paper estimates the risk of mortality posed to domestic cats (*Felis domesticus*) and dogs (*Canis familiaris*) from ingestion of voles (*Microtus* spp.) that succumb to 2.0%  $Zn_3P_2$  baits. Following a brief review of direct/indirect studies and incident reports relevant to nontarget- $Zn_3P_2$  effects and vole control, four scenarios of vole-carcass ingestions needed for light and heavy cat and dog predators/scavengers to receive approximate lethal doses (ALDs = 40 mg/kg) of undigested rodenticide are described. Scenarios were derived using values reported by Sterner and Mauldin (1995) as the maximum 8.2 mg  $Zn_3P_2$  ingested (ad libitum) and average 1.7 mg  $Zn_3P_2$  whole-carcass residue. Extrapolating these "worst-case" loads to 2 and 6 kg cats and 1 and 36 kg dogs showed that between 5 and 847  $Zn_3P_2$ -baited vole carcasses must be consumed in fairly rapid succession for these nontargets to ingest cumulative ALDs. The likelihood that even light ( $\leq 1$ -2 kg) cats and dogs will find and rapidly ( $\leq 24$  h) ingest multiple ( $\geq 5$ )  $Zn_3P_2$ -dosed vole carcasses under registered applications seems remote.

**KEY WORDS:** hazards, rodenticides, residual effects, toxicity, zinc phosphide, pesticides, field rodents, voles

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## INTRODUCTION

Zinc phosphide is an acute rodenticide that has numerous applications in agriculture and public health (Gratz 1973, Marsh 1988, Sterner 1994). For example, current Animal and Plant Health Inspection Service (APHIS) registrations include: 1.82% and 2.0% on wheat and steam-rolled oats for mouse control (*Microtus* spp. and *Peromyscus* spp.) in orchards/groves (non-bearing phase), rangelands, etc. (EPA Reg. Nos. 56228-3, -5 or -6) and 2.0% on steam-rolled oats for prairie dog control (*Cynomys* spp.) on rangelands (Reg. No. 56228-14).

That  $Zn_3P_2$  affords high acceptance and efficacy for numerous rodent species is well documented (e.g., Marsh 1988, Sterner et al. in press, Tietjen 1976); however, bait shyness (Marsh 1988, Sterner 1994) and broad-spectrum toxicity (Johnson and Fagerstone 1994, Marsh 1988) are recognized deficiencies. Mitigation of bait shyness usually involves pre-baiting to increase initial bait ingestion and reduce the frequency of sub-lethal dosings (Marsh 1988). Nontarget rodents are at risk, but selective use of baits reduces foraging by nontarget mammals and birds (Johnson and Fagerstone 1994, Marsh 1988). Additionally, residue hazards of  $Zn_3P_2$  to nontarget mammalian predators and avian scavengers/raptors remain a concern—loads of undigested rodenticide in the gastrointestinal (GI) tracts of target animals can be fatal to predators/scavengers (Bell and Dimmick 1975, Sterner and Mauldin 1995, Tkadlec and Rychnovsky 1990).

This paper reviews selected literature on nontarget hazards posed by the use of  $Zn_3P_2$  baits to control voles in agriculture. Scenarios of hazards that vole carcasses containing low ( $\bar{x}$  = 1.7 mg) and high "worst-case" (maximum ingested = 8.2 mg)  $Zn_3P_2$  loads pose to relatively light and heavy domestic cats and dogs are discussed.

## $Zn_3P_2$ VOLE, CAT AND DOG TOXICITY

The mode of action of  $Zn_3P_2$  involves hydrolysis to phosphine ( $PH_3$ ) upon reaction with stomach acids; circulating  $PH_3$  decreases electron transport and cellular respiration (Chefurka et al. 1976, Hazardous Substance Databank 1994, Murphy 1986). Acute-oral, median-lethal-dose ( $LD_{50}$ ) values for  $Zn_3P_2$  in diverse vole species are between 15 to 20 mg/kg; the  $LD_{50}$  for prairie and meadow voles are 16.2 and 15.7-18.0 mg/kg, respectively (see Bell 1972, Hood 1972). Hudson et al. (1984) reported  $Zn_3P_2$  ALDs for both domestic cats and dogs of 40 mg/kg; to the author's knowledge, no  $LD_{50}$ s for these nontargets are available.

## $Zn_3P_2$ FOR VOLE CONTROL: KEY NONTARGET LITERATURE

Johnson and Fagerstone (1994) provided a comprehensive review of the literature concerning primary and secondary hazards of  $Zn_3P_2$  to nontarget wildlife. These authors identified 61 acute oral toxicity studies of  $Zn_3P_2$  involving 28 mammalian and 16 avian species, plus 16 hazards studies involving 12 mammalian predators/scavengers, 6 raptor, 2 reptilian, and 1 amphibian species. Hazards of  $Zn_3P_2$  to nontarget predators/scavengers are not strictly secondary; undigested rodenticide within target animals (a primary-type hazard) pose the danger. Because the objective focuses on nontarget risks posed by the use of  $Zn_3P_2$  for vole control, a brief update of the literature relevant to voles as the source of  $Zn_3P_2$  for felids and canids is provided here.

Information of  $Zn_3P_2$ -residue effects in voles and potential consequences for nontarget species can be categorized under three headings: direct-effect studies, indirect-effect studies, and nontarget-incident reports.

"Direct-effect" studies refer to those in which carcasses of voles that died following ingestion of  $Zn_3P_2$  baits are fed to nontarget predators/scavengers. "Indirect-effect" studies refer to residue estimates of vole carcass  $Zn_3P_2/PH_3$  extrapolated to nontarget predator/scavenger doses based upon published  $LD_{50}$  or ALD doses. Nontarget-incident reports refer to documented or anecdotal cases where sub-lethal signs or nontarget deaths were associated with  $Zn_3P_2$  applications.

#### Direct-Effect Studies

Bell and Dimmick (1975) conducted the most often cited direct-effect study of  $Zn_3P_2$ . These authors force fed prairie voles fatal doses of  $Zn_3P_2$  pellets (86.94 mg/kg) 5 h prior to use of the carcasses. A three-day period to condition nontarget experimental and control animals/raptors to eating voles was used. Control nontargets were included to monitor food habits/behaviors of animals fed non- $Zn_3P_2$ -dosed voles. Results showed that two red foxes (*Vulpes vulpes*), two gray foxes (*Urocyon cinereoargenteus*) and two great horned owls (*Bubo virginianus*) ate an average 11.5, 11.7, and 8.5 non-dosed vole carcasses, respectively, during this conditioning period. No deaths in these animals were observed during the experimental period after ingestion of 4 to 12 vole carcasses containing mean doses of 10.64, 8.60, and 22.31 mg/kg  $Zn_3P_2$  for these species, respectively; however, some lethargy and altered behaviors occurred. For example, one red fox (♀) would neither eat nor cache a vole after the first test day; whereas, the owls roosted on the ground (beneath rain shelters), rather than on the rain shelters as observed prior to the first day's dosings.

Tkadlek and Rychnovsky (1990) studied both direct and indirect effects of 5.0%  $Zn_3P_2$  baits in common voles (*M. arvalis*)—5.0%  $Zn_3P_2$  baits are used for vole control in Czechoslovakia. In the direct-effects study, one cat died within a day after ingesting five vole carcasses that succumbed from eating 5.0%  $Zn_3P_2$  baits. This amounted to a maximum 103.5 mg dose for the cat (37 mg/kg  $Zn_3P_2$ )—a dose near the reported 40 mg/kg ALD cited for this species (Hudson, et al. 1984). A second cat, two weasels (*Mustela nivalis*), and three kestrels (*Falco tinnunculus*) did not die following ingestion of multiple vole carcasses containing maximum 60, 160 to 182, and 77 to 88 mg/kg  $Zn_3P_2$  doses, respectively.

#### Indirect-Effect Studies

In an indirect study, Tabata (1986) measured the dissipation and acid decomposition of  $Zn_3P_2/PH_3$  in red-backed wood mice (*Apodemus speciosus*) dosed orally with 10 mg  $Zn_3P_2$  (1.8 mg ALD). The mice exhaled a maximum 379  $\mu$ g of  $Zn_3P_2$  as  $PH_3$ ; this is equal to about 1.4 mg of  $Zn_3P_2$  or 14.4% of the total dose. Considerable undigested  $Zn_3P_2$  was detected in GI contents.

As mentioned, Tkadlek and Rychnovsky (1990) also provided analytical data on  $Zn_3P_2$  residues in common voles. Using a colorimetric method of  $PH_3$  absorption, they reported that ~58% ( $\pm 25\%$ ) of total ingested  $Zn_3P_2$  was found in the GI tracts of  $Zn_3P_2$ -killed voles; only 0.3% ( $\pm 0.3\%$ ) of ingested  $Zn_3P_2$  was found in the remainder of carcasses.

More recently, Sterner and Mauldin (1995) attempted to develop improved cryogenic-preservation and gas-chromatographic techniques for estimating whole-carcass  $Zn_3P_2/PH_3$  residues in a mixed sample of meadow (*M. pennsylvanicus*) and prairie voles (*M. orthogaster*). Voles ingested fatal doses of 2%  $Zn_3P_2$ /SRO-groats fed *ad libitum*. Cryogenic procedures did not enhance  $Zn_3P_2$  recovery; the main difficulty with analyses seemed to result from inadequate homogenization and hydrolyzation of  $Zn_3P_2$  trapped in the voles' pelts. Results showed that: 1) whole-carcass  $Zn_3P_2$  residues averaged 1.73 mg (min-max: 0.31-4.95)—~25-50% of the calculated  $Zn_3P_2$  intake—and  $PH_3$  residues averaged 10.6  $\mu$ g (min-max: 0.5-21.0); and 2) significant (positive) linear regressions were found between: 1) bait consumption/ $Zn_3P_2$  intake \* body weight ( $r^2 = 0.64$ ,  $p \leq 0.001$ ); 2) carcass  $Zn_3P_2$  \* bait consumption/ $Zn_3P_2$  intake ( $r^2 = 0.32$ ,  $p \leq 0.043$ ); and 3) carcass  $Zn_3P_2$  \* body weight ( $r^2 = 0.60$ ,  $p \leq 0.002$ ). Minimum and maximum  $Zn_3P_2$  intakes observed for specific voles were 2.0 and 8.2 mg, respectively; whereas, calculated doses of  $Zn_3P_2$  ingested by the voles averaged  $\geq 134.2$  mg/kg (min-max 79.2 to 243.2 mg/kg).

#### Incident Reports

Johnson and Fagerstone (1994) cited 12 published or unpublished accounts of  $Zn_3P_2$  baitings and nontarget incidents involving 14 species/genus. Of the nontarget species/genus involved in these accounts, seven bird [i.e., Canada goose (*Branta canadensis*), Snow goose (*Chen caerulescens*), ducks (e.g., *Anas* spp.), wild turkey (*Meleagris gallopavo*), partridges (e.g., *Perdix* spp., *Callipepla* spp., *Colinus* spp.), corvidae (*Corvus* spp.), chickens (*Gallus* spp.)] and seven mammal species/genus [i.e., red fox, domestic cat, domestic dog, gray squirrel (*Sciurus carolinensis*), cottontail rabbit (*Sylvilagus floridanus*), horse (*Equus caballus*)] were listed. With the exception of the data for corvidae and chickens, all nontarget avian effects occurred due to foraging on

Only four references (not provided here) cited by Johnson and Fagerstone (1994) deal with predator/scavenger consumption of  $Zn_3P_2$ -dosed rodents. Specifically, two red foxes allegedly died after eating mice that consumed  $Zn_3P_2$ -treated grain bait, unspecified numbers of dogs died after eating ground squirrels poisoned with  $Zn_3P_2$ , two cat carcasses were recovered near a no-till corn field in Illinois treated with 2.0%  $Zn_3P_2$  grain baits, and one cat death was noted in another poorly documented account.

#### $Zn_3P_2$ -HAZARDS SCENARIOS: CATS AND DOGS

To provide some perspective concerning  $Zn_3P_2$  residues in voles, the author prepared four "mortality-hazards scenarios" for two nontarget species—domestic cat and domestic dog. Mean (1.7 mg) and maximum (8.2 mg)  $Zn_3P_2$  residues (100% retention) observed in fatally-dosed voles by Sterner and Mauldin (1995), plus representative light and heavy predators/scavengers, were varied to produce four scenarios of risk. These residues were then used to calculate total carcasses needed to dose light/heavy cats and dogs with 40 mg/kg (ALD) of  $Zn_3P_2$

(Table 1). Tacit assumptions include: vole carcasses are consumed during continuous feeding and entire carcasses are ingested.

As shown, Scenario I reflects the hypothetical "worst case" situation—the least numbers of vole carcasses projected to deliver ALD doses to the nontargets. This scenario assumes that the maximum consumption of  $Zn_3P_2$  by a vole (8.2 mg) noted by Sterner and Mauldin (1995) would be retained by voles and that light cats (e.g., kitten) and dogs (e.g., puppy, Chihuahua) would ingest these voles during relatively continuous feeding. Interestingly, the "worst case" intake of 8.2 mg  $Zn_3P_2$  (assumed 100% retention and 2.0% bait) observed for a vole would equate to ingestion of ~12 to 13 voles for the cat reported by Tkadlec and Rychnovsky (1990).

Scenario II was developed using the same assumptions regarding  $Zn_3P_2$ , but hypothetical large cats (e.g., adult) and dogs (e.g., adult Labrador retriever) were substituted. As shown, the number of vole carcasses projected to cause mortality increased dramatically in this case to ~29 and ~176 for cats and dogs, respectively.

Scenarios III and IV are based on an assumption of the mean 1.7 mg  $Zn_3P_2$  residue detected in voles by Sterner and Mauldin (1995). Using this value, ~5-fold increases in the Scenario I and II carcass ingestions would be needed to attain the ALD cumulative doses for light and heavy cats and dogs, respectively. Even lightweight cats and dogs would have to consume  $\geq 24$  vole carcasses in Amount of  $Zn_3P_2$  in Vole(s) (mg) relatively continuous feeding bouts to ingest ALDs under Scenarios III and IV.

Table 1. Hypothetical hazards scenarios showing the numbers of vole carcasses that must be consumed (in relatively rapid succession) for domestic cats and dogs of different weight classes to ingest an ALD (Note: ALD for cat and dog = 40 mg/kg  $Zn_3P_2$ ; Hudson et al. 1984).

Scenario	Assumptions			Estimated carcasses to ALD (#) <sup>2</sup>
	Amount of $Zn_3P_2$ in vole(s) <sup>1</sup> (mg)	Nontarget predator or scavenger	Nontarget weight (kg)	
I. High $Zn_3P_2$ load & light nontarget	8.2	Cat	2	~ 10
		Dog	1	~ 5
II. High $Zn_3P_2$ load & heavy nontarget	8.2	Cat	6	~ 29
		Dog	36	~ 176
III. Mean (low) $Zn_3P_2$ load & light nontarget	1.7	Cat	2	~ 47
		Dog	1	~ 24
IV. Mean (low) $Zn_3P_2$ load & heavy nontarget	1.7	Cat	6	~ 141
		Dog	36	~ 847

<sup>1</sup> From Sterner and Mauldin (1995).

$$^2 \text{ Carcasses} = \frac{\text{ALD Dose (mg/kg)} \times \text{Nontarget Weight (kg)}}{\text{Amount of } Zn_3P_2 \text{ in Vole(s) (mg)}}$$

## CONCLUSIONS

Prior direct- and indirect-hazards studies, coupled with several incident reports, confirm that: 1) ingestion of multiple,  $\text{Zn}_3\text{P}_2$ -laden vole carcasses can prove fatal to domestic cats in single-choice feeding situations (Bell and Dimmick 1975, Tkadlec and Rychnovsky 1990); 2) although toxic signs have been noted for nontarget wildlife species in direct-hazards studies (see Bell and Dimmick 1975), the procedures used have involved conditioning of nontargets to carcass-feeding regimen and single-choice tests; 3) while only about half ( $\leq 69\%$  or 2.2 mg) of ingested  $\text{Zn}_3\text{P}_2$ , and negligible amounts of  $\text{PH}_3$  ( $\leq 21 \mu\text{g}$ ), have been recovered from carcasses using current analytical techniques (Sterner and Mauldin 1995, Tabata 1986, Tkadlec and Rychnovsky 1990), data suggest that undigested  $\text{Zn}_3\text{P}_2$  in the GI tracts ( $\sim 95\%$  of the ingested amount) of target rodents pose the main potential hazard to nontarget predators/scavengers (Tkadlec and Rychnovsky 1990). Together, these results, and the lack of much unequivocal incident data, suggest that multiple dead or dying  $\text{Zn}_3\text{P}_2$ -baited voles must be consumed for representative predators/scavengers to ingest a cumulative lethal dose of  $\text{Zn}_3\text{P}_2/\text{PH}_3$ .

Scenario I is supported as a conservative estimate of hazards posed to cats and dogs by ingestion of  $\text{Zn}_3\text{P}_2$ -killed voles. Still, the likelihood of even lightweight cats and dogs ( $\leq 1 \text{ kg}$ ) finding and rapidly ( $< 24 \text{ h}$ ) ingesting multiple ( $\geq 5$ )  $\text{Zn}_3\text{P}_2$ -dosed vole carcasses under field conditions seems remote. In a recent 14-day efficacy study involving a single 11.2 kg/ha broadcast application of 2.0%  $\text{Zn}_3\text{P}_2$  oat groats within 7, 0.2-ha enclosures planted in alfalfa, Sterner et al. (in press) found only 25 exposed vole carcasses during daily post-baiting searches (51 to 76 h total) over a 14-day period. Moreover, expected onset of hydrolysis-induced illness in nontargets,  $< 100\%$  retention of  $\text{Zn}_3\text{P}_2$  in carcasses, and selective avoidance of GI tracts containing undigested  $\text{Zn}_3\text{P}_2$  by certain nontarget species should preclude many predators/scavengers from ingesting fatal doses.

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# MONGOLIAN RANGELANDS: RODENT PROBLEMS AND APPROACHES TO ALLEVIATE DAMAGE

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**ABSTRACT:** Rodents are a major constraint to forage production for livestock in Mongolia. A technical program to identify the magnitude of the problem and strengthen the research capabilities of Mongolian rodent specialists was initiated in 1994. The Brandt's vole is the most widespread and the most detrimental rodent to the steppes of Mongolia. Limited resources inhibit activities by the Mongolian Plant Protection Service to reduce rodent populations. Alternative means to monitor vole activity were developed. Laboratory and field trials showed that voles were susceptible to zinc phosphide treatment and indicated how bait acceptance could be improved.

**KEY WORDS:** Brandt's vole, forage depredation, Mongolia, zinc phosphide

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## INTRODUCTION

Rodents are a major constraint to forage availability for livestock production on Mongolian rangelands. A technical program to address rodent problems in Mongolia was initiated during 1994 by the United Nations Food and Agricultural Organization (FAO) in cooperation with the Mongolian Ministry of Agriculture. The objectives of this program were to identify the magnitude of rodent problems and to strengthen the Mongolian national capabilities in integrated pest management.

An initial evaluation of rodent damage incidence and current use of rodent control methods was conducted during the spring of 1994. Information on agricultural resources and the incidence and control of rodent damage was obtained through visits with Mongolian scientists and farmers during this and subsequent trips. Cooperative field and laboratory trials helped to develop alternate strategies and to train local scientists on rodent research methods.

## MONGOLIA

Mongolia is a landlocked country in Central Asia (42-50° latitude and 88-120° longitude) located between Russia and China. Covering approximately 1.5 million square kilometers, Mongolia is roughly the size of the United States west of the Rocky Mountains. The central region of Mongolia is steppe or grassland; the Gobi Desert covers the southern part of the country. Northern and western Mongolia is mountainous. Mongolia is one of the least populated countries in the world with a population of 2.2 million people. Nearly 1 million of these people live in the capital city of Ulaan Baatar.

The Mongolian economy is heavily dependent on its agricultural resources. Nearly 80% of Mongolia's land and half of its working population are engaged in agriculture. Extensive grasslands, 132 million ha, provide the base for its animal production. Traditionally, nomadic lifestyles permitted the ready movement of livestock to available forage resources. Though traditional lifestyles persist, regional and social ties have reduced the extensive movements of the past.

The primary grasses are bluegrass (*Poa pretensis*), smooth brome (*Bromus inermis*), and crested wheatgrass

(*Agropyron cristatum*). Sheep, goats, cattle, horses, and camels raised on these grasslands produce meat, wool, leather and milk for domestic consumption, as well as provide Mongolia's principle exports, including about 30% of the world's cashmere.

Arable lands, 1.3 million ha, extend across the country, however, the majority of crop production occurs in the central region. State owned and cooperative farms are being privatized and converted to share-holding companies and private farms. Principle grain crops include wheat, barley, oats and millet. Potatoes are the primary vegetable, along with cabbages, carrots, onion and garlic. Crop production in Mongolia has declined in recent years because of structural changes, shortages in fertilizer and fuel, and an inadequate distribution system. Mongolia imports flour, sugar and sunflower seed oil.

Mongolia's agricultural production suffers from severe climatic conditions. The weather is characterized by long and harsh winters (October to April). The cropping period is generally around 110 days, however, in some years it can be limited to as few as 80 days. Scarce precipitation (avg. 117 mm) occurs generally as rain during July and August and as snow during the winter (Lavrenko and Karamysheva 1993).

## BRANDT'S VOLE

Mongolian Plant Protection Service (PPS) specialists regard the Brandt's vole (*Lasiopodomys brandti*) as the most destructive of the 67 rodent species present in Mongolia. Though population densities fluctuate, it is estimated that the Brandt's vole infests over 40 million ha of rangelands; 19 million ha contain densities as high as 2,000 to 3,000 individuals per ha.

The Brandt's vole is the most widespread rodent of the steppe zone of Mongolia. Strictly herbivorous, the vole is an important competitor for domestic livestock and its activities are clearly perceivable on the steppe region (Weiner et al. 1982). Small stores of forage are hoarded by voles in the summer, but as winter approaches the voles exert their energies to gathering forage for the winter. Voles may store as much as 10 kg of dry forage per hole (Lavrenko and Yunatov 1952). Numerous pits are formed and the ground surrounding burrows often

becomes barren. Voles ingest not only the above ground herbaceous matter, but also dig up the roots, slowing recovery of the vegetation. Due to this intense vole feeding activity, the plant species within a vole colony are generally altered to a less favorable composition for livestock production (Zielinski 1982).

Burrow entrances are connected by intertwining runways. Burrows can be divided into three types: refuge burrows, main summer burrows, and main winter burrows (Schauer 1987). Refuge burrows are of simple construction and short. They are located along the edges of main burrows and are used as shelter to avert danger. Summer burrows are a more complex structure but do not contain storage chambers. Winter burrows may have up to 30 entrances and a complex network of passages (3.5 to 4 cm) near the soil surface. The nesting chamber (dia. 30 cm) is located in the center at a depth of approximately 40 cm and surrounded by large oblong storage chambers (45 to 120 cm).

Seasonal climatic conditions greatly effect the above ground activity of voles (Anti-epidemic and Health Station 1975). During the summer the voles demonstrate bimodal above ground activity in the morning and evening. Seldom do they come to the surface at night. In late fall and early spring activity is primarily at mid-day. During the long, cold winters the animals seldom surface.

Fecundity in the Brandt's voles is high and during the course of a year, and over longer two to six year periods, its numbers fluctuate greatly (Schauer 1987). Voles have at least two to three litters per year, with five to nine pups per litter (Bannikov 1948). Offspring are generally first encountered in mid-May, and these first born produce their own young by July.

The economic consequences of the Brandt's vole to Mongolian agricultural are severe. Highly infested areas are virtually void of forage for livestock and associated grain fields can be devastated. Mongolian scientists report that more than 80% of the vegetation is consumed by rodents during the growing season. Losses on these areas are estimated to be 228 million metric tons of grain and between 226 and 304 million metric tons of natural forage. Though losses are less severe on the other 21 million hectares infested with Brandt's voles, they can still be substantial.

Lethal measures to reduce vole populations are the only approaches used by the PPS to alleviate rodent damage problems. Toxicants are generally applied in the spring (March to May) and then again in the fall (October to November). Prior to 1990, approximately 2 million ha of grassland were treated annually. Economic constraints in recent years, however, has limited the PPS efforts to slightly more than 100,000 ha per year.

Principal toxicants that have been used in Mongolia are zinc phosphide (50 to 60/kg bait), redentine (chlorophacinone: 3g/kg bait), bromdiolone (40g/kg bait) and *Salmonella enterides* (2mlrd/g). Zinc phosphide generally is applied in areas with high vole populations to quickly reduce densities. Anticoagulants are used in areas with less dense populations or as a follow-up treatment to maintain low rodent densities. The PPS also applies *Salmonella enterides* to approximately 23,000 ha (550g/ha) during the spring. The major deterrent to salmonella application is its potential hazards to humans

and livestock.

Baits are applied almost exclusively from an airplane. High mountainous regions makes these applications difficult and limited fuel resources further hamper application efforts. Bait spreaders mounted on tractors are used to treat some small areas.

Wheat coated with sunflower seed oil is the only bait used to entice rodents to ingest toxicants. Wheat is readily available and is recognized by Mongolian specialists as an adequate bait. However, since most baits are aerially applied and remain on the soil surface until collected by rodents, it would be desirable to develop a bait that was avoided by livestock. An alternative bait would also be beneficial on croplands. Rodents restrict their intake of treated wheat when untreated wheat is readily available.

## DEMONSTRATION ACTIVITIES

Trials were implemented to demonstrate several possible alternative approaches to monitor vole activity, and to demonstrate the efficacy of different zinc phosphide concentrations to reduce vole populations.

### Animal Activity

At present, population densities of Brandt's voles are estimated by multiplying the number of active burrows entrances per ha by the constant 0.392. This constant was derived by Russian scientists through observations of vole activity relative to population densities. The number of burrow entrances is determined by collapsing all burrow entrances within a given area, then returning the next day to count entrances reopened within a 24 hour period. Generally, Mongolian scientists monitor four 1/4 ha plots per 10,000 ha. This approach is used to monitor population fluctuations across the country, as well as to evaluate the efficacy of population reduction measures.

Monitoring four 1/4 ha plots per 10,000 ha permits only isolated sampling. Belt transects were examined as an alternative to sample a greater number of smaller plots. The number of burrow entrances on 15, 1/4 ha plots was determined by the traditional burrow count method and with a belt transect method. The traditional burrow count method consisted of four persons walking back and forth across the plots counting all open burrow entrances. For the belt transect method (50 x 1 m), a 50 m tape was strung across each plot at five randomly selected points, and then all burrows within .5 m of either side of the tape were counted.

A one-way analysis of variance revealed that the traditional system (2,082 burrow entrances/ha) and the belt transect method (2,213 burrow entrances/ha) estimated similar vole activity. These results suggested that the belt transect method would be a feasible alternative to the traditional method. This method would enable the PPS to more thoroughly stratify their sampling of rodent populations across infested areas.

A modified point-sampling method was also examined as a means to monitor changes in relative vole activity. For comparative purposes, activity data were collected on three 1/4 ha plots. Open holes were counted by the plot count method on two consecutive days as described above. The point method consisted of locating the three burrow entrances nearest to 25 randomly selected points



within each plot. Holes were then filled with rolled paper. The following day, burrows not blocked with paper were considered active. The paper was then replaced in the burrows and the process repeated the next day.

A two-factor repeated measures ANOVA was used to assess differences in activity estimates determined by the plot method and the point sampling method. The two methods indicated similar ( $P=0.22$ ) proportional declines ( $P<0.01$ ) in activity from day 1 to day 2. Thus, the modified step point may be a feasible alternative to evaluate changes in rodent activity. Additional efforts would be necessary to determine the optimal number of burrow entrances near a point, as well as the number of

points necessary to accurately estimate changes in vole activity. Trapping methods to monitor rodent populations were also examined. Sherman live-traps (8 x 9 x 23 cm) were placed at approximately 5 m intervals on a 10 x 10 grid. Trap openings were located either along runways or near a burrow entrance. Snap traps, located on a plot approximately 1 km from the live trap plot, were also set along runways or near burrow entrances at 5 m intervals on a 10 x 11 grid. All traps were baited with wheat coated with sunflower seed oil.

Trap success by either method was very low (Table 1). Trap methods were halted after the third day because a substantial number of traps had disappeared. Efforts to improve trapping techniques were not attempted.

Table 1. Brandt's voles caught on live trap and snap trap grids on three successive days.

Day	Time	Live Trap		Snap Trap	
		Male	Female	Male	Female
1	AM	traps set	traps set	traps set	traps set
1	PM	1	1	0	1
2	AM	1*	0	1	0
2	PM	0	0	0	1
3	AM	1	1	1	0
3	PM	0	0	0	0

\*Male that was previously captured on Day 1, PM.

#### Population Reduction

The PPS applies approximately 3 kg of wheat treated with 5 to 6% zinc phosphide per ha, based on recommendations developed some years ago. Applying zinc phosphide at such concentrations might be counter-productive to an effective program (Tkadlec 1990). Lower concentrations of zinc phosphide are adequately lethal and rodents generally restrict intake of baits treated with high concentrations. Laboratory and field trials were implemented to determine the response of Brandt's vole to wheat treated with different concentrations of zinc phosphide.

The laboratory trial was conducted to complement the concurrent field trial by demonstrating vole susceptibility to low concentrations of zinc phosphide, and by demonstrating vole reluctance to ingest wheat treated with high concentrations of zinc phosphide. Treatment foods were whole wheat coated with sunflower seed oil containing 0%, 0.75%, 1.5%, 3.0%, 6.0% and 9.0% zinc phosphide. Another treatment that consisted of malted wheat coated with sunflower oil treated with 3.0% zinc phosphide was also included in the trial.

Fifty-six adult Brandt's voles were randomly assigned to one of the seven treatments. All animals were caged (48 x 27 x 20 cm) individually with free access to water

throughout the trials. On day 1, after a three hour food deprivation period, voles were presented their respective treated foods in a two-choice test. Untreated wheat placed at the opposite end of the cage was the alternative choice.

All voles given wheat treated with zinc phosphide died within 12 hours; most of them died within 2 hours. Three of the eight untreated reference voles also died within the first 12 hours of the study; an indication that animals were probably stressed and a longer acclimation period should have been provided. Regardless, these results indicated that zinc phosphide at concentrations as low as 0.75% were lethal to Brandt's voles. Mean intake of food ingested across treatment was 0.1 g, suggesting that voles were licking the treated sunflower seed oil from the kernels rather than ingesting the wheat.

Low food intake negated attempts to evaluate the potential of malted wheat as an alternative bait. Malted grains may enhance bait acceptance because the malting process substantially increases sugar content relative to untreated wheat (B. A. Kimball, USDA/APHIS/ADC/DWRC, pers. comm.). Sweet flavors are generally attractive to rodents (Jacobs et al. 1977).

The field trial was conducted to determine the efficacy of two zinc phosphide treatments. One application reflected the current approach using 3 kg of

bait per ha treated with 6% zinc phosphide. The amount of bait was doubled for the other application (6 kg/ha) but was treated with 1.5% zinc phosphide.

The trials were established 60 km west of Ulaan Baatar, near Argalant on a uniform grassland steppe of predominately bluegrass and crested wheatgrass. The two applications described above and an untreated reference treatment were randomly assigned to one of three 150 ha (1 x 1.5 km) plots. A 1 km border was established between plots to minimize crossover effects.

Baits were prepared by the PPS staff. Treatments were applied by a tractor mounted spreader. Bait dispersal rate was determined by counting the number of wheat seeds on the ground per m<sup>2</sup> (20 to 25 seeds/m<sup>2</sup> = 3kg/ha; 40 to 50 seeds/m<sup>2</sup> = 6 kg/ha). Vole activity within each of these plots was determined on five 1/4 ha sampling plots. Sampling plots were placed in a line at 100 m intervals such that the middle plot was in the center of the 150 ha plot. Activity before and after treatment was determined by the standard plot count method used by PPS staff in Mongolia. Vole activity was determined for the two consecutive days immediately prior to treatment, for two consecutive days one week after treatment, and then again for two consecutive days at approximately four months post treatment. Differences among treatments within each evaluation period was assessed by a Chi-square goodness of fit test ( $P = 0.05$ ).

Activity was similar across all plots prior to treatment. One week after treatment, there were fewer active burrows on either of the treated plots than on the reference plot. The 1.5% zinc phosphide treatment plot had fewer active burrows than did the plot treated with 6.0% zinc phosphide. The number of active burrows on the reference plot four months after treatment was substantially greater than on the baited plots. However, after four months there were more active burrows on the 1.5% zinc phosphide plot than on the one treated with 6.0% zinc phosphide bait.

Vole activity was lower on plots treated with either concentration of zinc phosphide relative to the reference plot (Figure 1). Vole numbers were substantially less on treated plots than the untreated plot by the end of the summer, probably because reproductive adults were eliminated early in the year. This not only reduced the number of litters born to over-wintering animals but also restricted subsequent litters born to their offspring. The initial greater reduction on the 1.5% plot may have been because voles more readily accepted wheat treated with the lower zinc phosphide concentration. Results of the laboratory trial, however, suggest they would ingest sunflower seed oil treated with either concentration. A more plausible explanation is the increased amount of bait applied to the 1.5% plot. Doubling the amount of bait greatly increased the likelihood that treated kernels fell near burrows or on runways and were encountered by voles. It is uncertain why vole activity was lower on the 6.0% plot than the 1.5% plot after four months. Perhaps because a lethal concentration of zinc phosphide remained longer on wheat treated at the higher concentration than on the 1.5% bait. Therefore, this bait effectively removed voles that encountered it for a longer time after treatment than did reduced concentration.

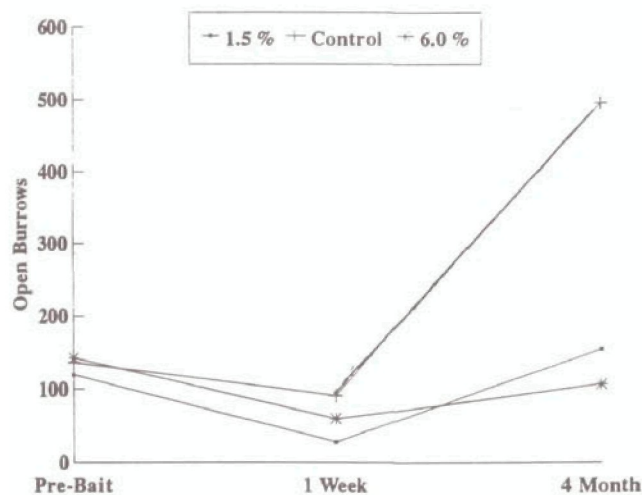


Figure 1. The number of active (open) Brandt's vole burrows on plots at pre-baiting, and at one week and four months post-baiting with wheat treated with 0% (control), 1.5%, and 6.0% zinc phosphide.

## SUMMARY

Populations of Brandt's voles, particularly in the southeast of Mongolia, disrupt livestock production. For example, 1,317 camps in the Suh-baatar region with 359,500 livestock were forced to move 200 to 300 kilometers to another region. These moves drain limited financial resources, disrupt social services and children attending school, and often cause increased competition among livestock for already limited forage resources.

The Mongolian PPS continues to work to reduce rodent depredations of grasslands. Additional means and resources, however, are needed to enhance its ability to identify problem areas reliably, identify more effective and safer rodenticide treatments, improve bait formulations, and enhance treatment procedures.

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# IMPACTS OF FIELD-DWELLING RODENTS ON EMERGING FIELD CORN

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**ABSTRACT:** The Conservation Reserve Program (CRP) has produced nearly 600,000 ha of exceptional wildlife habitat in Nebraska. Unfortunately, several species of rodents that inhabit CRP grass fields cause damage to agricultural crops. The emergence of corn seedlings in a 4-row strip of no-till field corn, planted in a 64 ha bromegrass field in northeastern Nebraska was examined. The most common rodent species in the study area was the deer mouse (*Peromyscus maniculatus*), of which 18 were captured within 10 m of the planted strip during one evening (400 trap nights). Corn seedling emergence in unprotected control areas ( $\bar{x}$  = 19.2 plants/dekameter of row (dor)) appeared to be lower than in areas protected with welded wire exclosures ( $\bar{x}$  = 23.7 plants/dor). An in-furrow application of 2% zinc phosphide pellets (2.75 kg/ha) also contributed to an increase in emergence ( $\bar{x}$  = 21.9 plants/dor). Differences among the treatments, however, were not significant ( $P$  = 0.76). Additional research is needed to develop methods to reduce wildlife damage in crop fields that incorporate conservation tillage practices or are adjacent to or converted from CRP fields.

**KEY WORDS:** deer mouse, rodents, wildlife damage

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## INTRODUCTION

The United States Congress passed the Food Security Act of 1985 (16 USC 3831-3840, Public Law 99-198) to reduce crop surpluses and stabilize agricultural commodity prices. Several conservation provisions were included in the Act that provided incentives to landowners nationwide to implement land management practices that reduce soil erosion and increase water quality. These conservation provisions, also known as the Conservation Reserve Program (CRP), led to the conversion of nearly 14 million ha of cropland to untilled land in semipermanent vegetative cover by 1996. These large fields of predominantly cool and warm season grasses provide exceptional habitat for wildlife. Recent publications have documented increased populations of ring-necked pheasants (*Phasianus colchicus*) (King and Savidge 1995; Riley 1995) and songbirds (King and Savidge 1995) due to the current CRP. Other long-term federal farm programs, such as the Soil Bank Program initiated in 1956 and the Crop Adjustment Program of 1965, have also contributed significantly to wildlife habitat (Erickson and Wiebe 1973). Unfortunately, some rodents and birds that inhabit these fields cause damage to agricultural crops. Voles (*Microtus* spp.), field mice (*Peromyscus* spp.) and ground squirrels (*Spermophilus* spp.) dig up and eat planted seeds and/or clip off emerging seedlings, usually before the fourth-leaf stage. Elton (1942) wrote of exceptionally high vole populations (2,500 voles per ha) in agricultural fields prior to the advent of effective herbicides and clean farming practices. He also provided anecdotal accounts of dramatic crop failures due to rodent plagues. More recent reports of rodent damage to emerging corn seed and seedlings in conservation tillage fields have varied considerably: 1% in Iowa (Young and Clark 1984), 5% to 8% in Nebraska (Holm 1984), 50% to 60% in Illinois (Beasley and McKibben 1975, 1976) and 80% to 100% in Illinois (Hines 1983). To a lesser extent, field-dwelling birds such as ring-necked pheasants and horned larks (*Eremophila alpestris*) pull up and eat

emerging seedlings. Although wildlife damage can be locally severe, few cost-effective methods are available to control such damage. In 1989, the U.S. Environmental Protection Agency (EPA) withdrew label clearance for the use of zinc phosphide-treated bait on field corn for rodent control. Currently, there are no toxicants or repellents registered for in-field application to reduce damage by small rodents.

Concern has been expressed by the agricultural community regarding the potential impacts of wildlife on crops that are planted in fields that incorporate conservation tillage practices or are adjacent to or converted from CRP fields. In addition, there is commercial interest in developing a toxicant formulation that provides cost-effective and environmentally safe protection for crops planted in conservation tillage systems. A research/demonstration project was conducted to address these concerns. The objectives were to: 1) determine the impact of rodents on no-till corn planted in a bromegrass field previously enrolled in the CRP; and 2) determine the efficacy of in-furrow applications of zinc phosphide for controlling rodent damage to no-till corn seed and seedlings.

## METHODS

This study is part of an interdisciplinary project conducted at the University of Nebraska Northeast Research and Extension Center, near Concord, Nebraska. The project is being conducted by the "CRP to Crops Team," which includes nine scientists from the following disciplines: agricultural engineering, agronomy, entomology, forestry, soil science and wildlife. Team members are working to identify the most cost-effective and environmentally sound means of converting land from the CRP back into agricultural production. The rodent damage study was conducted in a 64 ha CRP field planted to bromegrass in 1986. A 5 m wide, 500 m long strip was delineated in an East-West direction in the northern half of the bromegrass field. The strip was shredded with



a rotary mower to a height of 10 cm on 6 June 1995. The authors planted four rows of Pioneer 3394, 110-day field corn to the strip, using a no-till planter on 8 June 1995. The corn was planted at a row spacing of 76 cm and expected plant population of 48,000 plants per ha (3.7 plants/m of row). A post-emergence herbicide (Extrazine, 16.5 kg/ha) was applied to the corn on 20 June 1995. Most cornfields in Nebraska are planted in early to mid-May to take advantage of the long growing season. Unfortunately, corn planting was delayed a month for this study because during May 1995, mean rainfall was approximately 10 cm above normal and mean soil and ambient temperatures were approximately 6°C and 3°C below normal, respectively.

Experimental treatments were applied to the 500 m strip by 10 m plots within 40 m blocks (Figure 1). Every fourth 10 m plot was treated in-furrow at planting with 27.5 kg/ha (5 pounds/acre) of a 2% pelletized formulation of zinc phosphide rodenticide (Hopkins Agricultural Chemical Company, Madison, WI). Since the total area treated with zinc phosphide was less than 4 ha, no Experimental Use Permit was needed from the EPA. On the day of planting, one 2.2 m long welded wire enclosure was installed over each of the four corn rows within the second and fourth 10 m plots of each 40 m block. The enclosures were randomly located within the 10 m rows. The untreated 10 m plots that were located between the 10 m treatment plots served as buffers to reduce dependence among adjacent treatment plots. The resultant experimental design consisted of four treatments, in decreasing order of protection from rodent damage: zinc phosphide-exclosure (ZP-E), no zinc phosphide-exclosure (NZP-E), zinc phosphide-no enclosure (ZP-NE), and no zinc phosphide-no enclosure (NZP-NE). Since the primary concern was plant emergence, the number of emerging corn plants/dm of row was used as a response variable to determine the effectiveness of the treatments. On 9 July 1995, when the corn plants were at the third- to fourth-leaf stage, the authors counted the number emerged in a 2 m-of-row plot located within each enclosure and 2, 2 m-of-row plots located outside of each enclosure (Figure 1). A 2-factor split plot design and analysis of variance was used (Hays 1963; Wilkinson 1989) to test the null hypothesis:  $Y_{ZP-E} = Y_{NZP-E} = Y_{ZP-NE} = Y_{NZP-NE}$ , where Y equals the mean number of emerged corn plants/dm of row.

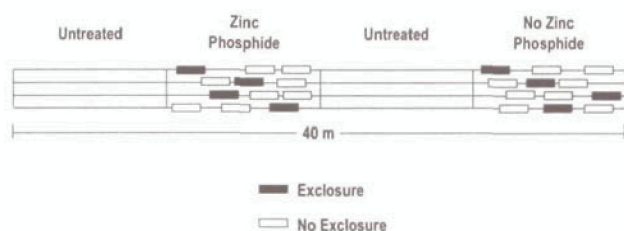


Figure 1. Experimental design for evaluating the impacts of field-dwelling rodents in a 4-row strip of no-till field corn and the efficacy of zinc-phosphide for controlling rodent damage.

To provide an indirect measure of rodent pressure on the corn seed and seedlings, 400 Museum Special snap traps were set out that were baited with peanut butter for a 12-hour period the night before the exclosures were removed and plants were counted. Two 500 m transects were located in the untreated brome grass, parallel to and 5 and 10 m away from the North edge of the 4-row strip of corn. Two other transects were located in a similar fashion from the South edge of the corn strip. One hundred snap traps were placed 5 m apart on each transect. Standard techniques were used to minimize exposure of researchers to hantavirus (Centers for Disease Control and Prevention 1993). The study protocol was approved by the University of Nebraska Institutional Animal Care and Use Committee. No effort was made to distinguish between rodent and bird damage in the corn rows. The amount of bird damage is assumed to be negligible.

## RESULTS AND DISCUSSION

The mean corn plant population in unprotected plots (NZP-NE,  $\bar{x} = 19.2$  plants/dor) was 20% less than the mean in the plots protected with welded wire exclosures (ZP-E,  $\bar{x} = 24.0$  plants/dor) (Table 1). Differences among the treatments, however, were not statistically significant ( $P = 0.76$ ) because of the variability among individual sample plots (range = 0-50,  $n = 120$ ). Although not statistically significant, it was believed that a potential 20% decrease in crop yield would be economically significant to most producers. In an average 64 ha cornfield in Nebraska, such damage would result in the loss of approximately \$3,200, assuming a profit of \$250/ha. Independent research on landowner attitudes has frequently identified landowner tolerance levels of wildlife damage at 10 to 20% of crop yield (Craven et al. 1992).

Table 1. Mean number of corn plants/dekagram of row (dor) that emerged, relative to four treatments applied to protect against rodent damage [zinc phosphide-exclosure (ZP-E), no zinc phosphide-exclosure (NZP-E), zinc phosphide-no enclosure (ZP-NE), and no zinc phosphide-no enclosure (NZP-NE)].

Treatment	$\bar{x}$	SE	$n$
ZP-E	2.34	0.17	40
NZP-E	2.40	0.17	40
ZP-NE	2.19	0.12	80
NZP-NE	1.92	0.12	80

Plots with in-furrow applications of 2% zinc phosphide pellets also appeared to have higher corn plant populations (ZP-NE,  $\bar{x} = 21.9$  plants/dor) relative to unprotected plots (NZP-NE,  $\bar{x} = 19.2$  plants/dor, Table 1). Differences among treatments, however, were not statistically significant ( $P = 0.76$ ). Similar studies conducted in the Midwestern United States during 1995

were confounded with similar weather problems and had similar results to our study (J. H. Pickle, Hopkins Agric. Chem. Co., pers. comm.). Research will be conducted in 1996 to further determine the efficacy of zinc phosphide. Beasley and McKibben (1975) reported significant reductions in vole damage to no-till corn in Illinois after an in-furrow application of zinc phosphide-treated bait, even under the pressure of high vole populations.

The most frequently captured small mammal species during the 400 trap-night period was the deer mouse (*P. maniculatus*, n = 18). In addition, five short-tailed shrews (*Blarina brevicauda*), two least shrews (*Cryptotis parva*) and two meadow jumping mice (*Zapus hudsonicus*) were captured. To the authors' surprise, no voles were captured during the trapping period even though several were observed during a casual walk through the field five months prior to the spring fieldwork. The overall capture rate (captures per 100 trapnights) was only 6.7 versus 14.6 in a similar study in Nebraska (Holm 1984). It is speculated that field rodent populations declined during the winter of 1994-1995 due to normal mortality factors and that recruitment in spring was inhibited dramatically by near record low spring temperatures and high rainfall. As a result, rodent pressure on the treatments was not as high as expected.

The CRP and conservation tillage practices have provided excellent habitat for wildlife. As a result, field rodent populations have increased in several cases. No producers want to return to the days of rodent plagues. To avoid resurrecting an "old pest," research and demonstration projects are needed to develop and promote cost-effective and environmentally safe methods to reduce rodent damage in crop fields.

#### ACKNOWLEDGMENTS

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# THE POCKET GOPHER AS A PEST IN MEXICO

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**ABSTRACT:** Pocket gophers of the genus *Orthogeomys* and *Pappogeomys* are major pests in rangeland and agricultural areas throughout Mexico. Control relies on the indiscriminate use of fumigants and poison baits. These controls are applied in a haphazard manner; do not provide long-term benefits and the non-target hazards and public safety risks are perceived to be extremely high. Studies indicate that as a result of reinvasion of treated areas or territory expansion of animals surviving the control procedure, controls relying on removal of animals may be limited unless applied at frequent (every three months or less) intervals.

**KEYWORDS:** *Pappogeomys merriami merriami*, Geomyidae, Rodentia, pocket gophers, Mexico, damage, control methods

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## INTRODUCTION

The creation of large cultivated areas, the change in soil conditions and a reduction in the number of natural predators has resulted in an increase in abundance of pocket gophers throughout Mexico. Species comprise those of the genera *Orthogeomys*, *Pappogeomys*, *Zygeomys*, *Geomys*, and *Thomomys*. Of these, species of *Orthogeomys* and *Pappogeomys* are the most economically significant, causing major damage to crops and rangeland.

Crops, including wheat, potatoes, cocoa, bananas, corn, alfalfa, and sugarcane suffer significant damage. Damage to tree fruit crops is also considerable. In the state of Michoacan, pocket gophers damage young avocado trees. They also cause significant damage to trees of up to four years in forest regeneration areas. Structural damage occurs in irrigation canals, roads, building foundations and underground cables.

Currently, losses due to damage by pocket gophers in Mexico have only been estimated for corn. For this crop, indications are that pocket gophers consume 52 kilos of grain per year and damage 1,441 stalks resulting in losses of approximately 4%. In sugarcane, where the crop remains in the ground for several years and it is not possible to replant during that period, losses may be much higher.

Control measures are generally only applied once the problem has been noticed and significant damage has already occurred. Techniques used include burrow fumigation with car exhaust, butane gas, and aluminum phosphide; use of poison baits including zinc phosphide, 1080, anticoagulants (primarily second generation anticoagulants); and traps. Strychnine is prohibited from use. Use of poison baits is excessive, with applicators receiving little or no training on dose or application rates and safe handling and storage of poisons. Consequently, public health risks and non-target hazards are perceived to be extremely high.

Despite their significance as pests, very little is known about the ecology and habits of the species and the impacts of control on their populations and reducing damage. In an attempt to provide some quantitative

information on the activity and impacts of pocket gophers in rangeland, a study of the species *Pappogeomys merriami merriami* was initiated in 1993.

*P. m. merriami* is probably one of the least studied pocket gophers in Mexico. It occurs in the southern part of the Valley of Mexico and Sierra de las Cruces, Sierra de Ajusco, Mount Popocateptl and Mount Iztaccihuatl bordering the valley. It also occurs from Lerma at the eastern end of the Valley of Toluca eastward into Western Puebla. It may be found at elevations of up to 13,500 feet and above the timber line on Mount Popocateptl, but most specimens have been taken at places between 7,300 and 10,500 feet elevation.

It is a large pocket gopher with head-body lengths as high as 180 mm (females) to 253 mm (males) and an average weight of 800 g (Villa-C 1989). Color ranges from pale yellowish-brown to glossy black. The brown phases are more common at lower elevations and tend to be replaced by the dark phase at higher altitudes.

Studies of the reproductive biology of this species indicates that these pocket gophers reproduce throughout the year with a peak in reproductive effort occurring from October through March (Villa-C and Engeman 1993). They have two young per litter.

*P. m. merriami* create mounds that are 20 to 30 cm in height and up to 1 m in diameter (Whisson and Villa-C 1994). The burrow systems are extensive with the length of the main tunnel being up to 60 meters (Villa-C 1989). Villa (1953) recorded a depth of 50 cm (approximately 20 inches) for the main tunnels of this species in loose volcanic soils of the Valley of Mexico. Mound building activity is variable throughout the year with most activity observed during the dry period rather than during the wet season. The burrow systems and mounds cause serious problems in crops by interfering with harvesting operations, irrigation systems and causing erosion. In rangelands, they can have a significant impact on plant species composition and biomass as well as being hazardous to livestock.

As control measures are applied haphazardly, they seldom provide long-term benefits. Only a small

proportion of the pocket gopher population may be removed during a control program so that the population is able to recover in a very short period of time. Furthermore, control is usually applied to small areas so that there is high potential for reinvasion to occur.

This study was undertaken to investigate the impact of control procedures based on removal of animals, on pocket gopher activity in a rangeland.

## METHODS

The study was undertaken at Ranch Lorenzo, Tres Marias (3000 m elevation), 53 km south of Mexico City. Two sites of approximately 1.3 ha each were chosen. Each of these sites were bordered by open forest. The fields were occasionally grazed by sheep during the study period.

The amount of pocket gopher activity in each site was assessed each month over the 11 month period May 1993 to March 1994. Prior to sampling, all pocket gopher signs (earth mounds and plugs) were erased by leveling mounds and scraping soil over plugs. In each of the following four days, the site was systematically searched and the location and type of sign recorded.

In one site, pocket gophers were removed by trapping every three months (May 1993, August 1993, November 1993, and March 1994). Trapping sessions were between five and eight days long. During each of these sessions, an attempt was made to catch and remove all pocket gophers in the field. Unbaited leg-hold traps were set in burrow systems that showed signs of recent pocket gopher activity. The number of traps set during each trapping session depended on the amount of fresh activity and varied between 10 and 35 per day.

Each pocket gopher caught was immediately euthanized and necropsied. The location of capture, sex, and weight was recorded for each individual.

## RESULTS

A total of 26 pocket gophers comprising 15 females and 11 males were trapped during the four trapping sessions of the study. From sign counts following pocket gopher removal, it was apparent that a proportion of individuals were able to elude being trapped. Mature individuals were trapped in all trapping sessions. Two

pregnancies were recorded in August, and juveniles were trapped in May and November. Weights ranged between 368 g and 751 g for females and between 453 g and 900 g for males (Table 1).

The effect of pocket gopher removal on the amount of activity in following months is shown in Figure 1. There was an immediate decrease in the number of mounds and plugs in the month following removal. However, this decrease was only temporary and within three months, the number of sign had increased to similar levels as before animal removal. An increase in the amount of sign within a 20 m radius of the point of capture two months following removal of the pocket gopher indicates that other pocket gophers had either invaded the site or shifted their home range to utilize the vacated burrow system (Table 2).

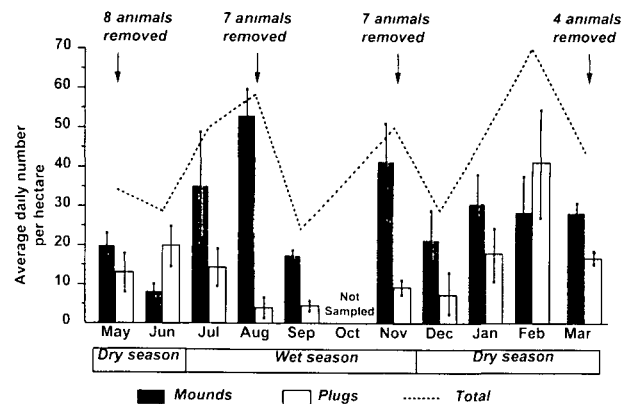


Figure 1. Activity and number of pocket gophers removed from the site over the period May 1993 to March 1994.

Although removal of animals only resulted in a temporary reduction in the amount of activity within the field, overall activity throughout the year was lower than in the field where no control was practiced (Figure 2). In that field, activity was extremely variable throughout the year with a peak in activity occurring from December to February (dry season).

Table 1. Characteristics of pocket gophers trapped in each trapping session

Trapping Session	Mature Females	Mature Males	Juvenile Females	Juvenile Males	Weight Range Females (g)	Weight Range Males (g)
May 1993	2	2	3	1	368-700	453-840
August 1993	4	3	0	0	650-751	650-900
November 1993	2	2	2	1	450-650	310-775
March 1994	2	2	0	0	625-750	625-725
TOTAL	10	9	5	2	368-751	453-900



Table 2. Amount of activity within 20 m of capture points.

Trapping Session	Month	Number of Mounds	Proportion of Total Mounds Within the Site
May	May 1993	27	0.47
	June 1993	8	0.24
	July 1993	37	0.27
	August 1993	34	0.16
August	August 1993	93	0.44
	September 1993	13	0.19
	November 1993	60	0.36
	December 1993	16	0.20
November	November 1993	45	0.17
	December 1993	16	0.20
	January 1994	29	0.24
	February 1994	41	0.36

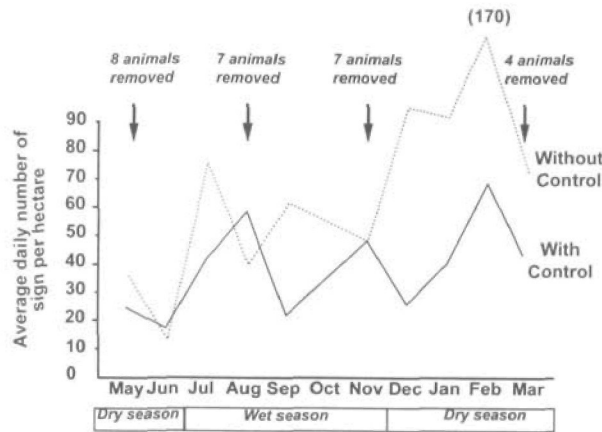


Figure 2. Pocket gopher activity in sites with and without control.

Figure 2. Pocket gopher activity in sites with and without control.

## CONCLUSIONS

Pocket gophers are significant pests of agriculture and rangelands throughout Mexico, yet little is known of the ecology and habits of the species which are responsible for the damage. Likewise, there is no information pertaining to the efficacy of current control procedures.

Deep burrow systems and the large size of pocket gophers causing damage to rangeland and agricultural areas of Mexico contribute to difficulties in being able to control these pests. This study indicates that although control relying on removing animals may provide short-term benefits, the population recovers in a short period of

time (within three months) and activity increases to a level similar to that prior to the control treatment. It is also likely that this short-term benefit is far outweighed by the costs of implementing the control procedure, and it is questionable if control procedures are even able to reduce activity and damage to a tolerable level in the short-term.

Economic losses due to damage by pocket gophers in Mexico will continue to be high unless research is undertaken to: a) investigate ways of optimizing current control practices (e.g., use of burrow builder); and b) explore possible alternative control measures (e.g., burrow ripping), to provide more effective long-term control.

Education of those applying chemical control measures, to reduce non-target and public safety hazards should also be a priority.

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# PERCEPTIONS OF WILDLIFE DAMAGE BY CONSERVATION RESERVE PROGRAM CONTRACT HOLDERS IN RILEY COUNTY, KANSAS

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**ABSTRACT:** Twenty-five Conservation Reserve Program (CRP) contract holders in Riley County, Kansas were surveyed by telephone to assess their perceptions of wildlife damage relative to CRP plantings. Sixty-four percent experienced wildlife damage on their farm or ranch. Respondents felt that five species causing damage on their farm or ranch had become more common due to enrollment of lands in the CRP. White-tailed deer (*Odocoileus virginianus*) accounted for 64.3% of these observations, followed by wild turkey (*Meleagris gallopavo*), eastern cottontail (*Sylvilagus floridanus*), striped skunk (*Mephitis mephitis*), and Virginia opossum (*Didelphis virginiana*), which accounted for 14.3%, 7.1%, 7.1%, and 7.1% of the damage observations, respectively. Only 12.5% of respondents attempted to control wildlife damage, and none felt that wildlife damage was severe enough to preclude future enrollment in programs such as the CRP. Most respondents allowed hunting or trapping by non-family members on their CRP lands (68.8%), but none felt that increased hunting or trapping would reduce the amount of wildlife damage they experienced. All respondents felt that the benefits of the CRP exceeded costs associated with wildlife damage and that the program was highly beneficial overall.

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## INTRODUCTION

The Conservation Reserve Program (CRP) was created by the 1985 Food Security Act to reduce soil erosion and commodity surpluses. A secondary benefit of the CRP has been the creation of wildlife habitat (Blackburn et al. 1991). The results of several studies have indicated that the CRP has been beneficial to several wildlife species (Johnson and Schwartz 1993; Kantrud 1993; Rodenhouse et al. 1993). However, few studies have assessed either actual wildlife damage problems or perceived problems, encountered by agricultural producers as a result of the CRP.

Several authors have stressed the importance of agricultural producers in providing habitat to increase wildlife populations (Harmon 1981; McConnell 1981; Noonan and Zagata 1982), but relatively few have recognized the costs that may be incurred by producers as a result of increased wildlife populations (Wade 1987). Agricultural producers control over 45% of the total surface area of the United States, and their role in wildlife conservation activities is substantial (Conover 1994). Enrollment of farm acreages in the CRP may increase wildlife damage by providing relatively high-quality habitat which increases numbers of wild animals in close proximity to human habitation. To determine if such a situation existed on a local scale, CRP contract holders in Riley County, Kansas were surveyed to assess their perceptions of the relationship between enrolling lands in the CRP and wildlife damage on individual farms and ranches.

## METHODS

The first author (Hughes) developed a telephone survey following the guidelines of Filion (1980). A random sample of 25 CRP contract holders was selected from contract files located in the Riley County Agricultural Stabilization and Conservation Service

(ASCS) office, and telephone interviews with contract holders were conducted between the dates of 10 April and 24 April 1995. Respondents were asked the size of their farming or ranching operation, types of land use included in their operation, ownership and residency patterns relative to their CRP lands, types of wildlife damage experienced and their relation to CRP lands, hunting activities on CRP lands, and general perceptions of the CRP. Land use categories included CRP, cultivated, pasture/hayland, wooded, and domestic animal operations. Ownership and residency categories included owner and operator (respondent resided in the immediate vicinity of his or her CRP lands), absentee landowner, renter and operator, and none of the above. Respondents were asked if they had experienced any wildlife damage on their farm or ranch, which species were responsible for the damage, and if this damage had increased, decreased, or remained the same since enrollment in the CRP. If no damage had been experienced, the interview was concluded. If damage had been experienced, respondents were asked if they had attempted to control the damage either by themselves or with the aid of outside assistance. Respondents were then asked if wildlife damage by species that they felt had increased due to CRP was severe enough to preclude enrollment in similar programs in the future. If respondents answered yes to this question, they were asked if compensation would be required for future participation and the amount of compensation in dollars per acre that would be needed.

All respondents who had experienced wildlife damage on their farm or ranch were asked if they allowed hunting or trapping on their CRP lands by individuals other than immediate family members. If the answer was yes, respondents were then asked if they leased any of their CRP lands for hunting or trapping. All respondents experiencing wildlife damage were asked if increased hunting or trapping would reduce the amount of damage

occurring on their farm or ranch. Lastly, respondents experiencing damage were asked if the CRP was a beneficial program and if the benefits derived from the program (if any) exceeded costs involved with wildlife damage. The age of each respondent was also recorded. Differences in responses to yes-no questions were tested using chi-square goodness-of-fit tests. Differences were considered significant at  $P < 0.05$ .

## RESULTS

Total farm or ranch area averaged 263.5 ha, while area of individual CRP contracts averaged 31.8 ha

(Table 1). Mean, maximum, and minimum areas for the land use categories listed above are found in Table 1.

The mean age of contract holders was 56, and most of these individuals (80%) classified themselves as owner and operator of their farm or ranch (Table 2). Significant differences did not exist in the number of individuals experiencing wildlife damage (64%) and those not experiencing damage (36%) ( $X^2 = 1.96$ , 1 df,  $P > 0.05$ ). Respondents experiencing damage mentioned white-tailed deer as the most frequently encountered damaging species (43.3%) followed by beaver (*Castor canadensis*) (13.3%). Damaging species are listed in Table 3.

Table 1. Land use categories and areas in hectares on farms and ranches surveyed.

Cover Type	Mean	Minimum	Maximum
Total area	263.5	8.5	849.9
CRP	31.8	1.6	113.3
Cultivated	80.0	0.0	404.7
Pasture/Hayland	133.1	0.0	453.7
Wooded area	8.6	0.0	60.7
Feedlots	0.9	0.0	8.1

Table 2. Ownership and residency patterns of Riley County CRP contract holders.

Type of Ownership	N	Percent
Owner/operator	20	80.0
Absentee	3	12.0
Renter/operator	2	8.0

Table 3. Species that CRP contract holders felt were responsible for damage on their farm or ranch.

Species	Number of Complaints
White-tailed deer	13
Beaver	4
Wild turkey	3
Eastern cottontail	2
Opossum	2
Striped skunk	2
Eastern woodrat	1
Raccoon	1
Red-headed woodpecker	1
Tree squirrel	1

Damaging species which respondents felt had become more common since enrollment in the CRP included white-tailed deer (64.3% of all responses), wild turkey (14.3%), eastern cottontail (7.1%), striped skunk (7.1%), and Virginia opossum (7.1%) (Table 4). Only two respondents (12.5%) had attempted to control wildlife damage, and none of the respondents sought outside assistance for their wildlife damage problems. In addition, none of the respondents experiencing damage felt that the damage was severe enough to preclude future enrollment in programs such as the CRP, and none felt that compensation for damage received was necessary.

The majority of respondents (68.8%) allowed hunting or trapping by individuals other than immediate family members on their land, but this number did not differ

significantly from the number of individuals who did not allow hunting ( $X^2 = 2.25$ , 1 df,  $P > 0.05$ ). The proportion of individuals who did not lease their CRP lands for hunting or trapping purposes (87.5%) was significantly greater than the proportion who did lease their lands for these purposes ( $X^2 = 9$ , 1 df,  $P < 0.05$ ). None of the respondents surveyed felt that increased hunting or trapping on their CRP lands would reduce the amount of wildlife damage that they experienced.

Respondents who had experienced wildlife damage were still very satisfied with the CRP. All respondents felt that the benefits provided by the CRP exceeded the costs associated with wildlife damage. Additionally, all respondents (including those who had not experienced wildlife damage) felt that the CRP was a beneficial program.

Table 4. Damaging species that CRP contract holders believed to be more common due to enrollment in the CRP.

Species	Number of Complaints
White-tailed deer	9
Wild turkey	2
Eastern cottontail	1
Opossum	1
Striped skunk	1

## DISCUSSION

Results of this survey indicate that CRP contract holders in Riley County, Kansas, experience relatively low levels of wildlife damage. Although the sample size was small, damage complaints were much lower than those recorded in other studies (Conover 1994; Diebel et al. 1993), where up to 89% of the respondents surveyed reported wildlife damage and 53% stated that losses due to wildlife exceeded their tolerance (Conover 1994).

Results from this study closely parallel the statewide survey of CRP contract holders conducted by Diebel et al. (1993). Diebel et al. (1993) reported that in the northeast Kansas crop reporting district (which includes Riley County), 62.5% of all respondents reported that white-tailed deer had increased due to CRP, which is very close to the 64.2% recorded in this study. Diebel et al. (1993) reported that statewide 70.8% of all respondents were owner and operator of their farm, while this study found that 80% of all respondents were in this category. This difference may simply be due to regional differences in ownership patterns, as ownership patterns by crop reporting district were not reported by Diebel et al. Evidence that owner/operators were less tolerant of wildlife damage than absentee landowners or renter/operators, as noted by Kellert (1981) and Conover (1994), was not apparent in this study.

Although slightly more than half of the respondents reported damage by wild animals, this damage was not severe enough to initiate damage control efforts by the

majority of respondents (87.5%). Interestingly, none of the respondents who experienced damage from wild animals and felt that damage had increased as a result of the CRP felt that increased hunting would reduce the amount of damage. This is in contrast to the findings of McIvor and Conover (1994), where 54.5% of farmers and 45.9% of non-farmers in Wyoming and Utah felt that hunting helped reduce damage by wild animals. Although white-tailed deer were the most frequently mentioned damaging species (43.3% of all complaints) and most respondents (64.2%) felt that they had become more common due to the CRP, the species appeared to be much less of a problem than in other studies (Conover 1994; Conover and Decker 1991). Somewhat surprisingly, coyotes (*Canis latrans*), a frequently-cited damaging species in Kansas in the past (Gier 1968), were not mentioned by any of the respondents in this study. This finding may be due to changes in the agricultural landscape in northeastern Kansas which has altered coyote food habits in the region (Gipson and Brillhart 1995).

While wildlife management plans on private lands should address the possibility of increased wildlife damage (Berryman 1983; Conover 1994; Wade 1987), in some instances the creation of additional wildlife habitat has not greatly increased wildlife damage on private lands. This appears to be the case in this study. Future acceptance of land set-aside programs such as the CRP that create additional wildlife habitat depends on many factors, including the amount of wildlife damage that

agricultural producers are willing to tolerate. While in localized situations wildlife damage attributable to such programs may be relatively minor, wildlife managers must take into consideration costs incurred by individuals whose losses may exceed the average losses of a community at large (Wade 1987). Without such consideration, wildlife management decisions may generate controversy when agricultural producers feel that their needs are not being met (Conover and Decker 1991). Agricultural producers remain a vital component of wildlife conservation in the United States, and their input must be appreciated if habitat improvement programs on private lands such as the CRP are to be successful.

#### ACKNOWLEDGMENTS

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# THE WASHINGTON ADCP—A PRIVATE COLLABORATIVE EFFORT TO ADDRESS BIOLOGICAL, ECONOMICAL AND SOCIAL CONSTRAINTS TO REDUCE WILDLIFE DAMAGE

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**ABSTRACT:** The Washington Animal Damage Control Program (WADCP) operates within the general structure of the Washington Forest Protection Association. The general goal of the WADCP is to resolve wildlife damage issues in an economically feasible and socially acceptable manner. The four components of the WADCP are program management and administration; support of individual member activities; research, monitoring, and surveys; and promotional and educational activities. An overview of each of these components is provided.

**KEY WORDS:** animal damage, collaborative management, forest, Washington Animal Damage Control Program

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## INTRODUCTION

The Washington Forest Protection Association (WFPA) was founded in 1908, originally as an organization to protect private forest from fires. At present, the WFPA works with and represents the interest of private landowners in the areas of forest taxation and economics, land use, environmental affairs, communication, educational activities, and forest policy. WFPA members represent a combined land base of nearly 5 million acres.

An increasing need to protect forest resources from animal damage led to the formation of the Washington Animal Damage Control Program (WADCP) within the general structure of the WFPA in 1959. The principal objective of the WADCP is to work with participating landowners to reduce spring black bear (*Ursus americanus*) damage to timber stands of Douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and western redcedar (*Thuja plicata*). The WADCP, however, also provides expertise and technical assistance in damage management for a broad range of wildlife species including beaver (*Castor canadensis*), mountain beaver (*Aplodontia rufa*), porcupine (*Erethizon dorsatum*), ungulates (*Cervus* and *Odocoileus* spp.), and other wildlife species.

The general goal of the WADCP is to resolve animal damage issues in an economically feasible and socially acceptable manner. The program had 37 participants during 1995, with a total land base of more than 3.4 million acres of forest. Participants ranged from small private landowners to large forest management companies, two Indian Nations, forestry consulting firms, city watersheds, and three major landowners in the neighboring state of Oregon.

Success of the WADCP depends on four equally important components: 1) program management and administration; 2) support of individual member activities; 3) research, monitoring, and surveys; and 4) promotional and educational activities.

## PROGRAM MANAGEMENT AND ADMINISTRATION

A wildlife biologist manages the WADCP and serves as staff biologist for the WFPA. Three temporary employees assist the biologist.

WADCP participants derive damage management strategies as a group. This permits landowners and managers to support each other's activities, as well as to address public concerns with a common voice. An elected committee provides direction, advice and support for the program. An ongoing exchange of information among participants is facilitated by the supervisor through telephone conferences, monthly and annual reports, and annual group meetings.

Financial support for the program is provided by members. The assessment strategy reflects a set membership fee along with a charge per acre. The 1995 assessment was \$0.0165625 per acre. Budget and assessment strategies are evaluated and adjusted periodically by the full membership. Costs are kept low by operating with minimum staff and using temporary employees during periods of high activity. Landowners also provide financial support for direct control measures. For example, the WADCP supervises the establishment, maintenance, and stocking of bear feeders, but the purchase cost of feeders, food pellets, and labor is covered by the individual landowner.

The WADCP supervisor actively recruits new members to retain the vitality of the program. Non-member landowners are contacted when damage is reported by neighbors or identified through annual surveys. Control specialists present information on the WADCP and alternative management options, as well as spend time in the field with landowners to develop specific approaches that fit within their individual forest management practices.

The WADCP maintains a working relationship with the Washington Department of Fish and Wildlife (WDFW) and the Washington Fish and Wildlife

Commission. These regulatory agencies are kept aware of land managers' concerns, long-term forest management objectives and preventive control measures. A cooperative approach to develop wildlife damage management strategies enhances the effectiveness of the program. The necessity of minimizing negative impacts on wildlife is appreciated by the WADCP. Similarly, the WFPA believes that an awareness of their concerns and operations helps regulatory agencies to recognize the need for lethal removal of some problem animals.

The WADCP also addresses policy issues and helps to develop proposed legislation and regulations. The group provides information and presents testimony to the legislature, commissions and regulatory agencies. These efforts provide the landowners a voice in decisions that impact animal damage control measures. For example, the WADCP negotiated for over two years with several working groups in Washington to develop new proposals to resolve conflicts between wildlife and timber management. The resultant proposed law will provide landowners a faster and more efficient response to nuisance animals that impact public health or safety, or damage to commercial resources.

#### **SUPPORT OF INDIVIDUAL MEMBER ACTIVITY**

Participants' timber stands are monitored for animal damage by aerial surveys in the spring. The WADCP maps areas with dead or physiologically stressed trees. Later these areas are ground-proofed to establish cause of injury or death. Ground-proofing generally reveals greater numbers of damaged trees than can be spotted from the air. Damage management strategies are discussed with the landowner once the cause and extent of the problem has been identified.

When bears inflict damage to forest resources the supplemental feeding program is the preferred management choice of the WADCP. The program was initiated in 1985 and has proven to be an effective tool to reduce bear damage to timber stands. Initial concerns that bears would become dependent on the feeders have not been validated. Bears naturally wean themselves from the supplemental feed as they revert to natural forage, such as berries when they become available. The WADCP managed 610 feeding stations and delivered 357,150 pounds of pellets throughout Washington during 1995. Oregon participants in the program established an additional 90 feeding stations and used 60,850 pounds of pellets.

Occasionally, a bear fails to adjust to the feeding stations and continues to strip trees. Such animals are generally removed to another location or euthanatized if necessary. The established working relationship with WDFW enables the ADCP to quickly obtain appropriate permits and respond to problem animals. Most population management is accomplished sufficiently by sport hunters during the regular hunting seasons from August through

October, and forest damage management programs can focus on the behavior of individual animals.

#### **RESEARCH, MONITORING, AND SURVEYS**

Alternative wildlife management strategies need to be developed and existing approaches continually improved. The WADCP actively supports black bear research in cooperation with federal and state agencies, as well as universities. The WADCP has collaborated with the WDFW to develop indirect population measures to determine bear densities in a game management unit in the Cascade Mountains. The WADCP has also cooperated with the WDFW to investigate black bear habitat requirements in managed forests. University students interested in wildlife damage management have received either direct or indirect support from the WADCP. Currently, the WADCP is working with the USDA/APHIS/ADC/Denver Wildlife Research Center (DWRC) to improve the understanding of bear damage management in timber. One study will assess the efficacy of the supplemental feeding program and its limitations, while another study will determine the forage selection criteria of bears.

The WADCP has assisted in developing mechanisms for private timber interests to have an ongoing dialogue with producers and forest damage researchers. The Collaborative Research Team (CRT) was established as an informal group to assess research needs among a diverse array of federal, state, and private managers in Washington and Oregon. The CRT works closely with the Denver Wildlife Research Center staff in its Forest Animal Damage Project to suggest areas of forest animal damage that are need of research.

#### **PROMOTIONAL AND EDUCATIONAL ACTIVITIES**

The WADCP recognizes public interest in wildlife and the need for public support to maintain damage control programs. Ignoring public opinion could lead to changes in regulations or laws, as well as the general political climate towards how landowners can prevent wildlife from damaging private property.

The WADCP works to educate its members and the public on the problems they encounter with wildlife and on the available methods to alleviate these problems. Presentations are given to interested groups, such as professional societies, regulatory agencies, hunting clubs, and schools. Media coverage of program activities is encouraged. Newspaper, radio and television reporters are invited to observe the severity of animal damage with the WADCP team in the field. The supplemental feeding program for managing bear damage is demonstrated and conflict solutions and damage management options are discussed. A balanced approach to bear damage management, focusing on the bear supplemental feeding program has been favorably received by the public.



# IMPACTS OF A DAILY TRAP CHECK LAW ON THE CALIFORNIA ADC PROGRAM

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**ABSTRACT:** Effective January 1, 1990 California law required that all steel-jawed leghold traps be inspected at least daily and all animals in such traps be removed. The inspection and removal could be performed by the individual who set the traps, the landowner, or an agent of either. Prior to the passage of this law, California Animal Damage Control (ADC) personnel were exempt from Department of Fish and Game trap checking regulations. The data suggest that a decrease in trap use occurred after the implementation of the daily trap check. Where the program could effectively substitute other control tools or methods for the leghold trap, impacts to cooperators serviced and coyotes taken per unit of effort were minimal.

**KEY WORDS:** efficacy, leghold traps, vertebrate pest control

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## INTRODUCTION

Public concerns about animal welfare, animal rights, and wildlife as a public resource have increased scrutiny of the methods and strategies used by the Federal ADC program to control wildlife damage. Various attempts have been made, in a number of states in recent years, to ban leghold traps, or require modifications to the basic trap or the way it is used, in order to make the device more "humane." The amount of time that a captured animal spends in a trap, or other type of restraining device, is considered a humaneness issue by some animal welfare organizations. Some members of the public feel traps and other restraining devices should be checked twice a day while others feel twice a week is adequate. What is economically feasible may differ from the public's perception of "humane."

The mission of the ADC program is to provide Federal leadership in resolving problems caused by wildlife. The ADC program strives to develop and use wildlife damage management strategies that are biologically, environmentally, and socially sound. In many cases the ADC program is faced with difficult decisions related to delivering a cost-effective program versus adopting control tools or strategies considered to be more humane, but more expensive to implement. Program funding frequently influences the outcome of these decisions.

On March 1, 1989 California Senator Milton Marks introduced Senate Bill 756 in the Legislature. As originally written the bill would have prohibited the use of all steel-jawed leghold traps. However, after hearings and numerous amendments in both the Senate and Assembly, the final bill allowed for the use of steel-jawed leghold traps with a specific provision that required daily inspection. Allowances were made for property owners or their agents to assist in the checking of traps placed by government personnel. On September 6, 1989 SB-756 was passed by the Legislature, on September 27, 1989 it was signed into law. This statute became effective January 1, 1990.

Another major change in California trapping regulations occurred in the 1991-1992 trapping year. To

reduce potentially adverse impacts on endangered species, the Department of Fish and Game modified its trapping regulations to require that commercial and recreational trappers use padded-jaw traps statewide. The new regulations also prohibited the use of conibear type traps, snares, and deadfall traps in the ranges of the San Joaquin kit fox (*Vulpes macrotis*) and the Sierra Nevada red fox (*Vulpes vulpes*). In 1992-93, the regulations were further modified to allow the use of un-padded leghold traps, for certain aquatic sets, outside the fox protection zones (Figure 1). Although it was legally exempt from these



Figure 1. Fox protection zones.



restrictions, the California ADC program implemented the use of padded-jaw traps in the ranges of both fox species, on October 1, 1991. EPA use restrictions, and California ADC policy, already in place at the time, prohibited ADC program personnel from using M-44's or neck snares in the range of the San Joaquin kit fox. Impacts of these regulation changes are not considered in this analysis with the exception of a discussion on how the program could not adapt other control methods in the fox protection zones.

The purpose of this paper is to evaluate some of the impacts of SB-756 on the California ADC program, specifically impacts to the program's ability to mitigate problems associated with coyote depredation on livestock.

## METHODS

Data from the Management Information System (MIS) were used to analyze the impact of SB-756 on the California ADC program (Blaney 1990). The MIS system has been functional in California since August 1980 and stores a variety of information on program activities such as number of properties worked, time spent on these properties, status of these lands (Federal, State, private, etc.), confirmed and reported damage, control tools placed or removed, numbers and species of animals taken, and control recommendations made to landowners by ADC personnel.

In preparing this paper, data were selected from counties in which ADC historically has done the most coyote damage control work. Specific data sets examined coyotes taken by method, the number of rural cooperators serviced, the staff time spent on each of these cooperators, and numbers of coyotes taken per staff day or month.

### Impacts on Coyotes Taken by Method

Two sets of data were analyzed to evaluate the impact of SB-756 on the number of coyotes taken by method. One set consisted of statewide data on annual coyote take by method for fiscal years 1985 to 1995. The other set, a subset of the statewide data, consisted of information from 25 rural counties where ADC funding and manpower were relatively constant during the years analyzed. Data from FY 1990 were not evaluated as that was the year of transition to the daily trap check which began one-fourth of the way through the fiscal year.

### Program Delivery

A theoretical analysis was performed on the impact to the number of rural cooperators that could be provided trapping service and the number of trap service nights<sup>1</sup> that could be provided, in changing from a twice a week check to a daily check. Three was arbitrarily selected, for the purpose of this analysis, as the average number of rural properties a single ADC specialist could service with leghold traps in one day.

An actual analysis of the impact of SB-756 on the number of rural cooperators provided service, and the average number of staff days provided to each, was done

using a separate subset of 20 counties. Fiscal years 1988, 1989, 1991, 1992 and 1993 were evaluated. These 20 counties were selected on the basis of program type (emphasis on coyote control) and the continuity of the program during the period of time analyzed.

### Coyotes Taken Per Staff Day or Staff Month

Two subsets of counties were analyzed to see if there was any difference in the number of coyotes taken per unit of effort before and after SB-756. One subset consisted of 20 counties where the time evaluated was that which was spent on properties with cattle or sheep listed as a resource. The other subset consisted of 25 counties where the majority of time recorded was spent protecting livestock, primarily sheep and cattle, from coyote depredation.

## RESULTS

### Coyotes Taken by Method

Table 1 shows the take of coyotes in the state from fiscal years 1985 to 1995 by each of six methods: M-44's, leghold traps, neck snares, denning/dogs, calling/shooting, and aerial hunting. During the five years preceding passage of SB-756, the California ADC program averaged taking 4,009, or 51% of its coyotes, per year, in leghold traps. During the five years following passage, the average take was 1,923, or 30%, per year. Thus, the average annual coyote take in leghold traps decreased 52%. Average statewide coyote take per year by all methods was 7,890 during the five years preceding passage of SB-756 and 6,495 during the five years following.

A further analysis was conducted on a subset of 25 counties considered to be rural. This analysis considered the two years preceding the passage of SB-756 and the three years following, excluding FY 1990. The average number of coyotes taken in leghold traps during the two years preceding SB-756 was 3,101 per year and the three years following was 1,356 per year, a decline of 56%.

### Impacts on Program Delivery

Figures 2 and 3 depict a hypothetical model which illustrates the expected magnitude of decreased trap service nights and cooperators serviced in going from a biweekly trap check to a daily trap check. Figure 3 indicates the results if cooperators were not allowed to assist with trap checking and specialists did not work on weekends. Traps would have to be covered or sprung on Friday and reset on Monday. Using the scenario prior to the passage of SB-756 (Figure 2), one specialist could provide 42 trap service nights to six cooperators per week. Following passage of SB-756 the same specialist could provide 12 trap service nights to three cooperators (Figure 3). This would represent a 71% decrease in the number of trap service nights provided and a 50% decrease in cooperators that were provided trap service.

Figure 4 indicates the average number of staff days spent on each rural cooperator, per year, in 20 agricultural counties for FY 1988, 1989, 1991, 1992, and 1993. The data indicates a gradual decrease in this average over a five year period. The number of cooperators provided service also decreased slightly during this period. When only the year before passage of

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<sup>1</sup>Trap service night is defined as a night with any number of traps on a cooperator's property.

Table 1. Coyotes taken by method, statewide, fiscal years 1985 to 1995

FY	Neck Snares	Denning/ Dogs	M-44	Calling/ Shooting	Leghold Traps	Aerial Hunting	Total
1985	496	554	451	1686	4390	787	8364
1986	485	639	754	1488	3835	274	7475
1987	582	625	877	1707	4069	0	7860
1988	717	701	638	1865	4075	0	7996
1989	687	679	1107	1510	3677	94	7754
1990	710	933	1539	1826	2708	68	7784
1991	616	914	1908	2108	1910	100	7556
1992	539	401	1251	1435	1746	76	5661
1993	547	731	1061	642	1021	231	4834
1994	487	731	1615	515	567	1392	6750
1995	576	567	1463	1317	436	1635	7675

## TRAP SERVICE SCENARIO

Prior To SB-756

Ranch	Sun	Mon	Tues	Wed	Thurs	Fri	Sat
1		x		x		x	
2		x		x		x	
3		x		x		x	
4			x		x		
5			x		x		
6			x		x		

"x" indicates traps set / checked

42 trap service nights to 6 cooperators per week

■ trap service night

## TRAP SERVICE SCENARIO

Following SB-756

Ranch	Sun	Mon	Tues	Wed	Thur	Fri	Sat
1		x	x	x	x		
2		x	x	x	x		
3		x	x	x	x		

"x" indicates traps set / checked

12 trap service nights to 3 cooperators per week

■ trap service night

Figure 2. Trap service nights and number of cooperators served prior to SB-756.

Figure 3. Trap service nights and number of cooperators serviced following SB-756.

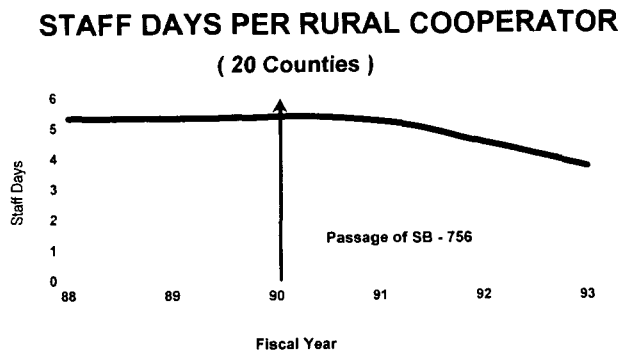


Figure 4. Staff days per rural cooperator.

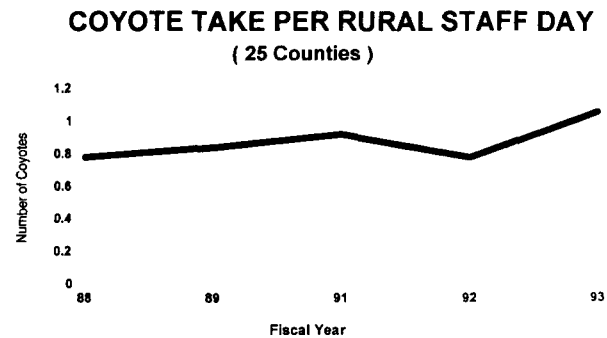


Figure 5. Coyote take per rural staff day FY 1988, 1989, 1991, 1992, and 1993.

SB-756 and the year after are examined, the average number of staff days spent on each rural cooperator and the number of cooperators serviced only slightly changed, 5.4 to 5.3 and 1,304 to 1,324.

#### Coyotes Taken Per Staff Day or Staff Month

Figure 5 indicates the total coyote take per staff day in a set of 25 rural counties during fiscal years 1988 to 1993. With the exception of FY 1992, these data suggest a gradual increase. Closer examination of the data used to generate this figure revealed a large increase in M-44 take during FY 1988, 1989 and 1991. It also revealed increases in the calling/shooting take and denning/dog take from FY 1989 to FY 1991. Neck snare and leghold trap take decreased between FY 1989 and 1991. It appears that the increased take with M-44's, calling/shooting, and denning/dogs, resulted in an analogous increase in the coyote capture/take rate per unit of effort. Another possibility would be that there were more coyotes to capture/take. The author considers this to be unlikely.

A second subset of data were evaluated in 20 counties where all of the staff time analyzed was spent on properties where sheep or cattle were listed as a resource. The total number of coyotes taken per staff month increased from 23 in FY 1989 to 29 in FY 1992, a 26% increase.

These data also suggest an increase in the number of coyotes captured/taken per unit of effort after passage of SB-756. A closer examination showed an increase in the number of coyotes taken per unit of effort in 12 of the 20 counties evaluated. In six of the eight counties where the number of coyotes taken per unit of effort decreased, a portion of the county was located in San Joaquin kit fox range.

#### **DISCUSSION**

Although reliable data were not available on numbers of leghold traps placed or removed before or after passage of SB-756, the author believes fewer were placed after implementation of SB-756. There is no reason to believe that the decrease in coyotes caught in leghold traps could be attributed to anything other than less trap use.

The decrease in the total number of coyotes taken, statewide, by all methods in fiscal years 1992 and 1993 can be attributed to a number of factors such as decreases in staffing, due to a state budget reduction, the daily trap check, decreases in certain resources protected (specifically sheep), and changes in program emphasis. Most of the increase in fiscal years 1994 and 1995 can be attributed to an expansion of the aerial hunting program.

These data suggest that the number of rural cooperators serviced and the number of staff days spent on each cooperator, were insignificantly affected by SB-756. A logical explanation for this would be that either the program was able to compensate for decreased trap service nights with other tools and methods, or cooperators assisted enough with trap checking to make the impacts to program delivery undetectable. It was probably a combination of both. The gradual decrease in staff days provided to cooperators in FY 1992 and 1993 (Figure 4) can be explained mostly by decreases in staffing.

These data suggest that in areas where the program could not substitute other methods such as dogs/denning, calling/shooting, or M-44's for the leghold trap, the coyote take per unit of effort decreased. To program managers and cooperators these data imply that significant impacts could be expected to program effectiveness in areas occupied by endangered species that could be taken by alternate methods when the use of traps is restricted. These same impacts would be expected on some public lands where the use of control tools such as the M-44 are restricted.

SB-756 provided that cooperators could assist ADC personnel with the checking of traps. In theory, if cooperators could provide the additional manpower necessary to check traps in between ADC program checks, there would be few impacts in going from a twice a week check to a daily check. In reality there are other impacts.

The California ADC program, in response to SB-756, has developed what is called a trap liability form. A cooperator may sign one of these forms and agree to check equipment on certain days of the week. Many cooperators do not wish the responsibility of signing the

form, but are willing to assist ADC. The number of cooperators who have actually signed trap liability forms during the last six years was not available.

There are some problems with this system. In several cases cooperators agreed to check traps on specific days but did not. When specialists questioned cooperators, and mentioned what could happen to him/her if the traps were not checked, the cooperator got angry. He/she was willing to help but did not want to be called on the carpet when other responsibilities took precedence. This caused a deterioration in cooperator-specialist relations. More seriously, in one case that the author is aware of, an ADC specialist was almost arrested because a cooperator did not check the traps as agreed and a domestic dog was restrained for a few days.

Many cooperators, at least initially, are willing to help ADC personnel check equipment. In some cases "too" much assistance was provided and traps were checked two to three times a day. Some cooperators will try to reset equipment without proper training or experience and in doing so will "educate" some coyotes or cause the capture of a non-target. Other cooperators are only willing to check equipment and then let the specialist know if a trap has been sprung or an animal captured. Delays in notification about sprung traps or captured animals can cause decreased effectiveness as well as additional trauma for captured animals. If cooperators are not furnished with proper training on release techniques for various non-targets they can become frustrated and kill the animal rather than trying to release it. ADC personnel routinely release non-target animals, but many cooperators have different feelings about what should be considered non-target and will kill animals that ADC personnel would have released.

ADC program costs to furnish cooperators with proper training and adequate release methods can be substantial. A good catch pole, which can be used to release most non-targets, averages \$80.00. The cost to equip each cooperator with a catch pole would be prohibitive in a program as large as California's.

Many specialists in the California program felt that an increased human presence around traps, due to daily checking, would decrease their effectiveness. An analysis of this impact would be interesting, but beyond the scope

of this paper. Such an impact might be offset, in part, by the increased attentiveness resulting in traps being functional for a higher percentage of the time, and therefore taking more target animals. This might be the case in areas where you have a lot of human activity and the coyotes are not affected by it, or in areas where you have a lot of trap interference from non-targets. The author believes that in the more rural areas of California the increased activity probably has a negative effect.

Some people would like to ban the use of leghold traps. Others feel that if the leghold trap is going to be used it should be used as humanely as possible. Many seem to support the use of padded-jaw traps. The ADC program has stated in its "Code of Ethics" that it will support the use of the most humane, selective, and effective control techniques in carrying out its mission. Sometimes the most selective or effective control methods are not necessarily the most humane. As was stated earlier in this paper, ADC program managers have to make difficult decisions when trying to balance cost effectiveness against humaneness. As was also stated earlier, funding has a major bearing in these decisions.

When the public insists, through legislation or the initiative process, that wildlife damage management be conducted using less effective or more expensive control methods or strategies, it would seem logical that some type of compensation be paid either to those trying to mitigate the wildlife damage or to the resource owners experiencing the damage.

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# NORWAY RAT INFESTATION OF URBAN LANDSCAPING AND PREVENTATIVE DESIGN CRITERIA

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**ABSTRACT:** Fifty-four landscaped areas in downtown Boston were surveyed for Norway rat (*Rattus norvegicus*) activity. Each location also was characterized based on size, types of plantings, density of plantings, type of mulch, and sanitary and maintenance conditions. Factors most associated with the presence of rats were dense contiguous stands of shrubbery (e.g., needled evergreens) and refuse/litter availability on the ground. Design criteria should include effective spacing of shrubbery, limiting mass plantings of dense shrubs, selection of plant varieties that grow with openness underneath, strategically-placed and rodent-proof refuse containers, and use of crushed-stone inspection strips. Rodent control should be considered when landscapes are designed, and proper maintenance of landscaped areas should be part of urban rodent control programs.

**KEY WORDS:** vertebrate pest control, urban rat control, habitat management

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## INTRODUCTION

Urban rodent problems exist because people provide resources that rats require to successfully colonize and sustain their populations. However, through effective planning, it should be possible to create and manage environments so that resources needed by rats are limited or not ideally provided. This would require shifting emphasis from a reactionary (poisoning/trapping) approach typically found in urban areas to a preventative rodent control strategy.

In highly urbanized areas, where asphalt and concrete environments prevail, landscaping can be a particularly attractive and prized resource for Norway rats (*Rattus norvegicus*) because soil in which to burrow is often a limiting factor. Additionally, many urban landscapes are located in and around where people congregate, thereby combining soil and plantings (harborage) with food resources (refuse, food litter). As a result, urban landscaping can become chronically infested or re-infested within a few days after poisoning.

Urban landscapes that serve as rat habitat can vary widely in size and complexity. They can include small planters with flowers near public sitting areas, "islands" of ground covers and shrubbery at entrances to commercial or government buildings, and parks with extensive plantings and shrubbery. In each situation, rats can pose public health and serious aesthetic problems. The impact of these problems is not only at the particular property that is rat infested; rats may use the landscaping on one property for burrowing while feeding on adjacent properties. They may also use landscaped areas as breeding sites, thus resulting in potential impacts to abutting properties and neighborhoods as young disperse.

As part of an integrated pest management (IPM) program in Boston (Colvin et al. 1990), downtown properties were surveyed for Norway rats. Because rats were frequently observed within landscaped areas, landscape features were further evaluated in an attempt to establish long-term population reduction through habitat alteration. The purpose of this paper is to describe those observations and design criteria that resulted.

## METHODS

During 1992 to 1995, standardized urban rat surveys were conducted on more than 650 land parcels (2,700 addresses) in downtown Boston within the commercial/financial district. This area is highly urbanized and includes businesses, restaurants, hotels, apartment buildings, and residences on the upper floors of commercial buildings.

Subsequently, 54 landscaped areas (34 with rats) identified in the original survey were re-evaluated in detail, and the following features were characterized: types of shrubs, ground covers, trees; size and slope of the area; dimensions of contiguous stands of shrubbery; average height of shrubbery; spacing of shrubbery (random, linear, patch); visibility underneath shrubbery from horizontal view (ranked 1 low to 5 high); percent of ground covered by shrubbery when viewed from above; proximity of shrubbery and ground covers to walls; shrub limbs touching walls (ranked 1 low to 5 high); quality of landscape (plant) maintenance (ranked 1 low to 5 high); presence of fruit/seed from plantings; type and amount of soil cover (bark mulch, crushed stone, weeds, grass, bare soil); number, type, and height of refuse containers; easy accessibility of refuse containers based on a 45 cm distance between the container and any surface from which a rat could jump; proximity to eating locations, food vendor (e.g., restaurant, market, push cart), and refuse storage areas; and overall presence and accessibility of food within 23 and 46 m.

Each landscaped area also was assigned an index value to characterize rat activity based on the number of burrows and persistence of infestation. Activity indices ranged from 1 = none to 5 = high, and the shrub species closest to the rat burrows was noted. Light was measured 8 cm above the soil next to the burrow entrance using a hand-held camera light meter; for plots without rats, light was similarly measured where the densest shade occurred. To help assess the food value of plant materials, fruits and seeds found within various landscapes were examined for signs of rat feeding.

In addition to field surveys, pen trials were used to

help evaluate the depth of crushed stone necessary to limit rat burrowing. These trials were conducted outside in a 1.5 x 1 x 0.6 m plastic (oval) arena using 19 mm (3/4 inch) stone placed at a depth of 30 cm. Fifteen rats (5 male, 10 female), locally trapped and with water and food provided *ad libitum*, were individually placed in the arena; their excavation performance was documented after 48 hours.

## RESULTS

Among the 1,141 shrubs found within the 54 plots examined, rat burrows were associated with needled evergreens such as yew (*Taxus* spp.) more often than broad-leaf evergreen and deciduous plants (Chi-square 13.18,  $P < 0.001$ ); the low relative abundance of juniper (a needled evergreen) among plots, in contrast to its high association with rat burrows, suggests preference by rats for that type of plant structure (Table 1). In contrast, there was no association between rats and the presence of ground cover plantings such as English ivy (*Hedera helix*), wintercreeper (*Euonymus fortunei*), and pachysandra (*Pachysandra terminalis*) (Chi-square = 0.16,  $P > 0.05$ ).

The proportion of the plot covered by shrub canopy was the landscape characteristic most associated with the presence of rats (Table 2). Other important variables included low visibility into shrubbery from side view,

high number of shrubs per plot, limbs touching the ground, large contiguous shrub stands, and lack of plant maintenance; shrubbery touching walls appeared important in the field and showed a trend towards statistical significance when tested. The size of the landscaped plot (soil area) was not significantly associated with the presence of rats (Table 3), and there was no significant difference between light intensity by burrow entrances and the shadiest location within landscapes that were not rat infested (Table 2). The primary landscape feature for cueing rat infestation appeared to be the density and contiguous area of shrubbery within the plot.

The amount of litter and the overall presence of food among all refuse sources (bird food, dumpsters, plastic bags on sidewalks for collection, refuse containers, food from homeless people) were strongly associated with the presence of rats (Table 3). Landscapes with dense stands of shrubs readily trapped litter, likely contributing to their infestation.

Among the landscapes, 33% had accessible stored refuse within 23 m, and 44% had accessible stored refuse within 46 m ( $n = 48$ ); however, there was not a significant difference in this regard between rat and no-rat plots (Table 2). Additionally, within 46 m, there were no significant differences in the number, height, or accessibility of refuse containers between plots with and without rats. Thus, stored refuse did not appear to be a

Table 1. Shrubby and associated rat activity within landscaped plots in downtown Boston.

Shrub ( <i>genus</i> )	Relative abundance ( $n = 1,141$ )	Plots where found ( $n = 54$ )	Plots with rats ( $n = 34$ )
Yew ( <i>Taxus</i> )	58%	50%	56%
Juniper ( <i>Juniper</i> )	8%	20%	55%
Rhododendron ( <i>Rhododendron</i> )	5%	19%	0%
Euonymus ( <i>Euonymus</i> )	4%	11%	0%
Boxwood ( <i>Buxus</i> )	5%	6%	0%
Azalea ( <i>Rhododendron</i> )	1%	6%	0%
Rose ( <i>Rosa</i> )	11%	4%	(1 of 2)
Holly ( <i>Ilex</i> )	< 1%	2%	(1 of 1)
Other*	8%	19%	0%

\*Includes mugo pine (*Pinus*), cotoneaster (*Cotoneaster*), arborvitae (*Thuja*), barberry (*Berberis*), and unidentified deciduous shrubs.

Table 2. Comparison of mean values for shrubbery, sanitary conditions, and other landscape elements between landscaped plots with and without Norway rats in downtown Boston.

Variable	Mean (n)		Test Statistic	P
	Rat	No-rat		
Plot coverage by shrubs - percent	48.4 (23)	16.3 (49)	4.901 <sup>a</sup>	<0.001
Number of shrubs	26.2 (23)	10.1 (49)	3.241 <sup>a</sup>	<0.01
Shrub visibility from side - 1 low, 5 high	1.7 (23)	2.8 (45)	3.124 <sup>a</sup>	<0.01
Limbs touching ground - 1 low, 5 high	3.0 (23)	2.1 (45)	2.499 <sup>a</sup>	<0.05
Area of contiguous shrub stand (m <sup>2</sup> )	81 (18)	40 (13)	2.122 <sup>a</sup>	<0.05
Perimeter length (m), contiguous shrub stand	28.6 (18)	15.2 (13)	2.042 <sup>a</sup>	<0.05
Shrubbery touching walls - 1 low, 5 high	2.6 (23)	1.6 (45)	1.553 <sup>a</sup>	>0.05
Shrub height (cm)	63.2 (23)	74.7 (45)	0.456 <sup>a</sup>	>0.05
Shrubbery distance to walls (m)	2.4 (21)	1.5 (39)	0.063 <sup>a</sup>	>0.05
Distance to nearest benching (m)	3.8 (26)	6.1 (19)	0.151 <sup>a</sup>	>0.05
Height of shortest refuse container within 46 m (cm)	75 (16)	72 (16)	1.492 <sup>a</sup>	>0.05
Distance to food vendors within 23 m	16.5 (14)	15.8 (7)	0.525 <sup>a</sup>	>0.05
No. accessible refuse sites (containers, dumpsters, bags) within 23 m	0.93 (28)	0.80 (20)	0.221 <sup>a</sup>	>0.05
Jump distance to access refuse containers (cm)	54 (16)	56 (16)	0.038 <sup>a</sup>	>0.05
No. public refuse containers $\leq$ 0.9 m in height within 46 m	3.8 (18)	3.2 (18)	0.879 <sup>b</sup>	>0.05
Light by burrow vs. max. shade in no-rat plot (F stop, 100 ASA)	5.3 (17)	6.9 (17)	1.250 <sup>b</sup>	>0.05

<sup>a</sup>Mann-Whitney U-Test

<sup>b</sup>Wilcoxon Test; differences were considered significant when  $P < 0.05$ .

Table 3. Norway rat association with sanitary conditions and landscape elements among landscaped plots in downtown Boston.

Variable	Mean (n)		Spearman $r^*$	P
	Rat	No-rat		
Overall food availability - 1 low, 5 high	2.5 (30)	1.1 (23)	0.508	<0.001
Refuse/litter on ground - 1 low, 5 high	2.7 (29)	1.7 (23)	0.465	<0.001
Plant maintenance - 1 low, 5 high	1.8 (29)	2.3 (23)	0.298	<0.05
Elevation above sidewalk (cm)	31 (30)	33 (23)	0.112	>0.05
Area of plot (m <sup>2</sup> )	139 (30)	323 (23)	0.082	>0.05
Area of bare soil (m <sup>2</sup> )	7.1 (30)	8.2 (23)	0.078	>0.05
Area of bark mulch (m <sup>2</sup> )	18.9 (30)	16.1 (23)	0.029	>0.05

\*Correlations were calculated using pooled data for all landscape plots surveyed; values were considered significant when  $P < 0.05$ .

deciding factor for rat infestation. Where it did appear important involved open refuse containers placed adjacent to bench walls (i.e., knee walls, copings, retaining walls), or an open restaurant dumpster on an adjacent property. The abundance of food left by people on the ground within and adjoining the landscaping appeared to be the primary food source cueing infestation.

Fourteen of the 15 rats tested for their excavation ability dug holes in the crushed stone. The mean depth was 5.8 cm, and the maximum was 11.4 cm. Field situations where rats excavated stone mulch and established burrows involved shrub beds with stone less than 7 cm deep.

There was only one confirmed situation where plants provided food for rats. This involved rats repeatedly climbing tall shrubbery and foraging on cranberrybush fruit (*Viburnum opulus*),  $\geq 1.7$  m above the ground. [Outside of the plots studied, rats have also been observed in Boston feeding on apples on the ground and blackberries. It was also found that caged rats (with water and lab chow available) readily accepted fruit from honeylocust (*Gleditsia triacanthos*), holly (*Ilex* sp.), scarlet firethorn (*Pyracantha coccinea*), autumn olive (*Elaeagnus umbellata*), cotoneaster (*Cotoneaster* sp.), and hawthorn (*Crataegus* sp.); whereas low acceptance of yew

and bayberry (*Myrica* sp.) fruit was observed, and no acceptance of juniper fruit.]

## DISCUSSION

Problems with Norway rats in urban landscapes usually are not a result of a single factor, but rather a mosaic of cumulative resources. For that reason, design planning requires that a composite of issues be considered, especially spatial relationships of dense plantings and food sources.

Even when a landscaped area itself does not have sanitation problems, the area may be exploited as harborage when food is available on adjacent properties or sidewalks. For example, dense plantings should be limited especially where the abutting property is a food vendor or where people gather to feed birds. Unfortunately, the landscape designer cannot control the neighborhood land use, maintenance, and sanitary enforcement. Yet, to be successful from a rodent control viewpoint, the surrounding land use and sanitary conditions need to be considered.

The incorporation of rodent control principles into a landscape design is intuitively important to a vertebrate pest specialist. However, aesthetics is the primary goal in landscape architecture. This frequently places the



vertebrate specialist and the landscape architect at odds, since aesthetics often translate into dense shrubbery (i.e., rat habitat).

It was found that the incorporation of rodent-proofing into landscape designs generally is novel to property managers and landscape architects. Even when property managers had chronic rat infestations, the primary approach that was observed was a long-term dependence on poisoning rather than habitat alteration. Once property managers were given recommendations for altering their landscapes, some made successful changes within budgetary limits.

Design criteria provided to landscape architects should detail the limiting and separation of potential resources for rats, to the extent necessary and practical, for the particular location. Urban sites abutting food markets, restaurants, and tourist locations warrant the most attention. Windswept designs (those with openness between landscape elements) will be less susceptible to infestation, will collect less debris, and be easier to clean and maintain.

#### Selection of Plant Materials

Certain types of plant materials are more susceptible to rodent infestation and damage than others (Marsh 1991). In California, Algerian ivy (*Hedera canariensis*) and Pampas grass (*Cortaderia selloana*) are two of the most troublesome species for roof rat (*Rattus rattus*) control because of their density; large areas of ice plant (*Carpobrotus edulis*) along California highways also provide food, harborage, and protected movement routes for roof rats (Frantz and Davis 1991). In Italy, climbing plants such as honeysuckle (*Lonicera* sp.) provide optimal conditions for roof rats living in parks (Santini 1987).

The specific plant varieties used for landscaping depend upon climatic and soil conditions, but deciduous shrubs and broadleaf evergreens are preferable to needled evergreens for limiting harborage for Norway rats. Additionally, because of leaf drop, deciduous shrubs do not provide the winter harborage afforded by an evergreen. Evergreens, however, will commonly and appropriately be selected for use in landscaping because of year-round greenery; minimizing their abundance or spreading out their distribution in single or linear patterns will be key to limiting rat harborage.

Plant varieties that naturally grow in a vase-shape or upright fashion are preferable to those that exhibit a mounded shape or spreading downward pattern. For example, plants that have open or airy growth patterns [e.g., winged euonymus (*Euonymus alata*) and rhododendron (*Rhododendron* spp.)] are less likely to have rat burrows underneath than plants with dense growth (e.g., *Taxus* or *Juniperus* spp.). Low growing (prostrate) plants or plants with dense understories (especially juniper) also are more difficult to inspect underneath for rat activity. Where needled-evergreen shrubs are to be used, seek varieties with more openness underneath. This is especially important where littering is expected, so that refuse will not readily accumulate underneath shrubbery and cleaning will be facilitated.

#### Spacing and Layout

Norway rats prefer burrow locations with overhead cover and associated thigmotropic conditions, as provided by a vertical surface or vegetation (Calhoun 1963). Thus, and as demonstrated by our data, dense contiguous understories should be avoided in a planting scheme. The amount of light under a single shrub appeared to be less important than the contiguous area of shrub cover.

As much as practical, space shrubbery to limit the potential for dense contiguous stands. Dense shrubbery in mass plantings will present the greatest risk, especially if needled evergreens are used. Individual plants or single rows of needled or dense broadleaf evergreens [e.g., boxwood (*Buxus* spp.)] are always preferable to mass plantings (e.g., concentrations of mound-shaped yews). Shrubby should be planted a minimum of 0.9 m from walls, and so that limbs when fully grown do not touch the walls. Planting in that manner will help limit harborage and provide access for inspection and cleaning. Where ground covers are used, break their distribution into "islands" with crushed stone between them.

#### Refuse Containers

Although accessibility of public refuse containers to rats did not appear to be a determining factor for landscape infestation, some rats did utilize them as feeding sites. Importantly though, inadequate numbers, distribution, and capacity of refuse containers for the volume of human activity may have contributed to public littering and food availability near rat-infested landscapes.

Specify an adequate number and size of rodent-proof refuse containers. Use containers with top openings at least 0.8 m above the ground; no lower openings (other than a drain hole) should exist. Locate and secure containers at least 1 m from benching, shrubbery, and walls to help limit rodent access and to facilitate cleaning. Strategically place the containers, especially along routes where food is likely to be eaten while people are walking or standing (e.g., radiating outward from food businesses and tourist locations).

Container covers will help prevent wind and animals from removing trash. However, covers increase the time needed to empty containers. A domed lid with a spring-loaded door is one type of cover that can be used to help prevent access by rodents. Dome lids without spring-loaded doors also are available and may be a better choice where covers are implemented because of less maintenance and lower costs. A third alternative is a metal ring cover with a center opening; this offers partial closure and represents a compromise between a dome cover and no cover at all.

The type of refuse container and the need for covers should be determined on a site-specific basis considering the surrounding decor, potential abuse, costs, refuse susceptibility to rodents, level of maintenance, and frequency of collection. However, the container should be made of a heavy-duty material that will not easily rust, crack, or puncture, such as a high density polyethylene; have a secure supporting system to prevent tipping; have a design and placement that allows inspection and

cleaning underneath; have any drain hole flashed with sheet metal or screened with hardware cloth; and be placed, where possible, on a paved (rather than soil) surface.

#### Landscape Plants as Rodent Food

Although refuse (e.g., food litter) was strongly associated with rat activity, our observations suggest that fruits and seeds associated with landscape plants may also be used by Norway rats, particularly with seasonal changes and the onset of winter. For that reason, we recommend choosing varieties which do not produce large amounts of fruit or seed, or which hold their fruit and seed longer. These include 'Shademaster' honeylocust, 'Spring Snow' (non-fruiting) or double-flowered varieties of crabapple (*Malus* spp.), 'Snowball' (sterile) cranberrybush, double-flowered varieties of cherry (*Prunus* spp.), 'Chanticleer' callery pear (*Pyrus calleriana*), 'Macho' Amur corktree (*Phellodendron amurense*), and male ginkgo (*Ginkgo biloba*).

#### Inspection Strips

Plantings immediately adjacent to walls are not always well maintained, probably because of confined access; they also may be planted too close to walls from a rodent control viewpoint. Thus, such areas can become overgrown and ideal for rats. To eliminate exposed soil for rodent burrowing along a wall, an inspection strip should be established; these have been described by Imholte (1984), Frantz and Davis (1991), Olkowski et al. (1991), and Timm (1991) using varying widths, depths, and diameter of stone. Inspection strips also provide access to inspect for rat activity, suppress weeds, and ensure space for bait station or trap placement.

Use an inspection strip along walls and fence lines, especially where plantings are extensive or local conditions are conducive to rat activity. Specify crushed stone (diameters of 6 mm to < 19 mm are acceptable), preferably rounded, out to a minimum of 25 to 30 cm from walls and down to a depth of 13 to 18 cm. Use steel or wood edging to confine crushed stone and to help prevent lawn mowers from throwing stones (10 cm deep x 3 mm thick; stakes 46 cm long every 61 cm).

Do not use an impervious layer underneath the crushed stone because of impacts to drainage, and thus the building foundation. Instead, use polypropylene landscape fabric or perforated polyethylene; both are permeable to water and air and also will suppress weeds. (The landscape fabric will also help limit intrusion of soil into the stone layer over time; see Williams and Williams 1991 for a review of landscape fabric.) Using stone  $\geq$  19 mm in diameter is also not recommended because of the potential for it to be thrown by people. A smaller and more rounded stone creates a better collapsing effect as a rat attempts to excavate; it also should collect less debris than larger stone, be easier to keep clean, and be more aesthetic.

#### Mulch

Use mulch for weed control in areas not covered by sod. This can include either bark or stone mulch, but landscape fabric should be used underneath. An even layer of crushed stone, 10 cm deep underneath shrubbery,

also can be used to inhibit rat burrowing. However, the stone mulch will have limited rodent-proofing value if the shrubbery remains overgrown or if the layer of crushed stone used around the shrub base is too thin. Although a deeper layer is desirable to better inhibit burrowing, it is not recommended around shrubbery because of potential oxygen stress to roots. In soil areas without plants, a stone layer can be spread 13-18 cm deep and used to limit rat infestation.

#### Fences, Walls, and Benching

The association between fence lines and urban rat problems has been described by Orgain and Schein (1953). Thus, limit fences and walls where possible and space shrubbery and benches away from them. Where fencing is used, ideally install it in pavement or use an inspection strip. A radius (curved) installation pattern is preferable to one with corners because of the potential for litter/debris accumulation and to facilitate mowing.

Bench walls are frequently used to encircle or retain landscaped areas. Because people commonly sit on these low walls while eating, food litter may collect in adjacent shrubbery (especially if densely planted). Also rats will burrow along the top edge of bench walls, especially when shrubbery overhangs them; thus space shrubbery back to allow openness along bench walls. Locate free-standing benches in more open areas, rather than abutting dense shrubbery, and situate a refuse container nearby (but at least 1 m distant).

#### Planters

Within small planters that are susceptible to rat burrowing, use hardware cloth (6 mm openings, 17 gauge, galvanized screening) within the entire planter below the soil surface (e.g., 8 cm, but as close to the soil surface as practical while still allowing plant growth). Roots of ground covers and flowers can grow downwards through the hardware cloth while rats will have a difficult time establishing burrows. Where shrubs are being planted, cut an "X" in the hardware cloth and insert the root ball through it. Once the transplant is set, press the hardware cloth back towards the plant base and trim it to fit snugly.

#### Water Management

Lore and Flannelly (1982) stressed the importance of eliminating water sources as part of Norway rat control. For that reason, grade landscapes so that water does not pond. This is especially important around faucets, sprinkler systems, fountains, and areas receiving runoff. Place crushed stone where water tends to accumulate in small pools on soil surfaces, such as around drinking fountains. Design and install irrigation systems to reduce the potential for leakage at joints.

#### Maintenance Considerations

The resources that are necessary and available to maintain a landscape should be part of design considerations. Landscaping that has excellent aesthetics when completed may degrade into an overgrown patch with rats if the maintenance budget has not been considered during design. It was observed that government institutions in particular had problems with

landscaping and rat activity, and this appeared directly related to limited budgets for maintenance.

Once a rat infestation is established in landscaping, institute poisoning/trapping followed by habitat alteration. This typically requires thinning, pruning, or complete removal of dense or overgrown shrubbery. As part of standard maintenance procedures, include pruning of lower limbs to maintain openness underneath, emptying of refuse containers and clean up of litter before nightfall, repair and replacement of refuse containers, and inspections for rat activity. Daily removal of litter and limiting accessible refuse is essential. Maintenance personnel should be trained to identify rat burrows, runways, and droppings so timely control practices can be implemented.

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# THE POTENTIAL IMPACT OF INTRODUCED COMMENSAL RODENTS ON ISLAND FLORA

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**ABSTRACT:** The impact of introduced commensal rodents on island flora has been relatively little studied compared with their impact on the fauna. The effects on vegetation composition, regeneration, and decomposition are largely unknown, but potentially great. Preliminary studies were carried out in the Galapagos Islands between 1993 and 1994 on the diet of introduced rats, *Rattus* spp. and feral house mice, *Mus musculus*, seed recovery rates and subsequent germination rates of seeds. *R. rattus* diet was primarily vegetation and 48% of rats had seeds in their stomachs. Significant differences were found between body size and overall contribution of both vegetable and animal foods, larger rats eating proportionately more animal foods and less vegetable. There was no significant difference between the sexes in terms of main dietary components. There was no significant difference in the selection of food types between *R. rattus* and *R. norvegicus*, both species tended to prefer banana and avocado, and only rats from the Miconia zones showed a preference for Miconia berries. No intact seeds were found in the stomachs of feral house mice from the same sites. Recovered seeds of two native and two introduced plant species were successfully germinated under laboratory conditions. *R. norvegicus* is potentially a better dispersal agent for seeds as it has a greater tendency to ingest them intact. The implications of these findings for the conservation of island flora are discussed.

**KEYWORDS:** rodents, commensal rodents, Galapagos, Ecuador, vertebrate pest control, islands, introduced species

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## INTRODUCTION

The commensal rodents are known to cause considerable damage to island fauna where they have been introduced. This is particularly well documented with respect to depredations by rats, *Rattus rattus* and *R. norvegicus*, on nesting colonies of seabirds, reptiles, amphibians and invertebrates (Atkinson 1985; Daniel 1973; Dingwall et al. 1978; Moors and Atkinson 1984; Moors et al. 1992; Pye and Bonner 1980). What is less well known is their effect on the native flora of islands. The diet of all three species of commensal rodent is notoriously broad and opportunistic (hence their potential as pests in many different situations), and in the wild is known to include seeds, buds, bark, invertebrates and carrion (Allen et al. 1994; Barnett 1975; Clark 1980; Dingwall et al. 1978; Gales 1982; Laws 1984). The effect on the vegetation may be direct, by the consumption of buds, leaves, bark and seeds, and by acting as dispersal agents by transporting intact seeds in the gut away from the parent plant. Indirect effects on the vegetation may occur by the predation of rats and mice on the invertebrate population and subsequent effect on decomposition and regeneration (Allen et al. 1994; Bremner et al. 1984; Crafford and Scholtz 1987). Indirect effects can also include burrowing activities, which may weaken root systems or break up dense plant structures (Laws 1984; Snell et al. 1994). All these can affect both native and introduced plants. The activities of small mammals are a normal part of ecosystem function (Fraser 1990; Janzen 1971), but conservation issues arise where invasive species differ from native species in the selection of items, or the quantities consumed. Where there are no native seed predators the problem is particularly acute as many island systems have evolved in the absence of this selection pressure. Overall, these more subtle effects on island fauna and flora would be

expected to have a long term impact on the plant composition and vegetation turnover on islands.

This paper reports preliminary studies to investigate this aspect on four islands in the Galapagos archipelago, and is intended to generate awareness of the need for more research in this area.

## THE STUDY SITES

The Galapagos archipelago, Ecuador, lies on the equator and consists of 13 large and ca. 40 smaller islands. The Black rat, *R. rattus*, now occurs on ten islands, while the Brown rat, *R. norvegicus*, is a relatively recent arrival in the archipelago and occurs on two islands. Feral house mice, *Mus musculus* are found on seven islands. Four of the original seven species of native rice rat (*Oryzomys* spp. and *Nesoryzomys* spp.) are extinct, probably due to the arrival of the commensal rodents, and the remaining three species are found on two uninhabited islands still free of commensal rodents (Key and Heredia 1994). The study was undertaken in the arid vegetation zone, where the climate is typically hot and dry.

The study was carried out over two years, 1993 and 1994, on the four inhabited islands, Santa Cruz, San Cristobal, Isabela and Floreana. Three main aspects were investigated: diet, food preferences, and the recovery and germination of seeds consumed, focusing on some important introduced invasive plants and some native plants of conservation concern. Plants included were limited to those fruiting at the time of study.

## METHODS

### Diet

Diet was determined by stomach content analysis of rats (*Rattus* spp.) and feral house mice. Rodents were live trapped in Tomahawk and Sherman traps, laid in

transects within 1 km inland of the port town on each inhabited island. A total of 65 traps was laid in each transect, placing alternate groups of three Tomahawk and two Sherman traps every 20 meters along the transect. Traps were baited with peanut butter, set at 1800 hrs and checked the following morning at 0600 hrs for four consecutive nights. Most of the rats caught were used for a study of behavioral ecology, of which results are presented elsewhere. Excess rats and all mice caught were sacrificed for stomach content analysis by an overdose of inhalation anaesthetic.

Stomach contents were flushed with water into a petri dish. Contents were examined with a x10 hand lens and 14 categories were identified: leafy vegetation, non-leafy vegetation, bait, meat, seeds, fruit, invertebrates, mucus, starch, metal (from the traps), fur, stones, cheese and unknown. The percentage contribution of each category by volume was estimated for each stomach, and then averaged for each species. This was carried out from July through August, 1994.

#### Food Selection

An investigation of food selection was carried out with rats on Santa Cruz island in 1993.

Rats were trapped at two sites on Santa Cruz island, the Miconia robinsoniana vegetation zone and around the port town, Puerto Ayora. Miconia zone rats eat a specialized diet based on Miconia berries due to the limited availability of alternative foods in this zone (Clark 1980). In contrast, rats living around the town have a wide range of foods available to them and so have a generalized diet. At both sites 5 to 20 Tomahawk traps were laid in transects along paths, or placed opportunistically where rats were expected to occur (e.g., near litter bins, toilets). At the Miconia zone, traps were left in place for five days prior to operation to overcome neophobia. Traps were baited with peanut butter, set at 1800 hrs, and checked at 2100 hrs and 0600 hrs. Captured rats were transported to the laboratory and maintained in cages; maximum journey time was ca. 2 hours. The aim was to have ten rats of each species (*R. rattus* and *R. norvegicus*) from each site. All feces produced in the traps were collected.

In the laboratory rats were housed in modified traps, 20 x 20 x 50 cm for *R. rattus*, and 30 x 30 x 60 cm for the larger *R. norvegicus*. Cages were raised off the floor to allow collection of droppings and scattered foods. Water and nesting material were provided ad lib. and all animals were maintained on a basic diet as shown in Table 1, designed to provide a balanced diet palatable for both species and developed on site (Platenberg 1994).

Caged rats were given seven days to habituate, and were then offered a selection of different foods known to grow locally: avocado (*Persea americana*), banana (*Musa* sp.), naranjilla (*Solanum quitoense*), cassava (*Manihot* sp.), tomato (*Lycopersicon lycopersicum*) and Miconia berries. Approximately 5 g of each food type was offered in a cafeteria selection, together with the basic diet, and the amount eaten was recorded on a daily basis. It was not possible to weigh the food uneaten due to the tendency of rats to scatter and soil foods, so the amount eaten was scored on a scale of 0 to 4: 0=food untouched; 1=food sampled; 2=about half of the food eaten; 3=most of the

food eaten; and 4=food completely consumed. Food preferences were averaged for each food type by using estimates of food taken over the five-day period.

These foods were offered every day for five days, except naranjilla which was only just coming into season and sufficient fruits were only available for one day. Other plants of interest, *Lantana camera*, guava (*Psidium guajava*) and blackberry (*Rubus* sp.), all serious invasive species in the islands, were not fruiting in abundance at the time of study and sufficient fruits were only available for the germination trials.

Table 1. Basic diet on which rats were maintained in captivity.

500 g	Quinea seeds ( <i>Chenopodium quinoa</i> )
500 g	flaked oats
350 g	wheat germ
325 g	maize flour
250 g	banana flour
150 g	sugar
150 g	vegetable oil
100 g	commercial seasoning
50 g	salt

#### Germination of Recovered Seeds

Rats of both species were given samples of various locally available fruits, both native and introduced, with relatively small seeds, estimated to be of a size to pass through the gut of a rat (approximately rice grain size and below). Feces were then collected and examined for the presence of intact seeds, and attempts were made to germinate them.

Fruits offered were as follows: maracuya (*Passiflora* spp.), guava, naranjilla, tomato, Galapagos tomato (*Lycopersicon cheesmanii*), blackberry and Miconia. Fruits were offered for one day and feces collected for the following two days, before another fruit type was offered.

The first germination trial simulated conditions in which feces containing viable seeds would occur in the natural environment. Vermiculite was used as a sterile substrate, and plastic drinking cups, with drainage holes in the base, were three-quarters filled and kept slightly damp by daily checking and watering, as required. Two treatments were compared. In the first, recovered feces were placed in the vermiculite, just below the surface. In the second, recovered feces were soaked for 48 hours in water, and then placed in the vermiculite just below the surface. After a minimum of 19 days, the cups were checked through for signs of germinated seeds. In total, 167 pots were established, with 12 control pots containing seeds extracted directly from the fruit types tested. As soon as it became evident that whole feces in damp vermiculite rapidly became very moldy, an alternative method of seed germination was tested. A total of 712 recovered feces were soaked in water, gently teased apart and examined individually for the presence of intact seeds. These were isolated and placed on damp tissue paper in petri dishes which were maintained in dark,

humid conditions. The dishes were checked daily for signs of germination for up to two months.

## RESULTS

### Diet

A total of 76 *R. rattus* and 24 house mouse stomachs were examined from the four islands (Table 2). No *R. norvegicus* were caught outside the vicinity of buildings and so are not included. As sample sizes for individual sites were not consistent, results are summed for analysis. Results for *R. rattus* and house mice are shown in Table 3. One rat had a stomach completely full of blood (presumed to be a victim of anticoagulant poisoning) and is excluded from the analysis.

Table 2. Numbers of stomachs examined from rats, *Rattus rattus*, and feral house mice, *Mus musculus*, on four inhabited islands, Galapagos.

Island	<i>R. rattus</i>	<i>M. musculus</i>
Isabela	16	6
San Cristobal	47	14
Floreana	3	0
Santa Cruz	10	4
Total	76	24

It can be seen that non-leafy vegetation and bait from the traps make up the greatest contribution to the stomach contents for both rats and mice. All 14 categories were identified from rat stomachs, with seven (starch, stones, leafy vegetation, metal, fur, cheese and unknown items) contributing on average less than 1% by volume. The fur was probably ingested while grooming, and the metal

came from damaged Sherman traps. The starch and the meat are both believed to come from human waste in the town, as the meat was not associated with fur. A total of 36 rats had recognizable seeds in their stomachs, comprising an average of  $8.7 \pm 1.4\%$  by volume. There was no significant difference in diversity of diet between male and female rats ( $t = -1.49$ ,  $df = 39$ ,  $p > 0.05$ ), with males consuming an average of  $2.5 \pm 0.3$  ( $n = 21$ ) categories of food, and females an average of  $2.98 \pm 0.2$  ( $n = 54$ ). A maximum of six categories was recorded from any one female, and five from any one male rat. When the diet of adult sized rats (head and body length 136 mm) was examined, there was found to be a significant correlation between size and total contribution of animal food (bait + invertebrates + meat + cheese) ( $r = 0.4$ ,  $n = 37$ ,  $p < 0.01$ ). There was no significant difference in the mean contribution by volume of animal food and sex ( $t = 0.54$ ,  $df = 32$ ,  $p > 0.05$ ), with adult male rats consuming  $32.2 \pm 7.7\%$ , and adult females  $26.7 \pm 6.7\%$ . The same analysis was done for the overall contribution of vegetation (non-leafy vegetation + seeds + fruit + leafy vegetation) and there was a significant negative correlation between consumption of vegetation and size ( $r = -0.4$ ,  $n = 37$ ,  $p < 0.01$ ). There was no significant difference between the mean contribution by volume of vegetation and sex ( $t = -0.01$ ,  $df = 32$ ,  $p > 0.05$ ), with adult males consuming  $66 \pm 8.6\%$  and adult females  $66 \pm 7.5\%$ .

Only nine of the categories were identified from mouse stomachs, with five (meat, fruit, leafy vegetation, fur, and stones) contributing on average less than 1% to total stomach contents (Table 3). Contents were dominated by the presence of trap bait which occurred in 22 of the 24 animals and comprised 75% by volume. Diversity of diet was lower than for rats, with mean number of categories  $2.1 \pm 0.1$ , and no stomach contained more than three categories.

Table 3. Mean percentage contribution  $\pm$  SE by volume of 14 categories of food found in 75 *R. rattus* and 24 *M. musculus* stomachs at four sites in the Galapagos islands.

Category	<i>R. rattus</i>		<i>M. musculus</i>	
	<i>n</i>	%	<i>n</i>	%
Vegetation	71	$55.0 \pm 3.9$	14	$17.3 \pm 5.6$
Bait	36	$18.6 \pm 3.3$	22	$75.4 \pm 5.8$
Seed	36	$8.7 \pm 1.4$		
Invertebrates	23	$3.3 \pm 1.9$	6	$2.5 \pm 1.2$
Fruit	16	$5.1 \pm 1.6$	2	$0.4 \pm 0.3$
Meat	7	$2.7 \pm 1.3$	2	$0.6 \pm 0.5$
Mucus	6	$3.3 \pm 1.9$		
Starch	5	$0.9 \pm 0.4$	2	$2.9 \pm 2.2$
Fur	4	$0.5 \pm 0.3$	1	$0.2 \pm 0.2$
Leafy vegetation	3	$0.3 \pm 0.2$	1	$0.3 \pm 0.3$
Metal	2	$0.4 \pm 0.4$		
Stones	2	$0.7 \pm 0.6$	1	$0.4 \pm 0.4$
Cheese	1	$0.4 \pm 0.4$		
Unknown	1	$0.1 \pm 0.1$		

### Food Preferences

Unfortunately, severe losses of caged rats occurred, both through escape (due to faulty cages) and death by anticoagulant poisoning. This was particularly evident with rats caught in the Miconia zone where a control campaign was in operation near the trapping site at the time of the study and data were consistently collected only from the town caught rats, with an effective sample size of ten *R. norvegicus* and eight *R. rattus*.

There was no significant difference in the selection of food types by *R. rattus* ( $X^2=13.26$ , df 7,  $p>0.05$ ) or by *R. norvegicus* ( $X^2=16.07$ , df 9,  $p>0.05$ ). The median proportions of food types selected are shown in Figure 1 where it can be seen that both species tended to prefer banana and avocado to the other foods offered. The selection of Miconia alone was compared to the selection of all other food types using a Wilcoxon matched pairs test. *R. rattus* avoided Miconia when offered other choices ( $T=36.0$ ,  $p < 0.05$ ,  $n=8$ ), while *R. norvegicus* showed no significant difference in selection ( $T=36.5$ ,  $p>0.05$ ,  $n=9$ ).

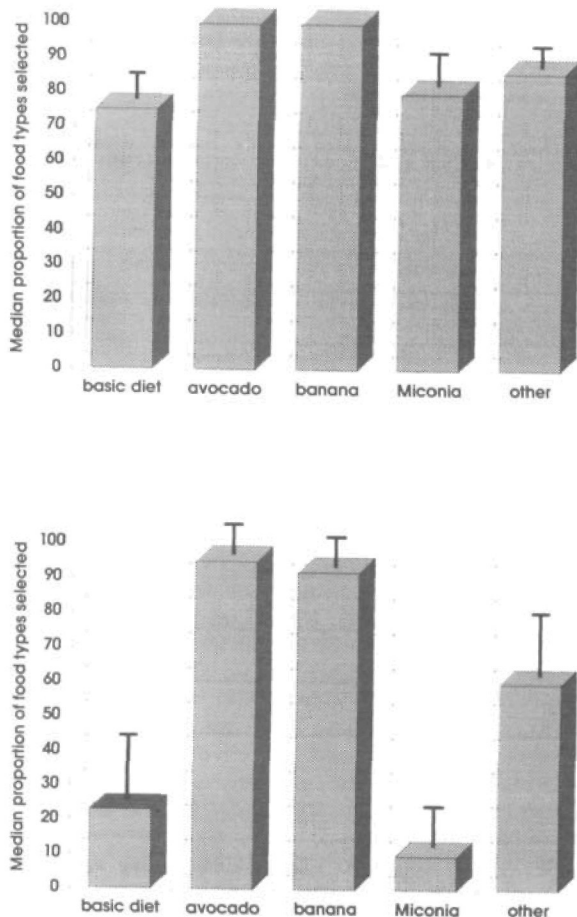


Figure 1. Food preferences of *Rattus norvegicus* (top) and *Rattus rattus* (bottom) showing median taken  $\pm$  third quartile for five food types offered.

Periodic checks made over the night on foods consumed first and last indicated that banana and avocado were the food types most often selected before other items. Both species ate these two foods within the first half hour 63% (*R. rattus*) and 70% (*R. norvegicus*) of the time over four nights. The basic diet was chosen within the first half hour by *R. rattus* and *R. norvegicus* 9% and 20% of the time, respectively, over the same four nights. In contrast, Miconia was consistently eaten only after these other food items had been consumed. Only limited supplies of fruits of Lantana camera and blackberry were available. Observations suggest that rats predate Lantana seeds and do not swallow them whole. Blackberry did not appear to be palatable to *R. rattus* and was not eaten, while it was accepted by *R. norvegicus* and seeds were recovered from the feces.

### Germination of Recovered Seeds

Black rats appear to chew their food more finely than do brown rats, and more intact seeds were recovered from *R. norvegicus* than *R. rattus*. For example, a mean of  $4.9 \pm 6.5$  Galapagos tomato seeds were recovered from 108 *R. rattus* droppings, compared to a mean of  $12.8 \pm 16$  recovered from 153 *R. norvegicus* droppings. The high standard deviations indicate the variation found.

Miconia, guava, tomato and Galapagos tomato seeds germinated having passed through the guts of rats (Table 4). Maracuya seeds were not recovered intact from gut feces. Sample sizes are small, but it can be seen that seeds which germinated did so both when recovered from rat feces and directly from fruit, indicating that passage through an animal gut is not a prerequisite for germination in these species.

### DISCUSSION

The diet of *R. rattus* reported here differs from other studies in being relatively low in animal food. The main component found in stomachs was vegetation, fruit and seeds, and invertebrates made up only 3.3% volume, having been consumed by only 30% of the rats. Clark (1980) studying rats at similar sites in the Galapagos found  $>30\%$  by volume of animal food in adult rats. Animal food has also been found to predominate in the diet of black rats in New Zealand (Daniel 1973; Gales 1982). The mean contribution of seeds and fruit combined is similar to that found by Gales (1982), but rats appear to be consuming a much greater proportion of vegetation. The reasons for this are unclear, but may relate to the nutritional qualities of the specific plants and plant parts consumed, which were not identified in this study. The results may be an artifact of the summing of specimens from four different sites, and the close proximity of houses offering alternative foods. The presence of starch, meat and cheese in the stomachs, and what was presumed to be an animal suffering from anticoagulant poisoning, indicate that rats are traveling up to 1 km to the houses in the town.

The significant correlation between body size and the consumption of animal food is typical of a breeding population of *R. rattus* in the Galapagos (Clark 1980). Larger animals were eating proportionately more animal foods and less vegetable foods. The diversity of diet for individual rats reported here is an underestimate as

Table 4. Percent germination of seeds recovered from droppings of *R. rattus* and *R. norvegicus*, and from unconsumed fruits, using the vermiculite (A) and petri dish (B) methods of germination. Sample size is given in parentheses.

Seed Type	Source		
	<i>R. rattus</i>	<i>R. norvegicus</i>	Fruit
<u>Introduced species</u>			
<i>Lycopersicon lycopersicum</i>			
A	*	*	*
B	17% (6)	50% (6)	100% (8)
<i>Psidium guajava</i>			
A	+	*	*
B	33% (3)	0% (22)	21% (14)
<i>Rubus</i> spp.			
A	*	*	*
B	*	0% (10)	0% (59)
<i>Solanum quitoense</i>			
A	*	*	*
B	0% (31)	0% (48)	0% (100)
<u>Native species</u>			
<i>Lycopersicon cheesmanii</i>			
A	*	*	*
B	0% (30)	<0.1% (242)	<0.1% (159)
<i>Miconia robinsoniana</i>			
A	*	+	+
B	0% (323)	0% (280)	+

+ indicates unquantified positive germination

\* indicates not tested

individual items were not identified, and as such compares well to findings by Clark (1982) who found ca. 4 items per rat stomach in 2+ broad categories. Food preferences for both species of rat in the laboratory were for the relatively soft, moist and nutritious foods, banana and avocado. *Miconia* berries were preferred only by rats from that vegetation zone, suggesting that *Miconia* is not inherently palatable to rats. The implication, therefore, is that the recent spread of *R. norvegicus* into the area (Key et al. 1994) is a result of population pressures and dispersal of rats from the adjacent, optimal agricultural area. Poison baits would, therefore, be expected to be more acceptable to *R. norvegicus* in this area than to the established *R. rattus*, at least in the short term. The basic diet was found to be palatable to both species in the food preference trials, but this may be a result of conditioning.

The stomach contents of feral house mice in the Galapagos were dominated by bait, reflecting the small stomach size and, clearly, trapping for mice with food baited traps is an unsuitable method of studying mouse diet. A subsequent study including the diet of feral house mice on Ilheu Chao, of the Desertas Islands, Madeira, using traps baited with vanilla essence found vegetation to

be the main food component, with 81% of mouse stomachs containing amorphous plant material, 22% recognizable fiber, and 37% seeds. Only 16% contained invertebrates, but the study was undertaken in the dry season when invertebrate populations would be minimal (Key et al. 1995). Other studies on feral house mouse diet have varying findings, with mice on Marion Island taking a large proportion of animal foods (Gleeson and van Rensburg 1982), on sub-Antarctic islands the diet was dominated by grass seeds (Laws 1984), while in different areas in Australia mice have been variously reported as granivores, omnivores and insectivores (Watts and Morton 1983). Mice are generally considered to be primarily granivorous but are clearly able to adapt to local resource availability.

The seed germination study indicates that rats are capable of acting as passive dispersal agents for both native and introduced plants in the Galapagos. Higher seed recovery rates were found from *R. norvegicus* than from *R. rattus*, and the brown rat is considered to have more potential for the spread of plants. It must be emphasized that this study was severely limited by the number of animals caught, the fruits seeding at the time



of study, and by the time available for the subsequent germination of seeds. Many plants require long periods to germinate, often following treatment in the form of chilling, or passage through an animal's gut. Rates and times to germination are not known for most Galapagos plants (Andre Mauchamp, CDRS, pers. comm.), but native plants (especially K-selected island endemics) would be expected to have lower germination rates and longer germination times than agricultural plants, such as the tomato. As an illustration of this, Clout and Tilley (1992) studying the New Zealand miro tree (*Prumnopitys ferruginea*) found no germination occurred for 18 months, and then continued for four years. Results presented here should, therefore, be considered only as an indication of potential.

On some islands in the Galapagos, such as Santa Cruz, introduced rats, *Rattus* spp., have replaced native rice rat species (*Oryzomys* and *Nesoryzomys*) whose feeding ecology is unknown, and the relative impact of the introduced species cannot be evaluated. Long-term conservation problems will particularly arise on islands where there are no native rodent species, and the vegetation and invertebrate fauna lack a native predator. No data were collected in this study on *R. norvegicus* diet in the Galapagos, but in other studies of island populations it has been found to include vegetation, seeds and invertebrates in varying proportions (Bremner et al. 1984; Goulding 1994; Moors 1985). The impact of commensal rodents on island flora is seen from two points, on their initial introduction to a new system, and also following their eradication. Some plant species increase, released from seed and seedling predation by rats, but others decrease as invertebrate herbivores increase, themselves released from rats predation (Allen et al. 1994). Extremes of predator-prey interactions occur on islands (Janzen 1971) and it would, therefore, be expected that introduced predators would selectively take introduced prey, the native species having developed severe chemical defenses against predation. This could have a positive effect on the conservation of the native flora in the Galapagos, if rats are selectively avoiding native plants in the presence of invasive, pest species. It is hoped that this paper will catalyze further work on this neglected aspect of the ecology of introduced rodents and long-term studies on the restoration of island systems will be initiated.

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# THE DISTRIBUTION AND SIGNIFICANCE OF ANTICOAGULANT-RESISTANT NORWAY RATS (*RATTUS NORVEGICUS*) IN ENGLAND AND WALES, 1988-95

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**ABSTRACT:** Between 1988 and 1995 populations of rats on agricultural premises were sampled to investigate the distribution of anticoagulant-resistant rats in England and Wales. In total, approximately 1,670 rats from 115 locations were tested for resistance to warfarin. Rats that were warfarin-resistant were subsequently tested for resistance to difenacoum, and since 1991 for resistance to bromadiolone. In some cases rats were also tested for resistance to brodifacoum, and in 1995 for resistance to flocoumafen. The results of these tests showed that there was a high prevalence of resistance to the first-generation anticoagulant, warfarin, in several regions of England and Wales. Rats from most populations sampled since 1991 appeared to be more resistant to bromadiolone than difenacoum, but in central southern England there were some populations where the reverse was true. In this same part of the country there was a relatively small focus where the rats had high degrees of resistance to several anticoagulant rodenticides. There was little evidence of resistance to brodifacoum or flocoumafen. The data are discussed with respect to the impact of anticoagulant rodenticide resistance on control of rats in the United Kingdom.

**KEY WORDS:** anticoagulants, brodifacoum, bromadiolone, commensal rodents, difenacoum, flocoumafen, laboratory testing, Muridae, Norway rats, rats, resistance, Rodentia, rodenticides, rodents, U.K., vertebrate pest control, warfarin

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## INTRODUCTION

Norway rats (*Rattus norvegicus*) resistant to the anticoagulant rodenticide warfarin were first discovered on a pig farm in Scotland in 1958 (Boyle 1960). Subsequently, populations of rats resistant to warfarin and other first-generation anticoagulant rodenticides were discovered in Denmark (Lund 1964), England and Wales (Drummond and Bentley 1967), Germany (Telle 1967), Holland (Ophof and Langeveld 1969), the United States of America (U.S.A.) (Jackson and Kaukeinen 1972) and Italy (Alessandrini et al. 1980). A second generation of anticoagulant rodenticides was developed (reviewed by Hadler and Buckle 1992) to overcome the control problems caused by resistance to the first-generation compounds. The newer anticoagulants such as bromadiolone and difenacoum were based on the same chemical structure and mode of action as warfarin. With the benefit of hindsight, it is not surprising that resistance was discovered within a few years of the first commercial use of difenacoum (Redfern and Gill 1978). Further studies (Greaves et al. 1982) indicated a significant and widespread incidence of difenacoum-resistant rats across an area of central southern England with a history of warfarin resistance in rats. Populations of rats that included individuals resistant to bromadiolone have been reported in Denmark (Lund 1981), Holland (Van Blaaderen and Bode 1989) and Germany (Pelz et al. 1995). Responses to a questionnaire indicated that laboratory tests have identified populations of Norway rats in Denmark, France, Germany and the United Kingdom (U.K.) that were resistant to one or more anticoagulant rodenticides (Myllymaki 1995). That same report indicated that *Rattus norvegicus* trapped and tested in Finland were susceptible to anticoagulant rodenticides.

The authors' laboratory has been funded by the U.K. Ministry of Agriculture, Fisheries and Food to investigate the occurrence and significance of anticoagulant-resistant rats in England and Wales. Historical data (Drummond 1966; Greaves 1970; MacNicoll and Gill 1987) indicated that warfarin-resistant rats predominated in most rat populations in Wales and the bordering English counties, southeast England, central southern England, and central Scotland (Figure 1). The present paper reports the results of tests carried out between 1988 and 1995 for resistance to warfarin, difenacoum, brodifacoum, bromadiolone (1991 to 1995 only) and flocoumafen (1995 only). Sampling of rat populations was based largely on reports of poor or unsuccessful control using anticoagulant rodenticides, and is, therefore, biased towards detection of anticoagulant-resistant rats. In addition, samples of some rat populations were tested for anticoagulant resistance prior to field studies designed to investigate the causes of control failure (Quy et al. 1992a, 1992b, 1994; Cowan et al. 1995).

## METHODS

### Animals

Rats were sampled from infestations on agricultural premises using single-capture live traps, and transported to the laboratory. They were treated with insecticide to reduce ectoparasite infestation, and housed singly in suspended wire cages. They were fed rat and mouse No. 1 low vitamin K (<1 mg/kg of vitamin K) pelleted diet (SDS Ltd., Witham, Essex, U.K.) ad libitum, and provided free access to water containing 100 mg/L of menadione sodium bisulphite (MSB; Sigma Chemical Co., Poole, Dorset, U.K.) to prevent vitamin K deficiency.



Figure 1. Location of populations of warfarin-resistant rats in the U.K. 1958 to 1987.

#### Testing for Anticoagulant Resistance

Between 1988 and 1991, warfarin resistance status was determined using the method of Martin et al. (1979). From 1992 onwards a revised method was used, which incorporated several refinements (MacNicoll and Gill 1993). Animals that were warfarin-resistant were, after a gap of at least one week, tested for resistance to difenacoum. Warfarin-susceptible rats were not usually subjected to further tests for anticoagulant resistance.

In 1988 and 1989, resistance to difenacoum was determined by survival of a five-day feeding test using 0.005% (w/w) difenacoum (Redfern and Gill 1978), and since 1990 by blood clotting response (BCR) four days after administration of a sub-lethal dose of difenacoum (Gill et al. 1993). From 1991 onwards warfarin-resistant rats were tested for resistance to bromadiolone by BCR test (Gill et al. 1994). There were gaps of at least three weeks between sequential tests for resistance to second-generation anticoagulants on the same animal.

Difenacoum (or bromadiolone from 1991 onwards) resistant rats were subjected to a seven-day feeding test using 0.0005% (w/w) brodifacoum in the diet (Gill and MacNicoll 1991). Rats that survived for more than three weeks after the end of the feeding regime had at least a low degree of resistance to brodifacoum.

In 1995 rats that had a degree of resistance to difenacoum and/or bromadiolone were tested for resistance to flocoumafen. Full details of this test will be published elsewhere. Flocoumafen (0.6 mg/kg body weight) was administered by oral intubation in conjunction with 10 mg/kg body weight of MSB. Proteolytic activity of blood clotting Factor X was measured four days later, and rats with greater than 0.1 units of Factor X per ml of plasma were classified as flocoumafen-resistant. Factor X levels in control animals were approximately 0.5 units per ml of plasma.

#### Mapping of Anticoagulant Resistance in England and Wales

The grid reference for each farm where rats were trapped between 1988 and 1995 was recorded. The results of warfarin resistance tests were used to determine whether <10%, 10 to 90%, or >90% of rats sampled from each location were warfarin-resistant. This information was entered, together with grid references, into a software package (DMAP for Windows, Alan Morton, Imperial College, London, U.K.) to provide the distribution map shown in Figure 2.

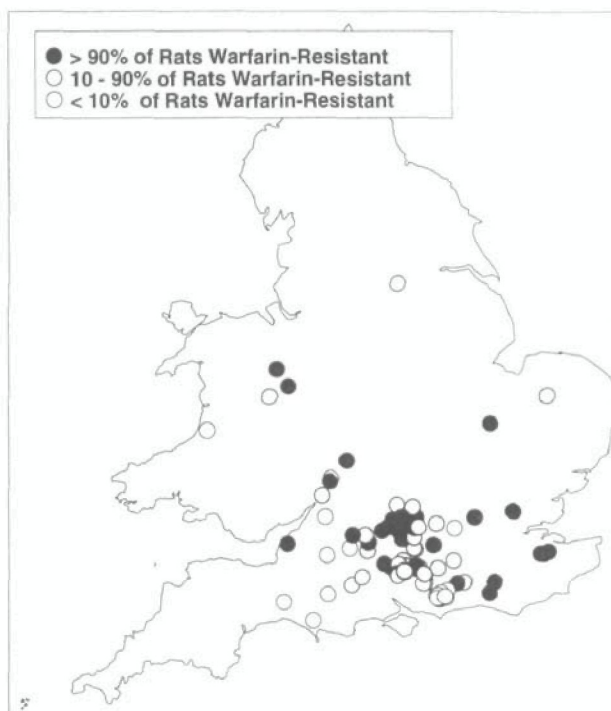


Figure 2. Location of rat populations sampled between 1988 and 1995 and tested for resistance to warfarin.

Figure 3a was produced in a similar manner, but each site sampled in 1988 and 1989 was categorized on the basis of <10%, 10 to 50%, or >50% of rats in each sample surviving a difenacoum feeding test. Figure 3b shows the results from 1990 to 1995, but in this case farms were categorized on the basis that the mean percentage clotting activity (PCA) on day 4 of BCR tests for difenacoum resistance was <10%, 10 to 50%, or >50% of activity measured at the time of difenacoum administration.

Figure 4 plots the distribution of brodifacoum resistance based on survival of a feeding test. Each location was categorized on the same basis as survival of a difenacoum feeding test in Figure 3a. The results of BCR tests for bromadiolone resistance between 1991 and 1995 were categorized on the same basis as for difenacoum resistance in Figure 3b, and are presented in Figure 5.

## RESULTS AND DISCUSSION

### Warfarin Resistance

Figure 2 summarizes the results of warfarin resistance tests carried out on 1,670 rats trapped on 115 farms between 1988 and 1995. The symbol at each location indicates that <10% (30 farms; open circles), between 10 and 90% (38 farms; shaded circles), or >90% (45 farms; filled circles) of the sample were warfarin-resistant. These groups were selected to highlight populations that contained few, if any, warfarin-resistant rats, and those where use of anticoagulant rodenticides had selected populations that included few, if any, susceptible rats. This enables identification of areas where warfarin (and other first-generation anticoagulant rodenticides) could be successfully used for control of rats because of the predominance of warfarin susceptibility. Conversely, predominance of warfarin-resistant rats indicates that the first-generation compounds would probably not be effective. Some success may be achievable in control of intermediate populations using warfarin, but the likelihood of further selection of higher degrees of anticoagulant resistance should influence the choice of active ingredient used.

It can be seen from Figure 2 that there are large areas of the U.K. where we have not sampled rat populations for warfarin resistance testing. Since the survey has been largely responsive to reports of rat control problems, and relies on the presence of relatively large infestations of rats, it is suggested that first-generation anticoagulants, such as warfarin, can be successfully used for control of rats on agricultural premises in more than 50% of the land area of England and Wales. Neither the authors' laboratory, nor any other organization, has routinely sampled rats from urban areas in the U.K. for the purposes of resistance testing. Reports of rat control problems in urban areas are not routinely investigated, and only two samples of rats have been subjected to laboratory tests for resistance. It is, therefore, difficult to comment on whether anticoagulant resistance is currently a serious problem in urban areas of the U.K.

The data in Figure 2 show, however, that many populations of rats in rural areas of central southern and southeast England included significant numbers of warfarin-resistant individuals. It is also interesting to note

that some samples of rat populations that included warfarin-resistant individuals were from locations (Figure 2) remote from the known foci of resistance (Figure 1). This may indicate that warfarin-resistant rats have been transported to those farms from other parts of the country. Alternatively, warfarin-resistant rats may have been common in neighboring populations, but effective control was achieved with second-generation anticoagulant rodenticides and problems were not, therefore, reported.

### Difenacoum Resistance

The results of testing 909 warfarin-resistant rats for resistance to difenacoum between 1988 and 1995 are shown in Figure 3. In 1988 and 1989 difenacoum resistance was determined by survival of a feeding test (Redfern and Gill 1978), and the results in Figure 3a for 11 locations (183 rats) are grouped on the principle that <10% (3 farms; open circles), 10 to 50% (7 farms; shaded circles), or >50% (1 farm; filled circles) of rats survived.

The new BCR test for difenacoum resistance (Gill et al. 1993) used from 1990 onwards had a number of advantages over the feeding test, including the possibility of testing difenacoum-susceptible animals for resistance to bromadiolone and other anticoagulants. The authors have grouped the results for 79 locations shown in Figure 3b into those samples where the mean PCA value of all (warfarin-resistant) rats tested was <10% (23 farms; open circles), between 10 to 50% (35 farms; shaded circles), and >50% (21 farms; filled circles). The data presented by Gill et al. (1993) showed that rats with PCA values of <10% on day 4 after administration of difenacoum were unlikely to survive feeding on 0.005% (w/w) difenacoum for five days, and that when PCA values were 50% then >50% and >70% of male and female rats survived, respectively. Using mean PCA values for population samples can be criticized on the grounds that BCR may not have been normally distributed within the sample, and the mean values were not, therefore, wholly representative. The only method to fully illustrate the data would be to use histograms of the results of BCR tests on rats from each location. Mean PCA values do, however, reflect the distribution of BCR within the sample. By dividing the samples into three broad categories the authors believe that this is the best means of concisely presenting the data. Thus, the three categories illustrated in Figure 3b could be considered as locations where difenacoum-susceptible rats predominated, where some rats in the population had a low degree of resistance to difenacoum, or where they had a high degree of resistance to difenacoum.

Difenacoum-resistant rats were first identified in central southern England (Redfern and Gill 1978; Greaves et al. 1982), and it was from this area that rats were sampled which had the highest degrees of difenacoum resistance. Several factors have been identified (Quy et al. 1992a, 1992b) that may have detrimental effects on control of rats on farms in central southern England, but there is evidence of selection pressure favoring difenacoum-resistant rats (Cowan et al. 1995). That same report also concluded that control of these rats with difenacoum did not represent a practical problem, although that was based on trials carried out on farms





Figure 3a. Location of rat populations sampled between 1988 and 1989 and tested for resistance to difenacoum by feeding 0.005 (w/w) difenacoum for five days (Redfern and Gill 1978).

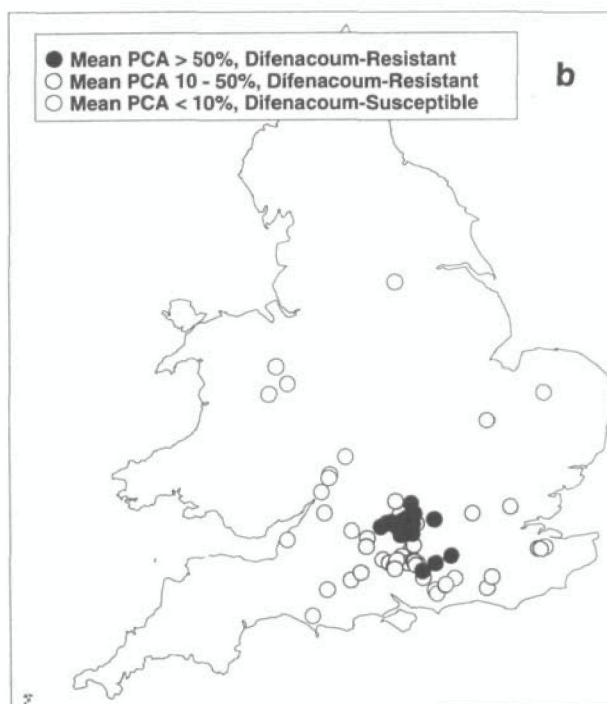


Figure 3b. Location of rat populations sampled between 1990 and 1995 and tested for resistance to difenacoum by blood clotting response to sub-lethal dose of difenacoum (Gill et al. 1993).

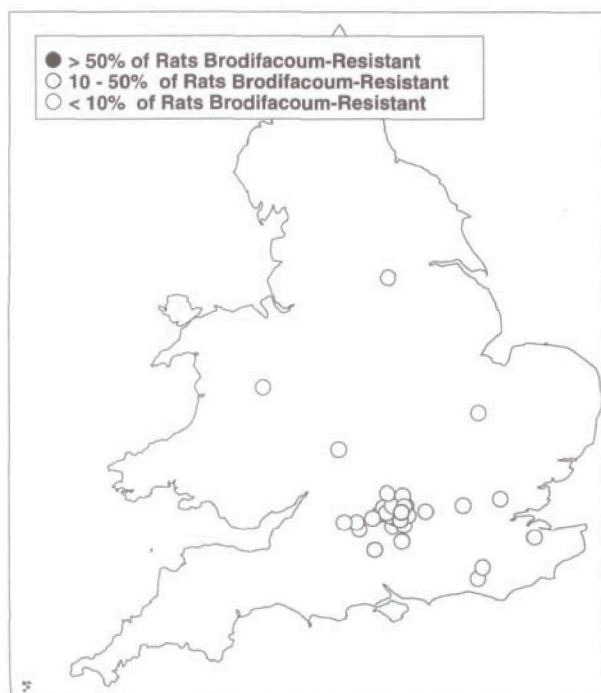


Figure 4. Location of rat populations sampled between 1988 and 1995 and tested for resistance to brodifacoum.

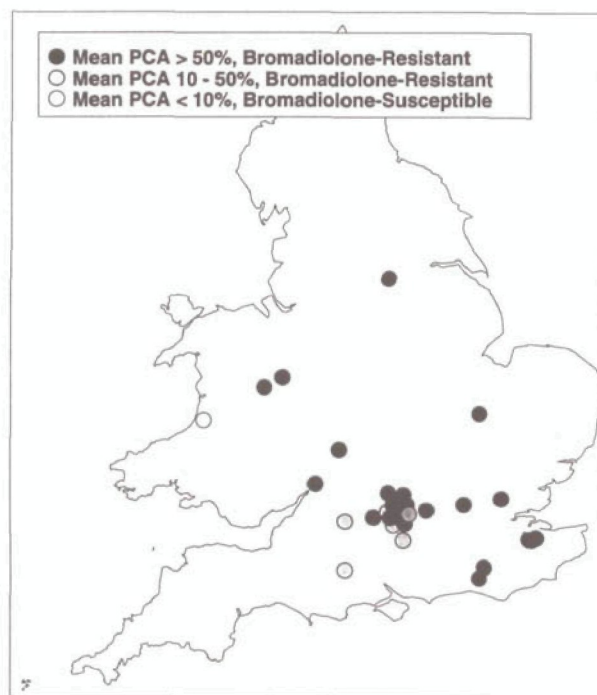


Figure 5. Location of rat populations sampled between 1991 and 1995 and tested for resistance to bromadiolone.

with rat populations within the category of a low degree of resistance to difenacoum. Figure 3b indicates that rats with the highest degrees of resistance to difenacoum were in the north of this area, where resistance may have a greater influence on the outcome of rat control on farms. Outside of central southern England it would appear that rats on agricultural premises are susceptible, or at worst have only a low degree of resistance, to difenacoum.

#### Brodifacoum Resistance

The data presented in Figure 4 summarize the results of brodifacoum resistance testing of 462 difenacoum or bromadiolone-resistant rats in 41 samples of farm rat populations trapped between 1988 and 1995. The results were categorized as <10% (37 farms; open circles), or 10 to 50% (4 farms; shaded circles) of rats surviving a brodifacoum resistance feeding test.

Figure 4 shows that samples from most farms contained <10% of individuals that were resistant to brodifacoum, even though those rats were difenacoum or bromadiolone-resistant, indicating that infestations should be successfully controlled with brodifacoum. Significant numbers of brodifacoum-resistant rats were only detected on four farms in a relatively small area of central southern England. Unfortunately, the authors have not been able to carry out field trials with brodifacoum in that area, and cannot assess the impact of an apparently low degree of brodifacoum resistance on control success or failure.

#### Bromadiolone Resistance

Between 1991 and 1995, approximately 600 warfarin-resistant rats were tested for bromadiolone resistance using a BCR test (Gill et al. 1994). The samples of rats from 41 locations shown in Figure 5 were categorized as described above for Figure 3b, i.e., locations where the mean PCA value for the sample was <10% (1 farm; open circles, bromadiolone-susceptible), between 10 to 50% (11 farms; shaded circles, a low degree of bromadiolone resistance), and >50% (29 farms; filled circles, a high degree of bromadiolone resistance).

This is the first time that widespread sampling of rats has been carried out in the U.K. for the purpose of bromadiolone resistance testing. The data in Figure 5 show that warfarin-resistant rats trapped from populations in different parts of England and Wales also had high degrees and/or high prevalence of resistance to bromadiolone. The population of bromadiolone-susceptible rats sampled in west Wales were the warfarin-susceptible rats tested to validate the BCR test (Gill et al. 1994). In central southern England some samples of rats were categorized as including rats with a low degree of bromadiolone resistance. This corresponds to locations where the rats also had low degrees of resistance to difenacoum.

A field trial on a heavily rat-infested farm in central southern England showed that a 23-day control program using surplus baiting with 0.005% (w/w) bromadiolone had little impact on the size of the population (Quy et al. 1995). Rats that had survived this treatment were sampled by trapping, and bait label analysis indicated that 51% (n=63) had eaten more than 100 g of bait. Laboratory tests showed that the rats had a high degree of

resistance to bromadiolone, and it was concluded (Quy et al. 1995) that the study provided the first unequivocal demonstration of control failure with a multiple-feed second-generation anticoagulant that was attributable to resistance. The BCR of rats sampled from farms within a few miles of the study site indicated that they also had high degrees of resistance to bromadiolone, which suggests that it may also have been difficult to control rats on neighboring farms with bromadiolone.

#### Flocoumafen Resistance

Use of a new BCR test for flocoumafen resistance began in 1995. Of the 159 difenacoum and/or bromadiolone-resistant rats from 14 locations tested for flocoumafen resistance, only two samples, from central southern England, included rats that had resistance to flocoumafen. In one sample only 1/9 rats tested had a low degree of resistance to flocoumafen. All six female rats and 3/10 male rats tested from a second farm apparently had significant degrees of resistance to flocoumafen.

#### Cross-resistance to More Than One Anticoagulant Rodenticide

The testing regime used in the laboratory begins with testing for resistance to warfarin, as a representative of the first-generation anticoagulant rodenticides. The results of many studies over the last 20 years have shown that warfarin-susceptible rats are susceptible to the whole group of anticoagulant rodenticides. The results presented in this paper indicate that 27% (21/79) and 71% (29/41) of populations of warfarin-resistant rats sampled included rats that had high degrees of resistance to difenacoum or bromadiolone, respectively.

Only 12 samples from central southern England (e.g., the study site used by Quy et al. 1995) included rats that had a high degree of resistance to both difenacoum and bromadiolone. Some of those rats also had a low degree of resistance to brodifacoum. Apart from in this small area, it should be possible to achieve control of warfarin-resistant rats using difenacoum or bromadiolone as appropriate, especially where the rats have only a low degree of resistance to these rodenticides. Nevertheless, the possibility of selecting higher degrees of resistance to anticoagulants should not be ignored.

Although there is no published test for resistance to diphacinone, 11 warfarin-resistant rats were tested in one sample from central southern England by feeding 0.005% (w/w) diphacinone for five days without alternative food. Ten of the rats survived more than three weeks after the end of the feeding period, each having eaten more than 85 g of the diet containing diphacinone. The farmer had been using a bait containing the same concentration of diphacinone in an attempt to control rats on his farm, but the authors' results indicate that those attempts were unlikely to be successful.

#### Temporal Changes

Although the authors' laboratory has been monitoring resistance to anticoagulant rodenticides in England and Wales for 30 years, it is not possible to make significant conclusions on temporal changes. Most apparent changes in resistance status arise following the introduction of a

new compound, application of a new test or sampling of rats from a new area. Early studies indicated that migration of warfarin-resistant rats, and continued selection, resulted in an apparent radial distribution of three miles per year from a focus of resistance (Drummond 1966). If the results of the present study are compared to earlier reports (Greaves et al. 1982), it is clear that the already extensive distribution of difenacoum-resistant rats in central southern England has not increased by three miles a year in any direction over the last 12 to 15 years. Studies are in progress to assess the deleterious effects of anticoagulant resistance genes on the fitness of rats in this area, which may help explain why they have not apparently spread further afield. Alternatively, there may be ecological factors in the area that favor large rat infestations requiring frequent control with anticoagulant rodenticides, which causes heavy selection pressure towards anticoagulant resistance.

#### Future Work

In 1995 the authors' changed their tactic for selection of rat populations to be sampled up to 1998. Rather than responding to reports of control problems, the aim was to sample rat populations in areas of England and Wales not extensively sampled in the past. Because previous results indicated that anticoagulant-resistant rats were found most frequently on pig or poultry farms, the authors preferentially selected those types of farms for sampling.

Early results from 1995 showed that warfarin-resistant rats were present on one farm in south-west England, and on one farm in the east. The small number of rats trapped on these two farms (two and three, respectively) indicated that the populations were small, and that there were not serious control problems. Testing for resistance to second-generation anticoagulants has not been completed.

The results of a survey between 1995 and 1998 will provide further insight into the distribution and significance of anticoagulant resistance in the U.K.

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# PLANT SECONDARY CHEMICALS AS NON-LETHAL VERTEBRATE REPELLENTS

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**ABSTRACT:** Few effective repellents are currently available for the non-lethal management of vertebrate pests. This is perhaps not surprising considering the ad hoc nature of past applications which assumed that the target pest species would have the same attraction/aversion preferences as man. A more rational approach is to identify compounds that have real biological significance for the pest species. Plants have evolved an array of defense chemicals (secondary plant compounds) that inhibit the feeding of vertebrate herbivores, because they are either innately aversive or they generate a conditioned aversion. These compounds are, therefore, ideally suited for use in the reduction of feeding damage to crops, forest plantations and stored food products. Several of these novel plant-derived materials (e.g., cinnamamide) are already undergoing commercial evaluation. This approach facilitates the use of a number of systems to increase a plant's resistance to attack: topical application of the defense compound, systemic stimulation of the plants own resistance mechanisms and genetic enhancement. The two latter systems will enable the utilization of potent repellents that are not commercially viable for topical application and to concentrate their expression in the most palatable and vulnerable tissues. This paper also discusses work undertaken to improve our knowledge of the feeding strategies of target species. A proper understanding of these behaviors is essential before it will finally be possible to predict the field conditions under which a repellent will be effective.

**KEY WORDS:** chemical repellents, pest management, aversive conditioning, food aversion, birds, mammals

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## INTRODUCTION

Plants are a promising source of pharmacologically active compounds including a number which can be used to manipulate the behavior of animals. This paper examines the potential of plant-derived compounds as non-lethal repellents for the management of pest species. This includes a review of the types of plant-derived repellents available, their mode of action, methods of application and factors which influence their efficacy in the field.

## WHY REPELLENTS?

Traditional methods of reducing pest problems by population control are becoming increasingly controversial in terms of humaneness and target specificity. Active-hunting methods are labor-intensive and, therefore, rarely cost-effective, and there are only a few examples where such control programs have been successful (Gosling and Baker 1989). Poison baiting is the most widely used method of lethal control. However, the use of poison has four major disadvantages: 1) control is only temporary as the area is often rapidly re-invaded by the target species; 2) the target species may develop a resistance to the bait formulation; 3) the bait may not be accepted in the presence of other familiar alternative foods; and 4) there is the risk of inadvertent poisoning of non-target species (Sullivan et al. 1988).

Repellents offer an alternative, non-lethal method of reducing damage by pests, by causing the animal to avoid certain foods or vacate a given area. For vertebrate pests, repellents can be visual (e.g., scarecrows), auditory (e.g., ultrasound), physical (e.g., netting, electric fences), or chemical (e.g., cinnamamide, methyl anthranilate) (Mason and Clark 1992). Physical exclusion techniques

are often costly to install and maintain, while audio and visual scarers are either ineffective or the initial aversion is rapidly overcome owing to the lack of reinforcement of the stimuli (Lund 1988). In some cases the animal may even learn to associate the stimuli with a good food source, and what was an aversive stimulus becomes an attractive one (I. R. Inglis, pers. comm.). Chemical repellents, if used appropriately in relation to the biology of the target species, are less likely to be compromised by these effects.

## SOURCES OF CHEMICAL REPELLENTS

Chemical repellents, often in combination with other pest management techniques, are now taking their place in the environmentally friendly scheme of integrated pest management (Feare 1995). However, it seems likely that they have yet to reach their full potential for a number of reasons. The development of this field was initially stalled by our limited knowledge of pest behavior and the parameters which determine the efficacy in the field of any putative repellent. Compounds were put forward as candidate repellents simply on the basis that they tasted bad to humans. These compounds, such as the bitter agent denatonium benzoate, have limited effectiveness with rapid habituation and, thus, poor performance in the absence of high quality alternative food (Nolte et al. 1994). Other strategies for the selection of a repellent involved screening of compounds from other agricultural applications such as insecticides (Woronecki et al. 1981) and fungicides (Avery and Decker 1991). These chemicals rely on sub-lethal toxic effects to establish aversions to their taste and as a result birds may ingest a lethal dose while learning to avoid the food (Crocker and Perry 1990).

A more rational approach to the search for effective repellents is to consider materials that are biologically meaningful for the target species. Recent successes in the identification of effective molecules are the result of detailed study and exploitation of the semio-chemicals involved in inter- and intra-specific chemical communication. A number of these repellents have found commercial application (Sullivan et al. 1990b). These compounds function as warnings that an aggressive conspecific (scent marks: Novotny et al. 1993) or a predator (predator odors: Sullivan et al. 1990a; Woolhouse and Morgan 1995) is close by. It is, therefore, likely that habituation to these aversive chemical signals will be slow. However, both conspecific and predator odors may require reinforcement by encounters with live animals to have a long-term effect (Muller-Schwarze 1994). Semio-chemical repellents are likely to be more effective in applications that seek to reduce general activity in an area, e.g., moles (*Talpa europaea*) (Gorman and Stone 1989). Many pest management problems, however, relate to consumption of food crops, trees and stored food products by, for example, rabbits (*Oryctolagus cuniculus*), voles (e.g. *Microtus agrestis*), and pigeons (*Columba palumbus*) (Gill 1992a; Lane 1984). A number of plant secondary compounds, in contrast to semio-chemicals, have evolved to protect the plant against such damage. One could thus take advantage of the "arms race" between plants and herbivores and identify chemicals whose specific function is to repel animals from eating plant material.

#### WHY PLANT DEFENSE COMPOUNDS?

Plants are continuously exposed to attack by vast numbers of pest organisms and as a consequence have evolved an array of defense systems for their protection. A number of these systems have a profound effect on food-plant selection by herbivores (Provenza 1995). These defense systems can be divided into those based on physical and morphological adaptations (e.g., thick cell walls, seed coats, thorns and hairs) and those based upon biochemical adaptations (secondary compounds). It is the latter group which are the most promising potential source of vertebrate repellents.

These secondary metabolites may be unpleasant to taste, poisonous, malodorous, or produce anti-nutritional effects. They can be advertised to the herbivore as exudates on the exterior surface or be located within the plant, to be released only when the tissue is damaged. In many cases these substances protect the plant from damage without causing the herbivore any significant, long-term harm. This may reflect a balance that must be maintained in order to minimize any selection pressure on the herbivore: The rate of adaptation of a herbivore to a plant defense-characteristic will be slower when it has less effect on herbivore fitness (Gould 1988). Consequently, many of the defense chemicals produced by plants can be exploited as agents for the non-lethal management of pests.

Not all secondary metabolites are equally effective as defenses against herbivory, and none provides complete protection (Reichardt et al. 1987). Identification of potential repellents is made difficult because the causal

relationship between inhibition of feeding and the presence of a class of secondary metabolite (e.g. resins, phenolics, tannins and alkaloids) can be hard to prove. Phytochemicals belonging to similar chemical classes do not necessarily have similar activities; camphor contributes to the defense of white spruce (*Picea glauca*), but the structurally related monoterpene, bornyl acetate, is ineffective (Sinclair et al. 1988). The situation is further complicated by the additive or synergistic effects of different metabolites and the spatial and temporal variations in their secondary metabolite chemistry. In addition, animals have evolved anatomical, physiological and behavioral strategies to counter these plant defenses (Lindroth 1988).

The range of secondary metabolites is immense; there are as many as 30,000 plant secondary compounds that were originally thought to be waste products but many are now suspected of having a defensive role (Harborne 1982). The three main classes within this natural armoury are: phenols, nitrogen-containing compounds, and terpenoids.

#### PHENOLS

Phenolic compounds are a diverse class of phytochemicals. They range from simple compounds such as phenol and the hydroxy-cinnamic acids, through complex anthocyanin pigments to the polymeric condensed tannins. With regard to mammalian and avian herbivory, the plant polyphenols that have attracted the most attention are the tannins. These polyphenols deter feeding primarily because of their characteristic astringency and anti-nutritional effects (Cooper and Owen-Smith 1993; Bennett and Wallsgrave 1994). Low molecular weight phenols also have a protective role as feeding deterrents (Greig-Smith and Wilson 1985). Capsaicin, the pungent principle found in Capsicum peppers, is a highly effective mammalian repellent causing irritation to the oral cavity (Mason et al. 1991; Mason et al. 1992). Snowshoe (*Lepus americanus*) and mountain hares (*L. timidus*) do not feed on balsam poplar (*Populus balsamifera*) twigs because of the presence of 2,4,6-trihydroxydihydrochalcone (Reichardt et al. 1990b) and the extremely low palatability of the Alaskan green alder (*Alnus crispa*) is due to two related compounds, pinosylvin and pinosylvin methyl ether (Clausen et al. 1986). Platyphylloside, a phenolic glycoside, strongly inhibits the digestion of the apical twigs of *Betula pendula* by ruminants (Palo et al. 1985). In willows (*Salix* spp.) an array of phenolic glycosides such as salicortin, acetyl salicortins, picein, and saldroside deter feeding by mammals (Tahvanainen et al. 1985). A number of phenolic glycosides are metabolized when the plant tissue is disrupted, producing compounds (e.g., trichocarpogenin and 6-hydroxycyclo-hexanone) that deter feeding of hares on quaking aspen (*Populus tremuloides*) and balsam poplar (Clausen et al. 1989; Reichardt et al. 1990b). Coniferyl and cinnamyl derivatives, which are found at high concentrations in plant resins (e.g., *Styrax tonkinensis*), bud scales and seed husks, have been shown to deter feeding in a number of bird species (Jakubas et al. 1992; Avery and Decker 1992).

## NITROGEN-CONTAINING METABOLITES

The distribution of nitrogen-containing metabolites in plant families is relatively sporadic. One reason for this restricted distribution is that the supply of nitrogen to the plant is often limited. Even when these compounds are produced by plants in response to herbivore damage their production is limited. However, in the plants where they are found, their low concentration is offset by their high potency (Barbosa and Krischik 1987).

Alkaloids are found in the leaves, leaf buds, and seeds of a small number of plant families, most notably the Leguminosae, Liliaceae, Solanaceae and Amryllidaceae. There is strong evidence in the literature that the primary role of all alkaloids is one of chemical defense (Wink 1987; Bennett and Wallsgrove 1994); the use of nicotine as an insecticide and fungicide demonstrates its value to the defense of the plant. Tissues with high nutritional value, such as seeds, buds, and young leaves, contain high concentrations of these compounds. To exploit these tissues, herbivores have to overcome the bitter taste of these compounds (even at very low concentrations) and cope with the pharmacological effects which include vomiting (e.g., ipecacuanha alkaloids) and anticholinesterase activity (e.g., steroidal alkaloids) (Frischknecht et al. 1986).

Plant proteins may also have a role in plant defense. Trypsin inhibitors from legumes have direct antinutritional activity through their effects on digestive enzymes, although their ability to inhibit feeding by vertebrates has yet to be demonstrated. Lectins are a diverse group of proteins classified on the basis of their ability to bind to specific carbohydrate ligands. The defensive role of lectins relies on their ability to interact with the glycoconjugates, on either the epithelial cells in the digestive tract of nematodes, insects, snails, and higher animals or on the surface of the micro-organisms (Pusztai, 1991). Lectins are found in seeds and vegetative tissue such as tubers, roots, phloem and leaves. The bark of at least two tree species, elderberry (*Sambucus nigra*) and false acacia (*Robinia pseudoacacia*) contain high concentrations of lectins (Peumans et al. 1986). These proteins are powerful aversive agents, causing adverse effects on the stomach and small intestine almost immediately after ingestion and may contribute to the defense of trees against bark stripping by voles and deer (Pusztai et al. 1990).

## TERPENOIDS

The largest and, structurally, the most diverse class of secondary plant metabolites includes the terpenes and the allied sesqui-, di-, tri-, and poly-terpenoid compounds. In addition to their many vital metabolic roles, terpenoids represent a major defense in plants against vertebrates (Reichardt et al. 1990a). These compounds are thought to deter herbivory by reducing palatability and digestive efficiency due to bactericidal effects on gut microbes. The association between feeding aversion and the deleterious effects of terpenoids has been clearly demonstrated. Snowshoe and mountain hares reject terminal parts of birch twigs containing high concentrations of the triterpenoid, papyriferic acid (Reichardt et al. 1984). In addition, D-pulegone, a terpene which can be readily isolated from pennyroyal

(*Mentha pulegium*), has been shown to be highly aversive to birds (Mason 1990). It appears that <1% of the known terpenoids have been investigated for their feeding-deterrent or toxic properties. Thus, the role of terpenoids in plant-herbivore interactions and as a source of new repellents is a fertile field for future research.

## MODE OF ACTION: INNATE OR LEARNED

The aversive response to some repellents is innate, a property that is the result of past evolutionary pressures to develop sensitivity to particular odors or tastes. Foods that are toxic usually taste bitter or cause irritation to the buccal cavity. For example, mammals show aversive orofacial responses to quinine and chili peppers despite having no prior experiences with these tastes (Chambers and Bernstein 1995).

Experience can also play a critical role in the response to a repellent. An initial preference for treated food is reversed when the post-ingestional consequences of eating the food are negative. The compound causes some form of transient upper-gastrointestinal discomfort or illness such as nausea or vomiting, which the individual then associates with the taste of the compound, or, if the compound has no taste, another salient cue within the food (Provenza 1995). The animal then becomes conditioned to avoid that cue in future encounters. In agriculture, this latter type of repellency has been successfully used to induce prey avoidance behavior in mammalian and avian predators (Conover 1990) and to train livestock to avoid certain plant species (Burrit and Provenza 1990).

Innate aversions appear to be weaker and more easily broken than conditioned aversions (Greig-Smith 1985). The effects of ingesting an innately repellent compound are often neutral and consequently any initial aversion may be lost and even reversed following repeated exposure. Millions of people use chili peppers as an essential flavoring ingredient, having "acquired a taste" for the burning sensation experienced following ingestion of the active constituent, capsaicin. Innately repellent compounds also appear to have a narrow spectrum of activity. Compounds that are aversive to mammals (e.g., capsaicin) are not aversive to birds at similar concentrations and vice versa (e.g., methyl anthranilate). This appears to be the result of physiological differences in the oro-sensory systems (taste, odor, trigeminal) of these taxa (Mason et al. 1992). This differential activity has a number of practical applications. For example, methyl anthranilate can be used to treat cattle feed in order to inhibit the feeding of avian pests but not livestock (Mason et al. 1985).

Repellents that are effective against both mammals and birds are unusual, and recent work suggests that such agents should, ideally, have innate activity and be able to generate a conditioned aversion (Crocker and Perry 1990; Gill et al. 1995b). About ten years ago scientists at the UK's Ministry of Agriculture, Fisheries and Food began to investigate the plant chemicals that underlie preferences of one avian pest species, the bullfinch (*Pyrrhula pyrrhula*) for varieties of pear-tree (*Pyrus communis* var. *sativa*). The flower-buds of certain varieties of pear-tree were prone to attack while other varieties, in the same orchard, remained undamaged. Captive birds were

presented with seeds treated with flower-bud extracts from a number of cultivars. There was a clear inverse relationship between the concentration of one class of phenolic compounds, the cinnamic acids, and the palatability of the flower-bud extract (Greig-Smith 1985). When these compounds and their derivatives were presented individually to the birds, several proved to be effective feeding deterrents both in the laboratory and in the field (Crocker and Reid 1993; Watkins et al. 1995).

The response to cinnamamide, the most potent cinnamic acid derivative, has been studied in detail. Cinnamamide, produces an instant (innate) aversive response in birds, consumption falling to 20% of normal consumption when treated food was first presented (Figure 1). However, studies with the chestnut-capped blackbird (*Agelaius ruficapillus*) and rock doves (*Columba livia*) suggests that the compound also has post-ingestional activity (Gill et al. 1994; Watkins et al. 1995). Birds show behavioral signs of malaise following ingestion of treated food and at high concentrations (>0.26% w/w) the palatability of the food is reduced following repeated exposure, a response indicative of a conditioned aversion. It is, therefore, unlikely that there will be an extinction in the response to cinnamamide since the animal will incur some form of physiological cost if it ignores the oral stimulus.

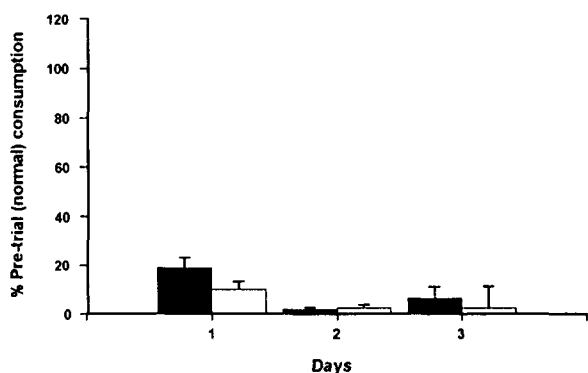


Figure 1. Mean percent normal (pre-trial) consumption ( $n = 5$ ) of cinnamamide-treated food (0.8% w/w) by rock doves (*Columba livia*) over the course of a three-day short-term, no-choice trial. For experimental protocol refer to Watkins et al. (1995).

In contrast, the response in mice (*Mus domesticus*) was delayed, indicative of a conditioned aversion. Consumption of cinnamamide-treated food (0.8% w/w) remained at normal (pre-trial) levels for a short period (three hours) before a marked decline to 17% of normal (pre-trial) consumption was observed (Figure 2). This observation was confirmed by subsequent experiments where animals intubated with cinnamamide (160 mg/kg) developed a strong and persistent aversion to what had been a preferred flavor (saccharin). Subsequently, this aversion remained undiminished for the entire course of the trial (64 days) (Watkins et al., in prep.).

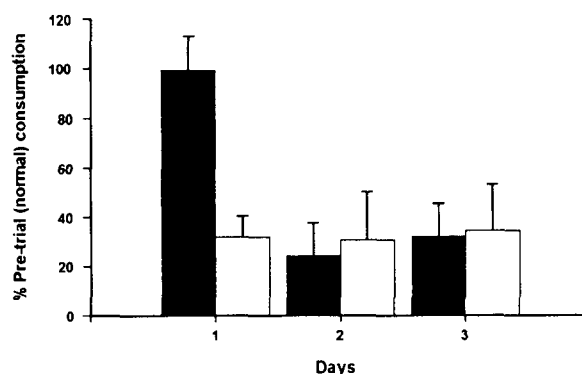


Figure 2. Mean percent normal (pre-trial) consumption ( $n = 6$ ) of cinnamamide-treated food (0.8% w/w) by house mice (*Mus domesticus*) over the course of a three-day short-term, no-choice trial. For experimental protocol refer to Gurney et al. (1996).

## APPLICATIONS

Non-lethal repellents derived from plant secondary compounds potentially have many agricultural and environmental applications (Mason and Clark 1992) and several are undergoing commercial evaluation. Topical applications of these repellents are being used to prevent bird damage to crops (Cummings et al. 1995; Gill et al. 1995a), inhibit non-target wildlife from consuming potentially toxic granular pesticides and chemically treated seeds (Mason et al. 1993; Watkins et al. 1996b), and prevent gnawing damage to electrical cables by rodents (Kurata et al. 1994).

However, the use of topical applications can be problematic: some compounds have poor persistence, due to weathering and chemical/biological degradation, and spray formulations often do not penetrate the crop canopy to protect the most palatable and vulnerable tissues (e.g., meristem). The choice of secondary compounds opens up opportunities to overcome these issues by helping plants to help themselves. The levels of secondary compounds in plants can increase significantly within a few hours of being damaged by the herbivore. These induced defense systems have been studied extensively in response to microbial infection and insect feeding (Bennett and Wallsgrave 1994). However, until recently, the dynamic defense response to grazing by vertebrates has received little attention. New studies have demonstrated that the production of phenylpropanoids, a class phenolic compound commonly found in plants, can be stimulated by the systemic application of metabolic precursors. The phenolic precursor, L-phenylalanine, when applied as a solution to the roots, was observed to increase significantly the phenolic pool in oilseed rape to 13% above the levels determined for the control plants. These treated plants were significantly more resistant to damage by feral pigeons than untreated plants (Scanlon et al. in prep.). This, to our knowledge, is the first report of increased resistance to vertebrate pest damage following systemic application of precursors for plant defense compounds.

This approach can potentially be taken one stage further. Breeding for resistance against pests is being pursued by farmers because modern, intensively managed plantations often represent a sizeable investment to the grower. As a result, growers are now focusing their attention on novel damage alleviation mechanisms, in particular the genetic enhancement of resistance by selective breeding and biotechnology. The enhancement of resistance to vertebrate damage by screening for resistant cultivars such as bird-resistant forms of sorghum and sunflowers (tannic acid and related astringents) (Greig-Smith 1985) and herbivore-resistant tree provenances (terpenes and phenols) (Gill 1992b) continues apace. The use of genetic insertion technology in this area is still in its infancy. However, this technology should enable us to utilize defense compounds that cannot be synthesized *in vitro* and has the potential to rapidly increase the fitness of the planting stock, as it has done for disease and invertebrate resistant plants (Boulter et al. 1990; Coghlan 1996). This, in turn, will be reflected in a reduction in the cost of establishing crops, an improvement in the yield and quality of the final product, and a reduction in the application of potentially toxic pesticides.

Plant secondary compounds have the potential to provide effective and humane solutions for the management of pest species. Previously, however, the effectiveness of an application may have been compromised in relation to the foraging behavior of the target species. For any application to be successful the costs imposed by the repellent on an animal (e.g., internal malaise) must be high enough to encourage the animal to change its foraging goal and seek alternative food or harborage. Foraging costs can be manipulated by using a more "aggressive" repellent and/or providing a more favorable foraging alternative, from an animal's point of view, as a diversion. It may be unnecessary to treat the whole crop to make foraging elsewhere a more beneficial option for the pest species. For instance, many species prefer to feed at the edge of crops to minimize the risk of predation. Treatment of only the edge of the crop can reduce total damage as the animals choose safer but, perhaps, less nutritious alternatives (Gill et al. 1995b). The development of optimal foraging models that have the potential to address the question, "Under what conditions will the repellent be effective?" demands that investigators take a more holistic approach to their research. Both the physiological cost imposed by the repellent and the cost-benefit decisions that animals have to make when foraging for food in the natural environment need to be defined. In the case of plant-derived repellents, it is fortunate that much of this information can be gleaned by studying the impact of herbivores on plants which already utilize the compound in their defense.

In conclusion, many of the plant secondary compounds described above merit further investigation with the aim of producing commercially viable non-lethal applications that can compete and/or complement established control techniques. If this goal can be achieved, we can look forward to a benign but powerful armory of natural weapons against vertebrate pests.

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# IMPROVED SEALANTS FOR M-44 CYANIDE CAPSULES

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**ABSTRACT:** The M-44 sodium cyanide ejector is one of the most important tools used by the Animal Damage Control (ADC) program to protect livestock from coyotes. Unacceptable performance of M-44 cyanide capsules due to inadequate seals stimulated research to develop a better capsule sealant. Comparative tests of crude beeswax, Scheel SC-100 wax, and other materials revealed that capsules sealed with SC-100 were most resistant to deterioration in adverse environments. Based on these results, SC-100 wax was selected as the sealant of choice. Beginning in April 1989, all M-44 capsules made for ADC program use have been sealed with SC-100 wax. Since that date, the average number of capsules sold annually for ADC use is 15% lower than it was before 1989 even though the numbers of coyotes taken by M-44s each year has nearly doubled. The improved sealant appears to have increased the service life and effectiveness of M-44 cyanide capsules.

**KEY WORDS:** predacides, canids, coyote, control methods, M-44, sodium cyanide.

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## INTRODUCTION

Sodium cyanide (NaCN) ejectors have been used to kill coyotes and other wild canids for more than 50 years. The Humane Coyote Getter® was used from about 1940 through the 1960s, followed by the safer, spring-activated M-44 cyanide ejector from 1970 to 1972 and again from 1975 to date. During most of these 55 years, the effectiveness of cyanide ejector devices has been compromised by several chronic problems including poor cartridge or capsule seals.

When set in the field, the M-44 ejector device holds a cyanide capsule that contains approximately 1 gram of a powdered or granular NaCN mixture. When a target canid activates the device by biting and pulling it, NaCN mixture is expelled rapidly from the capsule into the mouth of the animal. The dry powder reacts with moisture to produce hydrogen cyanide gas which kills the animal quickly; the time to death for coyotes is 90 to 150 seconds (Connolly et al. 1986).

All NaCN ejectors and capsules used by the ADC program are made at the Pocatello Supply Depot (PSD) in Pocatello, Idaho and are shipped to ADC offices where they are stored until needed in the field. With this supply system, the capsules typically are not used in M-44 ejectors until they are several months old. Once an M-44 is set, it may remain in place for many weeks or months before being pulled by a target canid. Thus, the capsule seal must maintain its integrity through many months of shipment, storage, and field exposure.

If the seal is defective or is damaged at any time during these many months, moisture will enter the capsule and react with the NaCN mixture to form a solid "cake." In time, the caked mixture will degrade into a discolored liquid. Caked or liquified NaCN mixtures are relatively unreactive and, when ejected, usually will not kill the target canid. Thus, an effective capsule seal is essential to the efficacy of this device.

ADC specialists' reports of poor M-44 performance stimulated research on M-44 improvement beginning in 1981. A team of specialists from ADC operations, research, and PSD identified and solved several of the

problems that were responsible for poor M-44 performance. The first experiment revealed that inadequate capsule seals were a major problem (Connolly and Simmons 1984). Subsequent study showed that the addition of beeswax on top of 3M #4693 adhesive (the standard sealant used before 1983) improved capsules significantly (Connolly and Simmons 1983).

Beginning in August 1983, all M-44 capsules made by PSD were finished with a hot beeswax seal. Melted beeswax was applied by gravity flow from a heated container in which wax temperatures varied between 133 to 166°C with an average of 154°C (DWRC, unpublished data, October 6, 1987).

Subsequent experience showed that hot beeswax, though superior to the 3M adhesive, was not a complete solution. Long-term weathering studies demonstrated that capsule seals were more likely to deteriorate during shipment and storage than in actual field use. Beeswax seals were found to be vulnerable to damage if the capsules were exposed to ambient temperatures over 140°F, a level often reached in closed tool boxes on warm, sunny days in the western U.S.

Late in 1986, PSD changed the capsule sealant from crude beeswax to a refined, white beeswax. At the time, there was no basis to think that such a change would affect capsule quality. However, increased numbers of field complaints stimulated an investigation in 1987. Ultimately, it was found that white wax seals were inferior to crude beeswax seals, possibly because the white wax melted at a lower temperature. This experience resulted in a new research initiative aimed at identifying a better sealant for M-44 cyanide capsules.

Screening of candidate sealants, followed by rigorous evaluation of the best candidates, resulted in the identification of two materials that were superior to beeswax. One of these—SC-100 (Scheel wax 100, Scheel Corporation, Brooklyn, NY)—was recommended for immediate adoption. All M-44 cyanide capsules produced since March 1989 have been sealed with this product. This paper summarizes the research effort that resulted in the identification of Scheel SC-100 wax as a superior

M-44 capsule sealant and reviews subsequent ADC program experience with the improved M-44 capsules.

## PROCEDURES

### Criteria For An Effective Seal

The first step in evaluating M-44 capsule sealants was to develop written criteria for an acceptable seal. An acceptable sealant must:

- Adhere to the polyethylene (high DIN, Marlex 6050, Phillips, or equivalent) from which M-44 capsules are made.
- Produce a water-tight seal lasting a minimum of one year from date of application, under all environments encountered in manufacture, shipment, storage, and use of M-44 cyanide capsules.
- Release instantly or not hamper ejection when the M-44 is pulled by a target animal.
- Be odor free, or the odor must neither repel target animals nor attract nontarget animals or insects.
- Be affordable, readily available, safe to workers, easy to apply, and fast drying (within 24 hours).

### Identification of Candidate Sealants

Samples of sealants to meet the criteria stated above were solicited from commercial manufacturers of sealing waxes. In addition, materials previously identified as potential sealants were considered. In all, nine products were evaluated including crude beeswax, refined white beeswax, and seven new materials. Six products soon were dropped based on preliminary testing and are not further discussed in this paper. The candidate sealants retained for rigorous evaluation were:

- Crude beeswax (BW) procured from local sources in the vicinity of Pocatello, Idaho.
- Daige Speedcote, Type BB9, pressure sensitive adhesive wax (Daige products, Albertson, NY).
- Scheel SC-100 microcrystalline, petroleum hydrocarbon wax (Scheel Corp., Brooklyn, NY).

### Evaluation of Candidate Sealants

The relative effectiveness of candidate sealants was evaluated by comparing the resistance of capsules sealed with each material to a series of environmental challenges. Following preliminary trials that are not detailed in this report, 600 capsules were filled with NaCN mixture on the PSD production line for a definitive evaluation. Two hundred capsules were sealed with each of the three materials listed above—Crude BW, Daige, and SC-100. In all other respects they were standard M-44 cyanide capsules as routinely produced for use by ADC personnel.

The 600 capsules were subjected to five rounds of increasingly severe environmental challenges over a six-week period during November-December 1988 at a DWRC research station in southern Idaho. Treatments proceeded as follows:

Round 1: Capsules (200 per sealant) were placed in a laboratory oven at 54°C for 5 hr, followed by 26 hr in a freezer at -17 to -20°C, followed by 3 hr in a water bath beginning at 40°C and cooling to 27°C. After air drying for 2 hr at 14.5°C, the capsules again went into the oven at 38°C for 2.5 hr. After overnight cooling to

ambient temperature, 25 capsules per sealant were examined.

Round 2: Capsules (175 per sealant) were placed in the oven at 52°C for 5 hr, followed by 18 hr in freezer at -15°C, followed by 3.5 hr in water bath beginning at 41°C and cooling to 26°C. After draining at ambient temperature, they again went into the oven for 23 hr at 40°C. During this treatment, open pans of water also were kept in the oven to maintain high humidity. After three days at ambient temperature (10-20°C), 25 capsules per sealant were examined.

Round 3: Capsules (150 per sealant) were placed in the oven at 55°C for 6 hr, followed by 1 hr in water bath at 13-15°C. The capsules were then placed outside for five days in late November weather that consisted of rain, snow, and cold temperatures. Fifty capsules per sealant were examined.

Round 4: Capsules (100 per sealant) remained in the outdoor environment for 15 days (until December 14, 1988). They were covered by ice or snow during most of this time. After 24 hr indoors to dry at ambient temperature (22°C), 25 capsules per sealant were examined.

Round 5: Capsules (75 per sealant) were placed in the oven at 62-64°C, followed by 3 days in an outdoor water bath during which time they became frozen within a solid block of ice. The ice block then was brought indoors to thaw 24 hr at ambient temperature (21°C), after which the capsules were spread to air dry. All capsules (75 per sealant) were then examined. The study was terminated at this time because all of the crude BW seals had failed.

The capsules that were selected for examination after each round were first inspected visually and the apparent condition of each top seal was noted. Each seal was recorded as condition 1 (intact; apparently like new), condition 2 (slight deterioration but seal appeared good), or condition 3 (deteriorated and no longer effective). Each capsule then was opened so that the consistency of the NaCN mixture could be assessed as condition 1 (normal dry powder), condition 2 (slight caking), condition 3 (more caking), condition 4 (harder caking), condition 5 (entire capsule contents solidified), condition 6 (cyanide mixture damp or liquid), or condition 7 (contents missing).

## RESULTS

The results of individual capsule examinations were summarized into percentage scores for each group of capsules (Table 1). As expected, all three sealants fared well through round 1 with few adverse effects seen. By the end of round 2, some deterioration was noted for the Daige and crude BW seals. The crude BW seals deteriorated further in round 3. By the end of round 5, all the crude BW seals appeared to have failed and only 15 percent of these capsules retained the cyanide contents in normal, dry condition. Capsules sealed with Daige and SC-100 fared much better. SC-100 appeared much superior to Daige in round 4 but slightly inferior in round 5.

## DISCUSSION

This research identified both Daige and SC-100 waxes as superior M-44 capsule sealants (Table 1). It is

believed the main reason for the superiority of Daige and SC-100 was their higher melting temperature; Daige and SC-100 melt at 170 to 180°F, compared to 140 to 150°F for beeswax. In addition, beeswax was found to shrink as it cooled, whereas Daige and SC-100 did not shrink.

The results of this study were submitted to the PSD manager in March 1989 with a recommendation that PSD immediately switch from crude BW to another sealant for M-44 capsules. Either SC-100 or Daige would have been superior to crude BW, but SC-100 was recommended as the sealant of choice because it scored higher than Daige in most comparisons. In addition, SC-100 had other, minor advantages:

- SC-100 produced less capsule flare (expansion of capsule mouth, a phenomenon associated with all hot wax seals on polyethylene capsules).
- SC-100 was had less odor, so was felt less likely than Daige to be detected by target canids or to repel them.
- Daige remained tacky when cool whereas SC-100 did not, indicating that SC-100 would be less likely to attract dirt under field conditions.
- SC-100 cost \$1.25 per pound, compared to \$6.80 per pound for Daige (September 1987 prices).

As noted previously, all M-44 cyanide capsules produced at PSD since March 1989 have been sealed with SC-100 wax. Experience since that date has confirmed expectations that this change would improve capsule quality; field reports of problems with M-44 capsules have decreased significantly. Nevertheless, occasional reports of defective M-44 capsules continue to be received, indicating that the SC-100 seal has not solved all capsule quality problems. Considering the conditions under which M-44 capsules are used, it may be unrealistic to expect a perfect sealant.

Trends in ADC program M-44 use were examined relative to the timing of research on M-44 improvement. ADC use of M-44s was near an all-time low in 1981 when the original studies began. This was reflected in the relatively low numbers of coyotes, approximately 6,000 to 7,000 per year, taken annually with M-44s by ADC

personnel in FY 1980-82 (Table 2). The coyote take by M-44s increased through the 1980s as improvements to the capsules and other M-44 components were implemented. From a low point in about 1980-82, the ADC coyote take by M-44s nearly doubled by 1989. The take has nearly doubled again since 1989 when the improved M-44 capsule sealant was adopted.

Of particular interest is the fact that the increased coyote take by M-44s since 1989 was achieved without a corresponding increase in the number of M-44 capsules produced (Table 2). The average number of capsules sold by PSD annually since 1989 was approximately 89,000, some 15% fewer than the annual average of about 104,300 capsules sold during 1983-88. Remarkably, this reduction occurred during the same years (FY 1990-95) in which the average annual ADC coyote take by M-44s increased to 23,444, almost double the annual average of 11,934 coyotes taken during FY 1983-88. Thus, the ADC program used an average of about 8.7 capsules per coyote taken by M-44 during 1983-88, but only 3.8 capsules per coyote taken during 1990-95. It appears that the improved capsules in use since 1989 are lasting longer and performing better.

Assuming that ADC's annual coyote take by M-44s during 1990-95 would have been the same with or without the capsule improvements that were implemented in 1989 and that, without those improvements, the number of capsules per coyote would not have changed from 1983-88 to 1990-95, the economic value of the improved capsule seal can be estimated as (cost per capsule) X (capsules saved per coyote taken) X (number of coyotes taken). The current PSD price is \$37.35 per box of 50 capsules, or about \$0.75 each. On this basis, the improved capsule seal has produced average savings of approximately \$86,000 each year since 1989.

Important nonmonetary benefits of the improved capsule seal include increased confidence among ADC specialists and ADC clients that the M-44 will perform as intended, as well as fewer target canids escaping after they activate an M-44 device.

Table 1. Effects of cumulative environmental challenges on the integrity of M-44 cyanide capsules sealed with Daige, SC-100, and crude beeswax.

Treatment Round	Number Examined	Capsules With					
		Intact Top Seals			Normal NaCN Contents		
		Daige (%)	SC-100 (%)	Crude BW (%)	Daige (%)	SC-100 (%)	Crude BW (%)
1	25	100	100	100	100	100	100
2	25	96	100	92	88	100	76
3	50	92	94	58	66	84	60
4	25	96	100	76	12	76	64
5	75	64	63	0	79	64	15

Table 2. Annual ADC program sales of M-44 cyanide capsules and numbers of coyotes taken by M-44 cyanide ejectors, 1980-1995.

Year	Capsules Sold <sup>1</sup> (Calendar Year)	Coyotes Taken (Fiscal Year)
1980	65,766	6,282
1981	59,725	6,123
1982	73,459	6,874
1983	113,250	9,680
1984	115,650	11,577
1985	94,450	11,896
1986	142,450	12,957
1987	71,050	11,826
1988	89,050	13,669
1989	101,050	15,610
1990	100,600	20,872
1991	93,750	24,762
1992	92,149	25,239
1993	84,259	23,183
1994	86,150	23,217
1995	77,236	23,390 <sup>2</sup>

<sup>1</sup>Includes all capsules sold from Pocatello Supply Depot for ADC program use under EPA Registration Numbers 6704-75 and 56228-15.

<sup>2</sup>Preliminary count subject to correction.

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# HOW TO CONTROL A PEST'S PEST—FLEA AND RODENT EFFICACY

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**ABSTRACT:** Fleas have caused health and sanitation problems for centuries. Most rodents are hosts to fleas. Baker Crop Protection Chemicals (BCPC) recently entered the rodenticide market (via SLN) with an efficacious fumigant for single burrow rodents, MAGNACIDE® H Herbicide/Rodenticide (a.i. acrolein). Noting that most burrowing rodents are flea infested, BCPC undertook an experiment to determine if fleas also succumb to acrolein under simulated field treatment scenarios. Results of the study under laboratory conditions demonstrated that fleas do succumb to acrolein treatments as well as the specific rodents targeted for treatment. This study also established rodent death rates from exposure to acrolein in a simulated closed system at 4 to 6 minutes, at a treatment rate of 20 milliliters.

**KEY WORDS:** acrolein, fumigant, fleas, MAGNACIDE®, burrowing rodents, efficacy

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## INTRODUCTION

Baker Crop Protection Chemicals is a division of Baker Performance Chemicals, Incorporated, a Houston, Texas-based corporation. Baker Crop Protection Chemicals specializes in agricultural water treatment. Baker Crop Protection Chemicals (BCPC) entered the rodenticide market in the early 1990s with strong encouragement from both customers and government agencies. The stimulus for entering this market was the loss of other rodenticide products due to registration, environmental and humane treatment issues. Early field efficacy demonstrated 90% mortalities on specific single burrow rodents (pocket gophers, ground squirrels). Ross O'Connell and Jerry Clark, Control and Eradication Specialists with the California Department of Food and Agriculture, presented the results of a field trial using MAGNACIDE® H Rodenticide on the California ground squirrel (*Spermophilus beecheyi*) at the 1992 Vertebrate Pest Conference. "The lower application rate (20 cc) of acrolein was as efficacious as the higher rate. This degree of control (approximately 90%) by either activity index is excellent, and shows the material to be very promising. Acrolein, if registered, used at the 20 cc rate should cost about 13 cents per burrow opening, making it more economical than the other fumigants" (O'Connell and Clark 1992). MAGNACIDE® H Rodenticide has subsequently been registered in California, Washington, Oregon, Nebraska, Utah, Wyoming and Idaho as a Special Local Need--Section 24(c).

Acrolein, the active ingredient in MAGNACIDE® H Rodenticide (92% minimum) is a three carbon aldehyde ( $\text{CH}_2=\text{CH}-\text{CHO}$ ), with a molecular weight of 56.06. It is a clear, colorless liquid with an extremely irritating odor. Acrolein is classified as acutely toxic, based on its acute inhalation  $\text{LC}_{50}$  in rats (26 ppm/1-hr exposure, 8.3 ppm/4-hr exposure). Asphyxiation is the mode of death for single burrowing rodents exposed to MAGNACIDE® H Rodenticide in a closed burrow system. In soil metabolism and dissipation studies, acrolein has a very short half-life (hours) and is readily

metabolized by soil bacteria. Simplified application procedures for the use of MAGNACIDE® H Rodenticide are as follows:

1. Locate the burrow to be treated.
2. Insert nozzle of jet gun assembly.
3. Cover with dirt.
4. Pull trigger--dispense metered dose.
5. Remove nozzle of jet gun.
6. Tamp down soil, if necessary.
7. Repeat application at next burrow.

MAGNACIDE® H Rodenticide has proven to be efficacious with smaller single burrow rodents but the amount of time from exposure to death has not been firmly established. Once a burrow was treated, in many cases it was immediately covered with dirt to increase efficacy, which limited animal retrieval. Many of the carcasses that were retrieved after treatment were flea infested. Since the animal being treated is in a closed environment, the question arises as to whether the acute toxicity of acrolein affect the fleas infesting the animal targeted for treatment. The question of flea control was especially pertinent with recent outbreaks of rodent/flea transmitted respiratory diseases on the Navajo Indian Reservations in northern New Mexico.

The flea has caused health and sanitation problems for many centuries. The rat was the rodent that carried the flea which spread the bubonic plague through Europe, killing at least 25 million people. In more recent times, India has been plagued with flea-infested rats spreading disease. Common rodents that are flea carriers which create commercial, agricultural and residential problems include: Pocket gophers, ground squirrels, prairie dogs, woodchucks, muskrats, chipmunks, tree squirrels, voles or meadow mice, nutria, beavers, deer mice, cotton rats, kangaroo rats, rice rats, wood rats, Norway rats, black rats and house mice.

Fleas are found all over the world. There are an estimated 1600 to 1700 species of flea. The bodies of the fleas are well adapted for their lifestyle; they are small,

wingless insects, flattened from side to side. Adult fleas vary in size from 1/25 to 1/4 inch (1 to 6.3 mm) and are black to brownish black in color. They are relatively good jumpers and have excellent mobility through hair or feathers. Their mouth parts are well adapted for piercing the skin and sucking blood.

The larvae are whitish, legless, blind, wormlike and less than 1/4 inch (6.3 mm) when full grown. The pupae are enclosed in cocoons that become encrusted with soil particles and debris, making them almost impossible to detect. Fleas lay four to eight eggs after each blood meal, (several hundred eggs during a lifetime). The eggs are laid off the host in the dirt, bedding or nest of the host. Occasionally, the eggs are laid by the adult female while on the host, but they eventually fall to the ground or other surfaces. It is interesting to note that fleas can have a delayed hatching time period. The life cycle of the flea is as follows: Eggs⇒Larvae 2 to 3 weeks; Larvae 9 to 200 days⇒Pupae; 7 days to 1 year. The egg, larva and pupal stages are rarely seen. Most fleas require 30 to 75 days to complete a life cycle when optimum conditions exist.

Fleas move about readily on the host and frequently transfer from one animal to another. Adult fleas are long-lived and able to survive several weeks off the host without feeding. Both sexes suck blood (Patrick and Hamman).

The objective of this study, under laboratory conditions, was to answer two questions. 1) How long after application of MAGNACIDE® H Rodenticide does death occur in the rodents? 2) Are the fleas living on the target rodent affected by MAGNACIDE® H Rodenticide?

#### METHOD AND MATERIALS

Study design proved to be challenging since burrowing rodents are not commercially available, flea suppliers are very specialized, acrolein is a very volatile material, and conditions must be simulated so as to give reliable results. The study was undertaken at MB Research Laboratories, Inc., Spinnerstown, Pennsylvania. Mr. Dan Cervan of MB Research Laboratories was the study director and participated in the study design.

One male and one female Wistar albino rat (burrowing rodents are not commercially available) were selected from larger groups of commercially available rodents and received from Ace Animals, Inc. The male weighed 224 grams and the female 225 grams. The weight of the rats was closely simulated to the California Ground Squirrel. Two hundred fleas (*Ctenocephalides felis felis*) were received from EL Labs in separate containers of 100 fleas per container.

Two identical 55 liter glass aquarium-style chambers (60x31x32 cm) with impermeable lids were used for this study. The bottom of each chamber was covered with common soil (obtained from the grounds of MB Research) to a depth of approximately one inch. A mercury thermometer was placed in each chamber to ensure a temperature between 65 and 75°F prior to initiation of dosing. This temperature range would ensure optimum temperature testing conditions.

The male rat was placed in one chamber and the female in the second chamber. One separate vial labeled as containing 100 live fleas was opened and placed in

each chamber. The chambers were immediately covered to prevent escape of the fleas.

The chambers were monitored to ensure that at least 90% of the fleas left the vial and infested the resident rat. The chamber temperature was then recorded and 20 ml of MAGNACIDE® H Rodenticide (acrolein) was poured into the dirt at the bottom of each chamber. The 20 ml rate has been determined by previous field trials (O'Connell and Clark 1992) to give optimum efficacy on this size rodent.

Each chamber was monitored until each rat died, and the time of death recorded. After a period of two hours, each chamber was opened and a flea attractant light and trap (Pulvex Flea Trap Model 2002, Zena Corp.) were placed inside the chambers. The overhead lights in the exposure area were then turned off and the trap allowed to remain in the chamber for one hour.

After one hour, the room was re-illuminated and the chambers, traps and carcasses were visually inspected for flea activity.

This study was conducted in accordance with the applicable Good Laboratory Practices Regulations of the EPA/FIFRA, 40 CFR Part 160.

#### RESULTS

Upon initiation of the study, the fleas were noted to immediately infest the rats. Within minutes of the MAGNACIDE® H Rodenticide administration, the fleas which infested the rats became animated and were noted jumping off the animals.

Both rats succumbed after the introduction of MAGNACIDE® H Rodenticide into each chamber. The male rat died within four minutes, the female within six minutes.

No live fleas were observed in the chambers or on the traps. The fleas were not readily visible nor accessible in the dirt at the bottom of the chamber. All efforts to locate additional live or dead fleas were stopped at the designated time period. There was no evidence of any movement indicative of live flea activity at the one hour time period. The rats were not combed for fleas, but were visually examined by ruffling the fur.

#### CONCLUSION

Under the conditions of this study, the application of MAGNACIDE® H Rodenticide resulted in a quantifiable timed mortality in the exposed rodents (4 to 6 minutes). Fleas exposed during this study also showed evidence of mortality to MAGNACIDE® H Rodenticide.

#### RECOMMENDATIONS

Further work is recommended to quantify numbers for mortality in fleas rather than using activity as an indicator.

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# THE USE OF TIP TRAPS TO CONTROL RABBIT DAMAGE IN SCOTLAND

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**ABSTRACT:** The factors affecting efficient use of tip traps to control rabbit populations were investigated in a series of field experiments. It was found that continual trapping at the same location was much less effective than periodic trapping. Night-time trapping operations produced larger catches of rabbits than day-time trapping. Traps were equally effective whether sited on existing runs through rabbit proof fences or on previously unbreached sections of fence. The sex ratio of rabbits caught was examined at four different locations and, in each instance, more females were caught than males. The installation of a network of tip traps and associated rabbit proof fencing on a study farm in southern Scotland provided a small positive income per rabbit when carcasses were sold to a local game dealer. Traditional trapping methods employing a professional trapper on the same study farm resulted in a large reduction in rabbit numbers, but despite the sale of carcasses to a local dealer, there was still a net cost to the farmer per rabbit caught. The catch time per rabbit using tip traps was considerably less than the catch time per rabbit using a professional trapper.

**KEY WORDS:** animal damage control, trapping, live traps, rabbit control

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## INTRODUCTION

The cost of rabbits (*Oryctolagus cuniculus* L.) to agriculture in Great Britain has been the subject of a number of studies. Damage caused by grazing has variously been evaluated as between £120 million and £150 million per annum (ADAS 1985; ADAS 1988). Before the arrival of the myxomatosis virus into Britain in October 1953, rabbit numbers were estimated to be in the region of 100,000,000. The disease reduced the rabbit population by over 95% in some areas (Sheail 1991). Gradually, populations have recovered until they are now believed to be at pre-myxomatosis levels again in some parts of the country (Anon. 1992; Haly 1992; Lovelidge 1994). However, Boag (1987) suggests that because of factors such as the urbanization of suitable breeding areas, numbers will never return to the levels of the early 1950s (Boag 1987). The presence of myxomatosis in wild rabbit populations was still a restraint on population build-up in the 1980s (Trout et al. 1992). Even so, rabbits still represent one of the major pest problems of British agriculture including Scotland, where Kolb (1994) surveyed farms in 1990-1991 and concluded that rabbits were causing damage worth £11,790,000 at that time.

Control of rabbit populations and their damage has been dependent upon either killing the pest or excluding it from crops by fencing. An important factor in the selection of methods of killing rabbits in Britain is the need for a humane approach. Methods of control are restricted by legislation such as the Wildlife and Countryside Act 1981 and the Pests Act 1954, which led to the ban of the leg-hold "gin trap" and the prohibition of the deliberate spread of myxomatosis (Parkes and Thornley 1989; Sheail 1991).

The most commonly used methods of killing are daytime and night-time shooting, the use of ferrets, fumigation with poisonous gases and the use of free-running snares (Trout 1994). These methods are all reliant upon high levels of skill and are time consuming. With the exception of fumigation, these activities are often

carried out primarily for recreational and sporting reasons and although they can also have a significant effect on numbers, they are very often not cost-effective (Henly 1992).

The technique of catching rabbits in tip-trap boxes, which is a re-introduction of an eighteenth century technique, has been the subject of much interest in the farming press in recent years. These multiple-capture traps comprise a treadle board covering a buried box. When a rabbit walks over the board, the board tips and the rabbit drops into the box from which it cannot escape. Thomson and Worden (1956) recorded that these "box-traps" were not effective in their experiments. However, it was reported that a farmer in eastern Scotland had caught 76,000 rabbits using 100 such traps over a five year period, with a maximum number of 62 rabbits being caught in a box on one occasion (Powell 1996).

This paper reports the following investigations which were carried out from 1993 to 1995:

1. The effect of continual trapping at the same location.
2. A comparison of day-time and night-time trapping.
3. Siting of traps on existing rabbit runs or unbreached sections of fence.
4. Determination of the numbers of females, males and juveniles caught.
5. The costs of installing and running the traps compared with more traditional methods of control.

## MATERIALS AND METHODS

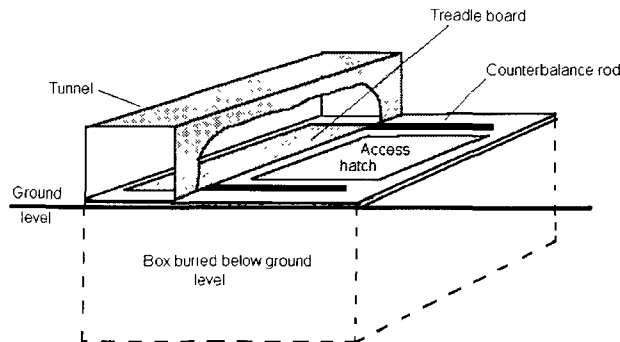
### Trapping

Galvanized steel tip traps are available commercially (Lauderdale Engineering) in Great Britain and were used in these experiments. Each comprises a tunnel, tip board with counterbalance rods and access hatch. The entire mechanism is placed on top of a box of dimensions 530 x 530 x 530 mm deep buried at ground level (see diagram). The sides of the underground boxes were made of either concrete paving slabs or galvanized steel. The earth floor of each was covered with wire mesh to

prevent rabbits from digging out and to permit drainage. The traps were sited under existing rabbit proof fences.

#### DIAGRAM TO SHOW CONSTRUCTION OF TIP TRAP

Cut away to show position of treadle board



The tunnel provides access for the animals to move freely from the warren areas to the field. Rabbits are allowed access to their normal feeding areas, so some degree of grazing loss will occur using this technique. When the rabbit moves through the tunnel, it steps on the board which tips and the animal drops into the box. Counterbalance weights cause the board to swing back into place preventing escape by trapped animals and resets the board ready to trap the next animal to pass over. A few days are allowed from installation of the traps, when the treadle board is rendered inactive, until rabbits are using the tunnels regularly. Traps are rendered inactive by placing heavy weights on the counterbalance rods. Tip traps are normally activated only for one 12-hour period every 5 to 14 days, or longer when population levels are not high.

In 1994 and 1995, eight traps were sited under existing rabbit proof fence lines which separated warren areas from valuable grazing. Traps were installed in pairs, about 100 meters' distance apart. The traps were operated as pairs to allow for comparative tests to be carried out. Once the traps were installed, existing breaches in the fence where rabbit runs had previously been established, were blocked to encourage rabbits to use the tunnels as the means of access to the grazing areas. Regular inspections were made of the fence line and any subsequent breaches were repaired to maintain an intact barrier.

Except where stated differently below, traps were operated on four or five day cycles. The treadle boards were activated at approximately 1800 hours in the evening and trapped animals were removed and humanely destroyed at approximately 0730 the following morning. The traps were then deactivated until the next trapping occasion though the tunnels were left open to allow free passage. Any non-target animals caught in the traps could be released unharmed.

The following field investigations were carried out in 1994 and 1995:

1. The effect of continual trapping at the same location—four traps were operated continuously over a 72-hour period, with animals being removed every 12 hours.
2. The success of day-time and night-time trapping was compared. Traps used to assess the effectiveness of day-time trapping were activated at approximately 0730 and animals removed at approximately 1830.
3. Two traps sited on existing runs were compared with two traps placed at previously unbreached sections of fence. All four traps were installed on the same day.
4. The sex ratio of caught rabbits was determined. All trapped rabbits were weighed and examined to determine whether they were male or female. It was difficult to determine the sex of young rabbits weighing less than 500 g without dissection and these were classed separately as "juveniles" (Thomson and Worden 1956).

#### Comparative Costs of Installing and Running Tip Traps

A detailed financial study was carried out on a predominantly livestock farm in the Scottish Borders region, 30 miles south of Edinburgh. The farm, extending to 577 hectares, carried 1,000 breeding ewes and 120 suckler cows. Grass for hay, silage and grazing was provided from 260 hectares of enclosed, in-bye land and 260 hectares of rough grazing. The farm had a long history of rabbit damage, which was considered by the owner to be costing in excess of £15,000 per annum. In an attempt to reduce the problem, a professional trapper was employed full-time for a period of 14 weeks in 1993 and provided with accommodation on the farm. Full costings were made available of all items relating to labor and trapping equipment purchased, including a rifle. A complete record was kept of rabbits caught and carcass sales.

When it became apparent to the farmer that the traditional methods of shooting and snaring were too costly, an initial network of 12 tip traps and associated rabbit proof fencing was installed on the farm later in 1993. Further traps were added up to June 1994, to give a final total of 46 traps. The costs of materials and establishment were available and records were kept of the number of rabbits caught, the number of traps used and the sale value of the carcasses. The total costs of both traditional trapping and the tip trap system were calculated and compared.

#### RESULTS

##### Results of Trapping Experiments

1. Effect of continual trapping at the same location.

When the traps were first activated, the number of rabbits trapped was high, with 20 being caught in the four traps in the first 12-hour period after activation of the traps (see Table 1). A further six animals were caught in the second 12-hour period. Later catches were much reduced, with only three animals caught over the next 48-hour period.

2. Comparison of day-time and night-time trapping.

Periodic, night-time trapping at four day intervals produced a more consistent number of rabbits caught per trapping occasion than had been recorded for the continual trapping experiment (see Table 1). The



results in Table 2 show that a significantly greater number of rabbits were caught by night-time trapping compared to day-time trapping ( $p < 0.01$ ). On four out of six trapping occasions, an average of two to three rabbits was caught in each of the traps that was activated over a night-time period. Only a small number of animals were caught by the traps that were activated during the day-time. On four of the six trapping occasions, no rabbits were caught in any of the traps activated during the day-time period.

Table 1. Total number of rabbits caught at 12-hour intervals of continual trapping using four tip traps (July 1994).

Hours From First Activation of Trap	Number of Rabbits Caught After Each 12-hour Period
12	20
24	6
36	0
48	0
60	1
72	2

Table 2. Total number of rabbits caught per trapping occasion in day-time (mean of four traps) and night-time (mean of four traps) (July 1994).

Days From Start of Experiment	Day-time Trapping	Night-time Trapping
4	0.25	3.75
8	0	2.75
12	0	2.50
16	0	0.67*
20	0	2.33*
24	0.25	0*

\*Mean of three traps.

### 3. Siting of traps in relation to runs.

There was no statistical difference in numbers caught in the two traps sited on existing rabbit runs compared with the two traps installed in areas of the fence where runs were not previously established ( $p > 0.05$ ). Rabbits were caught regularly in both

pairs of traps (see Table 3). A large total of 16 rabbits were caught in the two traps on the unbreached sections of fence on the final trapping occasion of this experiment. There did not appear to be any consistent pattern of catching which favored either pair of traps.

Table 3. Total number of rabbits caught using two tip traps installed on existing runs and two traps installed across sections of fence not previously breached by rabbits (July 1994).

Days From Start of Trapping	Sited on Runs	Installed on Previously Unbreached Areas of Fence
6	5	2
10	4	3
13	5	2
17	0	4
21	6	16
Totals	20	27

### 4. Sex ratio of rabbits trapped.

At every location, more females than males or juveniles were caught over a period of time (see Table 4). At Locations 1, 2 and 4, the sex ratio was similar. At Location 3, the ratio of females caught to males was much higher than at the other two locations. At this location, the trapping experiment coincided with an extremely warm, dry period of weather; an outbreak of myxomatosis killed many rabbits in the colony. No juvenile rabbits were caught at Location 2, where the traps were at least 50 meters distance from the warren area. The traps at Locations 1, 3 and 4 were adjacent to or very close to, warren areas. Trapping at Location 4 started in February. No juvenile rabbits were caught until April 20.

### Results of Comparative Costs

It can be seen from the results in Table 5 that traditional methods resulted in a net cost to the farm of £0.39 per rabbit caught. The cost of accommodation for the trapper was not included in this initial calculation, but when included, raised the cost per rabbit caught to £0.58. The initial investment to establish the permanent network of tip traps was expensive, costing £6115.00. The traps were expected to last for at least ten years without requiring any substantial maintenance and were, therefore, costed at 10% per annum for this exercise. Provided that there was a market for carcasses at the local game dealer, rabbit sales could be expected to offset the cost of installation and running by providing a small potential profit of £0.13 per rabbit.

It was estimated that the average time taken to activate the tip trap network was 15 minutes per trap. This gave an average time of 1.81 minutes per rabbit to trap a single rabbit. Trapping was carried out by unskilled labor already available on the farm. The average time taken to trap or kill a rabbit by the skilled traditional trapper was 7.14 minutes.

## DISCUSSION

Three aspects of the use of tip traps were investigated: the continual use of traps on the same location, the time of day when traps are set and emptied and the siting of traps in relation to rabbit runs. The sex ratio of rabbits caught was recorded.

Continual trapping at the same location with traps emptied at 12-hour intervals resulted in rabbits not using the trap, which concurs with anecdotal evidence from farmers (Sutherland pers. comm.) and confirms the general advice that periodic trapping is more effective. The reasons for aversion to the traps are not understood.

Few rabbits were trapped by day-time operation (Table 2). This would result from the known feeding habits of rabbits which graze most actively during dusk and early morning (Southern 1940; Thomson 1953). Day-time operation is likely to be most intense in the summer months when farmers are particularly concerned to reduce numbers to protect vulnerable crops during the growing season. Trapping during daylight hours would not be regarded as being as humane since any animals caught would be confined within the box during the hottest part of the day. Any trapping occasions should include dawn and dusk within the activation period.

The exact location of a trap along a fence line do not appear to be important, contrary to suggestions in the farming press. Allowance can therefore be made for difficulties of installation caused by factors such as rocky soils and tree roots. Some rabbits were observed to climb over fences rather than use the tunnels (Allan 1995),

while others will still attempt to breach the fence by digging and tunnelling. However, general habituation to the tunnels occurs within a few days, and attempted breaches of the fence line have been recorded to diminish with time (Mackintosh 1994; Allan 1995). Rabbits which habituate to the tunnels will use them as hiding places in times of danger, such as upon the approach of human beings or dogs indicating that fear of the tunnels has disappeared (Fuchs pers. observ.).

The sex ratio of rabbits caught at the four experimental locations (Table 4) was variable but always more females were caught than males. With the exception of Location 3, the ratios were similar to the results of studies reported by Thomson and Worden (1956) where the ratio of males to females was 100:131-132 for three-quarter grown or fully grown animals. They noted that the ratio could vary according to the methods of capture used.

Economic comparisons with traditional trapping methods supported the use of the traps as a feasible on-farm practice. The employment of a full-time professional trapper on the study farm resulted in nearly 5,000 rabbits being removed over a period of 14 weeks. However, despite the sale of rabbit carcasses to a local game dealer, there was still a net cost of £0.39 per rabbit to the farm. The installation of the tip trap system allowed the cull of rabbits to continue, using unskilled farm labor rather than the skilled labor of a trapper. If the initial high cost of installation of the traps was depreciated over the expected ten year life of the system, a small profit of £0.13 per rabbit was generated.

Although the market for wild rabbit meat in the UK has been very low since the arrival of myxomatosis, there is a potential to use a system of traps not just to maintain populations at an acceptable level, but to harvest rabbits for the human market. Rabbits caught by tip traps will provide undamaged carcasses and command a higher price than shot rabbits, where the body has been damaged by the passage of a bullet or lead shot.

Table 4. Percentage of rabbits of different sex caught by tip traps at four different locations in North East Scotland in 1994 and 1995.

	Location 1 June-August 1994	Location 2 June-August 1994	Location 3 June-August 1995	Location 4* February-May 1995
Females	45 (125)	68 (112)	62 (343)	47 (142)
Males	36	32	14	33
Juveniles	19	0	24	20+
Total Percentage	100	100	100	100
Number Caught	120	138	70	84

\*Data supplied by J. Osborne, Royal Society for the Protection of Birds.

+No juveniles caught before April 20.

Figures in brackets indicate sex ratio:males = 100.

The time allocated to taking a single rabbit under the traditional system was 7.1 minutes (Table 5). This estimate was based on the trapper working a 40 hour week, though in practice the working week was often in excess of 50 hours, which would have given a real value in excess of 8 minutes per rabbit caught or killed. The estimated time taken to activate and empty a single tip trap was 15 minutes, resulting in a much reduced time of 1.8 minutes (of unskilled labor) per rabbit. The tip trap was, therefore, more efficient in terms of time needed to trap a single rabbit, compared with traditional methods.

The difference in numbers of rabbits caught per trap per trapping occasion on the experimental sites—2.3 in

1994, 1.3 in 1995 (excluding the occasions when myxomatosis affected the colony)—compared with 7.7 catches on the case study farm and may be explained in part by the very high pest population on that farm. However, a complete system of traps and fences was integrated onto the study farm, whereas at the experimental sites, only individual boundaries between warren and affected fields were studied. In 1995, complaints from a neighboring farm to the experimental area suggests that some of the rabbits were foraging in a different direction from the study area (Allan 1995). This indicates that the traps are better used as a complete system and not as a "piece-meal" attempt to protect small areas.

Table 5. Comparative costs of tip trapping compared with traditional methods of catching rabbits (1993).

Period of Control	Traditional Trapping January 1993-April 1993	Tip Trapping August 1993-March 1994
Weeks of Control	14	31
Labor Costs Allocated to Control	£2,770.85	£326.00
Costs	£1,151.46	£611.50*
Total Costs	£3,922.31	£937.50
Number of Rabbits Caught	4,708	2,698
Income From Sale of Rabbits	£2,058.20	£1,349.00
Profit/Loss Rabbit	Loss £0.39	Profit £0.15
Average Labor Time to Catch One Rabbit	7.1 minutes	1.8 minutes

\*Cost of installation of tip trap network: £6115.00. Straight line depreciation equivalent to 10% per annum as capital items have an expected life in excess of ten years.

#### ACKNOWLEDGMENTS

Grateful thanks are accorded to Mr. John Osborne of the Royal Society for the Protection of Birds for the use of data; Mr. Jim Sutherland who allowed the use of financial information relating to rabbit control on his farm; and Dr. Stan Matthews for his many helpful comments about early drafts of this paper.

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# EFFECTIVENESS OF VICHOS NON-LETHAL COLLARS IN DETERRING COYOTE ATTACKS ON SHEEP

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**ABSTRACT:** Vichos non-lethal collars containing 45 to 105 ml of 3% capsicum oleo resin were evaluated as deterrents to coyote attacks on sheep. Each of five coyotes tested made neck/throat attacks on one collared lamb; four punctured collars and one pulled the collar from a lamb without puncturing it. One coyote did not resume biting the lamb for 60 min; it was retested two and four days later. At two days, the coyote punctured a second collar and briefly halted its attack. At four days, the coyote attacked a third collared lamb but made no attempt to grasp the neck/throat area. In tests resulting in collar punctures (n=5), coyotes immediately stopped their attacks and showed obvious signs of oral irritation; however, attack behavior resumed shortly thereafter (mean=17.6 min). Coyotes resuming attacks directed them toward the sides and rears of lambs. The Vichos collar is unlikely to prove effective in controlling coyote predation on sheep.

**KEY WORDS:** animal damage control, aversives, coyote, pen trial, predation, trigeminal

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## INTRODUCTION

When attacking livestock, coyotes (*Canis latrans*) typically bite the throat. For this reason, various collars have been designed (McBride 1974, 1982) and tested (Connolly 1980; Burns et al. 1988; Burns et al. 1996) as coyote control tools. One, the Livestock Protection Collar (LPC), is registered with the U.S. Environmental Protection Agency (Moore 1985) and used in several states (Connolly 1993). While the LPC is designed to kill coyotes by delivering a lethal oral dose of sodium monofluoroacetate (Compound 1080, Connolly and Burns 1990), it could also be used to deliver aversive or repellent substances (McBride 1974).

During development of the LPC, tests with repellents failed to identify promising aversive agents (Burns et al. 1984). This failure was consistent with the more general observation that aversive sensory stimuli do not curtail predation (Linhart 1984; Lehner 1987). Nevertheless, several studies have reported contrary results; there are data to suggest that some bitter chemicals (e.g., denatonium benzoate), irritants (e.g., capsaicin, cinnamaldehyde, creosol), and odorants (e.g., mercaptan) can deter predators (Botkin 1977; Faller 1975; Jankovsky et al. 1974; Lehner 1987; Lehner et al. 1976; Olsen and Lehner 1978; Shelton and Thompson unpublished, as cited in Lehner 1987; Swanson et al. 1975, 1976; Teranishi et al. 1981).

The Vichos anti-predator collar was developed in 1993. When punctured, the collar dispenses a formulation of 3% capsaicin oleo resin. Capsaicin is an effective irritant for most mammals, including all canids tested to date. Here, the results of an evaluation to determine whether Vichos collars deter attacks by captive coyotes on sheep are described.

## METHODS

Tests were conducted between January 9-14, 1995 at the Predator Research Site of the Denver Wildlife Research Center (DWRC), 12 km south of Logan, Utah.

During each test, one collared lamb was introduced into a 9,750 m<sup>2</sup> pen containing an adult coyote that had recently killed sheep and/or goats. Tests continued until five coyotes each made a neck/throat attack on a collared lamb and either killed the lamb without puncturing the collar or punctured a collar and showed some obvious reaction to the capsicum oleo resin that it contained. Coyotes that refrained from renewed attacks for 60 min after the initial collar puncture were tested twice more at two-day intervals. Coyote-lamb interactions were observed from a building overlooking the pens and salient information was recorded on prepared forms.

All animals were identified by uniquely numbered ear tags and kept in individually numbered kennels and pens. Animal care and handling were conducted under procedures approved by the Institutional Animal Care and Use Committee of the DWRC. Lambs severely wounded but not killed during coyote attacks were euthanized immediately, irrespective of test time constraints.

Before testing, sheep were collared, and coyotes and sheep were weighed on an electronic platform scale (Table 1). Vichos collars of various lengths were provided by Livestock Protection Products, Inc., Detroit, Michigan. Each collar contained a quantity of 3% capsicum oleo resin (Table 1). Collars were filled through valve stems, and a small bell was attached to the stems. The manufacturer wanted to explore whether the bell might act as a supplemental deterrent.

## RESULTS

All five coyotes attacked the neck/throat area of collared lambs. Four collars containing 45 to 105 ml of 3% capsicum oleo resin were penetrated during the attacks (Table 2). Coyotes that bit through collars reacted immediately by head shaking, mouth gaping, muzzle pawing and licking, muzzle rubbing in snow and grass, and snow eating. One coyote pulled the collar from a test lamb without puncturing the collar and then made a throat kill.

Table 1. Characteristics of coyotes, lambs, and Vichos non-lethal collars tested in January 1995.

Coyotes			Lambs			Collars		
Animal Number	Sex (M, F)	Weight (kg)	Animal Number	Sex (M, F)	Weight (kg)	Collar Number	Length (cm)	Amount <sup>b</sup> (ml)
5293	F	11.5	1	M	22.2	L-4	22.8	44
5345	M	13.1	5	F	22.9	L-6	22.8	44
5282	F	10.8	10	F	21.9	L-19	22.8	44
5150	M	13.2	12	F	22.7	L-23	22.8	44
5284 <sup>a</sup>	F	9.5	9	M	23.7	L-11	25.4	75
5284	(first retest)		7	M	32.5	E-1-A	30.5	85
5284	(second retest)		4	F	21.6	E-1	30.5	105
Mean Weight		11.6			23.9			

<sup>a</sup>Coyote was tested with two more collared lambs after being deterred from attack for 60 minutes in her first test.

<sup>b</sup>Amount of 3% oleo capsaisin formulation in each collar.

Table 2. Coyotes, test dates, and results of tests with Vichos non-lethal collars in January 1995.

Coyote Number	Test Date	Collar Punctured	Times (hr:min)		
			Collar Punctured <sup>a</sup>	Attack Resumed	Coyote Was Deterred
5293	9	yes	10:35	10:52	0:17
5345	9	no	---	---	---
5282	9	yes	15:23	15:29	0:06
5150	10	yes	10:06	10:07	0:01
5284 <sup>b</sup>	10	yes	13:37	14:37	1:00
5284	12	yes	10:22	10:26	0:04
5284	14	no	---	---	---

<sup>a</sup>Coyotes stopped attacks on collared sheep at time of collar punctures.

<sup>b</sup>Coyote was tested two more times after initial collar puncture deterred renewed biting attack for 60 minutes.

Coyotes that reacted to collar contents immediately stopped their attacks on lambs for a mean of 21.0 min (n=4, range=1-60 min) and then resumed their attacks (Table 2), usually at the sides and rear of the lamb. The single coyote that did not resume attack for 60 min was subsequently retested twice, at two day intervals. During the second test, the test lamb was immediately attacked at various locations and the collar was punctured. Attack was interrupted for 4 min. Including this result with the times of the other coyotes provided a mean latency of 17.6 min (n=5, range=1-60 min) for all tests with collar

punctures and deterred attacks. Two days later, after collar punctures, the coyote attacked a third collared lamb at the sides and rear, but made no attempt to grasp the neck/throat area. In this instance, and at three other times during the study, intervention in tests was necessary to euthanize lambs wounded by coyotes attacking from the sides and rear (presumably to avoid the capsicum-containing collar). It was evident that coyotes would have killed these sheep, but not with efficient throat-hold patterns.

## DISCUSSION AND MANAGEMENT IMPLICATIONS

Vichos collars briefly interrupted attacks on lambs, but coyote predation was not substantially deterred. This result is consistent with the general finding that sensory repellents do not stop predation by coyotes (Lehner 1987; Linhart 1984). It is worth noting that collars appeared to redirect attacks by coyotes away from the throat, resulting in less efficient killing than would have otherwise occurred.

It was concluded that the Vichos collar is not an effective tool for the control of coyote predation on sheep. More importantly, the Vichos collar appears to elicit predation that is more prolonged, and quite likely, more painful to prey than predation that would have occurred in the absence of the collar.

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# TECHNIQUES AND EXPERTISE IN WILDLIFE DAMAGE CONTROL: A SURVEY AMONG THE NATIONAL ANIMAL DAMAGE CONTROL ASSOCIATION (NADCA) MEMBERSHIP

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**ABSTRACT:** The membership of the National Animal Damage Control Association (NADCA) was surveyed during 1995 to collect information about specialty fields, preferred methods and experience. Respondents had broad experience that included 44 species or species groups. Members reported firsthand experience with an average of 17.6 different species and 2.9 vertebrate groups. Forty-three percent indicated that their specialization was among carnivores. In this group, coyotes, *Canis latrans* (45%), raccoon, *Procyon lotor* (23%) and skunk (13%) were most frequently mentioned. Members reporting carnivore experience had firsthand experience with an average of five different species. Rural and urban members did not significantly differ in breadth of experience with carnivores. Respondents most frequently specialized with coyote (11.8%), raccoon (11.5%), beaver, *Castor canadensis* (9.6%) and tree squirrel, *Sciurus* spp. (6.8%). Trapping was the most used technique for most mammals. Exceptions were deer or elk where exclusion was preferred. Blackbirds and starlings, *Sturnus vulgaris*, were most often controlled by repellents or scare tactics. Removal of an animal was the most common and preferred method and represented about 70% of responses for first choice.

**KEY WORDS:** animal damage control, questionnaire

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## INTRODUCTION

The National Animal Damage Control Association (NADCA) is an organization dedicated to supporting professionalism and education in the wildlife damage control field. Included in its membership are individuals associated with private business, universities, and government agencies. During late 1994, a committee for information and techniques was formed. The charge of the committee was to expedite the exchange of information between members and to better understand the expertise of the membership. Committee members identified a survey as a method toward fulfilling their charges.

## METHODS

A mail survey was sent to 454 NADCA members during February 1995. The survey document was kept brief and contained seven questions with space for comments and discussion. Members were asked about their specialty fields, preferred damage control techniques and primary experience with depredation situations and sites. They were also asked about firsthand experience with species, geographic area of operation and specialized training. During the summer of 1995, questionnaires were remailed to NADCA members who had not previously responded and to 74 National Urban Wildlife Management Association (NUWMA) members who had recently become NADCA members.

## RESULTS

The first mailing of the questionnaire had a 43% response rate. The second mailing had a 24% response rate. Respondents generally completed the questionnaire with only 19 respondents not answering all questions. These individuals typically were involved in laboratory research or administrative activities.

(To clarify discussion, questions from the survey are sometimes shown in italics with discussion following.)

*Your specialty field(s). Please write your first three areas of proficiency.*

*Species*

*Most proficient control method(s)*

*Depredation site/situation*

Forty-four species or groups of species were mentioned among the top three specialty fields of NADCA members, although only a few species predominated. Coyote, raccoon and beaver represented 40% of all first place rankings among specialty fields. Coyotes (11.8%), raccoon (11.5%), beaver (9.6%) and tree squirrels (6.8%) represented 40% of all responses to specialty fields. Deer (4.1%) and bats (3.2%) were also commonly listed. Animal groups most often mentioned were carnivores (43%), rodents (29%) and birds (19%). Table 1 illustrates how each species is represented within its animal group.

Species listed as specialty fields were grouped as rodents, carnivores or birds and analyzed by technique (Table 2). Members most often felt proficient in trapping as a technique for rodents and carnivores but selected other techniques more often for birds. These included repellents, scare tactics, exclusion and cultural methods.

Specialty fields were analyzed by techniques chosen for the ten most reported species (Table 3). Live trapping was most frequently chosen for rodents, carnivores, and pigeons, *Columba livia*. Exclusion was most chosen for deer and elk, *Cervus elaphus*, and repellents or scare tactics were most chosen for blackbirds and starlings.

Table 1. Areas of specialization among National Animal Damage Control Association members during 1995.

Percent of Response by Animal Group							
Carnivores		Rodents		Birds		Other Mammals	
	<u>%</u>		<u>%</u>		<u>%</u>		<u>%</u>
Coyotes	45	Beaver	45	Blackbirds/ Starlings	25	Deer/Elk	54
Raccoon	23	Tree Squirrels	23	Pigeons	20	Bats	30
Skunk	13	Woodchuck	15	Waterfowl	15	Moles	11
Fox	10	Commensals	8	Gulls	14	Rabbits	5
Bobcat/ Lion	7	Pocket Gophers	4	Birds (General)	11	Misc.	1
Opossum	2	Muskrat	3	Fish-eating birds	10		
		Prairie Dogs	2	Jays/Crows	5		
Totals	100		100		100		100

Table 2. Techniques chosen for rodents, carnivores and birds by National Animal Damage Control Association members, 1995.

Techniques	Percent Response		
	Rodents	Carnivores	Birds
Exclusion	7.7	5.3	19.2
Traps	60.0	56.6	10.0
Snares	10.7	14.7	
Firearms	5.9	11.1	11.1
Toxicants	7.0	7.8	11.1
Fumigants	2.6		
Scare Tactics	1.0	2.8	35.7
Cultural	4.8	<1	11.7
Miscellaneous		<1	1.2
Totals	100	100	100



Table 3. Techniques chosen for ten most reported species by National Animal Damage Control Association members, 1995.

Species/ No. of Respondents	Percent Response							
	Exclusion	Live* Traps	Kill Traps	Snares	Firearms	Toxicants or Fumigant	Repellent or Scare Tactics	Cultural
Coyote (176)	2	35	<1	20	19	17	5	<1
Beaver (123)	2	37	20	23	10	1		7
Raccoon (92)	12	75	4	5	1		2	1
Tree/Squirrel (63)	21	73	2				4	
Skunk (52)	10	87		1		2		
Deer or Elk (45)	42				24**	3	20	11
Blackbirds or Starlings (43)	7	9			9	23	40	12
Woodchuck (40)	5	65	13		8	8		1
Fox (38)		53		26	13	8		
Pigeon (36)	22	28			17	14	17	2
Totals for Ten Species	10	46	5	11	11	8	6	3

\*Includes cage and leghold traps

\*\*Includes hunting seasons

*Preferred techniques: (rank first (1), second (2), and third (3) your areas of expertise)*

*Exclusion*

*Traps*

*Snares*

*Firearms*

*Toxicants/Fumigants*

*Scare Tactics (Explain)*

*Reproductive Agents (Explain)*

*Cultural Practices (Explain)*

*Other (Explain)*

Members most often ranked trapping and exclusion as preferred techniques (Table 4). Toxicants/fumigants, firearms, scare tactics, snares, and cultural techniques followed in rank. Certain techniques were grouped by method. Removal method responses (live traps, kill traps, snares, firearms, calling, toxicants, fumigants, denning, and chase with dogs) represented 70% of first choice responses and 63% of all responses. Exclusion was the second most commonly chosen method with only 18% of first choice responses.

Another question asked members about their primary experience in different damage control situations

(Table 5). Most respondents had experience with private homes, range or pastures, and commercial areas or buildings.

*Your firsthand species experience: circle each species listed.*

Sixty-three species or groups of species were listed where members may have experience in control techniques. The list included and grouped 10 rodents, 14 carnivores, 17 birds and 6 amphibians and reptiles. Mammals not included as rodents or carnivores were grouped under the heading "Other Mammals." These 11 species included deer and other ungulates, insectivores, bats, and rabbits. An "other" option in each group allowed members to write in species not listed.

Members showed great breadth and diversity in firsthand species experience. They reported having worked with an average of 17.6 species within 2.9 different vertebrate groups. Least firsthand experience among members occurred with amphibians and reptiles. An average of less than one species was indicated by respondents who had experience with this group.

Table 4. Rankings of techniques by National Animal Damage Control Association members.

Technique	Percent Among First Ranked (n)*	Technique	Percent Among Top Three Ranked (n)
Trapping	51.1 (118)	Trapping	28.9 (181)
Exclusion	18.2 (42)	Exclusion	21.2 (132)
Firearm	6.5 (15)	Firearm	15.0 (94)
Snares	4.8 (11)	Snares	10.8 (68)
Toxicants/ Fumigants	7.3 (17)	Toxicants/ Fumigants	8.5 (56)
Repellents	1.7 (4)	Repellents	14.0 (9)
Scare tactics	5.6 (13)	Scare tactics	6.4 (45)
Cultural	4.3 (10)	Cultural	6.0 (38)
Miscellaneous	0.5	Miscellaneous	1.9
Totals	100		100

\*Number of respondents

Table 5. Firsthand species experience of rural and urban National Animal Damage Control Association members by animal group.

Animal Group	Mean Number of Species	
	Rural	Urban
Rodents	3.5	4.6
Carnivores	5.4	4.1
Other Mammals	2.9	3.1
Birds	4.4	4.1
Amphibians or Reptiles	0.5	1.1*

\*Significant at the 95% confidence level

Characterize your experience by circling one of the county codes below:

<u>County Code</u>	<u>Percent Respondents</u>
<i>Metro (500,000 per county)</i>	21.5
<i>Urban (100,000 per county)</i>	23.8
<i>Suburban</i>	15.3
<i>Rural</i>	39.4

Despite NADCA members being more involved in wildlife damage control activities in rural areas than elsewhere, the responses are noteworthy for their even distribution across population areas.

Table 6 compares members whose primary business is either rural or urban. Differences were examined between respondents who marked only "metro" or "rural" as to breadth of species experience. Only the category of amphibians and reptiles showed significant differences (95% confidence level) between the two groups.

Members were also asked about the geographic area where they had experience. Every state but Hawaii and South Dakota was represented in respondents to our survey. A few respondents also had experience in Canada, Europe, Asia, Australia and Africa.

Table 6. Situations where 1995 National Animal Damage Control Association members have most expertise.

Situation	Percent Respondents
Private residence	25.2
Range and Pasture Lands	17.1
Business/Commercial Buildings	17.0
Woodlots/Forests	11.1
Field Crops	9.1
Municipal Areas (specify)	6.1
Airports	4.8
Aquaculture Facilities	3.8
Other, (haystacks, rivers, & lakes, public utility sites, feedlots, etc.)	3.2
Truck Crops	1.6
Orchard	1.0
Total	100

## DISCUSSION

Recent surveys related to wildlife damage management include those that examine industry characteristics and attitudes Barnes (1995a, 1995b) and those that examine public attitudes (Schmidt Proc. 17th Vertebrate Pest Conf.).

The survey shows that NADCA members have a variety of experiences with different species. It also shows the use of different techniques, depending upon species, animal group, and depredation situation. Generally, members have most experience with carnivores and least with reptiles and amphibians. Most members choose a removal method, most commonly trapping, as a technique with each animal group. Birds are the exception. Most techniques chosen for birds are

repellents or toxicant and fumigants.

Many factors influence responses to questions about proficiency and preference. Included are issues in legality, agency or company policy, and public sentiment. Barnes (1995a) surveyed the nuisance wildlife control industry at a recent wildlife control operator's short course and, again, through a telephone survey of animal damage control operators in Kentucky (1995b). He found that live trap and release methods were preferred for raccoon, tree squirrel, skunk and woodchuck, *Marmota monax*. His survey and earlier studies suggest that preference for this non-lethal method might be related to public relations. It was also found the greatest use of live trapping among these species, but cautions that leg hold traps were not distinguished in the survey.

The main objective of the committee was to identify expertise and specialty fields of NADCA members and not to assess or directly compare effectiveness of techniques. However, the authors do propose that the legal constraints and public attitudes that influenced respondents in the survey need to be considered when comparing the usefulness of different techniques in the animal damage control industry.

About 48% of those responding to the survey answered a general question about specialized training. Many of these responses included formal education and on-the-job experience and training in field techniques. Barnes' (1995a, 1995b) surveys analyzed specialized training experience and needs in detail. In the latter, only a minority of respondents had specialized training or university level courses in wildlife management. Most of the respondents surveyed at an NWCO short course indicated no in-service training in wildlife management or wildlife damage management. The survey among NADCA members shows a wide range of educational background and formal training. A potential need is seen for specialized or formal training opportunities among animal damage control professionals.

A few respondents took the opportunity to express their concerns in the two page questionnaire, stating that it was too general for them to complete. A few were skeptical of the use or benefits of the survey to their

enterprise or occupation. Some commented upon issues in the animal damage control field like the prospect of too much regulation or certification requirements. One respondent expressed a trend that he saw when he stated, "Almost everything I grew up with is either illegal, immoral, or no longer made!" Others, spoke with self-effacing humor about the changing industry of animal damage control. One responded "Retired over 20 years. Now age 83. Don't know 'nuttin'."

Perhaps the survey reveals more about the nature of the animal damage control industry than ordinary tables suggest. A professional organization like NADCA needs to identify and express its strengths and weaknesses among its members to better the profession. Any future assessment should include how member and public attitudes affect the use of animal damage control techniques.

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# ASSESSMENT OF THE ENVIRONMENTAL IMPACT OF BRODIFACOUM DURING RODENT ERADICATION OPERATIONS IN NEW ZEALAND

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**ABSTRACT:** Although Talon® baits containing brodifacoum have been used successfully in eradicating rats from some of New Zealand's offshore islands, little is known about any environmental effects of this toxin. Invertebrates, blackbirds, soil, and water at intervals of two days to nine months were sampled to determine whether brodifacoum residues were present after aerial distribution of Talon® 20P cereal pellets on Red Mercury Island and after bait-station use of Talon® 50WB wax-coated cereal blocks on Coppermine Island. No brodifacoum residues were found in soil, water, or most (99%) invertebrate samples. Low concentrations (0.12 µg/g) were found in one sample of slugs collected two days after aerial sowing. Liver tissues from all birds (n=4) and rats (n=3) found dead, and from all six birds collected alive eight months after aerial baiting, also contained low-to-moderate concentrations of brodifacoum (0.004 to 11.0 µg/g). These preliminary results suggest that invertebrates are not likely to accumulate brodifacoum as a result of Talon® baiting. Laboratory studies showed that, although some invertebrates may eat Talon® baits, it appears that the brodifacoum is metabolized and/or excreted within a few days. The dead blackbirds found were, therefore, more likely to have been killed by primary rather than by secondary poisoning. Further monitoring for brodifacoum residues after Talon® operations should be undertaken to confirm that contamination of invertebrates, soil, and water is unlikely. Some bird species may be at risk from eating Talon® baits. Likely effects on population levels of such species should be assessed to help weigh the risk and benefits of Talon® use in rodent eradication.

**KEY WORDS:** animal damage control, rodenticides, field tests

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## INTRODUCTION

Three species of rats have been introduced to New Zealand. The Polynesian rat or kiore (*Rattus exulans*) was introduced by the Maori about 1,000 years ago. Ship rats (*Rattus rattus*) probably arrived with the early European colonists in the mid-nineteenth century, and Norway rats (*Rattus norvegicus*) arrived later. Rats have harmed the indigenous biota of New Zealand, reducing or eliminating populations of birds, reptiles and invertebrates (King 1990). Islands offer potential refuges for endangered wildlife, but many are inhabited by rats. Although Talon® cereal pellets (Talon® 20P) and wax-impregnated cereal blocks (Talon® 50WB) have been used successfully to eradicate rats from islands in New Zealand and overseas (Buckle and Fenn 1992), little is known about the environmental effects of control operations using these types of toxic baits in New Zealand. Brodifacoum, the active ingredient used in Talon® baits, acts by interfering with the normal synthesis of vitamin K-dependent clotting factors in the liver of vertebrates (Hadler and Shadbolt 1975). A review of the international literature (Eason and Spurr 1995) suggested that many of New Zealand's native vertebrates would be at risk if they ate Talon® baits directly or were exposed to brodifacoum via the food chain if the toxicant accumulates in invertebrate prey species. Invertebrates have been seen feeding on Talon® baits (Eason and Spurr 1995) and although no toxicological data were presented, Shirer (1992) considered it unlikely that invertebrates would be killed by brodifacoum as they have different blood

clotting systems than vertebrates. However, if invertebrates became contaminated with brodifacoum, either directly through eating bait or indirectly through ingesting contaminated soil or water, they may pose a risk of secondary poisoning to vertebrates that prey upon invertebrates (Eason and Spurr 1995).

Assessment of the risks to non-target species presented by a vertebrate pesticide should be determined by considering the likelihood of non-target species being exposed to the compound, the persistence of the compound in different parts of the environment, and the susceptibility of non-target species to the compound (Brown et al. 1988). In assessing the possible environmental risks posed by Talon® usage, the authors, therefore, determined the potential for exposure of non-target species to brodifacoum by monitoring its fate in soil, water, invertebrates and vertebrates under field conditions after rodent control operations. They monitored over time to assess the persistence of the compound in these components of the environment. To assist in interpreting the field data, they also monitored the feeding response of three species of native insects in the laboratory when offered Talon® baits and conducted a study on the toxicity and persistence of brodifacoum in one of these species.

## METHODS

### Field Monitoring

Environmental monitoring of brodifacoum was carried out after two Department of Conservation rodent control

operations—one using aerially sown bait, the other using baits in bait stations.

Talon® 20P pellets (ICI Crop Care Holdings, Richmond, New Zealand) of mean weight 2.5 g and containing green dye and 20 ppm brodifacoum were aerially sown at 15 kg/ha over the whole of Red Mercury Island (225 ha) on 1 October 1992. Live invertebrate samples (Table 1) were collected by hand at up to six widely distributed circular plots of 10 m radius (selected for relative abundance of invertebrates) 4 to 8 days before and 2 to 3, 9, 30, and 240 days after baits were sown. Samples were frozen shortly after collection using liquid

nitrogen and returned to the laboratory for sorting and brodifacoum assay. Five dead blackbirds (*Turdus merula*) and three kiore (*Rattus exulans*) were collected during ground searches in the week after aerial sowing. Six live blackbirds were collected nine months after (four in mist nets, two by shooting). Soil and water samples were collected one month after aerial sowing. Samples (200 g) of topsoil were collected in plastic bags at nine widely distributed sites, and water samples (200 ml) were collected in glass bottles from small streams in different parts of the island. The sampling schedule is summarized in Figure 1.

Table 1. Numbers of samples of invertebrate types collected on Red Mercury and Coppermine Islands. Samples comprised from one to eight individuals depending on abundance at sampling sites. Each value indicates the number of samples pooled for an individual assay.

Invertebrate Type (and Order, or Class where Order Unknown)	Red Mercury Island					Coppermine Island				
	Sampling Schedule in Relation to Control Operation					Sampling Schedule in Relation to Control Operation				
	Days Before	Days after Sowing				Days Before	Days after Start			
	4-8	2-3	9	30	240	16-19	13	27-31	57	101
Slater ( <i>Isopoda</i> )	11	6	5	3	0	4	2	3	6	2
Spider ( <i>Araneae</i> )	7	3	4	6	4	4	3	6	4	4
Millipede ( <i>Diplopoda</i> , order unknown)	11	2	2	2	4	12	5	8	5	7
Centipede ( <i>Chilopoda</i> , order unknown)	4	1	1	2	0	2	3	4	5	6
Cockroach ( <i>Blatoidea</i> , order unknown)	6	0	1	0	2	8	3	5	6	7
Ant ( <i>Hymenoptera</i> )	0	0	1	1	0	0	0	0	0	0
Wasp ( <i>Hymenoptera</i> )	0	0	0	0	0	1	0	0	1	0
Insect larvae (unidentified)	5	0	5	1	0	2	1	4	3	0
Ground weta ( <i>Orthoptera</i> )	0	0	0	0	0	4	4	5	2	9
Cave weta ( <i>Orthoptera</i> )	4	1	1	1	4	11	2	2	4	2
Slug ( <i>Gastropoda</i> , order unknown)	0	2	1	2	1	0	0	0	0	0
Snail ( <i>Gastropoda</i> , order unknown)	1	1	1	0	3	0	2	1	1	0
Worm ( <i>Opisthopora</i> )	4	4	5	7	4	0	4	6	6	7

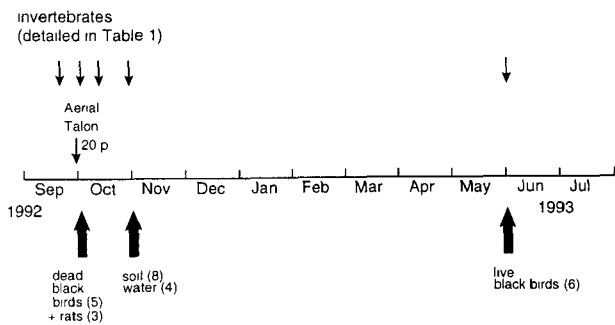


Figure 1. Schedule for collection of samples on Red Mercury Island.

Talon® 50WB baits (ICI Crop Care Holdings, Richmond, New Zealand) of mean weight 30 g and containing green dye and 50 ppm brodifacoum were placed in tunnel-type bait stations on Coppermine Island (80 ha) from October 1992 to May 1993. Live invertebrates were collected by searching vegetation from 0 to 1 m above ground within 12 m of six bait stations, 16 to 19 days before and 13, 27 to 31, 57, and 101 days after baiting started. Soil samples (200 g) were collected under five bait stations and at five sites equidistant between bait stations, one and nine months after bait stations were established. The sampling schedule is summarized in Figure 2.

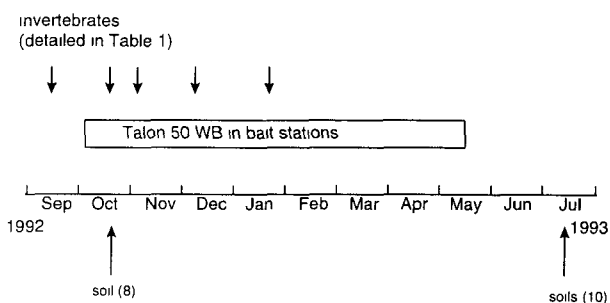


Figure 2. Schedule for collection of samples on Coppermine Island.

Invertebrate samples were sorted into orders (Table 1). To provide sufficient material for analysis, the invertebrate types (i.e., as orders) collected from all sites on each sampling occasion were pooled. Samples from the two islands were, however, sorted and pooled separately, and stored frozen until assay.

Pooled samples were weighed and chopped into small pieces with scissors before being assayed for brodifacoum content using High Performance Liquid Chromatography. The method used is described by Hunter (1983) and the detection limits are 0.0001  $\mu\text{g}$  brodifacoum/ml in water, 0.004  $\mu\text{g/g}$  in vertebrate tissues (liver or gizzard), 0.02  $\mu\text{g/g}$  in soil, and 0.05  $\mu\text{g/g}$  in invertebrate tissues.

#### Laboratory Studies

Laboratory colonies were maintained of three native insect species. Large-headed weta (*Hemideina crassidens*), cave weta (*Gymnoplectron edwardsii*), and ground beetles (*Megadromus bullatus*) were kept in glass tanks (72 x 38 x 38 cm) with a floor-lining of soil, leaf-litter and sphagnum moss. Each tank housed up to six individuals of a single species. Small logs of approximately 30 cm length and 8 cm diameter with a hollow core of 20 cm were supplied in weta tanks for shelter, as recommended by Barret (1991). Fresh native plant material and apple was supplied every second day, along with processed pet meat supplied about every two weeks. Water was always freely available.

Each animal was uniquely marked with a small amount of white typing paint applied to the dorsal surface of the carapace. Feeding behavior of the animals towards Talon® baits (20P and 50WB) was recorded from continuous time-lapse video recordings of overnight (16 h) activity in each tank. Each group of animals in a tank was offered four 20P pellets or one 50WB bait on different nights. The baits were placed on a small petri dish on a piece of white paper to facilitate observation. The identity of individuals seen feeding on baits and the time spent feeding were recorded.

The acute toxicity of brodifacoum to large-headed weta (selected for relative ease of dosing) was determined by dosing weta with brodifacoum using a 10  $\mu\text{L}$  syringe with a 28 gauge blunt needle (modified method of Sutherland et al. 1982). A constant dose of 1  $\mu\text{L/g}$  bodyweight was given to all weta, but different solutions were used to dose groups (three male and three female) at each of the following dose levels: 12.5, 25, 45 and 62.5  $\mu\text{g/g}$  bodyweight. The brodifacoum was administered with 10% dimethylsulfoxide (DMSO) in 60% monopropylene glycol (MPG). A control group of six male and six female weta was dosed with the DMSO and MPG mixture. Precise dosing proved to be difficult as some spillage of the mixture occurred and some weta regurgitated a small proportion of the mixture. Following administration, all animals were returned to their familiar glass tanks and closely monitored until no further deaths occurred.

The persistence of brodifacoum in live large-headed weta was determined by dosing 18 individuals nominally with 15  $\mu\text{g/g}$  brodifacoum in 10% DMSO and 60% MPG. This is equivalent to consumption of 6 g Talon® 20P pellets and such a large dose should be regarded as representing prolonged feeding by weta on Talon® pellets over a period of several days. At nine time points over a 14-day period, one male and one female weta were killed. Each entire animal was then macerated before analyzing for brodifacoum content.

## RESULTS

### Field Monitoring

No residues of brodifacoum were found in soil, water, or most (99%) invertebrate samples from Red Mercury and Coppermine Islands. One sample of slugs, collected on Red Mercury Island two days after aerial sowing, contained 0.12  $\mu\text{g/g}$  brodifacoum. Liver tissues from birds ( $n=4$ ) and rats ( $n=3$ ) found dead after aerial sowing contained low-to-moderate levels of brodifacoum (0.6 to 11.0  $\mu\text{g/g}$ ), and livers from all six birds collected alive contained low levels of brodifacoum (0.004 to 0.2  $\mu\text{g/g}$ ).

### Laboratory Studies

Many individual insects were observed feeding on Talon® baits on overnight video-recordings (Table 2). Talon® 20P pellets were preferred by the three species. All ground beetles were seen feeding on these pellets, and individual cave weta were seen feeding for up to 64 min during a 16 h period. Talon® 50WB baits were less palatable and were not fed on at all by large-headed weta.

All weta survived the two highest doses of brodifacoum (Table 3). Three died at lower doses but

since three also died in the control group, it is probable that all deaths were due to the trauma of dosing rather than effects of the brodifacoum.

When administered at 15  $\mu\text{g/g}$ , brodifacoum persisted in weta for a maximum of four days (Figure 3). There was no significant difference in the rate of elimination between males and females ( $F_{1,14} < 0.001$ ,  $p = 0.991$ ) and so the data were pooled to produce a highly significant regression equation that accounted for a high proportion of the variation in the data ( $r^2 = 0.946$ ,  $p < 0.001$ ). The amount of brodifacoum recovered from weta during the first two hours after dosing was less than expected, the regression equation predicting a value of 12.8  $\mu\text{g/g}$  brodifacoum at time zero. This is explained by the observed spillage during dosing and/or regurgitation after dosing, and possibly to incomplete recovery of the brodifacoum during laboratory analyses. The form of the curve suggests that most of the brodifacoum was eliminated within two days, and the rate of elimination decreased over time ( $F_{1,14} = 40.3$ ,  $p < 0.001$ ). This may have been due to some of the compound passing rapidly through the gut unchanged and some being metabolized.

Table 2. Feeding responses of three species of insect when presented with Talon® baits on separate occasions overnight.

	Talon® 20P			Talon® 50WB	
	Number of Individuals Observed	Number (and Percentage) Observed Feeding on Bait	Range of Individual Total Feeding Times (secs) During 16 h Overnight	Number (and Percentage) Observed Feeding on Bait	Range of Individual Total feeding Times (secs) During 16 h Overnight
Cave weta	17	10 (59)	12 - 3840	6 (35)	12 - 90
Large-headed weta	7	3 (43)	472 - 765	0 (0)	-
Ground beetle	15	15 (100)	1 - 151	7 (47)	1 - 24

Table 3. Proportions of large-headed weta dying after being dosed with brodifacoum.

	(Control) 0 $\mu\text{g/g}$	12.5 $\mu\text{g/g}$	25 $\mu\text{g/g}$	45 $\mu\text{g/g}$	62.5 $\mu\text{g/g}$
Male	1/6	2/3	0/3	0/3	0/3
Female	2/6	0/3	1/3	0/3	0/3



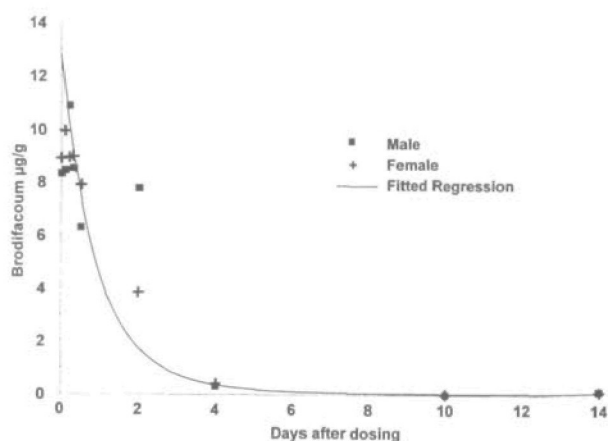


Figure 3. Elimination of brodifacoum from male and female large-headed weta following a nominal dose of 15 µg/g.

## DISCUSSION

Much of this study focused on the fate and persistence of brodifacoum in invertebrates as potential sources of secondary poisoning of birdlife. The findings suggest, however, that invertebrates are unlikely to accumulate brodifacoum as a result of bait station use of Talon® 50WB or aerial sowing of Talon® 20P. This could be because: 1) invertebrates do not find baits; 2) the baits are unpalatable to invertebrates; 3) natural food abundance or other environmental factors predisposed invertebrates against feeding on baits; 4) brodifacoum is readily metabolized and/or excreted by invertebrates; and/or 5) the brodifacoum assay is too insensitive or recovery of the brodifacoum incomplete.

Failure to find baits was improbable, especially after aerial sowing where baits were distributed on average at approximately 1 bait/1.3 m<sup>2</sup>. The authors' observations of the feeding response of three insect species towards Talon® suggest that baits being unpalatable to invertebrates is also an unlikely reason for the lack of residues in invertebrates: all three species ate one or both types of Talon®, and 20P was clearly the bait type preferred. It also seems unlikely that such a wide range of invertebrates would have been predisposed not to feed on baits by environmental factors such as food abundance, particularly on Coppermine Island where Talon® 50WB baits were presented continuously over a seven month period.

It is, therefore, possible that some invertebrates did feed on Talon® baits, but the brodifacoum was eliminated quickly through metabolism and/or excretion. This was supported by the results of the laboratory study, where elimination of a large (nominal) dose of brodifacoum (15 µg/g) in four days was recorded. This rate of elimination is much more rapid than the four months reported in vertebrate tissues (e.g., Lass et al. 1985; Eason et al. 1996). It also contrasts with a previous field finding at

Puketi forest of 1080 residues in invertebrates after aerial poisoning (Eason et al. 1993) where 1080 was found in two species of weta and a cockroach species for up to three weeks. The result requires further verification in weta and other invertebrates allowed free access to baits, but if elimination of brodifacoum by weta is representative of invertebrates, there is little likelihood that brodifacoum would accumulate in invertebrates following prolonged feeding on Talon® baits. Furthermore, the finding that most weta dosed with brodifacoum survived concentrations up to 62.5 µg/g (a dose well in excess of the LD<sub>50</sub> for all vertebrates listed by Eason and Spurr 1995) supports Shirer's (1992) view that invertebrates are unlikely to be killed by brodifacoum, but additional studies are required with other species to confirm that Talon® baiting has an insignificant impact on invertebrate species.

The sample pooling procedure adopted was designed to increase the chances of detecting brodifacoum contamination, and although contamination of individual animals may be diluted by pooling with uncontaminated animals, it is believed the procedure is more likely to detect residues than the same amount of laboratory analysis applied to spot-sampling of individual animals. The limit of detection equates to consumption of 0.002 g of bait by a large invertebrate, such as a weta, weighing 1 g, or a pooled 1 g sample of a smaller invertebrate, such as millipedes. Even if it is assumed that all invertebrate tissues contain brodifacoum at a concentration of 0.045 µg/g, which is just below the lower limit of detection (i.e., 0.05 µg/g), the risks of secondary poisoning are very low. For example, a southern black-backed gull [the most susceptible avian species for which data are given in Eason and Spurr (1995)] weighing 1 kg would have to consume 16.6 kg of such contaminated invertebrates to receive an LD<sub>50</sub> dose of the toxin. Therefore, even if the laboratory assay for brodifacoum in invertebrate tissues was too insensitive, it is nevertheless extremely unlikely that undetected levels of brodifacoum presented a hazard to insectivorous birds. It is possible that a small proportion of brodifacoum was not fully recovered in laboratory analyses of invertebrates, but the low initial concentrations recorded in laboratory-dosed weta were believed to be due to observed spillage and regurgitation rather than poor recovery.

As so few invertebrates were found contaminated, the brodifacoum residues found in dead blackbirds and those collected alive on Red Mercury Island probably resulted from direct consumption of bait rather than from feeding on contaminated invertebrates. [This suggests that the green dye that is incorporated in pest baits in New Zealand to deter feeding by birds (Caithness and Williams 1971) may not be a completely effective measure.] However, primary and secondary poisoning of blackbirds, and perhaps other bird species, did not result in measurable reductions in bird populations on Red Mercury Island (Robertson et al. 1993). Similarly, although a few individual birds were found dead after aerial poisoning of rabbits and kiore with Talon® 20P on Stanley Island, Towns et al. (1993) found no evidence of a detrimental effect on the population of any species, including the ground-feeding Saddleback (*Philesturnus*

*carunculatus*) and Red-crowned Parakeet (*Cyanoramphus novaezealandiae*) and the predatory Morepork (*Ninox novaezealandiae*). The possibility of non-target kills occurring after aerial operations may be outweighed by the benefits of habitat improvement gained by rapid removal of rodents. Nevertheless, such a management decision should be supported by information on the likely response of populations of non-target species to Talon® 20P baits.

Since no dead birds with brodifacoum residues were found on Coppermine Island, it appears that the risk of poisoning birds may be avoided by placing bait in bait stations. However, this may be impractical on larger islands with inaccessible terrain.

As no residues were detectable in the soil or water samples, significant soil and water contamination appear unlikely as a result of Talon® baiting, either from aerial or bait-station applications. Nevertheless, further monitoring for brodifacoum in invertebrates, soil, and water under normal operational use should be undertaken at other sites to determine the general applicability of these findings. Additional studies are also required to determine which species of wild birds (particularly in prospective wildlife refuges) are most likely to feed on Talon® baits, and the potential impact on bird populations.

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## THE EVOLUTION OF APHIS TWO GAS CARTRIDGES

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**ABSTRACT:** The U.S. Department of Agriculture, Animal and Plant Health Inspection Service (APHIS) has two federal (Section 3) vertebrate pesticide registrations with the U.S. Environmental Protection Agency (EPA) for gas cartridges to control damage to American agricultural resources and reduce threats to public health and safety. The gas cartridges are pyro-fumigant devices that produce primarily carbon monoxide when ignited. In sealed burrows or dens, carbon monoxide is highly toxic when inhaled, leading to tissue hypoxia. Carbon monoxide is recommended by the American Veterinary Medicine Association's panel for euthanatizing animals because it quickly induces unconsciousness without pain and with minimal discernible discomfort. APHIS's gas cartridges for rodent and predator control have been developed and maintained primarily by research conducted at the Denver Wildlife Research Center (DWRC). APHIS's Gas Cartridge (EPA Reg. No. 56228-2) for burrowing rodent control has evolved through various formulations and sizes. Formerly, the Gas Cartridge was formulated with six-active ingredients; however, in April 1996, an amendment to use only two-active ingredients [sodium nitrate and charcoal (carbon)] and two-inert ingredients (fuller's earth and borax) was approved by EPA. These two-active ingredients produce carbon monoxide, and the inerts increase the burn time. DWRC field studies have shown the gas cartridge to be effective for the control of rats, woodchucks and Richardson's ground squirrels, but not for Northern pocket gophers. The Large Gas Cartridge (EPA Reg. No. 56228-21) was originally developed using only two ingredients (sodium nitrate and charcoal) as a predacide to control coyotes in dens. Recent efficacy data led to the addition of the fox and skunk to the label; however, the Large Gas Cartridge was not effective in controlling badgers. This paper discusses the evolution of APHIS's gas cartridges and includes: 1) an introduction to APHIS's gas cartridges; 2) a synopsis of gas cartridge research conducted by personnel of the Denver Wildlife Research Center; and 3) a discussion of the management implications associated with the current status and future of APHIS's gas cartridges.

**KEY WORDS:** carbon monoxide, fumigant, predacide, rodenticide, vertebrate pesticide

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### INTRODUCTION

The U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS) has maintained, as required by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), two federal (Section 3) vertebrate pesticide registrations for gas cartridges used by APHIS's Animal Damage Control (ADC) program (Ramey et al. 1992). ADC provides federal leadership authorized by the Animal Damage Control Act of 1931 (USDA 1990) in managing wildlife conflicts with human activities that may result in damage to agricultural and industrial resources, pose risks to public health and safety, or impact other natural resources including wildlife species (Acord 1991). ADC has developed and/or maintains several low volume minor use vertebrate pesticides, including the gas cartridges, for these purposes (USDA 1994). Although the types and status of APHIS's pesticides and their active ingredients (AIs) have been summarized elsewhere (Ward 1962; Ramey et al. 1992 and 1994b; USDA 1994), a comprehensive history and status of APHIS's gas cartridges is presented in this manuscript.

The Denver Wildlife Research Center (DWRC) is the only major federal research facility in the U.S.

conducting research related to wildlife damage management (Reidinger 1990). Among its many activities, DWRC generates data according to Good Laboratory Practice guidelines (U.S. EPA 1991a) for submission to EPA. Many of these studies support current APHIS vertebrate pesticide registrations and the reregistration of their AIs (Ramey et al. 1994b). However, to meet the challenges of the next century, DWRC scientists are also investigating nonlethal repellents and new technology-based alternatives such as immunocontraception to provide more alternatives for use by ADC in its Integrated Pest Management (IPM) program (Ramey et al. 1994a). The search for new and/or improved IPM tools and techniques should require wildlife managers to develop selection criteria about ideal products. For vertebrate pesticides, Savarie and Connolly (1984) have suggested several criteria including: humaneness to the species of concern, efficacy under practical working conditions, safety to humans and the environment, availability at low cost, and the likelihood of registration with EPA or Food and Drug Administration. These criteria are similar to several suggested for an ideal fumigant by Fiedler et al. (1990), but they also recommended a preference for a solid

fumigant that is easy to handle, transport, apply, and store. One vertebrate pesticide that meets most of the criteria mentioned above is APHIS's gas cartridge.

#### Gas Cartridge

The gas cartridge is a pyrotechnic device and is composed of two parts: 1) the tube—a cardboard cylinder closed by cardboard caps at both ends containing the formulated product, predominantly sodium nitrate and charcoal; and 2) the fuse—a fireworks fuse inserted through one end cap into the combustible mixture. After the fuse is lit, it burns into the mixture and causes it to ignite. When the burning gas cartridge is used in a confined space with a limited air supply, such as a burrow or den, it can produce lethal concentrations of carbon monoxide.

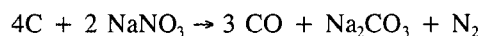
Using the gas cartridge for the control of vertebrate pests, the applicator carefully selects the den or burrow of the specific animal of concern and ensures that the cartridge will freely enter the burrow or den. Next, the applicator obtains material to plug the burrow entrance after ignition and plugs all other openings to the burrow/den system. The gas cartridge is prepared for use by puncturing one end of the cartridge, with a 1/8" diameter nail at one of the two central points marked, and the supplied fuse is inserted into the hole leaving a minimum of 3 inches of fuse exposed. After all secondary burrow openings are closed, the fuse is safely lit and the cartridge is placed, fuse-end first, into the burrow entrance as far as possible and this opening is immediately closed with dirt and/or rock(s). In burrows with steep entrances, the contents of the cartridge may flow out of the lighted end; therefore, in these instances the cartridge should be placed as deep into the burrow as possible with the fuse-end up before lighting and closing the burrow. During combustion, the applicator should prevent the escape of any generated gases using more soil/rocks as appropriate to plug any areas where gases are observed escaping from the burrow. Gases produced by the burning cartridge are mostly simple organic and inorganic compounds with carbon monoxide the primary toxic gas (Savarie et al. 1980; U.S. EPA 1991b).

#### Cartridge Mode of Action

Charcoal (carbon) and sodium nitrate are common chemicals, and they are widely accepted as safe. Human toxicity to carbon could occur only under very unusual or overwhelming dosage conditions (USDI 1981). Toxicity reports from DWRC research for albino rats show no signs of toxicity or mortality to oral doses of 3,000 mg/kg of either charcoal or sodium nitrate (DWRC 1979). Charcoal is used as a fuel for barbecuing foods and in the human food industry to process sugar and alcoholic beverages (USDI 1981). The adsorptive properties of charcoal have been utilized in removing toxic chemicals from water (Dawson et al. 1976) and as "activated charcoal" for the emergency treatment of some cases of poisoning (Picchioni et al. 1966). Similarly, sodium nitrate is considered safe and is used in the manufacture of various products including glass, explosives, ceramics, detergents, pulpwood and paper, charcoal briquettes, and fertilizer (USDI 1981). In the metallurgy industry, sodium nitrate is used as a flux or oxidizing agent, and its

use as a color fixing agent for meat is accepted by USDA (Olin Corp. 1978).

However, combustion of these safe chemicals produces carbon monoxide (CO) according to the following formula (Magram, no date).



Summary: Carbon + sodium nitrate → carbon monoxide + sodium carbonate + nitrogen gas

Carbon monoxide is a colorless, odorless, tasteless, and highly poisonous gas (Windholz and Budavari 1983). It is highly toxic to all animals that use hemoglobin in their blood to transport oxygen from the lungs to the cells of the body. Like oxygen, the primary route of entry of CO into the animal is through inspired air. Because CO has a much higher affinity than oxygen to combine with hemoglobin in the lungs, it displaces oxygen and forms a complex molecule (carboxyhemoglobin) which circulates through the body and quickly produces tissue hypoxia (Swinyard 1975). Secondary toxicity does not occur with CO poisoning (Savarie et al. 1980).

The acute inhalation toxicity of carbon monoxide to humans can be explained by two factors—concentration and duration of exposure. Symptoms of CO poisoning can occur after exposure to 0.05% (500 ppm) concentration for 1 hour or 0.10% (1,000 ppm) for 30 minutes. If the concentration reaches 0.15%, exposure for 1 hour may cause mortality, and higher concentrations produce death very quickly (American Industrial Hygiene Assoc. 1965). The signs and symptoms of carbon monoxide poisoning are directly correlated with the carboxyhemoglobin content of the blood (Swinyard 1975; USDI 1981). The American Veterinary Medicine Association's (AVMA) Panel on Euthanasia recommends CO for euthanatizing animals, because it quickly induces unconsciousness without pain, produces minimal discernible discomfort, and results in rapid death at concentrations of 4-6% (AVMA 1993).

The environmental fate of CO from natural and manmade sources has been studied extensively. Eventually, CO: 1) disperses harmlessly into the atmosphere in an insignificant amount (Seiler et al. 1978); 2) is entrapped in the soil where it is metabolized by soil microorganisms such as fungi (Inman and Ingersoll 1971) and bacteria (Heichel 1973); or 3) enters one of several carbon cycles (USDA 1994), such as conversion to carbon dioxide or fixation by bacteria.

Besides CO, sodium carbonate (Na<sub>2</sub>CO<sub>3</sub>) and nitrogen gas (N<sub>2</sub>) are also formed when the gas cartridge is used. The oral LD<sub>50</sub> for sodium carbonate in rats is about 4,000 mg/kg (Frank 1948), and its toxicity to humans depends upon its ingestion in large quantities producing corrosion of the gastrointestinal tract, collapse and death (Windholz and Budavari 1983). The nitrogen gas produced does not pose any biological hazard, because it either dissipates into the air where it already constitutes about 78% of the earth's atmosphere by volume (Windholz and Budavari 1983) or it becomes incorporated into various nitrogen cycles when exposed to soil or water. In summary, the use of gas cartridges does not produce a negative impact on the environment, and the

CO produced is well established as a humane euthanizing agent.

#### HISTORY OF GAS CARTRIDGES

The gas cartridge was developed during the 1940s by the Bureau of Biological Survey for the control of burrowing rodents. By 1945, the U.S. Fish and Wildlife Service (USFWS) recognized a need for a fumigant for controlling coyotes in dens. Arrangements were made with the U.S. Army Chemical Warfare Service to develop a better cartridge than the six-active ingredient gas cartridge being produced by the Pocatello Supply Depot (PSD) (238 E. Dillon Street, Pocatello, ID) (USDI 1981). Magram (no date) studied and compared various types of pyrotechnic fumigants and found that a cartridge with only two-active ingredients, sodium nitrate and charcoal, produced more CO than the six-active ingredient cartridge, and he implied that the former might, therefore, be more efficacious, although he provided no animal efficacy data. APHIS currently maintains two gas cartridge registrations for underground use to control burrowing rodents (Gas Cartridge) and coyotes (Large Gas Cartridge).

#### Gas Cartridge (EPA Reg. No. 56228-2)

The Gas Cartridge was originally registered by the U.S. Department of Interior (USDI), U.S. Fish and Wildlife Service (USFWS) (Reg. No. 6704-4) in 1960. It contained six-active ingredients (sodium nitrate, charcoal, sulfur, red phosphorus, black summer oil, and sawdust) and two-inert ingredients (borax and fuller's earth) (W. Jacobs, EPA, pers. commun.). It was registered for control of burrowing rodent pests, specifically woodchucks, prairie dogs, gophers, and ground squirrels (Savarie et al. 1980). This registration was transferred to USDA/APHIS in 1986, during the transfer of the ADC program from USDI to USDA, as EPA Reg. No. 56228-2 (Ramey et al. 1992).

Using a simulated rodent burrow (SRB), efficacy tests for a two-active ingredient rodent gas cartridge (65 g) were begun in the late 1970s. SRB laboratory studies using Norway rats (*Rattus norvegicus*) (Savarie et al. 1980), indicated the two-active ingredient gas cartridge formulation was as effective as the original six-active ingredient cartridge. In field studies, Savarie et al. (1980) reported the two-active ingredient gas cartridge was 77% effective with Norway rats in burrows (Table 1). Later the SRB was improved using polyvinyl chloride (PVC) plastic pipe (Elias et al. 1983), which allowed for the measurement of oxygen or toxic gases anywhere along the system. Using this system, Elias et al. (1983) reported 100% efficacy using six albino rats (Table 1).

Because of an accidental fatality from cartridge misuse in 1980, the EPA began to look at use warnings, fuse characteristics, and burn time attributes to increase cartridge safety. Citing other cases of gas cartridge injuries such as burns, the EPA sent USDI a notice of intent to cancel both of APHIS's gas cartridge registrations if revised labeling, warning notices, longer fuses, and minimum standards for fuse burn time were not made. In response, DWRC researchers made label changes that were approved by EPA, developed a formulation accepted by EPA with minimum fuse and

cartridge burn time characteristics (Savarie et al. 1991, 1993) (Table 1), and addressed endangered species considerations.

While DWRC personnel were adjusting the formulation to produce a safer and equally or more effective rodent gas cartridge, other DWRC scientists were field testing sizes of the two-active ingredient Gas Cartridge. Fagerstone et al. (1981) reported 67% efficacy using a 65 g cartridge to control Richardson's ground squirrels (*Spermophilus richardsonii*); radiotelemetry was used for carcass retrieval (Table 1). Because this cartridge did not attain the 70% efficacy arbitrarily established by EPA for rodenticide registration, the efficacy of a larger and heavier cartridge (97 g) was tested by Matschke and Fagerstone (1984) a few years later; they reported 84% control with the same species (Table 1). Later, Dolbeer et al. (1991) conducted a comparison efficacy study using both the PSD Gas Cartridge with six-active ingredients and a 117 g, two-active ingredient gas cartridge for controlling woodchucks (*Marmota monax*) in their burrows. Efficacy, determined by excavating 97 burrows and retrieving the carcasses, was similar for both gas cartridges and was 80% for the latter (Table 1). In addition, they found that careful use of gas cartridges led to low mortality (4%) of co-habiting nontarget species (Dolbeer et al. 1991). Recently, a 145 g formulation was used to control Northern pocket gophers (*Thomomys talpoides*) (Matschke et al. 1995); however, it was not effective (Table 1). These investigations demonstrated that gas cartridge efficacy was not compromised by using the new two-active ingredient formulation and that other sizes this gas cartridge was effective in the control of several rodent species.

On August 16, 1991 APHIS applied for a new gas cartridge registration for rodent control (Gas Cartridge II), including only carbon (charcoal) and sodium nitrate as AIs; however, small amounts (< 15%) of three-inert ingredients (borax, fuller's earth, and mineral oil) were added to the formulation to slow the burn time and to reduce the hazard to personnel placing these cartridges in burrows or dens (Savarie et al. 1991; Savarie and Blom 1993). This change in registrations was sought by APHIS to avoid the potentially extensive data requirements and expensive reregistration costs to support the continued use of primarily sulfur and phosphorus in the registered six-active ingredient rodent gas cartridge produced by the Pocatello Supply Depot. Reregistration Eligibility Documents for carbon and sodium nitrate were issued in 1992 by EPA, but they did not acknowledge the requested reduction in APHIS's Gas Cartridge from 6 AI to 2 (U.S. EPA 1991b). After extensive discussions with EPA about continuing to pursue both the registration and reregistration activities on two separate tracks, APHIS withdrew the application for the Gas Cartridge II in 1993. This allowed APHIS to reduce the number of active ingredients in the Gas Cartridge (i.e., for rodent control) through a formulation amendment rather than a new registration application. Eventually the new Gas Cartridge was reformulated, eliminating the mineral oil, and the final two-active ingredient (sodium nitrate and charcoal) and two-inert ingredient (fuller's earth and borax) Gas Cartridge formulation was submitted to EPA

Table 1. Efficacy results from DWRC studies supporting APHIS's two gas cartridges with two-active ingredients for control of selective vertebrate pests in burrows/dens.

EPA Reg. No.	Study Citation	Species Common Name	Cartridge Weight	Percent Efficacy
FUSE and CARTRIDGE BURN TIME				
56228-2	Savarie et al. 1991	NA	145 g	70%, n=30*
56228-2	Savarie et al. 1993	NA	145 g	93%, n=30*
GAS CARTRIDGE				
56228-2	Savarie et al. 1980	Norway Rats	65 g	77%, n ~ 500
56228-2	Fagerstone et al. 1981	Richardson's GS	65 g	67%, n=43
56228-2	Elias et al. 1983	Albino Rats	65 g	100%, n=6
56228-2	Matschke & Fagerstone 1984	Richardson's GS	97 g	84%, n=50
56228-2	Dolbeer et al. 1991	Woodchuck	117 g	80%, n=41
56228-2	Matschke et al. 1995	Northern PG	145 g	17%, n=42
LARGE GAS CARTRIDGE				
56228-21	Savarie et al. 1980	Coyote	240 g	95%, n > 500
56228-21	Ramey 1992a	Striped Skunk	240 g	100%, n=10
56228-21	Ramey 1992b	Red Fox	240 g	100%, n=10
56228-21	Ramey 1993	Badger	240 g	33%, n=6

\*Appearance of side scorch burn time characteristic  $\geq 25$  seconds.

in 1993 to replace its six-active ingredient predecessor. In April 1996, APHIS's new Gas Cartridge for rodent control was approved by EPA. APHIS now has 18 months to phase out production of the six-active ingredient Gas Cartridge and to phase in the production of the new Gas Cartridge.

#### Large Gas Cartridge (EPA Reg. No. 56228-21)

The Large Gas Cartridge was developed by the DWRC and was registered in 1981 (Savarie et al. 1980; EPA Reg. No. 6704-84) to control coyotes (*Canis latrans*) in dens. Savarie et al. (1980) described its development using a formulation containing only two ingredients (sodium nitrate and charcoal), based on earlier work conducted by the U.S. Army. In laboratory tests with adult coyotes, using the simulated coyote dens (SCD) developed at DWRC, Savarie et al. (1980) found that a 240 g gas cartridge produced 100% mortality (n=19) in young coyotes and similar efficacy (96%) in field studies with coyote pups (Savarie et al. 1980) (Table 1). In 1986, this registration was transferred with the ADC program and DWRC to USDA/APHIS; it was

renumbered as EPA Reg. No. 56228-21 (Ramey et al. 1992).

Results of additional field efficacy tests to determine mortality for other large carnivores with the Large Gas Cartridge have recently been completed. This cartridge produced 100% mortality with skunks (*Mephitis mephitis*) (Ramey 1992a) and red fox (*Vulpes vulpes*) (Ramey 1992b), but only 33% with badgers (*Taxidea taxus*) (Ramey 1993) (Table 1). Based on these data, the EPA approved the addition of fox and skunk to the Large Gas Cartridge registration.

The current Large Gas Cartridge formulation utilizes a loose mixture of sodium nitrate and charcoal. Because the formulation is not physically stabilized in the cartridge, some applications can result in incomplete combustion or the release of its contents without igniting. Although these problems might be avoided by carefully following the Use Directions on the label, the lack of formulation stabilization may result in reduced efficacy. APHIS will shortly reformulate the Large Gas Cartridge so that its contents will be exactly the same as the newly approved Gas Cartridge for rodent control.

## DISCUSSION AND MANAGEMENT IMPLICATIONS

The history of pesticide regulations (Fagerstone et al. 1990) and their effect on APHIS's vertebrate pesticide registrations have been previously presented (Ramey et al. 1992). Since these manuscripts were published, all required data submissions were completed for the gas cartridges in November 1994, including data for the recently approved reformulated Gas Cartridge. The reregistration process is complete for both of APHIS's gas cartridge products and we expect EPA approval in the near future.

As part of these efforts, DWRC has addressed concerns expressed by EPA and others (Schmeltz and Whitaker 1977) about the nontarget hazards posed by the use of gas cartridges. Although APHIS's gas cartridges have stated that they were to be used only in the underground burrows or dens of target animals, DWRC scientists observed the need for further clarifications for use. Dolbeer et al. (1991) emphasized that in the use of gas cartridges, nontarget mortality could be minimized by treating only burrows with signs of "active use" by the species of concern rather than indiscriminately treating all target species burrows in an area. Consequently, use instructions on the APHIS gas cartridge labels were recently modified to incorporate descriptive information on how to identify burrows with signs of active use by the target species (Palmateer 1993) and excluding use during the burrowing owl's nesting season.

In summary, APHIS's gas cartridges when carefully used have been shown to be effective in the selective control of several rodents (Norway rats, Richardson's ground squirrels, and woodchucks, but not Northern pocket gophers) and a few predators (coyotes, striped skunk, red fox, but not badgers). Undoubtedly, increased efficacy could result from a better understanding by applicators of all the factors affecting CO poisoning survival by target species in burrows or dens. Possible factors allowing mammal survival in the DWRC studies discussed above include: 1) intricate tunnel/burrow design (Savarie et al. 1980; Dolbeer et al. 1991; Matschke et al. 1995); 2) a tolerance for lowered oxygen levels (Kennerly 1964; Studier and Procter 1971; Ramey 1993); 3) burrow plugging behavior during burrow entrance disturbance (Minta and Marsh 1988; Ramey 1993); 4) soil porosity and moisture content (Fagerstone et al. 1981; McClean 1981); and; 5) body weight (Fagerstone et al. 1981; Matschke and Fagerstone 1984). Applicator experiential learning about these possible variables may enhance the effectiveness of APHIS's gas cartridges. Wildlife damage managers should be sure that such information is reported to APHIS/DWRC so its gas cartridges may be improved and continue to be an effective, safe, humane, and low cost tool in ADC's Integrated Pest Management program.

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# RESULTS OF A NON-LETHAL SURVEY AND REPORT PROVIDED TO THE NEW MEXICO LEGISLATURE

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**ABSTRACT:** Social and political pressures affect decision making regarding wildlife damage management issues tremendously. In fact, these areas are included in the Animal Damage Control decision model outlined in the programmatic Environmental Impact Statement. Growing concern regarding pain and suffering of animals trapped by ADC Specialists prompted two actions by the 41st Legislature of the State of New Mexico in 1994. The legislature directed New Mexico ADC not to spend over three-quarters of its \$304,000 appropriation on lethal methods. The legislature also passed a memorial bill requesting the New Mexico Department of Game and Fish, in cooperation with the U.S. Fish and Wildlife Service, and Animal Damage Control, to prepare a report with recommendations on non-injurious methods for controlling wildlife damage to private property. In response, the report was prepared and ADC employees in New Mexico conducted a survey of cooperators to determine what non-lethal methods they had implemented. Over 1,300 active agreements were surveyed to determine what non-lethal methods had been tried, what it cost to implement those methods, which methods were successful, why some methods were discontinued, and whether lethal methods were also used to reduce agricultural and other property losses. Survey results, the report on non-injurious methods, and a fiscal account of state appropriations spent on non-lethal methods was provided to New Mexico legislators during the 1995 session.

**KEY WORDS:** animal damage control, non-lethal control, surveys

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## INTRODUCTION

Increasing public concern regarding animal welfare and humane issues requires that Animal Damage Control (ADC) administrators, managers, and field staff carefully consider all aspects of any wildlife damage control project before taking corrective action. Leopold (1964) noted that efficiency, selectivity, safety, humaneness, and reasonable cost are the principal criteria needed to evaluate predator control. In fact, modern ADC employees evaluate sociocultural, economic, physical, and biologic impacts on the environment when deciding which wildlife damage control methods may be used (ADC EIS 1994). Legislators are often lobbied by groups which are unaware of this decision making process. It is not immediately obvious to persons outside animal damage management circles why some control methods are chosen over others. The public has no perception of the alternatives that are considered and applied in developing an integrated control program (Berryman 1992).

In November of 1992, former New Mexico (NM) State Land Commissioner Jim Baca, prohibited ADC from working on state trust lands. This position has been continued by current state land office personnel. At least part of the disagreement in this issue has centered around the use of non-lethal methods due to concerns about pain and suffering and impacts on nontarget species. Unless animal damage management professionals adequately explain how they arrive at decisions regarding what methods they use, public lands managers, legislators, and others will continue to question those decisions and view wildlife damage managers as uncaring, callous, cruel individuals. In the absence of accurate information, policies and practices may potentially be misdirected, counter productive, and wasteful.

Further, persons who conduct or need wildlife damage control are apt to be frustrated when bad policy, influenced by uninformed opinion, governs their actions (Timm and Schimnitz 1988). Our most immediate challenges are with the media, the public, and the legislators and regulators (Truman 1988).

In 1994 the NM state legislature passed a bill requiring that NM ADC spend no more than three-quarters of its state appropriation of \$304,000 on lethal control. The legislature also requested that the NM Department of Game and Fish (NMGF), in cooperation with the U.S. Fish and Wildlife Service (USFWS) and ADC prepare a report with recommendations on non-injurious methods for controlling wildlife damage to private property.

## SURVEY

Many wildlife damage situations require a cooperative Integrated Pest Management (IPM) approach with the cooperator conducting the non-lethal phase (Green 1993). In an effort to find out what non-lethal methods had been used and what the costs were, NM ADC field specialists surveyed over 1,300 agreements in 1994. For each resource that ADC protects, the following questions were asked: 1) What nonlethal methods were used? 2) What was the cost of those methods? 3) If the method(s) were discontinued, what was the reason (too costly, maintenance, ineffective, management conflict, or other)? 4) Were losses reduced to an "acceptable level"? No attempt was made to define "acceptable level" for the respondents.

Cooperators were also asked if lethal control methods were used in conjunction with non-lethal methods? Results of this survey are outlined in Tables 1-5.

Table 1. Number of non-lethal methods used on each agreement for the protection of a resource.

Resource	0	1	2	≥ 3
Cattle/Calves	190	523	139	54
Sheep/Goats	5	153	48	49
Multiple Resources (Beaver)	26	26	2	0
Multiple Resources (Bird)	9	17	23	20
Total	230	719	212	123

Table 2. Non-lethal expenditures by New Mexico producers for the protection of livestock.

Method	Resource		
	Cattle/Calves (Total \$)	Sheep/Goats (Total \$)	All Livestock (Total \$)
Harassment	49,200	7,600	56,800
Husbandry	802,950	269,310	1,072,260
Net-wire Fencing	5,293,875	36,549,050	41,842,925
Electric Fencing	500	96,500	97,000
Pens	47,800	--	47,800
Habitat Management	153,800	74,000	227,800
Guard Dogs	3,500	132,190	135,690
Guard Llama	--	1,400	1,400
Guard Burro	--	2,200	2,200
Propane Exploder	--	670	670
Scare Device	--	2,050	2,050
Night Pens	--	29,400	29,400
Lights	--	21,050	21,050
Total	6,351,625	37,185,420	43,537,045

Table 3. Number of agreements that continued or discontinued the use of a non-lethal method.

Method	Resource					
	Cattle/Calves		Sheep/Goats		All Livestock	
	Total Continued	Total Discontinued	Total Continued	Total Discontinued	Total Continued	Total Discontinued
Harassment	50	17	7	1	57	18
Husbandry	646	28	73	11	719	39
Net-wire Fencing	89	6	263	3	352	9
Electric Fencing	2	0	11	1	13	1
Pens	22	0	--	--	22	0
Habitat Management	105	4	3	4	108	8
Guard Dogs	2	0	34	4	36	4
Guard Llama	--	--	2	0	2	0
Guard Burro	--	--	2	0	2	0
Propane Exploder	--	--	1	1	1	1
Scare Device	--	--	4	0	4	0
Night Pens	--	--	14	0	14	0
Lights	--	--	6	0	6	0
Total	916	55	420	25	1336	80

Table 4. Reasons non-lethal methods were discontinued.

Resource Method	Too Costly	Maintenance	Ineffective	Management Conflict
<u>Cattle/Calves</u>				
Harassment	3	--	11	1
Husbandry	5	1	17	4
Net-wire Fencing	1	--	--	--
Habitat Management	--	--	4	--
<u>Sheep/Goats</u>				
Harassment	--	--	1	--
Husbandry	--	1	10	1
Net-wire Fencing	3	--	--	--
Propane Exploder	--	--	1	--
Electric Fencing	--	--	1	--
Guard Dog	--	--	4	--
Habitat Management	--	--	4	--
Total All Livestock	12	2	53	6

Table 5. Did non-lethal methods reduce losses to an acceptable level?

Method	Resource					
	Cattle/Calves		Sheep/Goats		All Livestock	
	Yes	No	Yes	No	Yes	No
Harassment	5	65	0	5	5	70
Husbandry	159	515	14	63	173	578
Net-wire Fencing	10	88	45	243	55	331
Electric Fencing	1	0	--	10	1	10
Pens	18	2	--	--	18	2
Habitat Management	11	92	0	8	11	100
Guard Dogs	2	1	11	28	13	29
Guard Llama	--	--	1	1	1	1
Guard Burro	--	--	0	2	0	2
Propane Exploder	--	--	0	2	0	2
Scare Device	--	--	0	4	0	4
Night Pens	--	--	8	6	8	6
Lights	--	--	0	6	0	6
Total	206	763	79	378	285	1,141

Following are some of the highlights from the survey:

- Over \$43.5 million was spent by livestock producers in NM to implement and maintain non-lethal methods.
- 83% of livestock producers surveyed used at least one non-lethal method to reduce losses to predators.
- Non-lethal methods commonly used by livestock producers include net wire fencing, electric fencing, husbandry practices, habitat management, guarding animals, and harassment.
- Over \$1 million was spent on husbandry methods, and \$227,800 was spent on habitat management to reduce predation on livestock in NM.
- Livestock producers in NM reported spending \$139,290 on guarding animals including dogs, llamas, and burros.
- 28% of the livestock producers in NM who had tried guarding dogs indicated that the dogs helped reduce losses to an acceptable level.
- Of 1,416 non-lethal methods implemented by producers, 94% are still being used.
- Livestock producers indicated that 80% of the non-lethal methods used did not reduce losses to an acceptable level.
- 90% of the livestock producers surveyed use an integrated wildlife damage management approach in which lethal methods are used in addition to non-lethal methods.

- 52% of agreements for beaver control used at least one non-lethal method to reduce damage caused by beaver.
- 87% of middle Rio Grande valley farmers surveyed reported that they used at least one non-lethal method to protect crops and pasture from damage caused by sandhill cranes and geese.

#### HOUSE MEMORIAL REPORT

The 41st Legislature of the State of NM, 1994, passed House Memorial 104 requesting that the NMGF, in cooperation with the USFWS and the USDA/Animal and Plant Health Inspection Service, prepare a report with recommendations on non-injurious methods for controlling wildlife damage to private property. Thirty-nine separate methods were discussed in the 32-page report and each method was placed into one of three general efficacy categories.

The recommendations section of this report indicated that an integrated wildlife damage management program is recommended and more likely to be successful over a longer period of time. Any animal damage control program that does not consider noninjurious, non-lethal and lethal methods will be incomplete and unrealistic.

#### TRACKING NON-LETHAL EXPENDITURES

To demonstrate compliance with the non-lethal mandate from the state legislature, NM ADC employees tracked the amount of time and resources spent

conducting non-lethal activities. A total of 6,570.1 hours were tallied during NM FY 94. This total reflects time spent conducting operational non-lethal activities, time spent providing technical assistance regarding non-lethal methods, time spent maintaining and repairing equipment used for non-lethal control, training in non-lethal methods, and time spent conducting office duties or in meetings directly related to non-lethal activities. An hourly rate of \$21.30 was multiplied by the total number of hours to arrive at a non-lethal expenditure of \$139,943.13. This hourly rate is a state-wide average operating expense which includes salary, benefits, vehicle operating and replacement costs, all terrain vehicle and horse expenses, radio repairs, uniforms, and supplies.

An additional \$11,227.16 was spent providing non-lethal information at state and county fairs bringing the total NM non-lethal expenditures to \$151,170.29 in NM FY 94. This was almost double the required state non-lethal expenditure of \$76,000.

#### MANAGEMENT IMPLICATIONS

It is important to point out that most non-lethal techniques must be implemented by the producers and are not methods that ADC Specialists may implement. For example, although ADC employees may recommend non-lethal methods such as moving livestock out of a pasture which is particularly vulnerable to predation, use of predator resistant fencing, removal of carrion, habitat management, shifting of calving or lambing seasons, or use of guarding animals, these methods must be implemented by the producer. ADC specialists often provide technical advice regarding availability and application of non-lethal methods. ADC is commonly called upon to provide lethal assistance where potentially viable non-lethal methods are in place but fail to prevent losses (Green 1993).

For the practitioners of animal damage control, the changing attitudes of Americans toward wild animals are resulting in new values for which it will be necessary to make professional and scientific adjustments (Wagner 1989). ADC managers should be prepared to provide a detailed account of how monies are spent. With the overwhelming political majority now resting within urban populations, how urbanites perceive wildlife and the kinds of interactions they have with wild animals will increasingly translate through the political process into legislative and regulatory authorities that will guide wildlife managers in the years to come (Hadidian 1992). We must live with political realities. However, this does not mean that we cannot try to influence those realities through education. Our credibility and, consequently our effectiveness, are dependent upon public understanding

(Owens and Slate 1992). Wildlife damage managers must continually evaluate all the complex social, biologic, economic, and physical impacts when making decisions. It will always be necessary to be aware of the conflicting sources at work in determining our attitudes (Rutzmoser 1972).

New control measures that are both effective and socially acceptable are urgently needed or the program will continue to lose its capability to protect livestock (Green 1993). As Dr. Dale Brooks (1988) says, "Each of us must become active vocal proponents of the benefits of what we are doing and that we are caring people who practice the highest standards of animal welfare."

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# MANAGING PLAGUE IN ENDANGERED SPECIES HABITATS

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**ABSTRACT:** Plague is an endemic disease among field rodents in the southwestern United States. Epizootic outbreaks of this disease increase the risk of human infection where man comes into contact with infected rodents or their fleas. The risk is further increased when colonial rodents are involved, since these animals are usually found in large numbers and are often found in locations where people live, work, or enjoy recreational activities. Elimination of large numbers of susceptible rodents from a particular location following a plague epizootic usually results in a quiescent period when plague is neither a threat to those rodents moving into the former colony confines or a threat to people using the same geographic area. In areas where the human health threat following an epizootic is unacceptable, susceptible rodents and their fleas may be eliminated through trapping or poisoning the animals and dusting the burrows with insecticide to kill the fleas. In recent years, however, the health (or death) of prairie dogs (*Cynomys* spp.) or California ground squirrels (*Spermophilus beecheyi*) has become a significant ecological issue in areas where these rodents are the predominant prey base for endangered species of animals. Prairie dogs often support populations of endangered raptors while California ground squirrels may support the endangered San Joaquin kit fox (*Vulpes macrotis mutica*). In some areas of central California, where the kit foxes are supported by ground squirrels, reduction in the number of rodents to reduce the threat of plague is prohibited. Confounding the management of plague, limitations may be placed on the types of insecticides used for flea control following an epizootic. When insecticide use is permitted, preventive flea control to protect rodents from plague results in a continuous, sustainable population of highly plague susceptible rodents. When flea suppression fails, replacement animals can be trapped and relocated to areas decimated by plague. Not only are these types of plague management expensive in terms of manpower, equipment and time, but the potential of epizootic plague is constantly present.

**KEY WORDS:** epizootics, rodents

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## INTRODUCTION

Plague was first introduced into North America in 1900 via Norway rats (*Ratus norvegicus*) aboard ships from Asia (Pollitzer 1954; Link 1955). The disease was quickly spread by infected fleas to urban rat populations in port cities along the Pacific and Gulf coasts (Prince et al. 1965). Human plague in the United States remained a largely urban disease until the 1920s (Barnes 1982) when improved sanitation programs and rat control projects virtually eliminated plague from the port cities where it was first introduced (Prince et al. 1965). During this time period, plague was being spread through sylvatic rodent populations in the west following transfer of the disease between the infected urban rodent/sylvatic rodent interface (Nelson et al. 1986). It was not until the 1960s that there was a resurgence of human plague cases in the United States (Barnes 1982). This phenomenon was brought about through the explosive migration of people from urban population centers into more rural suburban areas of the west. Suddenly, housing developments were built within or adjacent to habitats in which plague was maintained in an enzootic state by the local rodents and their fleas (Nelson 1984; Baker 1984). At the present time, evidence of plague has been found in the majority of counties located west of the 100th meridian (Barnes 1982).

## BACKGROUND

Plague is maintained in enzootic habitats through infected rodents (Nelson 1982). Some rodents may carry the disease without any outward signs of infection, other rodent species may have a variable response to plague,

and some species are highly susceptible to disease (Stark et al. 1966). When plague kills a rodent, fleas, many of which may be infected, remain alive and actively seek a new vertebrate host. If this occurs among relatively solitary rodents, then the infected fleas left without a host in the environment may pose little threat to humans on a geographical basis. However, the greatest threat to humans occurs when colonial rodents, such as California ground squirrels (*Spermophilus beecheyi*) and prairie dogs (*Cynomys* spp.) are infected with plague. These animals are almost universally susceptible to plague, die very quickly, and usually leave behind large numbers of live, plague-infected fleas following an epizootic. Not only do these rodents amplify plague in the affected area, but the peridomestic nature of these colonial rodents often places them in close proximity to human activity.

## EPIZOOTIC PLAGUE

Plague epizootics among colonial animals seem to occur on a cyclical basis. Widespread dieoffs of prairie dog or California ground squirrel colonies oftentimes follow a five to seven year period. This does not mean, however, that plague disappears from a particular geographic area since enzootic plague among solitary rodents can be found in almost any area which experiences epizootic plague on a recurring basis. One explanation for this cyclical phenomenon is based on geography and rodent density (Nelson 1980). For example, when prairie dog or ground squirrel colonies are somewhat contiguous within a geographic area, plague can be easily spread to nearly all of the animals regardless of where it is introduced into the population

(Stark et al. 1966). Plague-infected fleas may be carried within colonies and to adjacent colonies by the prairie dogs/ground squirrels themselves or by carnivores which are feeding on the rodents. When the plague epizootic is over, very few prairie dogs/ground squirrels are usually left alive and are usually isolated in small pockets within the former colony boundaries. Although plague may continue to be present in the following years, transfer of infected fleas across the long distances separating these small isolated prairie dog/ground squirrel colonies does not always occur. It may take years for the original dieoff area to be fully repopulated by those prairie dogs/ground squirrels which survived the epizootic and other prairie dogs/ground squirrels migrating from outside the formerly affected colonies (Crosby 1986).

#### PLAGUE CASE STUDY—PRAIRIE DOGS

The following example will illustrate a typical plague epizootic among black-tailed prairie dogs (*Cynomys ludovicianus*). The area in question was a 27-square mile military installation which contained approximately 4,500 acres of prairie dog colonies. In November 1988, installation personnel noticed the absence of prairie dogs in a colony comprising approximately 800 acres. Closer examination of the affected area indicated that prairie dogs had not been active for at least the past several months. Vegetation was encroaching on the burrow mounds, dried vegetation and other debris were found in many of the burrow entrances, fecal pellets were hard and weathered, and there were virtually no live prairie dogs within the area. Live prairie dogs were found in an adjacent colony just south of the affected area. Plague was suspected, but could not be immediately confirmed. Since coyotes are good sentinel animals for plague (Barnes 1974, 1982), four of the predators were captured in the die-off area and small blood samples were taken. Subsequent testing of the blood showed that all of the coyotes had positive titers to plague. While this indicated the carnivores had been feeding on plague-infected rodents, it was still not absolutely certain that their prey had been taken from the die-off area. Attempts were made to recover live fleas from the rodent burrows, but the cold winter temperatures made this approach impractical. In March 1989, fleas were extracted from prairie dog burrows in the die-off area. At the same time, prairie dogs in the colony adjacent to the southern end of the die-off area began to die; examination of the carcasses revealed plague infection. The local county and state health officials were notified that a plague epizootic was underway.

Permethrin dust, the insecticide of choice since it had been shown to provide long-term flea control, particularly in dry climates (Maupin et al. 1991), was applied at a rate of 3/4-ounce per burrow in a 1/4-mile band around the perimeter of the installation. This measure was taken to kill any live plague-infected fleas which could be carried by prairie dogs off the installation to the adjoining civilian community or which could be picked up and carried off the installation by dogs and cats wandering into affected colonies. Once the perimeter was dusted, flea control efforts were begun on interior prairie dog colonies. By June 1989, only 250 acres of prairie dogs were left alive. This plague epizootic had killed approximately 95 % of the

original prairie dog population within seven to eight months. From a human health viewpoint, the flea control efforts had been a success. Based upon the remaining numbers of prairie dogs, it would take a minimum of five to seven years before the 4,500-acre prairie dog habitat would be fully repopulated. Although plague could still infect the remaining prairie dogs, their small numbers and the relatively long distances between colonies significantly minimized the health impact of epizootic plague.

In terms of plague, the reduction in the number of highly susceptible animals and their fleas was an ideal situation. However, this military installation was undergoing a change in status under which the U.S. Fish and Wildlife Service was taking over the land management from the Army. One of the more important aspects of this newly emerging wildlife area was the use of the land by raptors, particularly bald eagles. These birds had a history of wintering on the installation, and utilized prairie dogs as a significant part of their prey base. With the upcoming bald eagle migration and the loss of virtually all of the prairie dogs to plague, extraordinary measures were taken. Prairie dogs were live-trapped from areas off the installation and were released into the previous plague dieoff areas. In order to minimize the potential for bringing in plague infected animals, the prairie dogs were sprayed with a light application of pyrethrin insecticide to kill any fleas prior to their relocation. Even if some of the animals had plague at the time of trapping, without a flea base, the death of some prairie dogs in the reintroduction area would have little impact on the rest of the prairie dogs. Eventually, some of the prairie dog colonies were repopulated in sufficient numbers to provide an attractive source of food for eagles in the area. These prairie dogs would also provide greater numbers of animals to breed and disperse into the former colonies decimated by plague.

From a wildlife point of view, the resolution of plague described above was highly desirable since the natural repopulation interval had been artificially accelerated. However, from a human health perspective, the chance of epizootic plague within the community had also been artificially accelerated. In situations such as this, flea dusting of burrows with healthy prairie dogs would reduce the chance of epizootic plague and insure a continuing prey base for the eagles. This methodology, while incurring labor and chemical costs, may not outweigh the cost of capture and relocation of prairie dogs. However, as the number of prairie dogs increases, the cost of constantly maintaining flea-free colonies rises exponentially. Along with the increasing number of prairie dogs and the rising cost of flea control, the chance of epizootic plague in these highly susceptible rodents rises significantly.

The illustration used in the case study described above is not unique. The same scenario can be applied where prairie dogs make up the prey base at black-footed ferret reintroduction sites. Preventive flea control must be weighed against the introduction of plague and the cost of reintroduction of prairie dogs following a dieoff. While human health is paramount in any plague epizootic, maintenance of plague-free prairie dog colonies in ferret areas is certainly a major consideration.

## PLAGUE MANAGEMENT—CALIFORNIA GROUND SQUIRRELS

Another example of departure from traditional plague management occurs in central California where the California ground squirrel forms the prey base for the endangered San Joaquin kit fox (*Vulpes macrotis mutica*). While the number of ground squirrels is not in jeopardy as in the case of prairie dogs mentioned above, management of plague from a human health perspective has been altered. Because of the peridomestic nature of the ground squirrels, they are often found in close proximity to offices, family housing, or recreation areas (Harrison 1995). Since the fleas which infest the squirrels are highly successful plague vectors (Kartman and Prince 1956) and readily bite man (Pratt and Stark 1973; Maupin et al. 1991), plague infection of these rodents poses an immediate threat to the humans in the vicinity of the burrows.

One of the traditional methods of ground squirrel control in plague endemic areas is the burrow application of aluminum phosphide fumigant (Salmon and Schmidt 1984) which not only kills the animals, but also kills the fleas. This method is preferred over control methods using poisons which kill the squirrels, but may leave live plague-infected fleas in the burrows. Because the label on the fumigant prohibits its use within one mile of a kit fox den, use of this material is virtually eliminated. The alternative method of control is live-trapping and removal of the ground squirrels from the immediate vicinity of high human use areas. While this method works, it is more costly in terms of the labor required. Flea control must be done in the burrows from which the animals have been removed (Poland and Barnes 1979), and the trapping efforts must be continuous since the void created by removing the ground squirrels is quickly filled by new animals migrating into the area.

Another confounding issue is the choice of insecticide for flea control during a plague epizootic. Some of the more effective, long-lasting insecticides are prohibited from use because of the danger they may pose to the health of kit foxes which eat squirrels which may have insecticide dust on their bodies. The insecticides which are deemed "safe" for use in the ground squirrel colonies may be effective in killing fleas for a limited period of time. This means that repeated insecticide application may be needed, adding increased costs which would not normally be incurred if the endangered kit foxes were not present in the control areas.

## DISCUSSION

Plague is a natural phenomenon in the western United States. Concern for human health in plague endemic areas is as keen as it has ever been. Traditional plague control efforts have been based on management of rodents which amplify plague during epizootics and on elimination of plague-infected fleas from rodent die-off areas. Increased emphasis has been recently placed on preserving habitats of endangered birds and mammals. Some of these endangered species utilize rodents, which amplify plague, as the primary prey base. Because plague can severely deplete this food source, prevention of plague in amplifying rodent populations has been undertaken as a way of maximizing rodent numbers. When prevention of

plague has not always been possible, rodents have been trapped and relocated into the plague die-off area in an effort to restabilize the prey base. Restrictions on the choice of insecticides and rodenticides in endangered species habitats have resulted in the use of less efficacious means of control. The artificial manipulation of rodent populations, preventive flea control on rodents, and limitations on the use of the most effective insecticides for flea control, have not only increased the potential for epizootic plague, but have also increased the cost of plague management in endangered species habitats.

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# OPERATIONAL CONTROL OF THE BROWN TREE SNAKE ON GUAM

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**ABSTRACT:** An operational control program for brown tree snakes (*Boiga irregularis*) on Guam began in April 1993. The program focused on minimizing the dispersal of brown tree snakes to other Pacific islands and the U.S. mainland. During the first year of operation, more than 3,000 snakes were caught within a kilometer of high risk port facilities using traps, detector dogs, and spotlighting. Additionally, habitat modifications and prey-base removal were used to reduce the attractiveness of these facilities to brown tree snakes. Public awareness was also an important part of the program such as the education of cargo packers, shippers, and Customs inspectors who could further minimize brown tree snake dispersal off-island. Initial control efforts in the program became more efficient with the recognition of brown tree snake characteristics, i.e., it was discovered that perimeter trapping a 5 ha patch of jungle was sufficient to remove most snakes instead of saturating the area with traps.

**KEY WORDS:** brown tree snake, snake control

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## INTRODUCTION

Brown tree snakes have caused significant environmental and economic impacts since their inadvertent introduction to the island of Guam in the late 1940s. Other islands in the Pacific and the U.S. mainland have been concerned about their potential introduction with their propensity to do damage. Hawaii was particularly concerned and assisted in obtaining funds for an operational brown tree snake program at commercial port facilities on Guam to reduce the risk of them being transported on air and surface carriers or in their cargo to Hawaii.

In April 1993, the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Animal Damage Control Program (ADC) started an operational control program involving containment activities at commercial air and seaports to minimize the dispersal of brown tree snakes. The ADC program was expanded to include military bases on Guam in August 1993 with funds provided by the Department of Defense. Control has been primarily focused at the highest risk areas on Guam including Anderson Air Force Base (AAFB), Apra Harbors (AH) Naval Station and commercial port, and Naval Air Station (recently changed to Tiyan Reuse Authority after base closure), and Won Pat International Airport (NAS) where cargo and craft depart. High risk cargo packing sites were also incorporated in the program as time allowed including sites where military personnel's household goods were being packed for shipment. Thus far, containment activities have appeared to be successful in minimizing brown tree snake dispersal and have provided additional insight into resolving the problem.

## BACKGROUND

Since it was discovered that brown tree snakes were responsible for the decline of native bird populations (Savidge 1987), extensive research was conducted, and is ongoing, on the brown tree snake in hopes of eliminating them and their continued threat; research was conducted on Guam, in its native range, and elsewhere to provide information on the natural history of the species, determine the extent of the problem, and develop potential

methods for resolving the problem. Background information is given here so that the complexity of this problem can be understood.

## Identification

The brown tree snake, kulepblla to the native people of Guam, is a member of the colubrid family. It is characterized by a light to dark brown coloration typically marked with indistinct narrow dorsal bands, a light yellow belly which becomes increasingly gray with age, an extremely narrow, long body, and a distinctly wide head with large eyes. Most brown tree snakes are about 1 m long with some reaching lengths to over 3 m. These snakes are primarily nocturnal, seeking refuge from bright light and high temperatures during the day. Unlike most colubrids, the brown tree snake is mildly venomous; toxin is contained in the Duvernoy's glands behind the eyes. It envenomates its victims with two upper rear teeth on each side; in contrast to the hypodermic fangs of vipers, the venom is channeled into the victim through grooves in the teeth as they chew. Also, unlike the vipers, it uses its flexible body to constrict its prey while it injects the toxin into it; the venom helps immobilize prey and facilitate ingestion with digestive enzymes. The brown tree snake is arboreal and has a prehensile tail which allows it to climb remarkably well.

## Range

Brown tree snakes range from western Indonesia through Papua New Guinea to the Solomon Islands, and the northern and eastern coasts of Australia. The introduced brown tree snake on Guam has characteristics that match those from Manus, an island in the admiralties. It was, therefore, assumed that they arrived on Guam when military bases on Manus were closed at the end of World War II and materials associated with these were shipped to Guam (Rodda et al. 1992). They spread relatively fast after their appearance in the late 1940s and by the early 1980s, they were found island-wide (Fritts 1987, 1988). They have since been found on several other Pacific islands including Oahu, Saipan, Tinian, Rota, Pohnpei, and Kwajalein and Diego Garcia

(Fritts 1987, 1988) and the U.S. mainland in Texas; these have all been associated with cargo or carriers from Guam. Saipan is of particular concern because it has had several reported sightings over the past ten years and a live snake was found along a fence line at their airport in 1994 indicating that they may currently have a breeding population; no snakes, though, have been trapped in extensive efforts by biologists in the Commonwealth of the Northern Marianas where sightings have occurred.

#### Geography

Guam is the southernmost island in the Marianas archipelago. It is approximately 212 square miles with mountains reaching 300 m. The temperature rarely goes below 75°F or above 95°F and it has an average annual rainfall of nearly 100 inches. The native people of Guam, Chamorros, have inhabited the island for more than a thousand years. The current population including military personnel is about 140,000 people with more than a million annual visitors. Guam has several surface shipping ports, airports, and marinas. Apra harbor, located on the west, central side, has a commercial shipping facility and military harbor. The commercial airport and recently closed Naval Air Station is in central Guam. Anderson Air Force Base is located on the northeast side of Guam and currently services most military aircraft. These facilities all transport cargo via surface or air to many of the other Pacific Islands as well as the U.S. mainland and the Orient. Cargo is packed island-wide prior to staging at the port facilities, making control of the brown tree snake a daunting task. Guam also has three marinas where boats from them travel regularly to other islands, especially Rota, Tinian, and Saipan in the Northern Marianas.

#### Habitat

Most of northern Guam consisted of limestone forests; currently, the only large tracts remaining are found near the rugged cliff line on military lands. The remainder of the north has been developed. The southern half of Guam consists primarily of savannahs, wetlands, and mountains with scattered stands of limestone forests and urban areas. Much of the native forests in the central part of the island have been replaced by introduced tangentangen scrub (*Leucaena leucocephala*) and urban developments. The climatic conditions on Guam and its habitats are ideal for brown tree snakes, but the greatest densities occur in large contiguous limestone forests and tangentangen stands; these habitats offer ideal hunting grounds for the remaining birds, commensal rodents, and lizards, and provide escape cover for them.

Brown tree snakes are typically reclusive during the day, retreating from the hot temperatures and sunlight; they are found in dark, cool, damp areas such as in *Pandanus* roots, rotting coconut trunks, or under air-conditioners. However, it is difficult to ever find them in their daytime retreats. Because of their nocturnal and reclusive habits, most visitors, and even some residents, never see brown tree snakes.

#### Food Habits

Brown tree snakes are opportunistic feeders, eating anything from lizards, birds, and rodents to bones, dog

food, and eggs. The primary diet of brown tree snakes less than 60 cm usually consists of ectothermic prey such as lizards—geckoes, skinks, and anoles; warm-blooded prey such as rodents and birds are included thereafter; and at lengths greater than 110 cm, their diets are shifted almost exclusively to endothermic prey (Fritts 1988).

#### General Biology, Reproduction and Behavior

Brown tree snakes have been uninhibited on Guam and have reached densities of up to 58 snakes/ha (about 15,000 snakes per square mile) in unfragmented jungle areas during the early 1990s (Rodda et al. 1992). These densities are much greater than any other snake in the world. Recent density data in 1995 found a significant drop in the population to 11-20 snakes/ha (about 3,000-5,000/mi<sup>2</sup>) (G. Rodda, pers. comm.). In urban habitats with fragmented stands of tangentangen or other forest plants near port facilities, ADC personnel trapped approximately 7 snakes/ha (1800/mi<sup>2</sup>) during 1993-1994.

Brown tree snakes reach sexual maturity when they are about 1 m in length. Hatchlings are about 35 cm, females rarely exceed 2 m, and males reach the greatest length at over 3 m. Males are distinguished from females only by their hemipenes located just below the vent on both sides and those of large size.

Brown tree snakes are oviparous (egg-laying). Little is known about their eggs and hatchling development even with the densities found on Guam. Few clutches of eggs have ever been found and documented. ADC personnel have recently found and hatched two clutches of eggs, and are gathering data about the eggs and hatchlings (M. Linnell, pers. comm.). Gravid females and clutches that are found are typically 5 to 8 and do not exceed 12. It is believed that females can store sperm for several years after copulation, giving them the most potential for colonizing other islands.

Brown tree snakes are aggressive and display threats if cornered. They often strike continuously at intruders when cornered or grabbed, more often than most other snakes. However, most threats are harmless and typically only serve to warn the intruder; they usually quit when the intruder retreats or lets go.

The population of brown tree snakes on Guam has mostly been uninhibited. Competition with other species for food and space is minimal, with the exception of rats for some prey. The only predators of adult brown tree snakes on Guam outside of people are feral cats, dogs, pigs, and monitors and the population appears to have been relatively disease-free, making for relatively low mortality rates. Thus far, the greatest limiting factor appears to have been themselves because their population expanded beyond the available food supply.

#### Damage

Brown tree snakes have severely impacted and extirpated many of the native avifauna (Savidge 1987), bats and lizards (Rodda and Fritts 1992), caused power outages, threatened human health and safety, primarily infants (Fritts et al. 1990), and preyed on pets, poultry and eggs (Fritts and McCoid 1991). They have also had an impact on tourism and cultural heritage.

The introduction of exotic species is one of the leading causes of extinction and endangerment of native

species in the world. No where else has this been illustrated more graphically than on Guam with the introduction of the brown tree snake. Nine of 11 forest species on Guam were extirpated or became extinct as a result of the brown tree snake: the Guam flycatcher (*Myiagra freycineti*) and Guam subspecies of the rufous fantail (*Rhipidura rufifrons*) and bridled white-eye (*Zosterops conspicillatus*) are extinct; the Guam rail (*Rallus owstoni*) and the Guam subspecies of the Micronesian kingfisher (*Halcyon cinnamomina*) are now found only in captivity; the Micronesian honeyeater (*Myzomela rubrata*), white-throated ground-dove (*Gallicolumba xanthonura*), Marianas fruit-dove (*Ptilinopus roseicapilla*), and nightingale reed-warbler (*Acrocephalus luscini*) have been extirpated, but still exist on northern islands in the Marianas (Savidge 1987). Only a few hundred Micronesian starlings (*Aplonis opaca*) and about 50 Marianas crows (*Corvus kubaryi*) remain of the native forest avifauna, along with a few hundred island swiftlets. Much of Guam's current avian wildlife consists of a few species of resident seabirds, migratory birds, and introduced species.

The only mammals native to Guam were three species of bats. The little Marianas fruit bat (*Pteropus tokudae*) and the Pacific sheath-tailed bat (*Emballonura semicaudata*) are extinct. An endangered colony of about 500 Marianas fruit bats (*Pteropus mariannus*), though, still exists on Guam and Rota. Brown tree snakes have partially been implicated in their decline, but their disappearance was complex and probably included factors such as hunting and habitat destruction. Currently, the juveniles of the population are threatened by the brown tree snake and the adults from poaching (G.Wiles, Div. Aquatics & Wildl., Guam, pers. comm.)

Several of the native geckos (i.e., rock gecko, *Nactus pelagicus*, and island gecko, *Gehyra oceanica*) and skinks (i.e., Snake-eyed skink, *Cryptoblepharis poecilocephalus*) have also declined. Some may have declined because of competition with introduced lizards, but brown tree snakes were also implicated in their demise (Rodda and Fritts 1992).

Brown tree snakes have caused considerable damage to the island's power supply. They cause an average of over 50 outages per year with damages estimated in the millions. Power outages and associated damages were especially a problem before Guam Power Authority switched from an island-wide power system to substations. It could take two days to find where the system was shorted before substations were installed, while it only takes an average of 45 minutes now. Typhoon Omar in 1992 helped reduce the problem because downed wooden poles were replaced with cement, "typhoon-proof" poles that do not allow snakes to climb. They still gain access to the electrical wires, though, from the guy wires.

Human health and safety is also a concern (Fritts et al. 1990). The island's hospitals treat numerous snake bite victims each year. Adults are rarely ever at risk of toxic poisoning from being bitten. The greatest threat is to infants under two years of age. Several infants have had their entire arm engulfed before parents are aware of a snake's presence. Fortunately in the most severe cases, the infants bitten have been taken to hospitals quickly

enough to stabilize them; a few children have suffered respiratory failure and cardiac arrest, but were revived. Brown tree snake bites, though, do have the potential for causing death to infants if treatment is not obtained.

Brown tree snakes have also affected poultry and pets (Fritts and McCoid 1991). Pigeons and chickens along with their eggs are commonly taken by the snakes. Greatest damage dollarwise occurs to racing pigeon and gamecock breeders. Pets as large as a Labrador puppy have also been preyed upon by the snakes.

Tourism has been affected because of the presence of the snake on the island and its publicity. Articles that described Guam as having "snakes like spaghetti in trees" have an obvious effect. Some tourists that read about such densities are likely to vacation elsewhere.

Finally, some of the cultural heritage of Guam has been lost. The native Chamorros revered the local wildlife and many legends involved these species. The rufous fantail, or chicharika locally, was said to help keep families together. Its loss has been blamed for the breakdown of family unity by some Chamorros and is said to have negative implications for future generations. The Marianas fruit bat, or Finihi locally, was commonly hunted and eaten at fiestas. The Chamorros relished the bats, but they no longer can be hunted because of their endangered status. Poaching, though, is common to obtain the delicacy and further endangers the bat.

## OPERATIONAL CONTROL

In April 1993, an operational control program to control and contain brown tree snakes on Guam was initiated by ADC. After reviewing the available literature on control methods for brown tree snakes and discussing options with people involved in different facets of the brown tree snake problem, several strategies were determined to be viable approaches for containing and controlling the snake near port facilities—trapping, spotlighting, detector dogs, prey-base removal, habitat management, barriers, and modifications of cultural practices. Once the techniques were selected and administrative duties were in place, personnel were hired to begin operational control in July 1993. By September, ten personnel were conducting brown tree snake control at port facilities. Following are some of the results from the first few years of trapping and methods used to reduce the chance of the snake dispersing elsewhere.

### Trapping

Traps have long been used to trap ground dwelling snakes. The U.S. Fish and Wildlife Service developed a trap for the brown tree snake using a modified Gee's® crayfish trap (Rodda et al. 1992). The funnels on each side are fitted with flaps to allow snakes to enter, but not get back out. The traps are baited with live mice inside a chamber placed into the trap. Since house mice are difficult to obtain on Guam, a breeding colony was established in cooperation with the Guam Division of Aquatics and Wildlife. The breeding colony produced an average of 500 mice/month. Mice were climatized prior to being put out in the field. Once put in the field, they were fed grain and half-sliced potatoes for their water.

The primary method used by the ADC snake control program has been the modified crayfish traps and each

ADC employee could monitor about 150 of them. The traps have been very successful at capturing snakes and making trapped areas relatively "snake-free." Traps are placed in appropriate habitat, typically fragmented forest stands, at high densities; initially traps were placed at 20 m intervals around the perimeter of selected areas and at 30 m apart on trails cut at 30 m intervals inside these areas. Research conducted with the traps determined that optimal trap density was about 25 m apart to trap all snakes in an area (Rodda et al. 1992). Areas were considered "snake-free" only after snakes had not been captured in a plot for at least a week. Research conducted for 15 days at Orote Point, an expansive area of tangentan, found that brown tree snakes, being highly mobile, would recolonize areas quickly (Rodda et al. 1992).

Port facilities were initially mapped, distinguishing between areas of good or poor snake habitat, to determine the most appropriate route to take with traps such that a "snake-free" zone could be established. Traps were initially placed in an area that could not easily be reinvaded at least on three sides. Once they were declared "snake-free," all traps were removed except those along the perimeter adjacent to the next stand to be trapped and adjacent to any area that had not been trapped to reduce reinvasion. Traps were placed into the next adjacent area until it was declared snake-free. Then traps from the first plot's perimeter and all but the appropriate perimeter trap would be moved to the next stand. This cycle was repeated until all areas were trapped. Paved roads and extensive urban areas with few plants, brush piles, and debris were considered relative barriers for snakes and did not threaten reinvasion of trapped areas significantly. If an area was not conducive to trapping (i.e., high-visibility) or it was developed, it was searched with spotlights to catch snakes and determine if a significant number of snakes were present warranting trapping.

During the first year of operational control (July 1, 1993 to June 30, 1994), 2,546 brown tree snakes were removed from areas within a kilometer of port facilities with traps (during the first quarter, 100 hagfish traps were used until the crayfish traps came and were assembled in September 1993 and only 156 snakes were taken with traps during the first quarter). This combined with other methods represented a take of about 7 snakes/ha from the overall habitat including urban areas. Since the first year, numbers of snakes taken per year with traps have increased to over 5,000 with additional employees hired and modifications in trapping techniques.

Trap success varied from plot to plot, 0 to 25 snakes/ha with an average of about 16 from plots greater than 1 ha. Typical removal rates from all urban areas with fragmented forest stands were approximately 6 snakes/ha during the first year of operation. The number of snakes trapped during the first 2 to 3 weeks in plots less than 30 ha was constant, but dropped off dramatically to zero at normally 4 to 6 weeks. These areas appeared to remain relatively snake-free after being trapped. A 14 ha plot at Naval Station had ten traps placed randomly after it had been trapped three months prior. No new snakes were trapped for two weeks, but eight rats were. During the initial trapping, only one rat was caught in

nine weeks with 140 traps placed; rats frequently are caught in the snake traps and an obvious inverse relationship is exhibited with the number of rats and snakes caught in a plot. Therefore, it was assumed that trapping efforts were mostly successful at removing snakes from an area and that roads and other urban features provided barriers for snakes to recolonize areas. Recent research determined that the authors' assumptions were correct in that areas did remain relatively snake-free for an extended period of time after removal where barriers such as roads surrounded the area (Engeman et al. 1996). Soon after the first few months of trapping, it was determined that the interior trails could be widened to 50 m apart without having an effect on the number of snakes taken thereby reducing effort needed to make an area snake-free. This was illustrated further in April 1994 when ADC personnel had placed perimeter traps around a 5 ha forested area (approximately 175 x 300 m) at NAS. ADC personnel were unable to cut interior trails for four weeks, but the perimeter traps caught over 100 snakes. After interior trails were cut, only 1 snake was caught in three weeks with the 45 new traps placed, indicating that perimeter trapping was highly effective at removing snakes from at least small fragmented forest stands. This had a profound effect on the trapping program as fewer traps and significantly less effort cutting trails was required to remove snakes from plots as little as 5 ha. Recent research corroborated this and determined that areas up to 8 ha were effectively trapped using only perimeter traps (Engeman et al. 1996); however, mixed results were obtained for areas over 20 ha. Brown tree snakes are highly mobile and probably hunt edges for a short period when they come to them where they eventually encounter a trap. Removal of snakes with this method enabled a much larger area to be trapped since fewer traps were required to make an area "snake-free."

The greatest number of snakes taken during the first year was from the edge of contiguous habitat surrounding the air operating area at AAFB that could not be completely trapped because of its expansiveness. Snakes were trapped along a cliff line to the north and east of the airfield in 75 perimeter traps. Native limestone forests lined the top and bottom of the cliffs and extended for up to a few kilometers beyond. Over 500 snakes were removed from the area in four months of trapping. Capture rates remained relatively high for a few months in the perimeter traps, but dropped to zero after four months. Snakes apparently reinvaded the area relatively quickly, though.

The crayfish traps were very effective, but needed minor improvements. The entrance doors or flaps often got stuck open, allowing snakes to escape. Several door designs were made and monitored for their success. Recently, a new door was made that had encouraging success (Linnell et al. 1996). Another problem is that the trap was time consuming to maintain. Several styles of traps were monitored to determine if one could be made that allowed easier access to the mice, yet maintained similar trap success rates. Unfortunately, the trap designs monitored required similar or a little less time for maintenance, but were much more costly to produce. Finally, an inanimate bait that attracts snakes nearly as

well as live mice would be significantly more efficient because maintenance of traps, and mouse colony, would be reduced considerably. Thus far, the most favorable inanimate baits tested such as chicken manure and commercial predator baits attract snakes only at a rate of 5 to 20% as well as live mice. The National Wildlife Research Center is currently researching baits and chemical attractants for an effective bait.

#### Spotlighting

Since brown tree snakes are nocturnal and found in dense numbers, one would expect that spotlighting would be an efficient method of capture. However, this is not completely true; snakes in optimal jungle habitats can be collected at only about 1 snake/hour, making this a less than acceptable method of capture (E. Campbell, pers. comm.). However, it has been found that when tree snakes encounter fencelines, they readily climb it (90% + of the time), but only if vegetation and debris are maintained or mowed on both sides. This makes fencelines ideal collecting surfaces and capture rates can often be as high as 10 snakes/hour.

Fencelines surround the airfields on Guam and many of the shipping port's facilities. Since fencelines offer ideal collecting surfaces close to high-risk cargo and carriers, they were monitored frequently for snakes. During the first year, 407 snakes were caught on fencelines surrounding port facilities. Most of these snakes were taken during the first quarter (over 50% July to September 1993) when few traps had been placed in the field. Once areas near fencelines had been trapped, capture rates dropped off significantly, often to less than 1 snake/hour; in addition, snake movements were less from October to May which decreased success rates for spotlighting.

#### Detector Dogs

Dogs can be trained effectively in locating pests because of their keen sense of smell. Detector dogs, as they are often referred to, have been used extensively in pest and wildlife management. Dogs have been used by USDA's Plant Protection and Quarantine at ports of entry to detect pests and products such as plants that may have undesirable organisms in them. Dogs have been used by ADC to detect problem wildlife species such as bears and mountain lions. Detector dogs have also been used to locate contraband including snakes by the Hawaii Department of Agriculture and have proven to be effective.

Breeds were selected for snake control after evaluating specific criteria: their tenacity with snakes (i.e., Beagles can become afraid of snakes if bitten whereas Jack Russell terriers become more aggressive), maintenance requirements, size (smaller dogs can get into more places), and ability to work in hot conditions. The selection of detector dogs was made after discussion with several Oregon ADC personnel, ADC guard dog specialists, Portland veterinarians and assistants, and APHIS employees from Plant Protection and Quarantine. The final consensus was that the best suggestions were short coat Jack Russell (K. Wells, pers. comm.) or Cairns terriers (J. Green, pers. comm.).

Jack Russell terriers were relatively easy to obtain and two were trained in California and brought to Guam in October 1993. Handlers for the two terriers were hired prior to their arrival and the dogs were put to work shortly thereafter. The dogs were used to inspect outgoing cargo and carriers, especially cargo heading for other Pacific islands and the U.S. mainland, at all port facilities. Since brown tree snakes are nocturnal and evening temperatures allowed the dogs to work longer, the dogs were primarily used during late evenings. During the first eight months of operation, the dogs found 15 snakes in or around outgoing cargo including two that were taken from cargo headed for Hawaii and Farralon Island just prior to loading. Currently, ADC is using eight Jack Russell terriers for control operations at port facilities and packing sites.

The primary problem noted with the terriers for snake detection was that they became very visual and relied less on their nose for detection, and therefore, required constant and consistent training. Another problem was that they got hot relatively quickly and were unable to use their nose effectively because of panting (panting basically cuts off the ability of the nose to detect). Another breed may be able to detect the snakes scent better and for longer periods in the high temperatures. A different breed that uses its nose effectively and withstands hot temperatures for longer periods of time could be teamed up with Jack Russell terriers to be more effective. The efficacy of these dogs will be researched by the National Wildlife Research Center.

#### Habitat Modification

Urban areas with fragmented jungle, brush piles, and other debris support moderate populations of snakes; these areas often attract commensal rodents which in turn attract brown tree snakes. Removal of this habitat, especially adjacent to port and cargo facilities, reduces the brown tree snake population and reduces the risk of snakes entering cargo or carriers.

Several of the port facilities were immediately adjacent to fragmented forests (primarily tangentangen), brush piles, and debris. These areas were identified and port directors or commanding officers were encouraged to have these removed. Several heeded the requests, especially the removal of brush and debris. For example, NAS had brush and tangentangen stands within 50 feet of a helicopter hangar where several brown tree snakes were caught, including in the hangar; the Commanding Officer had maintenance clear the area. Another sight near the flightline where snakes were commonly found had fragmented forests and debris; these were removed and no more snakes were caught there. Guam Airport Authority cleared a tangentangen stand adjacent to the commercial cargo shipping facilities where several brown tree snakes had been trapped. Naval Station at AH kept grass fields mowed more often after being notified that they were growing to heights of over three feet in areas that would support brown tree snakes. All of these modifications helped reduce the population of snakes as well as prey.

Brown tree snakes are attracted to areas with abundant prey. They can detect prey at long distances, especially if prevailing winds carry the scent and/or

danger at any distances. Guam has several introduced species that are prey for the brown tree snake including the house mouse (*Mus musculus*), roof rat (*Rattus rattus*), Norway rat (*R. norvegicus*), musk shrew (*Suncus murinus*), feral pigeon (*Columba livia*), Eurasian tree sparrow (*Passer montanus*), and black drongo (*Dicrurus macrocercus*). Therefore, control of these species at port facilities and cargo packing and staging locations would reduce the number of brown tree snakes attracted to these areas.

During the first year, the pigeons at NAS and AAFB and most at AH were removed with air rifles. Over 100 pigeons were removed from Won Pat International during the first year and after their removal, additional pigeons did not try to reestablish there for several months. Drongos and tree sparrows were controlled to a lesser extent, but those that seemed to be significant attractions near port facilities were removed. Commensal rodents were controlled at the commercial facilities with snap traps and registered rodenticides (zinc phosphide and brodifacoum products). After populations were reduced, they were monitored periodically to determine if control was necessary again.

#### Cultural Practices

Shipments from Guam are packed island-wide and the containers are then transported to port facilities. Educational programs for shippers, cargo handlers, and Customs inspectors (military and civilian) that describe the brown tree snake problem and appropriate methods of handling cargo could significantly reduce dispersal. Packers should inspect cargo prior to packing and shipment to port facilities, especially items stored outdoors such as household goods like outdoor washing machines, lawn mowers, and barbecues. Cargo should be packed in sealed containers that do not allow access to brown tree snakes. Once packed, containers should be staged in open areas on concrete or asphalt surfaces to reduce the likelihood of snakes seeking refuge in them. Cargo considered the highest-risk for brown tree snakes are uncontainerized such as open wooden crates, vehicles, machinery, outdoor washers and dryers, and construction materials. High risk items should be visually inspected thoroughly by packers and they should call for inspection by detector dogs where possible.

The Commonwealth of the Northern Marianas had developed the first educational poster on brown tree snakes. It was developed primarily to alert the public of the problem on Guam and the authorities to notify should a brown tree snake be found; it was posted at port facilities. Hawaii Audubon Society produced a video that graphically outlined the brown tree snake problem and focused attention on shipments from Guam. Quarterly training programs were given to Military Customs by National Biological Survey personnel and later by ADC to increase their awareness of the problem and where they could assist in minimizing the risks. The Hawaii Department of Agriculture in conjunction with ADC recently developed a training video for shippers and cargo handlers that outlines the problem and shows appropriate shipping techniques that minimize dispersal. ADC also

developed a poster for Guam and elsewhere that has been used extensively to educate the public of the problem. These types of educational programs and displays help reduce the threat of dispersal because more eyes are watching.

#### Exclusion

Non-electric barriers are fairly effective against ground snakes, but minimally for tree snakes. However, electric barriers have proven to be effective against entrance by brown tree snakes. Temporary mesh barriers at least 1 m high and angled slightly outwards do help keep brown tree snakes from particular areas or cargo staging areas. A one-way electric fence that allows brown tree snakes to exit fenced areas, but not to enter, kept hectare plots snake-free for extended periods of time (E. Campbell, Ohio State Univ., pers. comm.). The biggest problem with the design was that rats would gnaw holes through the fence, subsequently allowing brown tree snakes access into protected areas. These barriers are permanent and somewhat costly, making temporary control of small areas difficult. Barriers have great applicability for protecting cargo and ships from brown tree snakes, but only temporary mesh barriers have thus far been used.

#### Toxicants

Research is ongoing to provide an effective toxicant for the brown tree snake. An effective, safe toxicant(s) could provide island-wide control of the snake. Recently, the Great Lakes Chemical Company added brown tree snakes to their methyl bromide label, a fumigant proven very effective for brown tree snakes. Currently, no other toxicants are registered for the brown tree snake. The Denver Wildlife Research Center has tested several oral candidates that have been effective including rotenone, pyrethrins, propoxur, diphacinone, and aspirin. One of these will be selected for registration after the development of a suitable drug delivery system. Four commercially available insecticide aerosol products killed snakes when applied dermally and are candidates as a dermal toxicant (USDA 1996).

#### Continuing Research

Research is continuing on several other potential control methods for the brown tree snake. Researchers from the National Zoo and Oregon State University are looking into pathogens that potentially would infect only the brown tree snakes and not native reptiles. A few pathogens are known from zoo collections that infect snakes and another from the brown tree snakes native range. These could have significant impacts on the population if they were suitable to introduce into the population and would not infect the native fauna. The Denver Wildlife Research Center is currently looking into inanimate attractants for toxicant delivery systems and snake traps. If these research efforts find new tools, they will be incorporated into the brown tree snake control program and could have significant impacts on the control program, possibly eradicating the brown tree snake from Guam.

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# REDUCING LIVESTOCK DEPREDAATION LOSSES IN THE NEPALESE HIMALAYA

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**ABSTRACT:** In the Nepalese Himalaya conflict with rural communities due to livestock predation to large carnivores like snow leopard, common leopard, wolf and wild dog has risen sharply in recent years. This increase is attributed to a number of factors, including implementation and enforcement of wildlife protection laws (which have permitted a recovery in carnivore numbers), the creation of protected areas (which serve as refuges from which predators can populate the surrounding area), the depletion of natural prey due to poaching and loss of habitat, and lax livestock herding practices. However, little information is presently available upon which to design remedial programs. U.S. AID provided research funding for an in-depth assessment of snow leopard predation in the Annapurna Conservation Area (ACAP), a new innovative approach to nature conservation. Baseline information on livestock numbers and mortality were gathered during household interviews, followed by field surveys to assess animal husbandry systems, map pastures, establish periods of use and estimate stocking rates, and to characterize habitat using randomly located plots. Data substantiate the existence of depredation "hotspots," where high loss occurs, in some cases exceeding 14% to 20% of the livestock population over a short period. Losses varied seasonally, and from year to year. Small-bodied stock like goat and sheep were more vulnerable than large-bodied stock like yak, although horses were especially vulnerable. Factors most closely associated with predation included lack of guarding (or very lax supervision), especially during the daytime, and repeated use of pastures where livestock depredators were known to be actively hunting. Herders usually reacted to repeated depredation incidents by attempting to trap or shoot the suspected culprit until losses declined to an acceptable level. As large carnivore populations become increasingly fragmented and genetically isolated, new management strategies are urgently needed, especially within the buffer zones and intervening corridors between separated parks and reserves. People reside within nearly all Himalayan protected areas, and such issues as loss of livestock and competition between wildlife and livestock cannot be avoided. A plan is offered for alleviating livestock loss in the Annapurna Conservation Area that involves local institutions in decision-making, rewards sound husbandry practices, strengthens indigenous institutions, without further eroding ACAP's unique biological diversity and diverse carnivore population. The authors believe these measures and ideas could be fruitfully extended to other parts of the Himalaya.

**KEY WORDS:** snow leopard, predation, control strategies, damage assessment, Himalaya, Nepal

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## INTRODUCTION

Although the livestock sector contributed only 15% to Nepal's Gross Domestic Product for 1986-87, it constitutes an essential element of the country's subsistence farming systems, both in the mountains and the plains. Pastoralism is often the dominant livelihood of the diverse human communities occupying the Himalayan zone. High-altitude pastures are critical to local and transhumant herders, and many alpine pastures are located largely or entirely within Nepal's protected areas network. Examples include the Sagarmatha (Mt. Everest), Langtang and Shey-Phoksundo National Parks, as well as the renowned Annapurna Conservation Area. Known in short as ACAP, the latter is an innovative approach to nature conservation and resource management involving local people (Gurung 1989). Increases in livestock predation are attributed to several factors, including the implementation and enforcement of wildlife protection laws (which have permitted a recovery in carnivore numbers), creation of protected areas (which serve as refuges from which predators can populate surrounding

areas), the depletion of natural prey due to poaching or loss of habitat, and lax livestock herding practices. However, little information is presently available upon which to design remedial programs.

The role of protected areas like the Annapurna Conservation Area in sustaining local communities while protecting and enhancing natural values and biological diversity is widely acknowledged (IUCN 1993). There is also widespread agreement that conservation initiatives must have the political, social and economic support of local people if they are to succeed (Wells et al. 1992). Crop and livestock damage incidents have increased dramatically in the ACAP area in recent years, and people are voicing legitimate concerns. Even when loss is shown to be due to negligence on the part of a villager, the local community may still view wildlife negatively, holding the government responsible for ensuring that the protected area offers them benefits as well.

As large carnivore populations become increasingly fragmented and genetically isolated, new management

strategies are urgently needed, especially within the buffer zones and intervening corridors between separated parks and reserves. People reside within nearly all Himalayan protected areas, and such issues as loss of livestock and competition between wildlife and livestock cannot be avoided. Conservation agencies have typically espoused policies and regulations which restricted people's rights and engendered substantial animosity toward the regulatory agencies. Clearly, new models for protecting large carnivores both in and outside of protected areas are urgently needed. This paper reports on depredation patterns due to snow leopard (*Uncia uncia*) along the northern slopes of the Himalayan in the Manang Valley near the villages of Manang and Khangshar. Since the snow leopard is an endangered species, special emphasis is devoted to alternative options for resolving people-wildlife conflicts through means other than direct predator control or population reduction. A plan is offered for alleviating livestock loss in the Annapurna Conservation Area that involves local institutions in decision-making, rewards sound husbandry practices, strengthens indigenous institutions, without further eroding ACAP's unique biological diversity and diverse carnivore population. The authors believe these measures and ideas could be fruitfully extended to other parts of the Himalaya.

## STUDY AREA AND METHODS

### Study Area

The Annapurna Conservation Area Project (ACAP) was established in 1986 by the King Mahendra Trust for Nature Conservation, Nepal's largest non-governmental organization devoted to nature conservation and sustainable rural development (Gurung 1989). Encompassing over 2,600 km<sup>2</sup>, it has been described as the most geographically and culturally diverse conservation area in the world (Wells et al. 1992). About 40,000 people of diverse ethnic backgrounds inhabit the Annapurna area, where agriculture and trade have flourished for hundreds of years in the steep-sided Himalayan valleys. Most residents are farmers, but income from tourism is becoming increasingly important. Each year over 30,000 visitors trek in the area, primarily into the spectacular Annapurna Base Camp area or along a circular route through Manang into the Kali Gandaki Valley, one of the deepest gorges in the world. Expanding cultivation, grazing, water pollution, poor sanitation and littering along trekking routes have accelerated, compounded by a rapid growth in the human population. This deterioration led to a royal directive in 1985 to improve tourist development while safeguarding the environment, leading to the formation of the conservation area.

Relief is dominated by the Annapurna Range, with elevations ranging from 3,000 to over 7,000 m. The climate is cold and dry, with less than 500 mm of precipitation annually (Dobremez 1976). Because of a strong rain-shadow effect, the study area supports dry alpine or semi-steppe vegetation types (Stainton 1972). These consist of blue pine (*Pinus wallichiana*) and West Himalayan fir (*Abies spectabilis*) forests at lower elevations, juniper (*Juniperus indica*) woodland or scrub at mid elevations, and alpine meadows or barren snowfields, ice and rock at higher elevations. A wide band of alpine grassland occurs between

3,800 and about 4,300 m. Moist north-facing slopes support a narrow band of birch (*Betula utilis*) forest, but plant cover varies widely, depending upon slope steepness, soil or moisture conditions. Level areas near the eight settlements are cultivated, with large areas now abandoned due to the declining agricultural economy and a severe lack of labor. A single crop, mostly buckwheat, barley and potatoes, is grown annually, with fields under production between May and late September. Aridity, cool temperatures and poor soils limit agricultural potential, and people are more dependent upon animal husbandry, trade and tourism for their income. Human density is placed at three persons per square kilometer (Pohle 1986).

### Methods

All Khangshar households were interviewed for information on herd size, composition, mortality, and herding or guarding patterns. The reliability of information accruing was assessed through triangulation and other widely accepted social science techniques (e.g., Casely and Kumar 1988). Special effort was made to validate predation incidents by examining fresh kills. Known or suspected kill sites were visited, characterized and compared to randomly selected sites with respect to over 30 habitat and topographic features (Jackson et al. 1994). The hypothesis that kill sites are utilized in proportion to their occurrence was tested using the methods of Neu et al. (1974), as modified by Byers et al. (1984). Finally, pastures were mapped using GIS and depredation "hotspots" identified using a variety of techniques.

## RESULTS

### Livestock Ownership, Management and Herding Pattern

Eighty-one percent of the 69 families residing in Khangshar own livestock. According to interviews the village owns about 1,500 animals, with yak and chauri comprising 16.0%, cattle 19.6%, goats and sheep 61.3%, and horses 4.0%. Because of the large area grazed and its well-broken terrain, herd size was not easily verified. However, actual herd size is probably greater, especially with respect to goat and sheep. Ownership varied widely: for example, over half of the households had fewer than 20 animals, while 7% own more than 50. Only the wealthiest families kept horses or yaks. The largest herd consisted of 31 yaks/chaurs (a cattle-yak cross-breed), 11 cattle, 40 goats and sheep and several horses. The smallest family unit consisted of two goats.

The herding pattern varied according to season, type of livestock, and agricultural activities, but followed long-established, traditional patterns that demand a high degree of cooperation among community members. Women and children spend summer months in the main village tending crops, while men take on the task of animal husbandry. A village committee monitors livestock movements and imposes fines on villagers transgressing traditional rules. Animals are tended from two distinct settlements, the permanent village (Khangshar) and a summer settlement located higher. During winter, fallow barley, potato and wheat fields are fertilized by livestock grazing upon the stubble and by dispersing barn manure. Livestock is then moved to temporary shelters

(known as goths) in the nearby forest. In spring, after fields have been sown with a crop, livestock is moved to summer settlement to graze in open pasture, thus ensuring they are kept away from any crop-field. A series of tented goths are used to better distribute grazing and permit summer use of high elevation pastures located far from the village.

Yak and horses are largely free-roaming, but cattle are driven out each morning to forage nearby, to return of their own accord in late afternoon to spend the night in stables below the living quarters. During winter, sheep and goats often graze unattended, while in summer several hired shepherds tend to the village's flock but their guarding is lax. The flock, comprising some 800 individuals is grazed in ten distinct pastures, with the only guard dogs being those stationed near their nighttime corral. During daytime hours, all lambs, kids and young calves are kept within sight of the goth, being corralled with their mothers at night. Female yak, subadults and calves are mostly herded out of the summer settlement or temporary goths located in four distinct pastures. They may or may not be corralled at night.

All manure and bedding material from stalls or corrals are collected, stored and distributed on the fields in late fall or early winter. Spring snowmelt helps to distribute nutrients. Natural pastures are heavily utilized, hay is not cultivated, and hardly surprisingly, forage resources are scarce, especially during winter and early spring, when morality is high among all classes of livestock. Animals are stall-fed during periods of sustained snow-fall. During parturition, animals are stall-fed and closely guarded for the first few weeks after delivering. Most goats and sheep are born in late winter or early spring.

#### Predation Losses

Villagers reported predation accounted for 63% of all mortality over the 18 to 24 month study period (Table 1). Predators, mostly snow leopard, were blamed for most losses, even if pugmarks near the carcass were the only evidence to substantiate predation. Kill remains were rarely properly examined in order to verify predation as the cause of death. Although the degree of error could not be quantified, there was little doubt that villagers perceived predators as the major threat to their livestock. Using data from interviews, the village predation rates were estimated at 21.1% for yak-chauri, 0.8% for cattle, 7.1% for sheep and goats, and 19.6% for horses. This suggests that cattle are relatively immune to predation by snow leopard compared to high vulnerability of horses.

Adult yak-chauri were significantly under-represented in predation cohort, while subadult yak are significantly over-represented ( $\chi^2 = 49.625$ , 2 df, Bonferroni confidence interval  $P < 0.001$ ). The number of sheep and goats killed did not differ significantly from overall herd age composition. Cell size limitations precluded tests for cattle and horses, although they are likely taken in rough proportion to their availability. Although differences with regard to the sex of yak or chauri ( $\chi^2 = 37.491$ , 1 df,  $P < 0.000$ ), and sheep and goats ( $\chi^2 = 10.920$ , 1 df,  $P < 0.002$ ) killed by predation were detected, respective Bonferroni confidence intervals were not significant at the 95% level. Female horses were significantly more likely to

be killed by predators than males ( $\chi^2 = 82.160$ , 1 df,  $P < 0.001$ ).

Losses were not evenly distributed among household. Twenty-one households (37.5%) suffered 50% of the total loss due to disease and depredation. Loss due to disease was under-reported (especially among sheep and goat), but 22 of the 56 households owning livestock lost no animals to predators, while six households reported losing one animal and seven claimed they lost two animals. Nine families reported losing five or more animals, but only two families reported ten or more of their stock were killed by predators. Generally, households reporting depredation loss owned larger herds than households reporting no such losses. Thus, the average herd size among affected households ( $N=34$ ) was  $27.8 \pm 16.9$  animals, compared to herds of  $14.5 \pm 10.2$  among households ( $N=22$ ) with no losses. By contrast, disease rates of predated and non-predated herds were similar.

Depredation loss occurred throughout the year, but peaked in spring and early summer (April to June), with secondary peaks in late October through mid-December, after livestock arrives in the village area from the high summer pastures, and in early winter (mid-February through mid-April). Most goat predation coincided with the peak lambing period. Most loss of chauri occurred between February and May, while horses and chauri were killed throughout the year. All horse and cattle, virtually all yak-chauri (93%), and 78% of the goat and sheep kills reported were being poorly guarded at the time, especially during daylight hours. Predation also resulted after one or a few individuals had become separated from the flock and were forced to spend the night outside of a secure shelter.

Despite knowing several snow leopards (including a female snow leopard with two cubs) were active within the immediate area, villagers allowed their livestock to continue grazing unattended, even after several had been killed and although alternative "predator-free" pastures were available. Over a 24-day period in November 1991, the loss of 17 goats and 6 yak cross-breeds to snow leopard were documented. Clearly, presence of people in the vicinity is not sufficient deterrent. Virtually all of these incidents occurred in cover-rich areas and the affected livestock was either unguarded or poorly tended. Many of the kills occurred during daylight. Despite substantial loss, villagers made no attempt to guard their animals better or to attempt to drive snow leopard from the vicinity of the village where most incidents occurred. Field checks validated predation as the probable cause of death in at least 40% of these incidents; evidence for the remaining accrued from villager reports and kill site remains, but scavenging as a cause of death could not be ruled out.

#### Kill Site Characteristics

Fifty-five known or suspected kill sites were characterized and compared to the same features at 134 randomly selected sites in the same general area. No kill sites were detected on cliffs or in very broken terrain, although these landform features often occurred nearby. Sites with moderately broken terrain were significantly over-represented or "over-utilized" as kill sites, while sites with

Table 1. Livestock mortality reported by Herders from Khangshar village, Annapurna Conservation Area

Type of Livestock	Number of Animals Lost	Number and Cause of Mortality (percentages in parentheses)							
		Predator		Disease		Accident		Missing	
Yak-chauri	48	43	(89.6)	4	(8.3)	1	(2.1)	0	
Cattle	16	2	(12.5)	12	(75.0)	1	(6.2)	1	(6.2)
Sheep/Goat	123	71	(57.7)	42	(34.2)	1	(0.8)	9	(7.3)
Horses	13	10	(76.9)	1	(7.7)	2	(15.4)	0	
Totals	200	126	(63.0)	59	(29.5)	5	(2.5)	10	(5.0)

smooth-surfaced, rolling or level terrain were significantly represented in the data-set ( $\chi^2 = 13.404$ , 2 df,  $P < 0.001$ ). Macro-topographic features, such as major hill slopes, ridges and valleys occurred in approximate proportion to their availability, but there were distinct differences in use at a micro-topographical level ( $\chi^2 = 25.513$ , 1 df,  $P < 0.000$ ). Bonferroni confidence intervals indicated that basins and bowls ( $P < 0.001$ ) and gullies ( $P < 0.05$ ) were significantly over-utilized, suggesting that livestock is more vulnerable to predation when grazing in or near such a topographic feature. Open hill-slopes were significantly under-represented ( $P < 0.001$ ) among the kill sample.

Kill sites were significantly closer ( $\bar{X} = 132.9 \pm \text{SE } 11.9$  m) to cliffs than random sites ( $\bar{X} = 245.4 \pm \text{SE } 17.1$  m) ( $t = 4.593$ , 200 df,  $P < 0.000$ ) (Table 2). Very broken sites were also significantly closer at kill sites ( $t = 3.4$ , 146 df,  $P < 0.001$ ;  $\bar{X} = 175.5 \pm \text{SE } 15.2$  m versus  $365.0 \pm \text{SE } 27.2$  m), as were moderately broken sites ( $t = 4.7$ , 195 df,  $P < 0.000$ ;  $\bar{X} = 78.8 \pm \text{SE } 12.8$  m versus  $223.7 \pm \text{SE } 23.3$  m). Samples differed significantly with respect to distance to the nearest cliff ( $\chi^2 = 19.825$ , 2 df,  $P < 0.001$ ). Thus, sites within 100 m of a cliff were significantly over-utilized ( $P < 0.001$ ), while sites farther than 250 m were significantly under-utilized ( $P < 0.001$ ). Similarly, sites more than 250 m from very broken terrain were significantly under-represented ( $P < 0.05$ ) in the sample. By contrast, no differences were detected in terms of distance to smooth terrain.

Kill sites were more likely to be located in shrubland than grassland areas. Random ( $\bar{X} = 298.3 \pm \text{SE } 22.3$  m) and depredation sites ( $\bar{X} = 85.3 \pm \text{SE } 8.2$  m) differed significantly in mean distance to the nearest vegetation edge ( $t = 8.1$ , 201 df,  $P < 0.000$ ). Sites less than 100 m from a vegetation edge were significantly over-utilized ( $P < 0.001$ ), while sites farther away were significantly under-represented ( $P < 0.001$ ). Kill sites 50 m or closer to a water source were significantly under-utilized ( $\chi^2 = 12.958$ , 3 df,  $P < 0.005$ ). No difference was found with respect to distance to a well used trail. Violation of rules regarding Chi-square goodness of fit tests precluded statistical comparisons between kill and random sites with regard to the distance to large areas of heavily broken terrain. Forty-four percent of kill sites were located within 250 m of a heavily-

broken area, compared to less than 8.7% of sites using 184 randomly generated geographic information system points. Areas more than 2 km from the summer settlement were significantly under-represented in the kill sample ( $\chi^2 = 8.796$ , 3 df,  $P < 0.032$ ).

## DISCUSSION

### Loss Rates and Causative Factors

Snow leopard are capable of killing all livestock except for a fully-grown male yak. Horses, by far the most valuable of livestock kept by Khangshar herders, also appeared to be most vulnerable to attack, assuming the reported depredation rate of 19.6% is valid. A similar pattern was noted by Schaller et al. (1994) from Mongolia. Goats and sheep are predated upon most frequently, hardly surprising given their overall abundance, small body size and associated vulnerability. In an independent study in the Manang area, Oli (1991) estimated that four communities (including Khangshar) lost 72 animals out of a total herd of 2,737 in 1989-1990, for an overall depredation rate of 2.6%. This compares with our estimate of 2.8% for the same village for the period 1990-1992. Scat analysis indicated livestock contributed about a third of the snow leopard's diet Oli et al. (1993), but this does not rule out scavenging.

While the loss rates provided by the villagers cannot be fully validated, these are similar to independent predation reports from other high density snow leopard areas. Thus, Schaller et al. (1987) determined that 7.6% of sheep and goats were taken in one area in western China, while the same investigator (Schaller et al. 1994) placed losses in Mongolia as high as 9.6% (although rates of 0.34 to 0.38% were considered to be more typical). In the more remote parts of southern Tibet, herders claimed to lose up to 9.5% of their herd to predators wolf, snow leopard, lynx and golden eagle (Jackson 1991). Fox et al. (1991) placed sheep and goat predation at 2.3% in India's Hemis National Park, due largely to snow leopard. In the Khunjerab National Park of northern Pakistan, Wegge (1989) reported that about 10 percent of the domestic stock (mostly sheep and goats) were killed annually by snow leopard and wolf, with most of the loss occurring in winter and early spring. Finally, in the eastern Nepal, Braun et al. (1991) noted goat and sheep losses averaged 10.6 percent among sedentary herds, but

Table 2. Mean, maximum, and minimum distances (meters) to selected terrain features from pasture and depredation sites at Khangshar.

Terrain Feature	Sample Size	Minimum	Maximum	Mean	Std. Dev.
Cliff					
Pasture	133	15	1,000	245.4	197.5
Depredation	69	2	500	132.9	98.7
Very Broken Terrain					
Pasture	116	25	1,500	365.0	293.3
Depredation	32	60	350	175.6	85.7
Moderately Broken Terrain					
Pasture	129	0	1,500	223.7	264.3
Depredation	68	0	400	78.8	105.4
Smooth Terrain					
Pasture	133	0	500	101.4	112.2
Depredation	70	0	400	92.5	109.2

ranged from 2.9% to 4.7% for migratory flocks in the western part of the country.

None of these investigators attempted explicitly to determine which factor or set of factors contributed most to the observed predation. This study suggests that a combination of lax guarding practices, favorable cover and habitat conditions, and high snow leopard density are primarily responsible for the high depredation rates observed in ACAP. Oli (1994) placed snow leopard density at 4.8 to 6.7 adults per 100 km<sup>2</sup> in the Khangshar study site. Although it supports good numbers of blue sheep (*Pseudois nayaur*), livestock are the most abundant prey, at least in terms of overall biomass. The surveys indicated that some pastures supported a livestock biomass as high as 1,700 kg per km<sup>2</sup> during the winter, compared to only 330 kg per km<sup>2</sup> for blue sheep, the snow leopard's principal large natural prey item (Oli 1994). Presumably snow leopards are more likely to encounter domestic stock, while taking advantage of the excellent cover available to them in the form of vegetation, steep slopes, rocky areas and broken terrain. Several depredation incidents were associated with a female and her two young cubs, but a determination whether old or injured predators caused more damage than healthy ones was not possible (Fox and Chundawat 1988). By chasing a predator away to retrieve meat for their own use, herders force the predator to replace the loss by killing again.

Local residents are reluctant to hunt snow leopard for fear of being reported or fined by the government. Yet few appear willing to improve their obviously inadequate guarding practices, at least of their own accord. As the snow leopard population rebounds, the herders' feeling of anger and frustration at not being able to hunt or control large predators will only increase. With tourism rising in the area, attempts by the authorities to shoot or trap problem snow leopards (an endangered species under both international and Nepalese law) would be viewed extremely

negatively. The resulting "bad press" would tarnish Nepal's excellent and hard-fought reputation for nature conservation. Given such constraints in the Himalaya, what are the best alternatives to predator control?

#### Remedial Measures

Most herders consider total eradication of snow leopard as the only remedy worth considering (Oli et al. 1994), reflecting their traditional pattern of using professional hunters or shikaris to remove problem animals. Individuals displaying the carcass of a habitual livestock killer used to be given special gifts and lauded for their service to community, even among Buddhist communities who impose strong sanction upon the taking of life. All such hunting is now banned under the wildlife protection laws implemented by Nepal. While Tibetan mastiffs and other dogs are considered a deterrent to predator attack, the quality of local guard dogs is actually poor. The predator control measure currently favored, but highly illegal, involves the use of insecticides like dieldrin which are placed in kill remains and other items left as bait.

In an effort to pacify the villager while also protecting wildlife, government officials and protected area managers are increasingly resorting to non-lethal measures for reducing livestock loss. Within the context of a protected area like the Annapurna Conservation Area, the best long-term strategy lies in a combination of preventive and remedial measures which may include:

- Improved guarding of livestock, especially during winter, lambing or calving seasons, and when livestock is being grazed in pastures with broken, cover-rich terrain and at elevations in excess of 4,000 m.
- Encouraging communities to hire skilled shepherds, by developing a special fund to help pay for more experienced herders and by offering subsidized veterinary care for families demonstrating reduction in depredation.

- Promoting the use of improved breeds of guard dog and livestock showing a greater inclination for warding off or avoiding predators.
- Creating core areas for snow leopard and blue sheep which are largely or entirely livestock free.
- Establishing a village-based snow leopard conservation committee with preferential membership opportunities for herders, but operated under the overall supervision of ACAP.
- Offering incentives for community development projects in exchange for predator and wildlife protection and conservation action by the community.
- Developing safeguards against herders or communities making fraudulent claims, killing snow leopards or illegally poaching wildlife.

Since lack of guarding or poor supervision of herds contributed most significantly to livestock loss, herder education must be given a high priority. Some depredation could be avoided by ensuring that livestock are securely housed in predator-proof pens at night; this is especially a problem in Khangshar during summer months when animals are kept on the open range day and night, often bedding without any protection other than the presence of the shepherd's tent. Limiting the use of open rangeland by calves, subadults and lactating females, by stall-feeding removes vulnerable livestock from predator access. The use of guard dogs to protect sheep from predators has been extensively researched in the United States, but it has not been attempted in the Himalaya where people are poor and may lack adequate facilities for housing or taking care of imported sheep dogs. An alternative involves the use of traditional breeds of goat, sheep and cattle which are better adapted to local climate conditions and more predator wary like sheep and goats from Mongolia which "bunch-up" closely at any sign of danger. Programs to provide or improve forage could help to reduce the need to graze livestock in known depredation hot spots, such as areas of very broken terrain, places with an abundance of cliffs and stalking cover, and pastures located in wilderness areas.

In addition to a herder education program, Oli et al. (1994) recommended financial compensation for households suffering loss of livestock. However, limited financial resources, administrative constraints and a high potential for fraudulent claims augur against simple cash compensation or indemnity programs (Saberwal et al. 1993). An alternative approach, currently being attempted by ACAP, involves the provision of grants for community development work in exchange for community-wide agreements to better guard their animals while also protecting wildlife, including snow leopard and blue sheep. Such funds would be used to improve drinking water supplies, establish a health post, provide much needed school materials, assist in hiring better trained herders, or improve veterinary services, rangeland and fodder supplies. Progress has already been made with the establishment of a special "Snow Leopard Conservation Committee" with significant representation by herders. A long-term goal is the establishment of core wildlife areas and increasing tourism infrastructure so that local residents will have a more diversified set of income sources. While

the realization of income from "eco-tourism" for local people is by no means clear, properly managed ventures can be profitable if the export of profits to distant cities can be reduced. Nature viewing tours could be promoted, with local residents serving as guides once they have been trained.

## CONCLUSIONS

Although governments bear the cost of establishing a national park or protected area, it is the local people who must live with the consequences. Managers are increasingly relying upon community knowledge and traditional management systems, recognizing that traditional rights and practices must be balanced with other needs like protection of wildlife. This requires that specific management issues, such as grazing, wildlife protection or the control of livestock depredation, are effectively integrated into the broader socio-economic and ecological context of the area concerned. Compromises produced by participatory conflict resolution are usually preferable to forced decisions respected by no one, provided such agreements are consistent with important constraints, including those environmental factors governing resource availability and sustainability. In reaching conservation or resource management agreements with a local community, explicit linkages should be established between development components and conservation objectives, in this case the protection of predators and other wildlife. The nature of the exchange must be fully understood. Experience has indicated that "give-a-ways" must be avoided; commitment grows in relation to the time, energy and materials invested. Programs need to be monitored regularly to ensure goals and objectives are being achieved, with penalties or disincentives applied in the case of infringements.

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## ANIMAL RIGHTS AND THE NEED TO UNDERSTAND NATURE; A DEBATE

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As various societies, especially in the developed countries of the world, acquired a better life-style and standard of living, a common trend developed toward treating animals more humanely, especially the domestic ones. But the movement was too slow, and the animal rights movement captured this void and established a new ethic. Unfortunately, this was done without a full appreciation of the laws of nature. Even though this movement was clearly needed, some people have carried it too far.

Tonight, hopefully, we can have some good constructive discussions from the audience on this subject after Dr. Steve Sapontzis and I first present our introductory remarks. I respect Steve's views and his moral integrity. We are both professionally qualified persons who have the right to discover, teach and publish the truth as we see it in our fields of competence. From my point of view, I do not agree with animal rightists who claim it is morally wrong to use animals, no matter how humanely and responsibly they are handled. Examples include the dissection of animals in class rooms, or using animals in research, as game, or as food or for materials. But I do admit that most perspectives about animal welfare have both strengths and weaknesses, so during the discussion do not hesitate to express your own ethic about these issues and make Steve and me defend our beliefs.

One point that concerns me is that many animal rightists seem to ignore nature's life-death ethic. They do not agree that nature requires many animals to die prematurely. They seem to think that every pine nut and acorn will grow into a tree. They overlook that living in the wild is not a suffering-free existence. Nature does not have pain pills, tranquilizers, euthanasia, conscientious hunters, or humane slaughter. Compared to a natural death, being killed with euthanasia, in a slaughter house, or by a gun, arrow or trapped and then shot can be considered a relatively humane death. Sportsmen play a significant role in helping nature maintain healthy population densities of wildlife in human-modified environments, and do so much more humanely than can nature.

What is nature's life-death ethic? I think it is wonderful that so many domestic birds and mammals have a chance to be born. They would not exist if they were not wanted. Of course, many die prematurely if they are wanted for food or materials, but, in contrast to nature, they die quite humanely. If not harvested prematurely, domestic animals usually greatly outlive their wild counterparts, who generally die at a much younger age due to nature's death ethic.

Domestic animals usually do not have to suffer life-threatening competition, inclement weather, starvation, cruel diseases, parasitism, infections,

territoriality, sexual battles, cannibalism, or other ugly natural stresses that wild animals frequently encounter. Only domestic and game animals die relatively humanely, as nothing in nature dies a humane death.

Animal rights activists move from state to state attempting, with lobbying, public protests and political activity, to try to have animals like bobcats, bears and mountain lions listed as endangered species, when obviously their goal is to prohibit hunting, trapping, eating, or otherwise utilizing game species. They will not accept the fact that the main reason game animals are plentiful and not endangered is because it is the sportsmen's funds that provide the financial support for hiring biologists to determine how to maximize the welfare of the fauna and flora, enable wardens to protect them, and provide the necessary funds that preserve suitable habitat for game and associated non-game species.

The laws of nature require all species to have a death ethic to prevent them from obtaining devastating population densities. Look at what happened to the human population when science, technology, public health, and medicine controlled their natural death rate. Another close to home example is what has happened to mountain lions since subdominant lions can no longer escape from the dominant lions without conflicting with people.

Nature's life-death ethic requires that over time the rate of mortality equals the number of births. The fact that so many young animals are eaten before they reproduce is necessary to prevent the development of environmentally damaging excessive population densities of species. All organisms live by eating others. This high premature mortality rate of animals is what provides the energy needed to ensure that the balance of nature functions properly.

A common assertion is that animals have legal rights. Do they? Of course, animals have a right to do whatever is necessary for them to survive, no matter how brutal they may be to other animals, even if it means killing and eating their parents, offspring or siblings. However, animals do not have a right that guarantees how other animals treat them. Consequently, nearly all animals that die "naturally" suffer a great deal more than when people hunt or trap them.

People, on the other hand, establish legal rights on how other people can treat non-human animals. This is why the amount of suffering experienced by an animal dying from the hands of people is usually minimal.

There is not time to fully defend the right to use animals responsibly in agriculture, research or as pets, so I will put my main emphasis on just one area, hunting.

It is easy for me to understand why many people oppose hunting of birds and mammals, for most of these



people also would NOT want to be the person responsible for slaughtering livestock, chickens, turkeys, fish, or even clams. Without understanding nature, and, since such people obtain all their food from grocery stores, it is not surprising that they do not relish dropping crayfish or crabs into a pot of boiling water, yet still consider these animals a real delicacy in a restaurant.

It is no wonder that many people do not grasp the morality and pride they should have when animals are exploited responsibly, i.e., treated as humanely as is possible. In nature all animals must exploit others, and people are part of nature. In contrast to the predatory behavior of other species, hunters are a unique predator. They conscientiously avoid inflicting pain. Today's hunters actually show compassion and mercy toward their prey, which is indeed unusual for a predator, as natural predators are usually very brutal.

Since all environments of the world have been modified by people, a desirable harmony between people and the faunas only can be established if the animal populations are managed. However, in some wilderness areas, the best management scheme may be a hands-off policy. For an ecosystem to be balanced on a sustained basis, the surplus individuals of all species must be cropped each year one way or another, and in most environments, where natural predation is no longer effective, this can usually best be done by people.

Both hunting and trapping are long-standing American traditions and heritage, and can be a sound wildlife husbandry practice. Regulations governing these activities came about because sportsmen recognized the need to protect mammal and bird game species from market hunters and unrestricted hunting. Today, hunters and trappers are highly regulated, licensed predators, and this is at their choice.

In contrast to the killing by natural predators, hunters and trappers operate under many regulations designed to make the way animals are taken as humane as is feasible. How does one equate the suffering of animals that are shot or trapped with being eaten alive or dying of starvation or diseases? There are no biological bases for opposing regulated hunting and trapping, only religious ones, and religions also support the use of animals.

Nature cannot crop the annual surplus of animals as humanely as sportsmen. Also, hunting and trapping are the most effective and humane tools available for removing surplus animals of a population without damaging the capital. Why people like to hunt may be inexplicable, but these pursuits are as much conservation as they are recreation.

One is morally justified, in a modified environment, to hunt or kill surplus wildlife that can no longer be supported, because this can prevent unnecessary population die-offs from starvation, disease, fighting, cannibalism, territoriality, and other species self-limiting factors.

People have a moral obligation to manage nature once they have disrupted it. Animals which are pursued by hunters and trappers literally never had it so good on this overcrowded, human-dominated earth.

Hunters are the ones responsible for the dramatic recovery of species such as the wild turkey, wood duck, pronghorned antelope, whitetailed deer, and elk. If the endangered whooping crane had been declared a game animal 50 years ago, with hunting season closed until the population recovered, they would be common today.

Most of the funds for hiring wildlife biologists, game wardens and preserving wildlife habitats and biological diversity comes from sportsmen and excise taxes they pay on equipment they use. No other group, certainly not animal rightists, shows any inclination or preparation to pay for the protection of habitats now preserved by support from hunters, fishermen and trappers.

Animals are born to die, and the great majority of wild and domestic animals die prematurely. What is right or wrong concerning the rights of animals largely depends on one's personal ethics. People occupy a dominant position in nature, but I believe that, by conforming to the laws of nature, society clearly has the ethical and moral right to use animals in research, dissections in teaching, agriculture, hunting, trapping, fishing, and as pets as long as one does not inflict unnecessary pain and suffering. Responsible use of animals is biologically sound and fits well into the natural scheme of life.

# ANIMAL LIBERATION AND THE LESSONS OF NATURE

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Although they provide catchy labels, "animal liberation" and "animal rights" have occasioned considerable misunderstanding and much pointless debate. I want, here, to explicate what I believe is being sought for animals under these labels. This explication should help to undo some of the misunderstandings about liberating animals and extending moral rights to them. After this explication, I will turn to the issue of the way in which scientific knowledge of natural entities, processes, and organizations is and is not relevant to animal liberation.

## PART I: WHAT ANIMAL LIBERATION IS ABOUT

One of these misunderstandings concerns the use of "animal" in these labels. At most animal liberation presentations, there is someone who rises to inquire whether flies, cockroaches, and other vermin are to enjoy rights to life, liberty, and the pursuit of happiness. Is swatting a fly to be murder in the brave New World of animal rights? This heckler is soon joined, if not preceded, by another who accuses the animal liberationist of discriminating against plants and, consequently, being guilty of "fauna chauvinism." Do the arguments for animal liberation entail plant liberation as well? Of course, these hecklers are not sincere activists in the mosquito and tomato liberation movements. What they are attempting to do is to dispose of the animal liberation movement through a *reductio ad absurdum* argument. As William James noted many years ago, the first response to a revolutionary idea is ridicule.

The insect and flora *reductios* will not work, however, because most animal liberationists accept what has come to be called "the interest requirement" for having moral rights. According to this criterion, which was first proposed by Leonard Nelson in *A System of Ethics*, all and only beings with interests can have moral rights (Yale University Press 1956). Having interests is to be interpreted as follows: an individual has an interest in something if and only if that something affects (will affect, would affect) the individual's feelings of well-being. In turn, "feelings of well-being" is to be interpreted as referring to pleasure and pain, feeling fit and feeling ill, elation and depression, feelings of fulfillment and feelings of frustration, and the many other feelings which contribute to or detract from the enjoyment of or satisfaction with life. Now, the "animal" in "animal liberation" and "animal rights" refers to all and only those beings which meet the interest requirement. The phrase "sentient being" is often employed to make this reference.

Thus, the criterion for being an "animal," in this moral sense, is not the biological criterion which distinguishes fauna from flora. Nor are animal

liberationists confused about this, since most of them readily acknowledge that very probably not all biological animals have interests and, consequently, cannot have moral rights. As for the insects and the plants, all those which can meet the interest requirement must, if animal liberationists are to be consistent, be included in the concerns of this movement. However, to date, there has been no serious evidence showing that plants have feelings of well-being. Whether or which insects have interests is a more open question.

It does not follow from this, however, that the insect *reductio* carries the day against animal liberation. If some insects have feelings of well-being, then a morality which attempts to respect all sentient beings will be more complicated than it would be if no insects were sentient. Of course, this sort of consequence is true of all moralities; the more diverse the group owed respect, the more complicated the morality must be. For example, dealing morally with one's "fellows" is more complicated now that women and racial and ethnic minorities are included among the rights-holders due respect. To one degree or another, we probably all share a yearning for a simpler life, but that practicing a revolutionary morality would be more complicated than resting content with the *status quo* does not indicate that revolutionary morality is ridiculous, wrong, or even less warranted than the *status quo*.

Furthermore, acknowledging that some insects have moral rights would not by itself resolve the matter of how we are to deal with them, especially in conflict of interest situations. Since to have moral rights is not necessarily to have the same set of rights as or equal priority of rights with other rights-holders, extending moral rights to those who have not enjoyed them before does not settle the matter of how we are to treat them. Rather, it opens the door to questions about how we ought (morally) to treat them which had not previously seemed relevant (Caplan 1983). For example, the Emancipation Proclamation was not the culmination but the beginning of the civil rights movement. Also, in attempting to answer these new questions about how we ought (morally) to treat animals, if simple applications of ideas of equality, self-determination, and similar concepts commonly associated with liberation and rights would be ridiculous, then we can expect that those simple applications will, for that very reason, be rejected. This is what has happened in working out other liberation movements (e.g., the recent rejection of the claim that an end to sexual discrimination entails that male workers are entitled to maternity leave). In actual practice, ridiculous consequences do not discredit the basic principles of moral reform; rather, such consequences lead to a more

subtle and practical understanding of those principles—an understanding which eliminates the ridiculous consequences.

Finally, we may note that although these "where do you draw the line" questions may be amusing and conceptually intriguing, they are irrelevant to the current, major, practical concerns of the animal liberation movement (e.g., the immorality of factory farming, animal research, hunting, rodeos, etc.). If any non-human animals have interests, then the animals (e.g., pigs, monkeys, bears, horses, etc.) that the animal rights movement is currently seeking to liberate surely do. Once the questions currently being raised concerning how we ought (morally) to treat these animals have been settled, it may be time to wonder whether insects have moral rights, need to be liberated, and what form such an enlightened morality should take. To bring up the question of insects before these current questions have been resolved is merely an attempt to avoid facing the real and clear issues at hand.

"Liberation" also requires some explication when applied to animals. Advocates of liberating or extending moral rights to animals view this extension as being a revolutionary break with moral tradition, including the anti-cruelty to animals part of that tradition, and as providing for animals something of great moral importance. The predominant attitude regarding animal interests today is that what animals require for an enjoyable, satisfying life (e.g., freedom to roam, freedom from pain, and life itself) may be routinely sacrificed in the pursuit of human happiness, provided the animals are not treated sadistically and are spared suffering that can be conveniently and economically avoided. Thus, the anti-cruelty to animals tradition continues to consider and treat animals as fundamentally resources for human consumption, limiting moral concern to the humane handling and processing of those resources. On the other hand, "liberating" animals refers to putting an end to the routine sacrifice of animal interests for human benefit, even where the sacrifice is executed humanely.

Animal liberationists emphasize respecting the interests of animals themselves, as opposed to being solely or even primarily concerned with the interests that humans have in using animals. The primary purpose of extending moral rights to animals would be to ensure that their interests could be sacrificed for fulfilling the interests of others only in the sorts of situations and according to the sorts of principles which justify sacrificing the interests of some humans to fulfill the interests of others. For example, just as current regulations basically restrict risky medical research on humans to experiments which seem likely not only to benefit the wider community but also to be therapeutic (or otherwise beneficial) for the research subjects themselves, so the extension of moral rights to animals would basically limit risky medical research on animals to experiments which would have a good chance of being therapeutic (or otherwise beneficial) for the animal subjects of that research. Such a restriction would, of course go far beyond even the most liberal of our current humane regulations concerning the use and sacrifice of animals in biomedical research, and its adoption would mark a revolutionary step beyond our anti-cruelty to

animals tradition.

Thus, talk of "liberating" animals and extending moral "rights" to them refers to *changing our attitude* toward animals from one which regards them as beings which must be treated humanely but which are, nonetheless, fundamentally resources for fulfilling human interests to an attitude which regards animals as fellow beings whose interest in an enjoyable, satisfying life must be respected and protected in the way basic human interests are respected and protected. In this way, liberating animals would require changing our attitude toward animals in basically the same way liberating blacks and women requires changing the attitudes concerning them held by whites and men.

Another source of misunderstanding lies in the use of the phrase "equal rights" when discussing animal liberation. As already noted, animal liberationists routinely deny that they are seeking for animals the same set of rights already enjoyed by humans. Recognizing that rights are tied to interests and that animals do not have all the interests we do (e.g., in religion and education) animal liberationists recognize that it would be nonsensical to seek for animals all the rights we require. For example, Roger W. Galvin, the attorney who prosecuted the famous Taub case, proposes the following rights for animals: 1) all sentient beings have a right to live out their lives according to nature; 2) all sentient beings have a right to live in a habitat ecologically sufficient for normal existence; and 3) all sentient beings have a right to be free from exploitation (News magazine of the Animal Rights Network). These are sufficiently different from our "Bill of Rights" and "Declaration of the Universal Rights of Man" to make clear that animal liberationists are not seeking extensional equality of rights for animals.

It might be thought that what animal liberationists are seeking is completely equal priority of rights for animals. For example, it has been suggested that animal liberationists would feel an obligation to show no preference for feeding starving children over feeding starving dogs. However, once again matters are not nearly so simple. First of all, assertions of equal rights do not entail completely equal priority even among humans. For instance, people who believe that men, women and children have equal moral standing have, nonetheless, commonly believed that women and children should be given priority in an emergency. And conversely, no one would suggest that if we hold the traditional belief that women and children are entitled to first place in the lifeboats, consistency requires us to conclude that they would be justified in using men as research tools, eating them for dinner, and hunting them for sport.

We cannot infer from the principles used when we are forced to choose the lesser of two evils to the principles of moral status in force when such a hard choice is not required. Such emergency principles are invoked not as extensions of common moral principles, but as auxiliaries needed because those common principles do not provide satisfactory guidance in these uncommon situations. This distinction of ordinary from extraordinary cases in morality undercuts the many "burning building," "desert island," "lifeboat," etc.,

supposed *reductios* of the animal liberation position. That animals' lives could justifiably be sacrificed in preference to human lives in certain situations where such a hard choice had to be made, does not entail that their lives can (morally) be routinely sacrificed to support our eating habits, clothing preferences, entertainment, reluctance to control the size of our own population, unwillingness to adopt healthier ways of life, desire to avoid certain risks, etc. Consequently, such "them or us" cases are logically isolated and insignificant for the animal liberation debate, since that debate is primarily concerned with the principles governing our ordinary moral practice.

Thus, animal liberation seeks neither to extend to animals the same set of rights enjoyed by humans nor to deny that human life can have a greater moral worth than animal life. Rather, animal liberationists contend that just as it would be immoral to follow Swift's "modest proposal" routinely (and avoidably) to sacrifice some people's interest in life in order to fulfill others' interest in food, so it should be immoral routinely (and avoidably) to sacrifice animals' interest in life for such purposes (Swift 1729). Of course, what is and what is not "avoidable" will always be a slippery issue. The animal liberation literature suggests that, roughly, "avoidable" here means "eliminable without severely compromising the general welfare." For example, it is repeatedly emphasized in this literature that a vegetarian diet can be a healthy, appetizing one, that we can both keep warm and be ostentatious without furs, and that we can enjoy the wilderness without hunting. I am unaware of any animal liberationist saying something like, "We must liberate animals, even if that means an end to human civilization!" It should go without saying that issues of what is and what is not avoidable can become quite complex and must (logically) be decided on a case by case basis. What is important to the general animal liberation position is that the burden of proof is to be on those who would sacrifice animal interests for the general welfare, just as it is on those who would sacrifice the interests of some humans to help other humans (e.g., in time of war), and that justification requires demonstrating not merely some marginal increase in utility through the sacrifice but, rather, requires demonstrating both that prohibiting the sacrifice would severely compromise the general welfare (which is not to be restricted to human welfare) and that the sacrifice is distributed fairly.

It is in thus sharing legal and moral protections against the routine, avoidable sacrifice of one's interests that animal liberation seeks "equal rights" for animals.

## PART II: THE IMPORTANCE OF THE SCIENTIFIC STUDY OF NATURE TO ANIMAL LIBERATION

One of the traditions of response to the animal liberation movement has been to portray it as the product of ignorance. Sometimes this is supposed to be ignorance of the nature of morality; sometimes it is supposed to be ignorance of how animals are actually treated in laboratories or on farms; sometimes it is supposed to be ignorance of the order of nature. For example, in a recent article entitled, "The natural wrongs about animal rights and animal liberation," Randall S. Ott, writes: "The beliefs espoused by animal rightists/liberationists are in conflict with scientific knowledge about the place of all

animals, including the human animal, in the biosphere" (Journal of American Veterinary Medical Assoc. 1995). Ott's claim is that science teaches us that all forms of life are in a struggle for the survival of the fittest, are living off one another in biotic communities, and that ideas of liberating animals are in conflict with such teachings. Is this so?

One of the well-established principles of moral philosophy is that "*ought* implies *can*." According to this principle, it would be nonsensical to say that we *ought* to do something, if it is *not possible* for us to do it. For example, a commandment that instructed us to live without breathing would be nonsensical, simply because we cannot do that. Moral imperatives are supposed to give us *practical* guidance; that is, to direct us toward doing what we can to make the world a better place. Consequently, proposed values which conflict with natural law, and therefore with what is physically possible, can have no place in actual moral practice.

Now, is it the case that animal liberation directs us to do things we cannot do? For instance, is it physically impossible for us to stop sacrificing animals in biomedical research? Is it physically impossible for us to stop factory farming animals? Is it physically impossible for us to stop sport hunting and trapping animals? The answer to these questions is that it is obviously possible for us to stop exploiting animals in these ways. While the law of gravity may prevent us from levitating ourselves just by wishing to do so, no law of evolutionary natural selection or ecological holism makes it impossible for us to stop exploiting animals in these ways. Since there are many people leading healthy, satisfying, reproductive lives who, for religious or ethical reasons, consciously avoid exploiting animals, it is mind-boggling that anyone would even think of saying that it is impossible for us to liberate animals from human exploitation. Anyone making such a preposterous claim must be woefully—and perhaps willfully—ignorant of the diverse ways in which people choose to live.

Since the advent of modern science, it has been common for some moralists to recommend patterning morality after science. In the 18th century, the science to emulate was physics, in the 19th century was biology, and in the latter half of the 20th century the science of ecology has become a candidate for moral paradigm. All such programs to transform morality into a science are logically doomed to failure for two reasons. The first is that, to cite a famous slogan, "you cannot derive an *ought* from an *is*." The second is that it is the function of moral imperatives to counterbalance natural tendencies.

A basic principle of logic is that any idea asserted in the conclusion of a valid argument must have some evidence to support it in the premises of that argument. It follows that any argument in which all the premises concern matters of fact, that is, concern the way things *are*, cannot justify a conclusion about the way things *ought to be*, precisely because the idea of *ought to be* is not found in any of the premises. An argument of the form, "Driving bamboo shoots under people's fingernails causes them excruciating pain; therefore, we should not do that" is invalid, unless some sort of unstated, imperative premise, such as "We should not cause people excruciating pain," which contains the idea *should not* is

included. Thus, while the facts and principles discovered by science can be of immense help in accomplishing our moral goals, moral values can never follow just from scientific discoveries, and moral philosophy can never become an empirical science.

Turning to the second reason why morality cannot be a natural science, this is because we turn to morality precisely because we find our natural inclinations wanting. If by natural instinct we always did, or even just attempted to do, those things which would make the world a better place, we would have no need of moral imperatives to do this rather than that. Presumably, angels do not have to be commanded to respect the rights of others, for they have no inclination to do other than love others. We humans have aggressive, domineering, selfish, greedy, violent, and other inclinations which lead us routinely to destroy the well-being of others, humans as well as animals. We have elaborated and teach moral rules in an attempt to inhibit those destructive tendencies. Consequently, moral values never arise merely from a study of the way things are; they always arise from a study which includes projections of what would be a better world than the way things are.

Thus, the function that natural science can fulfill for morality is not and can never be that of establishing what is morally right and wrong. It can establish boundaries for moral imperatives by determining what it is physically possible for us to do, but this function is seldom important, since moralists seldom, if ever, command people to do what is physically impossible. Certainly, no animal liberationist of my acquaintance commands us to do what we cannot do. It does not follow, however, that because natural science cannot dominate morality, it has no function to perform for morality.

Another famous phrase is that, "the best laid plans of mice and men often go astray." Sometimes they go astray because people did not understand how to get where they were going. Morality is a program of trying to get somewhere, namely, to a better world. Understanding the way the world is, what forces have led to its being the way it is, what forces are available for changing it, and what forces obstruct such changes are all important factual understandings for those who would improve the world. For example, understanding why men want to dominate women, the different forms that tendency can take, what sorts of behavioral and pharmacological strategies are effective at inhibiting that tendency, and what the side effects of those strategies are, are all important understandings for someone who seeks effectively and without generating even greater problems to reduce the incidence of men battering women. People who espouse moral ideals but who do not learn the facts needed to

work effectively toward those ideals will be ineffective at best and are actually likely to cause a great deal of harm in their ignorant pursuit of good.

In the case of animal liberation, natural science can help us understand, first of all, what actually causes animal suffering and what may appear to do so but actually does not. For example, some animals like to cluster, so that confining them in areas that seem overcrowded from our perspective does them no harm. Similarly, natural science can help us find effective ways to relieve animal suffering. Again, science can help us find alternatives which satisfy our needs without exploiting animals. Finally, natural science objectively directed at ourselves could help us understand why we are inclined to exploit animals and what could be effective strategies for controlling the destructive expressions of those inclinations. For instance, why is it that some people enjoy killing animals, and what can be done to cure them of this disease?

In all areas of human endeavor, moral and otherwise, factual knowledge is useful for reaching the goals we seek. It is regrettable that well-meaning people sometimes waste valuable time and energy trying to make the world a better place, but failing to do so because they do not understand the natural forces which make the world the way it is and which need to be controlled in order to make it a better place. Animal liberationists need to inform themselves about natural science in order to be effective, just as morally concerned natural scientists need to inform themselves about logic and moral philosophy in order to understand how moral values originate and how moral reasoning works.

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## CLOSING REMARKS—SEVENTEENTH VERTEBRATE PEST CONFERENCE

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As chair-elect of the council, I would like to thank all of those who participated in this 17th Vertebrate Pest Conference.

We had a total attendance of 340 from 27 states in the U.S., including 27 attendees from 8 countries outside the U.S. The contributions and sacrifices made by foreign speakers is genuinely appreciated and has, as always, added greatly to the diversity of the conference.

As most of you know, the council's primary goal is fostering education and advancement in the field of vertebrate pest management. We have always tried to draw noted experts to present a broad range of information on animals, large and small, from areas around the world. Our program chairpersons, John O'Brian and Gary Simmons, have accomplished this goal by providing a new program with a variety of information regarding development of new materials, techniques and improvements in integrated pest management. In addition, we have also listened to environmental and regulatory issues and have been challenged to consider new and varying public values, attitudes and philosophies covering a very broad spectrum of vertebrate pest control and Animal Rights vs. Animal Welfare issues.

The council also tries to provide a forum for networking between professionals with all levels of expertise. It is for this reason the commercial exhibit and poster presentation area were used to offer refreshments at breaks and the complimentary buffet reception. I feel these changes were successful thanks to Paul Gorenzel, the Commercial Displays Chair, and Lew Davis, who once again did an outstanding job of handling arrangements for us.

Greg Giusti provided us with a field trip with the help of Pierre Gadd that illustrated many of the wildlife problems faced by area producers (including excess moisture) and for introducing participants to the Hopland

Research Station with the help of Bob Timm, the Station Director. Bob Schmidt handled publicity in his usual reliable manner, hence the good attendance, and thanks to Sydni Gillette, who once again handled the massive job of registration. Sydni was assisted by Pat English and on-site by council members Robyn Breckenridge, Art Bischoff, and Wendy Halverson-Martin. John Borrecco handled continuing education and Terry Mansfield spearheaded the poster session. A great "thanks boss" to Bob Timm, the chair of this 17th Vertebrate Pest Conference, who kept us all headed in the right direction. Thanks also to the many other individuals from the Department of Food and Agriculture, U.C. Cooperative Extension, USDA, ADC, and students and retirees who help run projectors and other support functions.

A special thanks from all of us to Walter E. (Howdy) Howard, who was instrumental in forming the council despite resistance from administrators in several agencies, and to other legends in our field in California—Rex Marsh, Richard Dana, Charlie Siebe and others—whose inspirational leadership, research, and teaching has had such a profound impact on our profession and our lives. Without their guidance, the Vertebrate Pest Conference would not be what it is today.

The next conference, in March 1998, will be held at the Red Lion Inn, Costa Mesa, California. Costa Mesa is in Orange County about 10 miles south of Disneyland and close to many other Southern California attractions.

I invite your comments and suggestions for the next and future conferences and ask that you fill out the Conference survey so that we can continue to provide you with a good quality program. For those staying for the post conference tour, enjoy tomorrow.

Thank you for attending this 17th Vertebrate Pest Conference, and I hope to see you at the 18th in 1998.

## CONFERENCE PARTICIPANTS

The number of registered attendees was 340. The participants came from 31 states, the District of Columbia, and from 9 other countries. The wide representation from the United States and countries throughout the world contributed to the success of the Conference by providing a highly knowledgeable and diversified group for the exchange of research progress, new ideas, and information on a wide range of vertebrate pest topics.

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