Wildlife Services—A Leader in Developing Tools and Techniques for Managing Carnivores

KATHLEEN A. FAGERSTONE, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center, Fort Collins, CO, USA
GAIL KEIRN, U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center, Fort Collins, CO, USA

ABSTRACT Did you ever wonder who invented the breakaway snare or the Livestock Protection Collar? These and many other wildlife management tools and techniques are the result of the ingenuity and creativity of U.S. Department of Agriculture Wildlife Services (WS) program scientists, technicians, and field specialists, with the help of collaborators at universities, other federal and state agencies, and private partners. This manuscript will highlight some of the tools and methods that were developed, tested, or registered by WS National Wildlife Research Center scientists for use in predator damage management.

KEY WORDS National Wildlife Research Center, techniques, tools, predator management, Wildlife Services.

INTRODUCTION AND HISTORY

The National Wildlife Research Center (NWRC) and its predecessor laboratories have a long history of developing tools for managing livestock predation. The NWRC is the research arm of the U.S. Department of Agriculture Wildlife Services program (WS), whose mission is to resolve problems caused by the interaction of wild animals and society. WS has been in existence since the establishment of the Bureau of Biological Survey (BBS) in 1886. The NWRC began in 1922 with the establishment of The Eradication Methods Laboratory of the BBS, whose mission was the "investigation of poisons . . . to aid the effectiveness of campaigns to destroy predators and rodents." That mission was quickly changed when the laboratory was renamed the Control Methods Research Laboratory and in 1931, a division of food habits research was established. At this point, the laboratory began its emphasis on systematic laboratory and field studies, as well as a focus on nonlethal and lethal means of managing damage by mammals and birds. In 1939, the BBS became the Fish and Wildlife Service under the U.S. Department of Interior, the Denver Wildlife Research Center (DWRC) was established, and predator management research became a major research area. Early research consisted mainly of experiments with lethal baiting techniques and studies to assess the effects of strychnine, thallium, and 1080 bait stations on the populations of predators and other wildlife. Other predator methods research between 1930 and 1960 focused on coyote (*Canis latrans*) food habits, movements, and development of the Coyote Getter—a sodium cyanide ejector. During the 1960s, research was conducted on coyote population dynamics, fertility control, and tranquilizers for use with traps.

In 1972, President Nixon's Executive Order 11643 banned the use of poisons in cooperative federal programs. Following this ban, two federal agencies received funding for predator research. Between 1973 and 1987, the USDA Agricultural Research Service (ARS) at the U.S. Sheep Experiment Station near Dubois, Idaho, conducted predator research and funded extramural research at 7 universities. ARS made significant contributions to methods development, particularly in the areas of anti-predator electric fencing, livestock guarding dogs, and synthetic coyote lures (USDA ARS 1987). Meanwhile, the DWRC increased its predator research focus, conducting studies on livestock losses, coyote biology, ecology, and behavior, along with increased emphasis on nonlethal predation management tools (USFWS 1978), including studies of electric fencing, livestock guarding dogs and husbandry practices, chemical repellents and aversive agents, and frightening devices. Selective or site-specific lethal techniques were also developed, including the Livestock Protection Collar (LPC), the M-44 cyanide ejector, and the large gas cartridge for coyote den fumigation. The mission of the DWRC at that time included not only research on wildlife damage management, but also on migratory birds and endangered species.

In 1985, Congress transferred the Animal Damage Control Program, including part of the DWRC and some of its field stations, to the USDA's Animal and Plant Health Inspection Service (APHIS). The DWRC's mission narrowed to wildlife damage management. From 1986 to 1990, research (directed by Congress) focused primarily on maintaining existing chemical tools by completing the Environmental Protection Agency (EPA) re-registration process for predation management products, including the LPC, the M-44, and the gas cartridge (Fall 1990, Fagerstone et al. 1990). With the successful completion of the re-registration process, and with new Congressional direction to develop nonlethal management methods, the predator research program focused on nonlethal techniques, methods selective for individual problem animals, and procedures perceived by the public to be more humane (Fall and Mason 2002). In 1997, the Animal Damage Control Program formally changed its name to Wildlife Services (WS) and the DWRC was officially moved to Fort Collins, Colorado, at Colorado State University's Foothills Research Campus, and renamed the National Wildlife Research Center.

A primary objective of the NWRC has always been to transfer information and technology to user groups, including private industry. However, after a tool or technique has been transferred, used, manufactured, or sold by others, the NWRC's role in methods development is frequently forgotten. Although general reviews of predation management research on methods and strategies are available (Connolly 1996, Rollins et al. 1995, Knowlton et al. 1999, Mason et al. 2001, Fall and Mason 2002), the goal of this manuscript is to provide historical information on specific contributions of the NWRC and its predecessor—the DWRC—to the development of predator damage management tools and techniques. Both centers have worked closely with numerous partners, including WS operations, universities, other government agencies, non-governmental organizations, private companies, and international agencies. As such, development of most of the tools and techniques mentioned in this manuscript was done in partnership with other individuals and agencies.

CHEMICAL EFFECTS DATABASE

Between 1943 and 1987, numerous chemicals were evaluated by the DWRC and by the U.S. Geological Survey's Patuxent Wildlife Research Center (formerly part of the U.S. Fish and Wildlife Service) for their potential use in preventing wildlife damage to agriculture, property, and natural resources. These historical studies led to the development of new chemical management tools and now provide valuable information for scientists involved in environmental risk management and the development of safe, effective damage management tools. The NWRC's chemical effects database contains approximately 11,000 published bioassay records and data for over 2,000 chemicals analyzed and evaluated for toxicity to animals and plants, repellency, immobilization, and reproductive inhibition. The NWRC has published much of the information from those studies and in March 2011 placed this database on the NWRC web page www.aphis.usda.gov/wildlife_damage/nwrc/index.shtml. Several of the chemicals discussed below were evaluated during this period and then commercialized.

PREDACIDES

During its long history, the NWRC has developed and conducted research on several predacides (Savarie et al. 1979, Savarie and Connolly 1983). The predominant application of predacides has been for the control of mammalian carnivores such as red foxes (*Vulpes vulpes*) and coyotes that prey on livestock and poultry. Predacides are also used in conservation programs for control of native and invasive predators that prey upon threatened or endangered species, or are vectors of communicable disease. NWRC employs staff dedicated to obtaining approval for the use of pesticides from the EPA and for drugs from the U.S. Food and Drug Administration (FDA). Managing only animals that cause predation is a goal of lethal predator management, so predacide labels are written with strict requirements on the use of specific delivery systems and placements that limit exposure to non-target animals and to the environment (Fagerstone 2002). Through NWRC's registration unit, APHIS has registered active ingredients and end-use products with the EPA for the following unique predator applications.

COMPOUND 1080

Sodium monofluoroacetate's (Compound 1080) toxic nature was noted in the 1930s, but it was not seriously investigated as a pesticide until World War II, when shortages of strychnine and red squill necessitated the development of other toxicants (Fagerstone et al. 1994). Sodium monofluoroacetate was tested beginning in 1944 as part of the chemical screening program described above. It received the acquisition number 1080 and is now commonly known as Compound 1080, or just 1080 (Atzert 1971). The early studies in the 1940s marked the beginning of NWRC research on 1080 linked to its use as a vertebrate pesticide to control coyotes. The NWRC was also instrumental in the development and registration in 1985 of 1080 for use in the Livestock Protection Collar, a device that targets only those animals causing livestock depredations. The LPC is a rubber collar filled with a dilute solution of Compound 1080 that is placed around the neck of a lamb or kid goat. It is used in areas where coyotes are killing livestock. The toxicant is dispensed as the coyote attacks the neck of the sheep and punctures the collar (Connolly 1993). Compound 1080 has also been widely used since the 1950s in New Zealand and Australia for invasive species management.

SODIUM CYANIDE (M-44)

The NWRC's predecessor began research on sodium cyanide in the 1920s, and sodium cyanide ejectors have been used in predator damage management programs since the late 1930s. The first device, the Coyote Getter, was developed by a private individual who introduced the product to government trappers (Blom and Connolly 2003). When the coyote pulled on the top of the ejector, sodium cyanide was ejected into the coyote's mouth. The Coyote Getter was used in federal predator control programs until the 1970s despite some performance and safety issues. Over the years, WS Operations and NWRC conducted considerable research to enhance the safety and effectiveness of the product, resulting in its increased use (Connolly 1996). The M-44, where the cyanide capture contents are expelled by the release of a spring-driven plunger, officially replaced the Coyote Getter in federally-supervised predator damage control programs in the 1970s. It is now used to control coyotes, red fox, gray fox (*Urocyon cinereoargenteus*), and wild dogs that are: 1) suspected of preying upon livestock and poultry; 2) suspected of preying upon federally designated threatened or endangered species; or, 3) vectors of communicable disease such as rabies. It is also used to control arctic fox (*Alopex lagopus*) that depredate federally designated threatened or endangered species in the Aleutian Islands, Alaska.

GAS CARTRIDGE

Gas cartridges were developed by the NWRC's predecessor more than 50 years ago and have been used since then to control burrowing rodents and smaller predators in dens. The original WS cartridge contained 7 active ingredients, but this was reduced to 2 ingredients during the 1970s, to make the cartridge safer and its registration easier to obtain (Savarie et al. 1980).

The APHIS gas cartridge is a fumigant cartridge containing carbon and sodium nitrate, enclosed by a cardboard cylinder. The gas cartridge is ignited and placed into a burrow or den, with all entrances closed to prevent the escape of gas; ignition results in high concentrations of carbon monoxide gas. The American Veterinary Medicine Association's 2007 panel on euthanasia recommends this method to quickly induce unconsciousness without pain. APHIS maintains a gas cartridge for use on coyotes, red fox, and striped skunks (*Mephitis mephitis)* in dens (Savarie et al. 1980, Ramey et al. 1992). It is a selective management tool because the dens of the target animals can be identified by size, tracks, remains of prey, scat, and observation of animals at the site.

PARA-AMINOPROPIOPHENONE (PAPP)

A major thrust for NWRC has been the continual development of safer yet still effective management tools. NWRC scientists conducted research during the 1970s on para-aminopropiophenone (PAPP), a more humane and safer predacide to replace Compound 1080 for the control of coyotes (Pan et al. 1983, Savarie et al. 1983). Formulation difficulties and regurgitation by dosed animals caused problems with its development, and research on PAPP was not pursued as a priority after Compound 1080 was registered for use in the animal-specific Livestock Protection Collar (Connolly 1980). However, NWRC transferred the research findings on PAPP to New Zealand scientists, who have pursued PAPP as a new predacide. The New Zealand Environmental Risk Management Authority has recently approved the use of 3 products containing PAPP within bait stations to control stoats (*Mustela erminea*), ferrets (*Mustela putorius*), and feral cats (*Felis catus*) (Murphy et al. 2007, Eason et al. 2010). PAPP induces methemoglobinemia, which acts to prevent oxygen from binding to red blood cells. This reduces oxygen supply to the brain, causing animals to become lethargic, sleepy, and unconscious prior to death. PAPP is considered a humane alternative to Compound 1080, as animals dosed show few symptoms before unconsciousness. The chemical exhibits low toxicity to most bird species, no secondary poisoning risks, and has a simple effective antidote (Savarie et al. 1983).

CHEMICAL REPELLENTS

NWRC has a long history of research into repellents, and has investigated the effectiveness of many commercially available or candidate coyote deterrents, including the aversive agent lithium chloride. The only substance identified that is reliably aversive is d-pulegone, for which the NWRC was awarded a patent in 1999 (Mason et al. 1999). This mint-scented compound deters feeding and is effective because it is irritating and causes post-ingestive malaise. However, it has not been used operationally due to difficulties in delivering it effectively to coyotes.

BAITS, LURES, AND ATTRACTANTS

Odorous chemicals are routinely used to lure predators to traps, bait stations, and census stations. During the 1970s and 1980s, several NWRC investigators evaluated various odor attractants in an attempt to improve the efficacy and selectivity of coyote control techniques (Linhart et al. 1977). The studies resulted in development and field-testing of effective synthetic coyote attractants, such as CFA (synthetic monkey pheromone) (Linhart et al. 1977), SFE (synthetic fermented egg) (Bullard et al. 1978, Turkowski et al. 1983), and FAS (fatty acid scent) (Roughton 1982).

Windberg (1996), Mason and Burns (1997), and Mason et al. (1999) examined novelty and visual cues to manipulate coyote bait acceptance, and applied their research results to improve M-44 performance. Efforts have also continued to use odor attractants to elicit varying coyote behaviors, such as rolling, licking, or biting, during development of lures and slow-release formulations (Phillips and Blom 1994, Mason and Blom 1998, and Kimball et al. 2000). More recently, NWRC scientists worked with collaborators to develop the bait formulation and attractants currently used to deliver recombinant rabies vaccine to coyotes and foxes in Texas and raccoons in the northeastern United States.

DISEASE VACCINES AND CONTRACEPTIVES

Limiting coyote numbers by inhibiting reproduction has been an attractive research area for NWRC for many years, and chemical compounds such as stilbestrol have proved effective in initial trials (Linhart et al. 1968). However, it has proved difficult to deliver baits to a sufficiently large fraction of the coyote population (Connolly and Longhurst 1975). The use of contraceptives remains an attractive idea, as NWRC studies have shown that most depredations can be attributed to territorial, dominant coyotes (Till and Knowlton 1983). Researchers suggest that sterility could be used to reduce predatory behavior by these territorial pairs of coyotes, because they would have no need to provide for pups (Till and Knowlton 1983; Knowlton 1989; Bromley and Gese 2001a, 2001b).

WS has a long history of involvement with state, local and federal agencies in the effort to control the spread of rabies in the United States. In 1995, WS cooperated with the Texas Department of Health and other agencies and organizations to develop and implement an oral rabies vaccination (ORV) program in Texas. The ORV program aimed to prevent the northward spread of a strain of canine rabies that was prevalent in coyotes. An important contribution of NWRC was verifying that coyotes would be immunized if they consumed baits containing the rabies vaccine. While canine rabies was eradicated from the United States in 2007, the risk of reintroduction from wildlife populations is still high in areas with feral and free-roaming dogs.

Throughout the world, there is a critical need to control population growth in dogs, especially in areas where canine rabies remains endemic. The GonaCon™ Immunocontraceptive Vaccine (GonaCon) was developed and patented by NWRC scientists (Miller et al. 2008) and has demonstrated contraceptive effects lasting at least 1–3 years in most mammal species. The vaccine is registered by the EPA for use in adult female white-tailed deer (*Odocoileus virginianus*). GonaCon also has potential to address worldwide dog overpopulation issues that are a serious problem in developing countries. Millions of animals are destroyed annually because they pose risks of spreading rabies (Carroll et al. 2010). Rabies continues to challenge public health systems in developing countries, especially Africa and Asia, where many of the estimated 55,000 annual human rabies deaths occur. The threat of rabies virus transmission to humans from dogs increases when the density of dogs exceeds the threshold density at which canine rabies is maintained. Integration of GonaCon into national rabies vaccination programs represents a potentially cost-effective strategy to complement or replace other population control methods. NWRC scientists, in collaboration with the Navajo Nation Animal Control Program in Arizona, have shown the simultaneous injection of the GonaCon with a canine rabies vaccine in feral dogs did not affect the development of rabies antibodies (Bender et al. 2009). These findings could aid in the development of new vaccination programs, as well as a combined rabies-contraceptive vaccine strategy, for use with feral dog populations.

TRAPS AND CAPTURE DEVICES

For more than 50 years, WS Operations, the NWRC, and its predecessors have engaged in collaborative research to improve animal traps and trapping systems (Fall 2002). Most of this research has focused on improving the efficiency, selectivity, and safety of coyote traps; results of this research have led to the availability of greatly improved designs for foothold traps, pan tension devices, snares and cable restraints, trap monitors, and trap tranquilizers. NWRC researchers have even been instrumental in improving box-type traps for small carnivores. For instance, design modifications to an enclosure system affixed to a box trap allowed for increased trapping success for kit fox (*Vulpes macrotis*) and increased trap mobility (Kozlowski et al. 2003).

Foothold traps have been in use for capturing wild animals for centuries and remain one of the most important capture techniques used by Wildlife Services. However, public concern about the humaneness of their use has encouraged research on safer, more selective designs. NWRC scientists have worked with Wildlife Services field personnel for many years on modifications to increase the selectivity and humaneness of foothold traps (Linhart et al. 1981). Rubber-padded traps were introduced into the United States from Europe in the 1930s, and became of interest to NWRC in the 1960s because of their potential application in capturing and releasing animals during radio-telemetry studies (Fall 2002). NWRC researchers tested padded jaw traps beginning in 1983 (Linhart et al. 1986, Olsen et al. 1986) and worked with a manufacturer to produce a padded jaw trap (Woodstream Corporation's SoftCatch® System) for coyotes that reduced injuries, but was able to effectively capture coyotes (Linhart et al. 1988, Linhart and Dasch 1992, Phillips et al. 1992). Traps and capture devices have been improved and changed as a result of NWRC testing for capture rate, injury rate, and selectivity (Phillips and Mullis 1996, Shivik et al. 2000). NWRC has been heavily involved in a national program to evaluate traps according to international standards for animal welfare and to develop guidelines of best management practices for trapping furbearers (Fall 2002).

NWRC researchers also worked with trap manufacturers to assess and modify pan tension devices for traps. These devices prevent activation of traps by smaller nontarget animals and are important in providing trap specificity in areas where threatened or endangered species are present. Linhart et al. (1981) and Turkowski et al. (1984) evaluated early pan tension devices and suggested modifications. Phillips and Gruver (1996) evaluated a newer after-market pan tension system. Several pan tension devices are now available for traps to make them safer for nontarget animals.

WS Operations and the NWRC have been instrumental in devising and improving predator capture devices using cable restraints. Using employee designs, WS has produced versions of cable restraints, such as the WS Turman (WS-T) snare originally produced by employees in Idaho and subsequently modified by WS in California (Shivik et al. 2005). Phillips et al. (1990) looked at the biomechanics to determine how much force domestic and native ungulates and coyotes could exert on snare cables. They used this data to predict which snares would effectively hold coyotes while releasing livestock and wildlife (Phillips et al. 1990, Phillips 1996). Shivik et al. (2000) and Darrow et al. (2008) made further evaluations of cable restraints and suggested improvements. The lock design approach may have application for auto-collaring coyotes for remote attachment of radio telemetry collars or aversive conditioning collars (Shivik et al. 2000, Shivik and Martin 2001). NWRC research has highlighted the importance of thoroughly testing restraining devices using standardized injury and efficacy scores.

Stricter state legislation of traps has required a greater frequency of trap check intervals, which can reduce trapper efficiency and increase the costs associated with wildlife damage management programs. NWRC electronics engineers and researchers were instrumental in developing early trap monitoring devices. Halstead et al. (1996) developed and examined a variety of trap monitors, with the assistance of WS Operations personnel. Trap monitors have been found to reduce time required to check traps and snares in remote areas, and allowed trappers to meet requirements for daily trap checks (Darrow and Shivik 2008).

TRANQUILIZER TRAP DEVICE (PROPIOPROMAZINE HYDROCHLORIDE)

During the 1960s, researchers, field specialists, and others recognized a need to sedate animals captured in foothold traps. Such a tranquilizer trap device could reduce damage to the animal caused by the trap, reduce animal stress, and prevent animals from escaping. The original drug tested by NWRC was diazepam (Balser 1965); however, because diazepam was on the Drug Enforcement Administration list of controlled substances, WS Operations could not authorize it for use. NWRC researchers therefore identified and tested a variety of other drugs (Savarie and Roberts 1979). Ultimately, an alternative formulation using the sedative propiopromazine hydrochloride (PPZH) was chosen for development. In 1998, APHIS obtained an Investigational New Animal Drug (INAD) number from the FDA allowing shipment of PPZH in a tranquilizer trap device for use to sedate coyotes, wolves (*Canis lupus*), and feral dogs caught in foothold traps (Fagerstone and Schafer 1998, Sahr and Knowlton 2000, Savarie et al. 2004). The device is currently used primarily during wolf research and management activities.

FENCING AND BARRIERS

Though the effective use and installation of wire and electric fences to protect livestock have been described for many decades, costs associated with installation, and low-density stocking rates for livestock, often preclude the use of fencing in the United States. Electric fencing and fence-charging technology were developed primarily in Australia and New Zealand and were introduced into the United States in the mid-1970s. Since that time, the evaluation of barrier and electric fences to exclude coyotes has received considerable research attention from NWRC scientists and others. Linhart et al. (1982) field-tested various configurations of electric fencing for protecting pastured sheep from coyote predation and found that properly configured fences reduced coyote predation. About 35% of livestock producers surveyed (U.S. Department of Agriculture 2000) use fencing to reduce livestock predation.

FRIGHTENING AND AVERSIVE TECHNIQUES

Although visual and sound-emitting devices, such as lights, radios, loud noises, scarecrows, plastic streamers, propane cannons, and aluminum pie pans have been used for many years to frighten predators and reduce predation on livestock, NWRC scientists were the first to fabricate and test a portable multi-stimulus device specifically for that purpose called the Electronic Guard (Linhart 1984, Linhart et al. 1984). Field tests of these electronic frightening devices for protecting farm flock sheep confined to fenced pastures showed that devices emitting light and sound stimuli could abruptly stop coyote predation for varying time periods and substantially reduce losses (Linhart 1984, Linhart et al. 1984). The devices, which emit bursts of light or sound with varying frequencies, also deterred coyotes from attacking sheep in some open-range situations (Linhart et al. 1992). The Electronic Guard was sold by the Pocatello Supply Depot from 1991 through 2005.

VerCauteren et al. (2003) more recently developed two versions of animal-activated acoustic frightening devices, one with, and one without, an added pop-up scarecrow and strobe light. Both were effective in reducing predation by coyotes on lambs and ewes. However, neither has been commercially manufactured. A more recent innovation by NWRC researchers is the Radio Activated Guard (RAG), which contains lights and a siren that are activated when a radio-collared animal comes close to a livestock herd (Breck et al. 2002; Shivik et al. 2003). The RAG has been used to deter endangered species such as wolves from causing livestock depredations. A version of the RAG system is commercially available as the Model 9000 Frightening Device (Avian Systems Louisville, Kentucky) and is designed to keep radio-collared predators out of small areas (Breck et al. 2002). Shivik et al. (2003) also designed a movement-activated guard device (MAG), which uses a strobe light and recorded sound effects. The MAG is activated by movement using a passive infrared detector. In field tests, the MAG device effectively protected a carcass from feeding by a variety of mammalian and avian predators for up to 29 days (Breck et al. 2002). Frightening devices confer enough protection that about 6% of producers used frightening devices in 2000 (USDA 2000).

NWRC researchers were also the first to test shock collars as aversive training tools for wildlife. Linhart et al. (1976) was able to deter coyotes from killing rabbits during a pen trial using shock collars manufactured by the NWRC. Other NWRC studies have shown that electronic dog-training collars, which produce a mild electrostatic shock when triggered by a radio signal, can be effective aversive conditioning tools to interrupt or prevent coyote attacks on domestic sheep (Andelt et al. 1999, Mason et al. 2001). Shivik and Martin (2001), in collaboration with a manufacturer, constructed a sound-activated collar. Devices are triggered when a radio-collared animal approaches a protected pasture and the collar detects domestic animal calls, such as bleating (Shivik 2001, Shivik and Martin 2001).

GUARDING ANIMALS

Although guarding animals have been used successfully for many centuries in Europe and Asia to protect livestock from bears and wolves, they were not evaluated as a method of reducing livestock losses in the United States until NWRC researchers began investigating them in the 1970s (USFWS 1978). The first scientific experiments with guarding dogs were conducted by Linhart et al. (1979), who demonstrated a significant reduction in sheep losses to coyotes by use of Hungarian Komondor dogs. Much of the subsequent research through 1987 was conducted by ARS and others (Green and Woodruff 1987). However, in the 1980s, WS implemented a plan to encourage the use of guard dogs in concert with other predation damage management methods. This initiative resulted in widespread use of guard dogs by livestock producers. By 2004, 32% of sheep producers in the United States were using guard dogs to protect their livestock from predators, primarily coyotes (USDA 2005). Use of guarding animals continues to expand and NWRC scientists continue to evaluate their use. Gehring et al. (2011) found that electric fencing enhanced the effectiveness of guarding dogs by preventing them from leaving livestock pastures. Researchers also determined that llamas could be effective livestock guards in fenced pastures (Cavalcanti and Knowlton 1998, Meadows and Knowlton 2000). Livestock protection dogs are now essential management tools in the United States. Without livestock protection dogs, thousands of sheep and lambs would be injured or killed by predators in the United States every year.

CONCLUSION

Over the past 80 years, NWRC researchers have developed a large number of methods and tools that are now in use by wildlife managers to manage livestock predation. An emphasis on traditional predator research related to livestock depredations is continuing at the NWRC Logan, Utah field station. In addition, NWRC researchers have conducted novel research on nontraditional predators. For example, techniques developed by NWRC researchers to manage vampire bat rabies include topical and systemic treatment of bats with an anticoagulant (Linhart et al. 1972; Thompson et al. 1972); the techniques have been used throughout Latin America. Many techniques have been developed for managing invasive predators. Techniques developed to control invasive mongoose depredations on endangered species include the development of a diphacinone toxicant bait (Stone et al. 1994), effective lures, and a standard operating procedure for detecting and monitoring mongoose. Repellents, lures, traps, toxicants, fumigants and detector dogs have all been developed for managing the invasive brown treesnake (*Boiga irregularis*) (Engeman and Vice 2001, Savarie et al. 2001, Savarie et al. 2005).

NWRC researchers have been instrumental in the development of techniques that are broadly applicable to all taxa, including use of passive integrated transponders (PIT tags) for wildlife (Fagerstone and Johns 1987). During the late 1970s, the NWRC developed innovative technologies, including miniaturized telemetry transmitter methodologies for birds and small mammals that were transferred to private companies. In collaboration with the National Aeronautics and Space Administration, the NWRC developed the first satellite tracking systems for use with polar bears (*Ursus maritimus*) and loggerhead sea turtles (*Caretta caretta*). NWRC has developed hundreds of analytical methods for identification of chemicals and pesticides in various matrices, including water, soil, and tissues. More recently, NWRC has developed the ability to apply molecular genetics technology for the identification of canine predators (species, sex, individual animal) by analyzing saliva collected from predated livestock carcasses. Currently, NWRC researchers are continuing the traditional predator-livestock work, but researchers are also conducting investigations in several other areas as well. Urban predator conflicts are being investigated, looking at coyotes as well as other species such as bears. And additional research is being conducted in the areas of human health and safety and human dimensions.

LITERATURE CITED

American Veterinary Medicine Association [AVMA]. 2007. AVMA Guidelines on Euthanasia.<http://www.avma.org/issues/animal_welfare/euthanasia.pdf>. Accessed 18 April 2011.

Andelt, W. F., R. L. Phillips, K. S. Gruver, and J. W. Guthrie. 1999. Coyote predation on domestic sheep deterred with electronic dog-training collar. Wildlife Society Bulletin 27:12–18.

Atzert, S. P. 1972. A review of sodium monofluoroacetate (Compound 1080), its properties, toxicology, and use in predator and rodent control. Special Scientific Report Wildlife No. 146, U.S. Bureau of Sports Fisheries and Wildlife, Washington, DC, USA.

Balser, D. S. 1965. Tranquilizer tabs for capturing wild carnivores. Journal of Wildlife Management 29:438–442.

Bender, S. C., D. L. Bergman, K. M. Wenning, L. A. Miller, D. Slate, F. R. Jackson, C. E. Rupprecht. 2009. No adverse effects of simultaneous vaccination with the immunocontraceptive GonaCon™ and a commercial rabies vaccine on rabies virus neutralizing antibody production in dogs. Vaccine 27:7210–7213.

Blom, F. S., and G. Connolly. 2003. Inventing and reinventing sodium cyanide ejectors: a technical history of coyote getters and M-44s in predator damage control. USDA-APHIS-WS-National Wildlife Research Center Research Report 03–02. National Wildlife Research Center, Fort Collins, Colorado, USA.

Breck, S. W., R. Williamson, C. Niemeyer, and J. A. Shivik. 2002. Nonlethal radio activated guard for deterring wolf depredation in Idaho: Summary and call for research. Proceedings of the Vertebrate Pest Conference 20:223–226.

Bromley, C. and E. M. Gese. 2001a. Effects of sterilization on territory fidelity and maintenance, pair bonds, and survival rates of free-ranging coyotes. Canadian Journal of Zoology 79:386–392.

Bromley, C. and E. M. Gese. 2001b. Surgical sterilization as a method of reducing coyote predation on domestic sheep. Journal of Wildlife Management 65:510–519.

Bullard, R. W, S. A. Shumake, D. L. Campbell, and F. J. Turkowski. 1978. Preparation and evaluation of a synthetic fermented egg coyote attractant and deer repellent. Journal of Agricultural and Food Chemistry 26:160–163.

Carroll, M. J., A. Singer, G. C. Smith, D. P. Cowan, and G. Massei. 2010. The use of immunocontraception to improve rabies eradication in urban dog populations. Wildlife Research 37(8): 676–687.

Cavalcanti, S. M. C., and F. F. Knowlton. 1998. Evaluation of physical and behavioral traits of llamas associated with aggressiveness toward sheep-threatening canids. Applied Animal Behaviour Science 61:143–158.

Connolly, G. 1980. Use of compound 1080 in livestock neck collars to kill depredating coyotes: A report on field and laboratory research. U.S. Department of the Interior, Fish and Wildlife Service, Denver Wildlife Research Center, Denver, Colorado, USA.

Connolly, G. 1993. Livestock protection collars in the United States, 1988–1993. Proceedings of Great Plains Wildlife Damage Control Workshop 11:25–33.

Connolly, G. 1996. Animal Damage Control research contributions to coyote management. Pages 61–71 *in* Proceedings of the 1995 Joint Fur Resources Workshop. Brown, C. editor. West Virginia Division of Natural Resources, Charleston, West Virginia, USA.

Connolly, G. E., and W. M. Longhurst. 1975. The effects of control on coyote populations. Bulletin 1872, Division of Agricultural Sciences, University of California, Berkeley, California, USA.

Darrow, P. A., and J. A. Shivik. 2008. A pilot evaluation of trap monitors by the USDA Wildlife Services Operational Program. Proceedings of Vertebrate Pest Conference 23:213–217.

Darrow, P. A., R. T. Skirpstunas, S. W. Carlson, and J. A. Shivik. 2008. Comparison of injuries to coyote from 3 types of cable foot-restraints. Journal of Wildlife Management 73:1441–1444.

Eason, C. T., E. Murphy, S. Hix, and D. Macmorran. 2010. The development of a new humane toxin for predator control in New Zealand. Integrative Zoology 1:31–36.

Engeman, R. M., and D. S. Vice. 2001. Objectives and integrated approaches for the control of brown tree snakes. Integrated Pest Management Reviews 6:59–76.

Fagerstone, K. A. 2002. Professional use of pesticides in wildlife management—an overview of professional wildlife damage management. Proceedings of Vertebrate Pest Conference 20:253–260.

Fagerstone, K. A., R. W. Bullard, and C. A. Ramey. 1990. Politics and economics of maintaining pesticide registrations. Proceedings of Vertebrate Pest Conference 14:8–11.

Fagerstone, K. A., and B. E. Johns. 1987. Transponders as permanent identification markers for domestic ferrets, black footed ferrets, and other wildlife. Journal of Wildlife Management 51:294 297.

Fagerstone, K. A., P. J. Savarie, D. J. Elias, and E. W. Schafer Jr. 1994. Recent regulatory requirements for pesticide registration and the status of Compound 1080 studies conducted to meet EPA requirements. Pages 33–38 *in* A. A. Seawright, C. T. Eason, editors. Proceedings of the Science Workshop on 1080. Miscellaneous Series 28, The Royal Society of New Zealand, Wellington, New Zealand.

Fagerstone, K. A., and E. W Schafer, Jr. 1998. Status of APHIS vertebrate pesticides and drugs. Proceedings of Vertebrate Pest Conference 18:319–324.

Fall, M. W. 1990. Control of coyote depredation on livestock—progress in research and development. Proceedings of Vertebrate Pest Conference 14:245–251.

Fall, M. W. 2002. The search for acceptable animal traps. Proceedings of Vertebrate Pest Conference 20:371–377.

Fall, M. W., and J. R. Mason. 2002. Developing methods for managing coyote problems—another decade of progress, 1991–2001. Proceedings of Vertebrate Pest Conference 20:194–200.

Gehring, T. M., K. C. VerCauteren, and A. C. Cellar. 2011. Good fences make good neighbors: implementation of electric fencing for establishing effective livestock-protection dogs. Human-Wildlife Interactions 5:106–111.

Green, J. S., and R. A. Woodruff. 1987. Livestock guarding dogs for predator control. Pages 62–68 *in* J.S. Green, editor. Protecting livestock from coyotes. U.S. Department of Agriculture, Agricultural Research Service, Sheep Experiment Station, Dubois, Idaho, USA.

Halstead, T. D., K. S. Gruver, R. L. Phillips, and R. E. Johnson. 1996. Using telemetry equipment for monitoring traps and snares. Proceedings of Great Plains Wildlife Damage Control Workshop 12:121–123.

Kimball, B. A., J. R. Mason, F. S. Blom, J. J. Johnston, and D. E. Zemlicka. 2000. Development and testing of seven new synthetic coyote attractants. Journal of Agricultural and Food Chemistry 48(5):1892–1897.

Knowlton, F. F. 1989. Predator biology and livestock predation management. Proceedings of the Western Section, American Society of Animal Science 40:504–509.

Knowlton, F. F., E. M. Gese, and M. M. Jaeger. 1999. Coyote depredation control: an interface between biology and management. Journal of Range Management 52:398–412.

Kozlowski, A. J., T. J. Bennett, E. M. Gese, and W. M. Arjo. 2003. Live capture of denning mammals using an improved box-trap enclosure: kit foxes as a test case. Wildlife Society Bulletin 31:630–633.

Linhart, S. 1984. Strobe-light and siren devices for protecting fenced-pasture and range sheep from coyote predation. Proceedings of Vertebrate Pest Conference 11:154–156.

Linhart, S. B., F. S. Blom, G. J. Dasch, R. M. Engeman, and G. H. Olsen. 1988. Field evaluation of padded jaw coyote traps: effectiveness and foot injury. Proceedings of Vertebrate Pest Conference 13:226–229.

Linhart, S. B., H. H. Brusman, and D. S. Balser. 1968. Field evaluation of an antifertility agent, stilbestrol, for inhibiting coyote reproduction. Transactions of the North American Wildlife and Natural Resources Conference 33:316 327.

Linhart, S. B. and G. J. Dasch. 1992. Improved performance of padded jaw traps for capturing coyotes. Wildlife Society Bulletin 20:63–66.

Linhart, S. B., G. J. Dasch, R. R. Johnson, J. D. Roberts, and C. J. Packham. 1992. Electronic frightening devices for reducing coyote predation on domestic sheep: efficacy under range conditions and operational use. Proceedings of Vertebrate Pest Conference 15:386–392.

Linhart, S. B., G. J. Dasch, C. B. Male, and R. M. Engeman. 1986. Efficiency of unpadded and padded steel foothold traps for capturing coyotes. Wildlife Society Bulletin 14:212–218.

Linhart, S. B., G. J. Dasch, J. D. Roberts, and P. J. Savarie. 1977. Test methods for determining the efficacy of coyote attractants and repellents. Pages 114–122 *in* Jackson, W.B., and R. E. Marsh, editors. Vertebrate Pest Control and Management Materials. ASTM STP 625. American Society for Testing and Materials, Philadelphia, PA, USA.

Linhart, S. B., G. J. Dasch, and F. J. Turkowski. 1981. The steel leghold trap: techniques for reducing foot injury and increasing selectivity. Proceedings of Worldwide Furbearer Conference 3:1560–1578.

Linhart, S. B., R. Flores Crespo, and G. C. Mitchell. 1972. Control of vampire bats by topical application of an anticoagulant, chlorphacinone. Boletín de la Oficina Sanitaria Panamericana 6(2):31–38.

Linhart, S. B., J. D. Roberts, and G. J. Dasch. 1982. Electric fencing reduces coyote predation on pastured sheep. Journal of Range Management 35:276–281.

Linhart, S. B., J. D. Roberts, S. A. Shumake, and R. Johnson. 1976. Avoidance of prey by captive coyotes punished with electric shock. Proceedings of Vertebrate Pest Conference 7:302–306.

Linhart, S. B., R. T. Sterner, T. C. Carrigan, and D. R. Henne. 1979. Komondor guard dogs reduce sheep losses to coyotes: a preliminary evaluation. Journal of Range Management 32(3): 238–241.

Linhart, S. B., R. T. Sterner, G. J. Dasch, and J. W. Theade. 1984. Efficacy of light and sound stimuli for reducing coyote predation upon pastured sheep. Protection Ecology 6:75–84.

Mason, J. R. and S. Blom. 1998. Coyote lure ingredients: what factors determine success? Wildlife Control Techniques 5(5):26–30.

Mason, J. R., and R. J. Burns. 1997. Coyote responsiveness to novel visual stimuli. Journal of Wildlife Research 2:6–8.

Mason, J. R., R. A. Dolbeer, and G. Preti. 1999. Naturally-occurring odoriferous animal repellent (U.S. Patent #5,887,223).

Mason, J. R., J. A. Shivik, and M. W. Fall. 2001. Chemical repellents and other aversive strategies in predation management. Endangered Species Update 18(4):175–181.

Meadows, L. E., and F. F. Knowlton. 2000. Efficacy of guard llamas to reduce canine predation on domestic sheep. Wildlife Society Bulletin 28(3):614–622.

Miller, L. A., J. Gionfriddo, K. A. Fagerstone, J. Rhyan, and G. Killian. 2008. The single-shot GnRH immunocontraceptive vaccine (GonaCon™) in white-tailed deer: comparison of several GnRH preparations. American Journal of Reproductive Immunology 60:214–223.

Murphy, E. C., C. T. Eason, S. Hix, and D. B. Macmorran. 2007. Developing a new toxin for potential control of feral cats, stoats, and wild dogs in New Zealand. Pages 469–473 *in* G. W. Witmer, W. C. Pitt, and K. A. Fagerstone, editors. Managing Invasive Vertebrate Species: Proceedings of an International Symposium. USDA APHIS National Wildlife Research Center, Fort Collins, Colorado, USA.

Olsen, G. H., S. B. Linhart, R. A. Holmes, G. J. Dasch, and C. B. Male. 1986. Injuries to coyotes caught in padded and unpadded steel foothold traps. Wildlife Society Bulletin 14:219–223.

Pan, H. P., P. J. Savarie, D. J. Elias, and R. R. Felton. 1983. Alkyl chain length and acute oral toxicity of paminophenones. General Pharmacology: The Vascular System 14(4):465–467.

Phillips, R. L. 1996. Evaluation of 3 types of snares for capturing coyotes. Wildlife Society Bulletin 24:107–110.

Phillips, R. L. 1996. Evaluation of 3 types of snares for capturing coyotes. Wildlife Society Bulletin 24:107–110.

Phillips, R. L., and F. S. Blom. 1994. Field evaluation of chemical attractants for summer use of M-44s. Proceedings of Vertebrate Pest Conference 16:51–56.

Phillips, R. L., F. S. Blom, G. J. Dasch, and J. W. Guthrie. 1992. Field evaluation of 3 types of coyote traps. Proceedings of Vertebrate Pest Conference 15:393–395.

Phillips, R. L., F. S. Blom, and R. E. Johnson. 1990. An evaluation of breakaway snares for use in coyote control. Proceedings of Vertebrate Pest Conference 14:255–259.

Phillips, R. L., and K. S. Gruver. 1996. Performance of the Paws-I-Trip pan tension device on 3 types of traps. Wildlife Society Bulletin 24: 119–122.

Phillips, R. L., and C. Mullis. 1996. Expanded field testing of the No. 3 Victor Soft Catch® trap. Wildlife Society Bulletin 24:128–131.

Ramey, C. A., E. W. Schafer, Jr., K. A. Fagerstone, and S. D. Palmateer. 1992. Back to the future for APHIS's vertebrate pesticides. Proceedings of Vertebrate Pest Conference 15:17–21.

Rollins, D., C. Richardson, T. Blankenship, K. Canon, and S. Henke, editors. 1995. Symposium on coyotes in the southwest: a compendium of our knowledge. Texas Parks and Wildlife Department, Austin, Texas, USA.

Roughton, R. D. 1982. A synthetic alternative to fermented egg as a canid attractant. Journal of Wildlife Management 46:230–234.

Sahr, D. P. and F. F. Knowlton. 2000. Evaluation of tranquilizer trap devices (TTDs) for foothold traps used to capture gray wolves. Wildlife Society Bulletin 28:597–605.

Savarie, P. J. and G. E. Connolly. 1983. Criteria for the selection and development of predacides. Pages 278–284 *in* D. E. Kaukeinen, editor. Vertebrate Pest Control and Management Materials: 4th Symp. ASTM STP 817, American Society Testing Materials, Philadelphia, Pennsylvania, USA.

Savarie, P. J., D. J. Hayes, R. T. McBride, and J. D. Roberts. 1979. Efficacy and safety of diphacinone as a predacide. Pages 69 79 *in* E. E. Kenaga, editor. Avian and Mammalian Wildlife Toxicology, ASTM STP 693, American Society for Testing Materials, Philadelphia, Pennsylvania, USA.

Savarie, P. J., H. P. Pan, D. J. Hayes, J. D. Roberts, G. J. Dasch, R. Felton, and E. W. Schafer. 1983. Comparative acute oral toxicity of para-aminopropiophenone (PAPP) in mammals and birds. Bulletin of Environmental Contamination and Toxicology 30(1):122–126.

Savarie, P. J., and J. D. Roberts. 1979. Evaluation of oral central nervous system depressants in coyotes. Pages 270–277 *in* J. R. Beck, editor. Test methods for vertebrate pest control and management materials. ASTM Special Technical Publication 680, American Society of Testing and Materials, Philadelphia, Pennsylvania, USA.

Savarie, P. J., J. A. Shivik, G. C. White, J. C. Hurley, and L. Clark. 2001. Use of acetaminophen for large-scale control of brown treesnakes. Journal of Wildlife Management 65:356–365.

Savarie, P. J., J. R. Tigner, D. J. Elias, and D. J. Hayes. 1980. Development of a simple two-ingredient pyrotechnic fumigant. Proceedings of Vertebrate Pest Conference 9:212–221.

Savarie, P. J., D. S. Vice, L. Bangerter, K. Dustin, W. J. Paul, T. M. Primus, and F. S. Blom. 2004. Operational field evaluation of a plastic bulb reservoir as a tranquilizer trap device for delivering propiopromazine hydrochloride to feral dogs, coyotes, and gray wolves. Proceedings of Vertebrate Pest Conference 21:64–69.

Savarie, P. J., W. S. Wood, G. H. Rodda, R. L. Bruggers, and R. M. Engeman. 2005. Effectiveness of methyl bromide as a cargo fumigant for brown treesnakes. International Biodeterioration & Biodegradation 56:40–44.

Shivik, J. A. 2001. The other tools for wolf management. Wolf! 19(2):3–7.

Shivik, J. A., K. S. Gruver, and T. J. DeLiberto. 2000. Preliminary evaluation of new cable restraints to capture coyotes. Wildlife Society Bulletin 28(3):606–613.

Shivik, J. A., and D. J. Martin. 2001. Aversive and disruptive stimulus applications for managing predation. Proceedings of the Wildlife Damage Management Conference 9:111–119.

Shivik, J. A., D. J. Martin, M. J. Pipas, J. Turman, and T. J. DeLiberto. 2005. Initial comparison: jaws, cables, and cage-traps to capture coyotes. Wildlife Society Bulletin 33(4):1375–1383.

Shivik, J. A., A. Treves, and P. Callahan. 2003. Nonlethal techniques for managing predation: primary and secondary repellents. Conservation Biology 17(6):1531–1537.

Stone, C. P., M. Dusek , and M. Aeder. 1994. Use of an anticoagulant to control mongooses in Nene breeding habitat. Elepaio 54: 73–78.

Thompson, R.D., G. C. Mitchell, and R. J. Burns. 1972. Vampire bat control by systemic treatment of livestock with an anticoagulant. Science 177:806–808.

Till, J. A., and F. F. Knowlton. 1983. Efficacy of denning in alleviating coyote depredations upon domestic sheep. Journal of Wildlife Management 47:1018–1025.

Turkowski, F. J., A. R. Armistead, and S. B. Linhart. 1984. Selectivity and effectiveness of pan tension devices for coyote foothold traps. Journal of Wildlife Management 48:700–708.

Turkowski, F. J., M. L. Popelka, and R. W. Bullard. 1983. Efficacy of odor lures and baits for coyotes. Wildlife Society Bulletin 11:136–145.

U.S. Department of Agriculture. 2000. Sheep and goats predator loss. National Agricultural Statistics Service, Agricultural Statistics Board, Washington D.C., USA.

U. S. Department of Agriculture. 2005. Sheep and goats predator loss. National Agricultural Statistics Service, Agricultural Statistics Board, Washington D.C., USA.

U. S. Department of Agriculture-Agricultural Research Service. 1987. Protecting livestock from coyotes. A synopsis of the research of the Agricultural Research Service. Jeffrey S. Green, editor. USDA-ARS, U.S. Sheep Experiment Station, Dubois, Idaho, USA.

U. S. Fish and Wildlife Service. 1978. Predator damage in the west: A study of coyote management alternatives. U. S. Fish and Wildlife Service, Department of the Interior publication, Washington, D.C., USA.

VerCauteren, K. C., M. J. Lavelle, and S. Moyles. 2003. Efficacy of coyote-activated frightening devices of reducing sheep predation. Proceedings of the Wildlife Damage Management Conference 10:146–151.

Windberg, L. 1996. Coyote responses to visual and olfactory stimuli related to familiarity with an area. Canadian Journal of Zoology 74:2248–2253.