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ABSTRACT: The coyote is highly adaptable in exploiting man's livestock production systems and, indeed, thrives in such situations. Recent research by the Denver Wildlife Research Center has drawn upon earlier studies to focus effort on priority needs of the U.S. Department of Agriculture's (USDA) cooperative Animal Damage Control (ADC) program. Substantial improvements have been made in some control methods and several new methods or effective modifications have become available for use by ADC and by producers. Additional developments have occurred in improving chemical delivery systems and in understanding the ecological requirements for effective control programs. With the substantial investments being made by USDA in test facilities and personnel to meet new regulatory requirements, prospects for the development and registration of new control methods and materials have greatly improved.

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For more than 50 years, the Denver Wildlife Research Center (DWRC) and its predecessor laboratories have engaged in research on the problem of livestock predation by coyotes and on methods that could be used by wildlife specialists and producers to minimize predation losses. The primary purposes of such research have been, and continue to be, to devise, evaluate, and improve predator control methods useful to producers and animal damage control specialists and to assure a sound biological basis for the management methods used or recommended by the Federal-Cooperative Animal Damage Control (ADC) Program.

Numerous reviews of the ADC program, the dimensions of the problems it addresses, and the management methods used have been published at intervals during this time period, making it possible to follow historical changes in approach and perceptions. Examples spanning several decades include Young and Jackson (1951), Leopold et al. (1964), Cain et al.(1972), U.S. Department of the Interior (1978), and Wagner (1988). Also during this time period, beginning with Robinson's (1962) summary at the First Vertebrate Pest Conference, regular reviews and critiques of research progress have summarized the increasing knowledge of the impact of predation on the livestock industry, the biology and population dynamics of coyotes, and the effectiveness of available predation management techniques. Balser (1974), Wade (1982), Connolly (1982), Bowns (1982), Knowlton and Stoddart (1983), Linhart (1984a), Andelt (1987), Green (1987), and Knowlton (1989) provide excellent overviews of various aspects of research progress.

The purpose of this paper is to provide a brief overview of the strategies and methods of managing coyote predation, to summarize some of the accomplishments in the past decade of control methods development, and to comment on some recent research on predation control methods conducted by DWRC scientists. A related paper (Phillips and Fall 1990) provides additional discussion of some of the control methods and their application that are summarized here.

PREDATION CONTROL STRATEGIES

A variety of options are available to producers and wildlife managers experiencing predation problems, however they may be defined. The same basic strategy options apply whether the "problems" are coyote predation on livestock, small carnivore predation on nesting waterfowl, or predation that threatens the loss or recovery of endangered species populations. Such options include:

- cease production of susceptible animals
- tolerate losses
- move susceptible animals to other areas
- time animal production to avoid predation
- manage susceptible animals to minimize predation
- exclude predators from production areas
- modify behavior or activity patterns of predators
- relocate predators away from production areas
- remove individuals or local groups of predators causing losses
- reduce relative abundance of predators
- eradicate predators
- integrate predation management techniques to minimize losses

Despite much that has been written to the contrary, livestock producers and the specialists of the cooperative ADC program have long employed an integrated management approach, using knowledge of a particular situation and patterns of damage to choose what management practices and control methods might be used appropriately and effectively. Perhaps, because of the controversy that grew up surrounding the use of Compound 1080 in meat bait stations (culminating in the cancellation of all predacide registrations in 1972), little attention has been paid to the pioneering work of the ADC program in "integrated pest management," long before the approach was popularized by entomologists. Unfortunately, throughout the history of livestock production in the U.S., the function, effectiveness, details of application, and the potential for associated hazards of particular predation control techniques have been much more widely studied than the problem itself or the overall effectiveness of integrated management. As a consequence, public, professional, and legal debate has continued to the present about the relative merits of approaches to managing coyote predation on livestock, and the available data seem insufficient to convince any of the sides of another's position.

PREDATION CONTROL TECHNIQUES

An overwhelming variety of techniques for managing predation has been proposed, investigated, used, or advocated (Table 1). While most have been studied to some degree, the amount of effort reflected in technical literature has been highly uneven. Perhaps not surprisingly, much more has been published about techniques that have thus far not proven effective, such as bounties, aversive conditioning, and chemosterilization, than about techniques that are acknowledged as effective and selective in particular situations.

Techniques that can be utilized by sheep producers to manage coyote predation include husbandry practices such as fencing, penning sheep at night, shed lambing, removal of carrion, and frequent checking of flocks. Other techniques such as shooting, trapping, frightening devices, livestock guarding dogs, or other aggressive animals may be used to kill coyotes or reduce coyote activity around pastures or bedgrounds. A few states have allowed use of sodium cyanide ejectors (M-44s) and Compound 1080 Livestock Protection Collars by certified applicators. Techniques used by the ADC program in managing predation, in addition to providing technical assistance to producers on the choice and application of methods, include traps and snares, M-44s, den removal, and ground and aerial shooting. Of these, trapping, aerial hunting, and M-44s are currently the most widely used techniques (Connolly 1988).

None of these methods of predation control is practical or effective for use in all of the diverse situations in which coyote predation on livestock occurs. Much of our research has focused on the need to maintain a variety of techniques of proven effectiveness that can be used or adapted to varying conditions and, increasingly, on the need to assure that such techniques can be effectively and selectively used in compliance with changing federal, state, and local laws and regulations. A few of these efforts can be summarized here. Reference to trade names for identification does not indicate endorsement by the author or by USDA.

TRAP IMPROVEMENT

Steel leghold or foothold traps used by a specialist can be highly selective in capturing coyotes active in livestock production areas. Researchers have examined a number of questions concerning their use.

Balser (1965) described tranquilizer trap tabs as a means of reducing foot injury to carnivores captured for study. Savarie and Roberts (1979) examined candidate tranquilizers for this use. In field tests of a number of candidate tranquilizers and delivery configurations, Linhart et al. (1981) found up to 90% of coyotes taken in traps with tabs containing propiopromazine HO or a mixture of propiopromazine HC1 and chlordiazepoxide had little or no evident foot injury. Although no drug has been registered, the approach is still considered viable and may have particular application if coyotes, wolves, or other animals must be trapped and relocated. The technique may also have potential as a means of reducing escapes from traps.

Table 1. Methods and techniques for predation control that have been suggested, tested, or used for various predation problems.

Physical	Chemical	Biological	Other
Fencing	Toxicant ejectors	Disease	Bounty
Penning	Den fumigants	Parasitism	Fur price
Herders	Toxicant collars	Carrion removal	Compensation
Shed lamb	Single-dose baits	Immunogens	Insurance
Check sheep	Bait stations	Competitive exclusion	
Frightening	Bait collars		
Guard animals	Liquid baits		
Den hunting	Bait posts		
Mech. ferret	CLOD		
Ground hunting	Smear posts		
Call and shoot	Systemic toxicants		
Hunt with dogs	Aversive agents		
Aerial hunting	Repellents		
Trapping	Sterilants		
Snaring			

Investigations of various prototype and commercial padded traps by Linhart et al. (1986, 1988) and Olsen et a!. (1986) showed padded traps substantially reduced foot injury to coyotes but were considerably less efficient than unpadded traps used by ADC specialists. In more recent tests, Linhart found comparable efficiency between standard ADC double long-spring traps and the most recent commercial Soft Catch® No. 3 double-coil traps (Woodstream Corp.) under ideal trapping conditions in dry, sandy soil (S. Linhart, pers. commun). Linhart et al. (1988) also found that shortened, center-mounted 15-cm trap chains produced less foot injury than 90-cm spring-mounted chains, in contrast to findings of Linhart et al. (1981).

Turkowski et al. (1984) evaluated 3 types of trap pan tension devices and found all capable of excluding a high proportion of smaller nontarget species from traps set for coyotes. In addition to making trap sets more selective, reduction of accidentally sprung traps can increase the efficiency of trap exposure for coyotes.

Knowlton et al. (1985) and Windberg and Knowlton (1988), using radio telemetry, have shown the potential for analysis of coyote territorial patterns to improve efforts to capture specific coyotes. Windberg and Knowlton (in press) found that traps set outside territorial boundaries were more likely to capture resident coyotes than those set within their territory.

Research efforts on improvement of traps and trapping have also resulted in insights and improvements in materials and methodology (Dasch 1984, Johnson et al. 1986, Andelt et al. 1985) and in proposed standards for future testing (Linhart and Linscombe 1988, Linhart 1990).

M-44 IMPROVEMENT

Cancelled in 1972, along with other predacides, the M-44 sodium cyanide ejector was registered in 1975 by the Environmental Protection Agency (EPA) after an abbreviated, but extensive, nearly westwide research effort (Matheny 1976). Although a number of problems with mechanical function and caking of the cyanide formulation were noted by experimental users, they were not fully resolved before registration. Beginning in 1981, research efforts were organized under the supervision of an M-44 Study Team formed by the ADC program to evaluate performance of the variety of M-44 models and to identify aspects of the device and sodium cyanide formulation that could be modified to improve performance (Connolly and Simmons 1984). Studies of a variety of modifications were conducted to improve capsule seals to avoid caking, to increase the mechanical reliability and useful life of the unit, and to reduce problems with corrosion. Connolly (1988) in reviewing ADC program use of this technique found that use had steadily increased during the cooperative research effort, with the coyote take by M-44s in 1986 more than double that of 1981. Continuing efforts are under way to maintain the M-44 registration and to identify other desirable technical improvements in the device. Additional research has included identification and evaluation of inert marking agents for the cyanide formulation (R. Burns, pers. commun.) and evaluation of candidate odor attractants that might improve the device's utility during summer (R. Phillips, pers. commun.).

FRIGHTENING DEVICES

Linhart et al. (1984) reported the development of multi-stimulus coyote frightening devices that combined battery-operated strobe lights, sirens, and high-frequency horns that were activated for short, irregular intervals. A photocell started the devices at dusk and with a timing circuit turned off the signals about 2 hours after dawn. The devices were designed to reduce coyote habituation to disturbance that was believed to limit the utility of devices such as electric lights, portable radios, tape players, and exploders. In field tests, Linhart's et al. (1984) second-generation devices protected pastured sheep for an average of 91 nights in 5 trials where 3 to 6 devices were put in place after 5 sheep were killed by coyotes within a 2 to 3 week pretrial period. A test was terminated whenever 2 cumulative sheep kills had occurred, or when normal pasture operations ended due to marketing of lambs or the onset of winter. Later prototype devices, designed to be smaller, cheaper, lighter, weatherproof, and maintenance free, were provided to herders in an evaluation of the effectiveness of this approach for protecting sheep on bedgrounds on unfenced rangeland (Linhart 1984b). In 10 of 12 of these trials sheep losses to coyotes were reduced an average of 73% (S. Linhart, pers. commun.). Such an approach, using portable devices, may have particular utility in reducing predation in remote areas that are difficult to access or where the use of other management techniques is restricted. The effect observed in pasture trials where a consistent pattern of predation stopped immediately might also make the devices useful as an emergency measure in addition to their potential for more regular seasonal use.

BAITING TECHNIQUES

Baiting techniques for carnivores have been investigated for delivering a variety of control agents, including toxicants, reproductive inhibitors, aversive agents, and rabies vaccines. Several trials were conducted in the early 1980s by DWRC and ADC program personnel to examine the feasibility of using low-density applications of Compound 1080 single-dose baits (SDBs) for selective removal of coyotes from sheep production areas. Since then, work has continued to develop improved baits, baiting techniques, and the background chemical and toxicological data that would be needed for registration. Many of these data parallel those required for the 1080 Livestock Protection Collar, and considerable progress has been made in developing analytical methods to determine Compound 1080 residues in different matrices and animal tissues. A problem encountered in earlier studies of baiting methods for coyotes was consistently low bait consumption, assessed by the use of nontoxic baits containing marking agents (Larson et al. 1981; S. Linhart, pers. commun.). More recent work by Knowlton et al. (1985) and R. Nass (pers. commun.) appears to have partially overcome this problem. R. Nass (pers. commun.) was able to mark 42, 50, and 60% of coyotes active on southern Idaho study areas during spring, fall, and winter, respectively, using 5 baits per square mile and following M-44 use restrictions. Additional work is underway or planned to assess variations in the proportion of coyotes taking baits at different seasons and at different bait exposure rates, and to determine whether individual coyotes taking baits also kill livestock.

CHEMICAL CONTROL MATERIALS

A considerable number of chemicals have been examined for toxicity or for activity as drugs, markers, attractants, or repellents. Tests with alternative toxicants have included several trials with materials for use in Livestock Protection Collars (Connolly and O'Gara 1988, Burns et al. 1984, Savarie

and Sterner 1979, Sterner 1979, and Savarie et al. 1979). Connolly et al. (1986) evaluated several possible alternative toxicants for use in M-44s. Savarie and Connolly (1983) reviewed criteria used in selecting toxicants that might have application for predator control. Other investigations have been made of coyote attractants for use with control devices (Turkowski et al. 1983, Bullard et al. 1983), oral central nervous system depressants (Savarie and Roberts 1979), and marking agents that have utility for studying delivery systems or for marking chemical formulations, summarized by Phillips and Fall (1990).

A number of candidate chemicals have potential for application in coyote control techniques, either as alternatives in currently used devices or in new delivery systems such as single-dose baits or Coyote Lure Operative Devices (CLOD; Fagre and Ebbert 1988). Most of these materials must await expansion of DWRC's very limited capacity for conducting chemical testing in compliance with EPA's requirements for Good Laboratory Practices (GLP), described by Goldman (1988), before much further evaluation is possible. A number of important changes have been made in DWRC's organization and in its testing programs to provide the framework for this to occur. Renovation of existing analytical chemistry laboratories is nearly completed, and plans are underway to build new facilities that would allow chemical testing and registration efforts to proceed more rapidly in the future in full compliance with GLP.

OTHER CONTROL METHODS

Beginning with De Grazio's observations in Turkey (De Grazio 1973), DWRC scientists made preliminary investigations of the applications for livestock guarding dogs in protecting sheep from coyotes in the U.S. Linhart et al. (1979) found significantly reduced sheep predation by coyotes in fenced pastures during and following the use of trained Komondor dogs. Since these initial efforts, other investigators have extensively researched the use of guarding dogs (Green and Woodruff 1983, Coppinger et al. 1988, Green 1990), and the technique is now considered, along with other operational methods, for use in appropriate situations.

A variety of types of fencing have been used for many years to protect livestock from predation and a number of evaluations and construction guides (summarized by Linhart 1984a) have been published since the mid-1970s. Linhart et al. (1982) reported early DWRC evaluations of low impedance fence chargers and fence configurations and surveyed use of electric fences by sheep producers. Nass and Theade (1988) interviewed 101 sheep producers in Oregon, California, and Washington to determine experience with electric fencing after several years of use. Fence maintenance and vegetation control were cited as essential for proper operation; most producers believed additional control efforts were needed in conjunction with fencing. High initial cost of electric fence construction is probably the primary reason this technique is not more widely used.

During the past 15 years, a number of scientists at DWRC and elsewhere have studied the potential for using lithium chloride in baits to condition coyotes to avoid prey as proposed by Gustavson et al. (1974). Summaries by Burns (1983), Linhart (1984), Burns and Connolly (1985), and Forthman Quick et al. (1985) provide critical reviews of various aspects of this research. Although Linhart et al. (1976) found that some coyotes could be conditioned to avoid prey animals for long periods using electric shock, the evidence that lithium chloride baits can produce useful prey aversions in coyotes has remained, at best, inconclusive. As more investigators have examined the proposed technique, it has become clear that the experimental costs would be prohibitively high for obtaining conclusive scientific evidence on whether this is an effective and practical method for protecting sheep from coyote predation.

Several other important studies of predation control methods have been conducted by DWRC investigators during recent years. Till and Knowlton (1983) examined the biological basis for den hunting and demonstrated that removal of either coyote pups or territorial adults from dens effectively stopped predation on sheep. Although the technique has limited seasonal application, the study resolved long-standing questions about its effectiveness and selectivity. The effectiveness of removing only pups raises the interesting possibility of reducing predation by sterilizing territorial adults (Knowlton 1989).

Knowlton et al. (1985) used radio telemetry techniques for a preliminary study of the efficiency of aerial hunting in finding coyotes known to be present in an area. Connolly and O'Gara (1988) obtained data to verify that local coyotes responsible for sheep predation are taken by aerial hunting. A study still in progress (G. Gantz, pers. commun., summarized by Phillips and Fall 1990) is examining movement patterns of coyotes on mountain grazing allotments to determine whether the local coyotes associated with spring and summer predation on livestock remain exposed to winter aerial hunting operations in the same area.

Data from studies of the tension loads exerted by coyotes, lambs, calves, and deer are now being used as a basis to develop snare mechanisms that capture and hold coyotes selectively (R. Phillips, pers. commun.).

CHEMICAL REGISTRATION RESEARCH

Because of the small quantities of chemicals that even intensive application in predation control techniques would require, private industry has had little incentive to develop new materials for this use or to maintain older ones as additional registration data are required. DWRC has worked for a number of years on the development and registration of pesticides for minor use in vertebrate damage control. In developing or updating EPA registrations, considerable numbers of separate studies are necessary to provide data for characterization of chemicals, toxicological assessment, and determination of ecological and human health effects. Many of these studies, even though they involve intensive, long-term efforts, do not lend themselves to scientific publication. As a consequence, research progress relating to registered materials is harder to follow in the technical literature. Since the cancellation of predacides in 1972, DWRC scientists and cooperators in the ADC program have completed the following federal registrations or modifications related to predation control techniques:

- M-44 sodium cyanide ejector, 1975
- Carbon monoxide fumigant cartridge, 1981
- Modified gas cartridge fusing, 1983
- 1080 Livestock Protection Collar (LPC), 1985
- Modified sodium cyanide formulation, 1989
- Modified 1080 LPC formulation, 1989
- 1080 Technical (90%) for production of LPC, 1989

Recent amendments to the Federal Insecticide, Fungicide, and

Rodenticide Act and regulatory changes by EPA will require a major effort over the next several years to acquire the data needed to maintain these registrations.

DISCUSSION

The coyote has been, throughout recorded history in North America, extremely successful in exploiting man's livestock production systems. Despite intensive historical control efforts by a variety of methods on the limited areas where livestock are produced, and despite sport hunting and trapping for fur, the coyote has continued to thrive and to expand its continental range to areas where it was never before considered a threat to livestock production. Coyotes and other large carnivores that prey upon livestock are increasingly viewed as desirable wildlife species to be fostered and appreciated-from a distance. This changing view of the coyote need not diminish the nation's capacity for livestock production, but continuing cooperation among producers and animal damage control specialists, creative efforts by researchers, and, perhaps, greater sensitivity to the differing viewpoints about wild predators are needed. Predation control by the livestock industry with assistance from the Federal-Cooperative ADC Program has established an excellent framework for integration of effective management techniques. With continued public support, the prospects are excellent that coyote predation on livestock can be reduced to acceptable levels without detrimental effects on desirable wildlife populations.

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