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TOXIC COLLAR FOR CONTROL OF SHEEP-KILLING COYOTES: A PROGRESS REPORT

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ABSTRACT: The toxic sheep collar is the most selective method known for killing coyotes that prey on domestic sheep. The concept dates back to the early 1900's, and has been studied at the Denver Wildlife Research Center (DWRC) since 1974. Field tests with sodium cyanide (NaCN) in 1975 were unsuccessful due to repellent properties of the toxicant and to the apparent reluctance of coyotes to attack tethered lambs wearing bulky collars. Coyotes attacked one or more tethered, collared lambs in 7 of the 19 test pastures. In all, 14 collared lambs were attacked. Eight of the collars were punctured but no dead coyotes were recovered.

A smaller collar containing diphacinone was field tested in 1976. The diphacinone-filled collars were readily accepted by coyotes and lethal to them, but the slow action (5-16 days between dosing and death) of diphacinone made it difficult to assess the effectiveness of these collars under field conditions. Target flocks containing 1 to 12 collared lambs plus uncollared ewes were placed in 15 fenced pastures from which the larger ranch flocks had been removed after repeated coyote predation. One or more collared lambs were attacked in 11 of the 15 tests. An unknown number of coyotes was killed, and in most tests the subsequent incidence of predation was lower than that before the test. Captive coyotes continued to kill sheep for 4 or 5 days after they received a lethal dose of diphacinone; therefore a faster-acting toxicant is needed.

This research has shown that problem coyotes can be killed with toxic collars, but further studies are needed to determine the feasibility of this approach compared with traditional means of control. In most tests to date the frequency of coyote predation has been too low and too irregular to permit effective use of the collar; target flocks were in the field for an average of 10 days before being attacked. The known disadvantages of the method include the need to sacrifice live lambs, the human hazards associated with the use of toxicants under field conditions, and the costs of managing target flocks and other sheep in the problem areas.

For many years the Animal Damage Control (ADC) Program of the U.S. Fish and Wildlife Service has attempted to limit predator control as closely as possible to the individual predator or local predator population that is causing or about to cause damage. In keeping with that objective, the ADC Program, through its research arm at the Denver Wildlife Research Center (DWRC), has worked to improve the safety and selectivity of methods for reducing coyote depredations on livestock. Of all the methods available, the toxic sheep collar is the most selective one for killing coyotes that prey upon domestic sheep. Since coyotes typically kill sheep by biting them on or under the neck (Figure 1; Connolly et al., 1976; Nass, 1977; Henne, 1977), the coyotes that attack collared sheep usually rupture the collar with their teeth and thus receive a lethal, oral dose of the toxicant.

The toxic collar concept dates back at least to Duncombe (1920) who patented a wire-ring device consisting of two toxicant-filled syringes attached to either side of a sheep's neck. The DWRC has worked with the toxic collar concept since 1974. Earlier, a collar containing 1080 solution had been developed in Texas by Roy McBride, a former employee of the ADC Program and the DWRC. Before the 1972 Presidential ban on the use of toxicants in predator control, McBride used the collars to stop depredations on sheep ranges where problem coyotes had eluded all other means of control. His procedure was to put collars on 15 to 20 lambs and place them with their ewes on the bedground where kills had been taking place. The remaining sheep were corralled or herded away from the trouble zone until one or more collared lambs were killed. On 13 of 14 ranches where these tactics were used, dead lambs with ruptured collars were found and the predation losses immediately stopped (R. McBride, personal communication). On the basis of these results, McBride (1974) patented the leather-sheathed collar containing a rubber bladder to be filled with either a toxicant or aversive solution.

In February 1972, all uses of toxicants for predator control by Federal agents or on Federal lands were prohibited by Executive Order No. 11643. This prohibition applied to research as well, but when it appeared that the Order might be modified to permit the use of NaCN in the M-44 device, or sodium cyanide spring loaded ejector mechanism (Matheny, 1976), the DWRC began work on a toxic collar to use this toxicant. The collar research program of the DWRC proceeded through seven phases, as follows:

(1) Development of a sheep collar that killed captive coyotes with NaCN.

(2) Field tests of the NaCN collar.

(3) Pen tests to develop alternate toxicants and to improve the collar configuration.

(4) Field tests of the diphacinone collar.

(5) More pen tests to develop alternate toxicants, including 1080, and to further improve the collar device itself.

(6) Negotiations with the Environmental Protection Agency (EPA) for an experimental use permit for 1080 in the toxic collar.

(7) Field tests of the 1080 collar.

Phase (1), the development of the NaCN collar, has been reported elsewhere (Savarie and Sterner, 1977), and the field tests with 1080 (phase 7) are now in progress under EPA Experimental Use permit No. 6704-EUP-14 issued in September 1977. Therefore this report is limited to the field tests with NaCN and diphacinone, together with the related chemical screening and collar modifications that led to the issuance of the current experimental use permit.

FIELD TESTS OF THE SODIUM CYANIDE TOXIC COLLAR

By early 1975, a polyvinylchloride (PVC) toxic collar had been developed at the DWRC. It consisted of 10 packets, each containing 50 ml of 33% NaCN in water, that were assembled and attached to the lamb with nylon cord (Figure 2). Of 12 captive coyotes that attacked sheep equipped with this collar or previous models, 9 were killed. Four of these coyotes attacked tethered, collared lambs, and all 4 were killed (Savarie and Sterner, 1977).

Figure 1. Coyotes usually kill sheep by biting them on the underside of the throat. This characteristic attack pattern led to the idea of a sheep neck collar filled with toxicant, so that any coyote biting through the collar would be poisoned. University of California photo by G.E. Connolly.

Figure 2. A sodium cyanide toxic collar at a test site in North Dakota in 1975. This collar contained 500 ml of 33% NaCN solution. The lamb is tethered by its right hind foot. USFWS photo by G.E. Connolly.

Field tests of the NaCN collar were conducted in North Dakota (13 ranches), Montana (3 sites on 1 ranch), and Texas (3 ranches) from August through October 1975. Most of the work was done in North Dakota because, through previous experience, a key man on the project (R.E. Severson) had intimate knowledge of the coyote problem areas in that state. The intent of each test was to document this sequence of events:

(1) Occurrence of frequent and regular coyote predation on sheep;

(2) Removal of one or more coyotes with the toxic collar;

(3) Reduced incidence of predation after removal of the problem coyotes.

Because it would have been neither feasible nor safe to put a NaCn collar on every sheep in a large flock, collars were placed only on a few tethered lambs (Figure 2) in each test. Previous trials without collars had shown that coyotes could be induced to attack lambs that were tethered along the routes habitually traveled by sheep-killing coyotes. In each pasture where the NaCN collars were tested, we attempted to place the collared lambs where they would be encountered by approaching coyotes. The number of collars in each test varied from one to five.

Under these test conditions, the NaCN collar was ineffective. Coyotes attacked collared lambs at only 7 of the 19 test sites. In 574 exposure nights (1 exposure night = 1 collared lamb tethered in the field for 1 night) only 14 collared sheep were attacked. Eight of the 14 collars were punctured. Because NaCN takes effect within minutes, we expected to find the carcasses of attacking coyotes within a few hundred yards of the punctured collars. However, no dead coyotes were recovered. Most of the attacks on collared sheep were followed by additional kills of uncollared sheep in the test areas; therefore we believe that the problem coyotes were neither killed nor repelled from the test areas. The failure of the NaCN collar was attributed to 3 causes: (1) reluctance of coyotes to attack tethered lambs; (2) frequent avoidance of collars by attacking coyotes, presumably because of repellent properties of the collar or toxicant, or both; and (3) repellent properties of the toxicant, which caused coyotes to break off the attack before they received a lethal dose.

The apparent failure of the NaCN collar under field conditions was unexpected, in view of its effectiveness against captive coyotes (Savarie and Sterner, 1977). We are unable to offer an explanation for this difference between captive and wild coyotes, other than to speculate that the captive animals were exposed and possibly accustomed to a variety of unnatural artifacts, so that they may have been less wary of the collar and toxicant than were wild coyotes. In any event, it appeared that a smaller, less conspicuous collar and a non-repellent toxicant were needed. And because the rate of attack on tethered, collared lambs was low (1 attack per 41 exposure nights), we felt that the tethered lamb concept should be abandoned in favor of other means of inducing coyote predation on the collared lambs. All three of these avenues for improvement were explored.

THE SEARCH FOR ALTERNATE TOXICANTS

After the unsuccessful field tests with NaCN, a systematic search was made for other toxicants (including alternative formulations of NaCN) that might be more effective. Computer searches, literature reviews, and personal contacts with chemical companies and universities were used to seek chemicals that met the following criteria:

(1) No taste or odor, or non-repellent taste or odor.

(2) Single, low oral dose that would kill the coyote within 24 hours.

(3) Commercially available and economical.

(4) Low residue after death of the coyote, so as to minimize secondary toxicity problems.

(5) Antidote or practical treatment available.

(6) Potential for EPA registration for use in predator control.

Chemicals with established pesticide uses were given high priority because the published data on these compounds could be used in support of registration. Not all of the toxicants that have been considered for possible use in the toxic collar are listed here. The search for effective toxicants is still in progress and will be reported elsewhere. In 1976, this search resulted in the identification of 4 compounds that appeared to merit at least preliminary trials in the collar. These compounds--diphacinone, mandelonitrile, 4-aminopyridine, and phosphamidon--were tested against captive coyotes in 1976, and 1080 was tested in early 1977.

In addition to the search for alternate toxicants, a concerted effort was made to reformulate NaCN so as to reduce its repellent properties. Because we believed that NaCN in water had an offensive taste due to its high pH (+12), we attempted to reduce the pH with phosphate and boric acid buffers. NaCN also was formulated in five thixotropic suspensions, in glycerine, and in microencapsulated form in the hope that these treatments would mask its undesirable taste and odor. All of these efforts were unsuccessful.

Pen tests with a variety of toxicants and formulations were conducted with both pen-reared and wild, captive coyotes in 1-hectare (2.5-acre) pens at Logan, Utah (Table 1). Before exposure to a collared sheep, each coyote was fed lamb meat and penned with sheep until it would readily attack and kill lambs of at least 60 pounds (27 kg) live weight. The candidate toxicants were tested in toxic collars on sheep that were exposed to the coyotes. Twenty-six coyotes were killed in 60 tests; one or more coyotes was killed with most formulations.

Of all the chemical mixtures that were tested in toxic collars at Logan, only diphacinone and 1080 appeared to be effective enough to warrant field use. A 5% concentration of diphacinone killed all the coyotes exposed to it. At lower concentrations about half of the coyotes were killed. Compound 1080 killed all 6 coyotes that punctured PVC collars containing 5 mg/ml or more, and was partly effective at lower concentrations. Neither diphacinone nor 1080 appeared to have the repellent or aversive properties that were seen with every other toxicant, including all formulations of NaCN.

The coyotes that punctured collars containing NaCN, mandelonitrile, 4-aminopyridine, or phosphamidon characteristically released their grip on the lamb as soon as they detected the toxicant. Immediately they shook their heads and rubbed their muzzles on the ground in what we interpreted as efforts to clear the undesirable taste from their mouths. Mandelonitrile and phosphamidon exhibited the additional disadvantage of chemical incompatibility with the PVC collars.

These results reinforced our conviction that a non-repellent toxicant was essential to a successful toxic collar. The only alternative would have been a pressurized device to expell the toxicant rapidly upon puncture; this concept was rejected on grounds of excessive hazard to humans.

Throughout these evaluations of alternate toxicants, 1080 appeared to be the chemical of choice except for two problems: it has no effective antidote and it may be unregisterable because of its controversial history of use in predator control. Nevertheless we believe that 1080 can be used safely in the toxic collar. Limited field tests with this compound are planned in 1978.

Table 1. Effectiveness of selected toxicants in toxic sheep collars against captive coyotes at Logan, Utah, in 1976 and 1977.

Formulation	Collar configuration[1]	Numbers of tests/ collars punctured/ coyotes killed	Time to death
NaCN-glycerol[2]	I	3/ 3/ 0	--
NaCN Thixotropic gel[3]	I	6/ 5/ 3	3 min
Microencapsulated NaCN[4]	III	2/ 2/ 1	3 min
Mandelonitrile[5]	I	3/ 2/ 1	1 1/2 min
4-aminopyridine[6]	II	5/ 5/ 1	40 min
Phosphamidon[7]	II	9/ 5/ 3	1 hr
Diphacinone 5%[8]	I	6/ 4/ 4[9]	6-8 days
Diphacinone 2 1/2%	I	8/ 5/ 3[9]	4-13 days
Diphacinone 1 1/4%	I	2/ 2/ 1	5 days
1080, 11.1 mg/ml[10]	III	2/ 2/ 2	1/2-2 hr
1080, 5.6 mg/ml	III	4/ 4/ 4	1 1/2-20 hr
1080, 4.4 mg/ml	III	2/ 1/ 0[11]	--
1080, 3.3 mg/ml	III	2/ 1/ 1	not recorded
1080, 1.7 mg/ml	III	4/ 3/ 0	--
1080, 3.3 mg/ml	IV	2/ 2/ 2	18-20 hr
Totals		60/46/26	

[1]Collar configurations:
- I: Four PVC packets, each containing 40 ml of the formulations, arranged as shown in Figure 3.
- II: Two PVC packets, similar to configuration I but with one packet on each side of the neck of the sheep.
- III: One-piece PVC collar with two reservoirs containing 20-25 ml each, mounted underneath the neck of the sheep (Fig. 4).
- IV: One-piece collar similar to configuration III, but made of rubber rather than PVC.

[2]30.6% NaCN, 43.5% H_2O, 23.1% Glycerol, and 2.8% KOH.

[3]33% NaCN, 66% light mineral oil, and 0.1% Atlas G-1702 surfactant.

[4]25% NaCN in vinyl resin capsules with 48% cod liver oil and 2% Silanox 101; Southwest Res. Institute formulation #6-957.

[5]$C_6H_5CH(OH)CN$, technical grade.

[6]Avitrol, 100 mg/ml in cod liver oil.

[7]Commercial spray, 958 mg/ml. Low rate of punctures was due to chemical reaction which made the PVC bladders flaccid.

[8]Vampiricida suspension made by Motomco, Clark, NJ. This was diluted with water to obtain the 2 1/2% and 1 1/4% concentration s,

[9]Several coyotes that killed the lambs missed the collars, apparently because of deep snow that altered the attack pattern. In addition to the attacking coyotes that were killed, 3 other coyotes also died after feeding on the carcasses of the collared sheep.

[10]Compound 1080, technical grade, made by Tull Chemical Co., Oxford, AL. This material is warranted to contain at least 90% sodium monofluoroacetate. Thus the collars with 11.1 mg/ml of 1080 contained 10 mg/ml of sodium monofluoroacetate.

[11]The second collar ruptured along a seam when the coyote bit it, so that the poison was not expelled into the coyote's mouth.

IMPROVEMENTS IN THE CONSTRUCTION AND CONFIGURATION OF THE TOXIC COLLAR

As noted earlier, the field tests of the NaCN collar indicated an apparent reluctance by coyotes to attack and bite it. Therefore we reduced its size and bulk, and also improved the mode of attachment and camouflage. These aspects of the collar development program were pursued both by project personnel and by Roy McBride under contract with the DWRC, and all improvements were tested against captive coyotes at Logan, Utah. In most of these tests the collars contained water, cod liver oil, or other non-toxic materials so as to reduce the number of coyotes sacrificed in the testing program.

Beginning with the 10-packet collar (Figure 2) used in the NaCN tests, the following modifications were tested: (1) reduced number of packets; (2) reduced size of individual packets; (3) variations in thickness of PVC from which packets were made (original material was 0.020 inches thick); (4) use of other plastics and rubber, rather than PVC; (5) redesigned fill value to protrude internally rather than externally; and (6) use of velcro rather than nylon cord to attach collars to sheep.

The packets used in the NaCN collars were made of white PVC. Numerous types of camouflage were tested, including wool glued on with rubber cement, fiberglass flocking, burlap fabric covering, and pieces of women's pantyhose. No camouflage was satisfactory. A completely different, and apparently successful, approach to this problem was suggested by R.J. Burns (personal communication), a cooperating biologist with another project at Logan. He had observed that coyotes were attracted to black-colored areas on other coyotes, so he proposed that the collars should be black. We have been using black, uncamouflaged collars since August 1976 and find that coyotes bite them readily.

The NaCN collars were assembled and attached to the lambs with nylon cord. This worked well in pen tests where the collars were in place for only a few hours, but in field trials the cord cut into the skin of the lambs and caused open wounds. We solved the abrasion problem by using 0.75-inch wide velcro straps in place of the nylon cord. In addition, the velcro holds the collars more securely and permits more rapid attachment and removal of the collars.

By March 1976, these efforts to improve the configuration of the toxic collar had resulted in a 4-packet collar (Figure 3) that contained only 40 percent as much toxicant as did the earlier model (Figure 2). The 4-packet collar was used in field tests during spring 1976. Experience soon revealed that whenever a collar of this type was broken by a coyote, one or both of the uppermost packets were broken. Therefore the bottom packet on each side was deleted, reducing the total number of packets to two. During field tests in 1976, sixteen lambs with 4-packet collars and 33 lambs with 2-packet collars were attacked by coyotes; 11 (69%) of the 4-packet collars and 24 (73%) of the 2-packet models were punctured.

While field tests with these 4-packet and 2-packet collars were in progress, laboratory work to improve the collar configuration continued. A single, under-the-neck unit (Figure 4) is now believed to be superior to the under-ear models, although it has not yet been tested extensively in the field. This model contains two toxicant reservoirs of 20-25 ml each and can be made of either 20-mil (0.020 inches thick) PVC or rubber. On current rubber models the side exposed to coyotes is approximately 0.030-0.050 inches thick. The rubber units are more expensive than PVC, in prototype at least, but may be more acceptable to coyotes and more effective in delivering toxicants. Both rubber and PVC are chemically incompatible with many toxic formulations, although they appear to be equally suitable for use with 1080 in water.

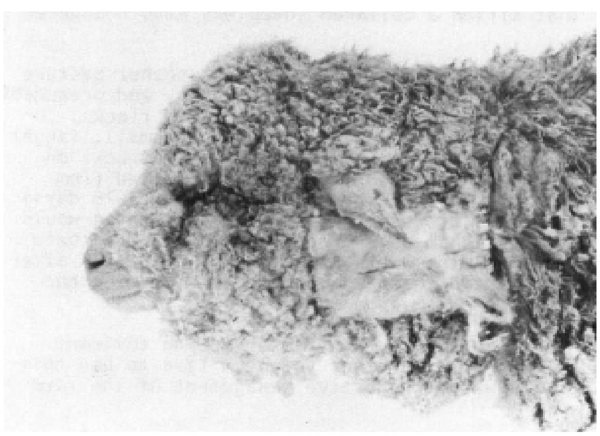

Figure 3. The 4-packet toxic collar tested with diphacinone in 1976. Only 2 of the 4 packets are visible in this photograph. USFWS photo by G.E. Connolly.

Figure 4. The current model of the toxic collar is made of black PVC or rubber. It contains 40 to 50 ml of toxicant. USFWS photo by G.E. Connolly.

In conjunction with our efforts to improve the toxic collar device, warning labels were also improved. We tested many kinds of gummed labels, along with various inks and rubber stamps, and found labels that adhere well to both the PVC and rubber collars. Each collar in the field bears one or more pre-printed warning labels with skull and crossbones, the identity of the toxicant, and the address and telephone number of the DWRC. Warning signs are also posted at each logical point of entry to our test areas.

FIELD TESTS OF THE DIPHACINONE COLLAR

In early 1976, diphacinone and 1080 were the only available toxicants that appeared to be feasible for use in the toxic collar. At that time, 1080 was not a viable option but diphacinone was. In particular, diphacinone was non-repellent, highly toxic to coyotes (oral LD_{50} = about 0.6 mg/kg), had a readily available and effective antidote (vitamin K_1), and was safe for use under field conditions. Consequently, we used it in the toxic collar from March through October 1976. All of the tests took place in western Montana, with the Eight Mile ranch of L.W. Cook, near Florence, as the main test site. The history of coyote predation on this ranch has been well documented (Henne, 1977; Brawley, 1977).

The diphacinone formulation used in these tests was an aqueous suspension (50 mg/ml) manufactured by Motomco, Inc., Clark, NJ, for vampire bat control in Latin America. This material was loaded into the collar packets with a hypodermic syringe. As in the NaCN collar tests, each cooperating rancher agreed to withhold other means of predator control during the test, and was reimbursed at market value for predator kills verified by us. Since the tethered lamb procedure had been ineffective with the NaCN collars, the diphacinone collars were placed on free-ranging lambs. Again it was not feasible to collar every lamb, so special tactics were needed to induce coyote attacks on the collared ones. The approaches used in these tests were:

(1) Small groups (up to 10) of collared lambs were placed in pastures 2 to 3 weeks before the arrival of the main flocks, with the object of killing the problem coyotes before larger flocks of uncollared sheep were exposed to predation.

(2) When coyotes were traveling through a vacant pasture to kill sheep in an adjacent pasture, we put collared sheep in the vacant pasture to intercept or attract the coyote en route to the main band.

(3) Flocks in which kills were occurring regularly were moved to a different pasture, and a small flock of collared sheep was left behind.

(4) The main flocks were corralled at night, while collared sheep were left out in the pastures.

Two series of field tests were made with diphacinone collars. The first tests, during March-June 1976, were limited to the Eight Mile ranch where chronic and serious coyote depredations were being documented by Brawley (1977) of the Montana Cooperative Wildlife Research Unit under contract to the DWRC. When these tests began in mid-March the ranch sheep were in the lambing barns, so that only collared lambs were available to coyotes. Fifteen lambs were killed between March 23 and April 16, and 10 of the 15 collars were broken. An unknown number of coyotes was killed. Because of the delayed action of diphacinone we did not expect to recover the dead coyotes; however, K. Brawley found the fresh carcass of one poisoned coyote. A domestic dog that killed a collared sheep was also recovered after it died at the office of a local veterinarian.

One of the ranch flocks went to the field on April 24 and a second flock entered another pasture on May 4. In spite of our previous success in inducing coyote attacks on collared sheep, and presumably in killing some of the attacking coyotes, heavy predation ensued in the large, uncollared flocks. Of 106 coyote kills documented in May, only 4 were collared lambs. The coyotes ignored the small, target flocks but killed lambs almost every night in the larger herds. It appeared that coyote attacks on the collared lambs could be assured only if the main flocks were removed or somehow protected from coyotes. At the same time the effectiveness of the collar was obscured by the time delay (5-16 days) between dosing and death of the attacking coyotes. Pen studies at Logan had shown that coyotes would continue to kill sheep for 4 or 5 days after they received a lethal dose of diphacinone from a toxic collar. On the Eight Mile ranch, therefore, we could not determine whether continuing predation after an attack on a collared lamb was attributable to poisoned coyotes that had not yet died, or whether different coyotes were involved.

The best course of action at this point would have been to switch to a faster-acting toxicant. However, the only known alternative to diphacinone was 1080 and we were not yet permitted to use this compound. Therefore the tests were moved to smaller ranches where protective management of the farm flocks was easier.

In the second series of field tests with diphacinone collars (Table 2), 15 trials were made in 14 pastures ranging from 5 to 300 acres (2-121 hectares) in size. The test sites were selected on the basis of damage complaints received by Jerry Lewis, District Field Assistant in the ADC Program. In every case but one (Ranch #6) the farm flock was moved or protected while the collared sheep were in place. On Ranch #6, circumstances dictated that the collared sheep should be tethered at strategic points, and tethering was successful in this instance.

To facilitate analysis of test results (Table 2), we show the dates of collar placement and coyote attacks on collared and uncollared sheep in reference to Day 0, when collars were first placed in the field. The figures for Ranch #1, for example, indicate that a ranch sheep (uncollared) was killed 2 days before the start of the test. Collars were in the field for 5 nights and one collar was broken by an attacking coyote on the 5th night. On the 6th day of the test (Day 5), the collars were removed and the ranch flock returned to the pasture. A ranch sheep was killed on Day 14, so the collars were put out again on Day 24. The test was stopped on Day 36 and there were no further coyote kills through

Table 2. Summary of field tests in Montana, June-October 1976, of toxic collars containing 5% diphacinone.

Ranch	Kills before test in ranch flock	Collars in field	Collars broken by coyotes	Kills during and ater test in ranch flock
	(Days)[1]	(Days)[1]	(Days)[1]	(Days)[1]
Group 1: Collars broken, kills stopped				
# 1	-2	0-4	4	14
		24-35	--	None through day 129
# 2	-1 (2 kills)	0-41	22[2]	None through day 75
# 3	None[3]	0-11, 16-26	0,4.5[4]	None through day 64
# 4	-2	0-18	6,8,10[4]	None through day 56
# 5	-1	0-19	16	None through day 64
# 6	-17	0-7[5]	7	None through day 51
# 7	-1	0-19, 27-44	17,19,30[6]	None through day 57
# 8	Daily[7]	0-20	1	3,6,12,13,20,21
Group 2: Collars broken but coyotes taken by other means as well[8]				
# 9	None[3]	0-28	15	None through day 42
#10	NR[9]	0,6-21	0[10]	Several between days 0-10; none during days 10-37[11]
Group 3: No collars broken				
#10	-1	0-11	--[12]	None through day 34[13]
#11	-2 (3 kills)	0-9	--[14]	None through day 72
#12	-12	0-11, 16-26	--	Two on about day 50
#13	-10	0-8	--[15]	Two on day 25
#14	NR	0-11	--	1,5

[1]Counting from Day 0, when toxic collars were placed on the ranch. Day -2 is two days before collars were placed.

[2]Three collars were broken.

[3]Ranch flock was corralled each night because of earlier predation.

[4]Four collars were broken.

[5]Collared lambs were tethered.

[6]Eight collars were broken. One broken collar was missing, as was an unbroken collar from another collared sheep killed. Two decaying coyote carcasses were found on a neighboring ranch on day 57.

[7]Twenty-one lambs were killed in the 20 days just before the test.

[8]Several coyotes were shot or taken with M-44's during these tests. Therefore the subsequent pattern of predation cannot be interpreted solely in terms of the toxic collar,

[9]Not recorded.

[10]The entire target flock (6 large lambs) was chased out of the pasture by attacking coyotes. Four were killed and 3 collars were recovered (2 had been broken). The other 2 sheep were never found.

[11]Rancher attributed the lack of kills during days 10-37 to removal of over 100 coyotes from the area by ADC personnel. He also sold his lambs and corralled his ewes each night.

[12]Two collared lambs were attacked but neither collar was broken.

[13]Sheep were not returned to the high risk pasture.

[14]Four coyotes taken by helicopter on day 8.

[15]Four coyotes shot by rancher during test.

at least Day 129. In this case the coyote that broke the collar on Day 4 could have been poisoned and yet made the kill on Day 14 before succumbing to the toxicant. Unfortunately, this interpretation of the observed results must remain speculative.

In Table 2, the tests are arranged in three groups, depending on their outcome. Group I consists of those ranches where losses of sheep to coyotes stopped or were reduced after coyotes broke toxic collars. In these 8 cases the problem coyotes may have been killed by the toxicant in the collars. Group II includes two ranches where toxic collars also were broken by attacking coyotes, but these tests were confounded by other forms of predator control while toxic collars were in the field. In the remaining 5 tests (Group III) no toxic collars were punctured and therefore the use of the collar could not have influenced the subsequent pattern of predation.

The results of these tests illustrate the difficulty of determining with certainty whether coyote predation was stopped through use of the toxic collar. Even though some problem coyotes may have been killed in 10 of the 15 tests and predation subsequently was lower than it had been before the tests, in no case can we be certain that the coyotes were killed. The evaluation problem is particularly difficult with diphacinone because of its slow action. But even with a faster-acting toxicant such as 1080, many unknown and uncontrollable variables will continue to influence the tests. If coyote predation continued after one or more collars had been punctured by a coyote, one could conclude that the collar failed to stop losses in that case. But if the losses stopped it usually would not be possible to attribute this result positively to the collar. The coyotes might have been shot by a neighbor or frightened away by unusual human activities associated with the test. During the field work with NaCN, for example, we found that predation dropped substantially during the field tests even though no coyotes were killed. The most likely explanation is that the coyotes were sensitive to increased human presence and changed their habits to avoid the test areas.

These evaluation problems are by no means peculiar to the toxic collar; they apply in some measure to every predator control technique, whether operational or experimental, lethal or non-lethal. Because of the intractable variables and expense involved, these problems are all but impossible to resolve by experimental design. Our approach to this problem, as far as the toxic collar is concerned, is simply to conduct as many tests as possible on sites with the greatest possible rate of predation, while withholding other forms of predator control to the best of our ability. But we must accept the fact that the tests will be influenced by many factors beyond our control.

SAFETY CONSIDERATIONS

As with any toxic device, the use of the toxic collar entails certain hazards, not only to the human user but to other persons who may contact the collars through chance or ignorance. We are attempting to minimize these risks through careful control of the collars and collared sheep, warning labels on the collars, warning signs around the test areas, and notification of hospitals near test areas. In addition to the human hazards, there is the possibility of secondary poisoning of non-target wildlife species that scavenge upon the carcasses of the collared lambs or poisoned coyotes. In our judgment these risks are minimal with the current toxic collars as used with 1080. The model to be field-tested in 1978 (Figure 4) contains approximately 3 to 8 human LD_{50}s of 1080, compared with 650 to 1300 LD_{50}s of NaCN in the collar that was used in 1975 (Figure 2). Still it must be acknowledged that toxic collars can be lost in the field. Eight toxic collars or parts of collars were lost during the field tests with diphacinone. Such losses are unavoidable; they usually occurred when the collared lambs were killed and eaten, scattered, or carried off by coyotes. One lost collar was later found intact approximately one-half mile away from and 2 1/2 months after the kill.

In addition to the possibility of lost collars, several other collars were ruptured accidentally when the target sheep ran into or through fences. Coyotes also broke the collars on 6 lambs that were attacked but not killed. These "walking wounded" lambs with leaking collars present special risks to anyone who might handle the lambs without being aware of the hazard involved. It is noteworthy that the firms supplying our prototype collars have expressed concern over the product liability aspects of collar manufacture, even though they would not logically be held liable for incidents resulting from our uses of the collar in research.

OUTLOOK AND FUTURE PROSPECTS

The work to date has shown that sheep-killing coyotes can be killed selectively with toxicant-filled, sheep neck collars. The outstanding advantage of this method is its selectivity for coyotes that attack sheep. The collar may be effective against coyotes that have eluded other means of control. The known disadvantages include the need to sacrifice lambs to the offending coyotes, hazards associated with the use of toxicants under field conditions, and the expense of collaring and managing the target lambs as well as removing or otherwise protecting uncollared sheep in the problem area.

We believe that the toxic collar will be most useful where depredations are frequent and regular. Where predation is infrequent and unpredictable, as is often the case, one would have to keep collared sheep in position for several days or even weeks before coyotes attacked them. A major obstacle in our field work, in fact, has been the difficulty of finding test sites where the incidence of predation was sufficiently high to make a test feasible. In the latest diphacinone tests (Table 2), the lapsed time from placement of collared lambs to puncture of the first collar ranged from one to 23 days with an average of 10 days. From an operational standpoint, however, the collar will be most useful where an attack can be obtained in one or two days. It remains to be seen how many actual damage cases will meet this criterion.

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