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ABSTRACT: The use of LiCl-treated baits and carcasses has been advocated as a means of controlling coyote predation on sheep through a process known as "aversive conditioning or taste aversion." While some investigators have made well publicized claims of damage reduction through the use of LiCl on sheep ranges, other researchers have experienced difficulty establishing prey aversion in captive coyotes. The conflicting results suggest a need for extensive, carefully controlled research in both pen and field situations before valid conclusions can be reached regarding aversive conditioning as a depredations control method.

Aversive conditioning through the use of LiCl-treated baits has recently been proposed as a method of reducing sheep losses to coyotes. Theoretically, if coyotes eat prey-like baits and/or prey carcasses treated with a physiological illness producing drug (LiCl), negative associations will be formed between the baits and subsequent gastrointestinal disorders. The dislike for the bait will then be transferred to live prey, inhibiting future attacks on that prey. Although the concept of drug-induced bait aversion has received widespread attention (Riley and Baril, 1976; Riley and Clarke, 1977), the use of LiCl baits to suppress predatory behavior in coyotes (Gustavson et al., 1974) represents an extension of that concept. As used in this paper, the terms aversive conditioning, bait aversion, and prey aversion refer to the process of conditioning coyotes to reject or avoid normally desirable food items as a result of negative physiological experiences following consumption of LiCl treated baits and/or prey carcasses. A coyote is truly averted to a prey or food item only if he refuses to attack or eat the item when it is readily available to him.

In order to apply aversive conditioning to the problem of coyote predation on sheep, coyotes must be induced to eat lamb-like baits that make them ill. However, it may be difficult to get all of the coyotes on a range to eat the baits. In most field trials to date, sheep carcasses and/or sheep meat baits containing LiCl placed on the range have been fed on by coyotes. Unfortunately, no study has shown that the baits were eaten by sheep-killing coyotes, and there is reason to suspect that some coyotes will not take carrion baits when live lambs are available. A study of predation on a Montana ranch showed that coyotes rarely returned to feed on old carcasses; instead, new kills were made almost every night (Henne, 1977). Under these circumstances, it is unlikely that the presence of LiCl in carcasses would reduce predation. On the contrary, the use of LiCl in carcasses could reinforce the avoidance of carrion in favor of live prey. In baiting studies on larger areas, investigators were able to mark only 28-34% of the coyotes with 16 baits per square mile (Linhart et al., 1968).

Theoretically, illness subsequent to ingestion of a bait should cause coyotes to become averted to similar baits and transfer that aversion to the live sheep. This suggests that baits should resemble sheep as closely as possible, in odor, taste and texture, so that coyotes will become averted to the baits rather than the chemical they contain, since some researchers have shown chemical rather than bait aversion (Burns, 1977; Griffiths, 1978). The extent to which an aversion will transfer from dead baits to live prey is uncertain since prey-killing may involve behavior not directly related to consumption.

The final requirement for effective use of the conditioned aversion concept is that the aversion must persist for a long time either with or without periodic reinforcement from additional treated baits. Assuming the above problems can be resolved, taste aversion would present an attractive alternative to traditional lethal methods of depredation control.

Interest in aversive conditioning as a means of reducing coyote depredations on sheep was sparked by a report of successful pen tests by Gustavson (1974). Subsequently, Gustavson and his collaborators have claimed generally promising results in field tests conducted in Washington, California, and Saskatchewan (Stream, 1976; Ellins et al., 1977; Gustavson et al., 1974, 1975, 1976, 1977). However, other investigators working in laboratory situations have been less successful. Conover et al. (1977), Lehner and Horn (1977), Burns (1977), and Griffiths (1978) experienced difficulty in establishing an aversion to live prey in captive coyotes. Additionally, some of the methodology and interpretations from field tests of LiCl baits for reducing coyote predation have been questioned (Bekoff, 1975; Sterner and Shumake, 1978). Stream (1976a) originally reported that LiCl baiting was effective at the Honn Ranch, but later revised that conclusion (Stream, 1976b).

As noted above, not all investigators have had favorable results. In this report we examine the research conducted to date and offer some possible reasons for the contradictory results. We have also outlined a series of pen and range studies that we feel are needed before sound recommendations can be made regarding the use of LiCl in controlling coyote depredations.

STUDIES WITH CAPTIVE ANIMALS

Originally, Gustavson et al. (1974) produced illness in coyotes by combined feeding of LiCl-laced sheep baits and intraperitoneal (ip) LiCl solution injections. When lambs were later placed in the coyote pens, the coyotes usually refused to attack them. Some of the coyotes even retched when exposed to lambs. Since injecting coyotes is not feasible in the field, in subsequent studies the captive coyotes were allowed to feed voluntarily on jackrabbit baits or carcasses injected with LiCl. Following consumption of a bait, or a bait and a carcass, coyote attacks on live rabbits were inhibited, but the appetite for alternate prey (chickens) was unaffected (Gustavson et al., 1976).

Other investigators attempting similar work have had problems in producing prey-killing aversions in coyotes. Conover et al. (1977) fed chicken carcasses injected with 4-6 g of LiCl in solution to five coyotes that had previously eaten live and dead chickens. The coyotes became ill at all dose levels, but did not become completely averted to the baits. Rather, they selected the uninjected portions of carcasses to eat and readily killed live chickens following the bait treatment. These workers were able to avert coyotes to dead mice by giving the coyotes ip injections of LiCl after they ate the mice, but the coyote continued to kill and eat live mice.

Lehner and Horn (1977) studied the effectiveness of prey aversions induced by various modes of LiCl administration (bait or carcass ingestion and ip injection) in a 6400-m^2 enclosure. They measured the attack and kill latencies of captive coyotes; gave these "rabbit killers" LiCl in baits or carcasses and/or by injection. Treated animals were watched for changes in their subsequent attack and kill latencies during daily one-hour pairings with a live rabbit. The study indicated that prey aversions following ingestion of LiCl baits and/or injection are not as easily established nor as long lasting as previously suggested by Gustavson et al. (1974, 1976). Even with multiple dosings, the aversions were only temporary. However, a relatively long-lasting aversion following ingestion of a single treated bait was produced by using additional sensory cues (ribbons, bells, and perfume) applied to the bait and the prey (Lehner and Horn, 1977). This suggests that the aversion was to the physical characteristics of the bait rather than its flavor.

An attempt by Burns (1977) to study the transfer of prey-killing aversion from adult coyotes to their offspring, failed because he was unable to establish prey-killing aversion in the adults. Adult coyotes became averted to chicken carcasses injected with 6-7 g of LiCl in water but later killed and ate live chickens. In subsequent tests, the same coyotes ate dead chickens that were treated with tap water but did not eat carcasses treated with table salt (NaCl). These results were interpreted to indicate that salt flavor repellency and not conditioned taste aversion had been formed in the coyotes.

Griffiths (1978) tried to avert four experienced sheep-killers and one naive coyote by presenting them with 6-7 g of LiCl in ground lamb baits on two successive days followed by a LiCl-injected sheep carcass on the third day. By the third day, each coyote appeared to eat carefully, rejecting salty-tasting portions of carcasses. The coyotes subsequently killed live lambs at the first opportunity following their "conditioning."

Reasons for inconsistent results from similar studies are not clear. However, the various studies have differed in details such as bait material and prey, LiCl dosage, route of administration, criteria for aversion, and experimental design. Variations in baits or prey are perhaps the least important variables, since widely varying results have been reported from studies utilizing similar baits and prey (Gustavson et al., 1974; Lehner and Horn, 1977; Griffiths, 1978). Although dose levels have varied from 3 to 15 grams per bait and the actual dosage ingested per coyote was not always known, all dosages were sufficient to cause emesis in test animals. However, emesis is used by coyotes to eliminate poison, or to give food to mates and pups and place food in caches (Burns, personal observation). Emesis in coyotes may not be as unpleasant an experience as it is in humans, and emesis shortly after ingestion of LiCl could reduce the degree of illness.

The method of LiCl administration could be important to creating an aversion. Although Gustavson et al. (1975) stated that the peripheral pain caused by an injection is not important in establishing taste aversion, capture and restraint of the coyote in addition to the injection might be. Pain and fear of electric shock has been found to produce food avoidance in dogs (Krane and Wagner, 1977). Only three to five electric shocks were required to condition captive coyotes to select white over black domestic rabbit (Linhart et al., 1976). Hence, pain-fear alone can produce food avoidance and if pain-fear were coupled with LiCl-induced illness, the reason for subsequent food avoidance would be uncertain.

Another variable between experiments has been the criteria for measuring aversion. It seems likely that a coyote that appears to be averted for 15 minutes may not be averted at the end of an hour. Connolly et al. (1976) found that the average attack latency for pen-raised coyotes on lambs was 47 minutes. Pairings of coyotes and prey lasting less than one hour may not be adequate to demonstrate prey aversion. The strength of the aversion also needs to be measured in terms of its duration. For management purposes, aversion would be useful only if the coyotes avoid the bait or prey for a period of weeks rather than days or hours.

FIELD TESTS WITH LITHIUM CHLORIDE

The Honn Ranch, Washington

LiCl was used on the Honn Ranch in Whitman County, Washington, in 1975 (Gustavson et al., 1975,

1976) and in 1976 (Stream, 1976). In both years the sheep were off the range in January and February when the first LiCl baits were placed. Early in 1975, dog food baits containing LiCl and covered with sheep hide were placed at 12 sites on the 3,000-acre ranch. Sheep were released onto the range in early March, and additional bait stations established as sheep carcasses became available. All carcasses were injected or sprayed with a solution of 82.4 g LiCl per liter of water. By mid-May, approximately 214 lithium baits or carcasses were available to coyotes. In 1976 fewer baits were used and the concentration of LiCl solution used to inject carcasses was lower (32.4 g LiCl/liter). Both Gustavson and Stream reported high bait consumption initially, decreasing late in March and early April as predation on sheep increased. Stream (1976) found that the switch from baits to live sheep coincided with the time that sheep were placed on the range, so one might conclude the coyotes were not averted to live sheep.

Both investigators calculated the reduction in sheep losses attributed to the use of LiCl by comparing the average number of ewes and lambs killed by coyotes (according to Honn's records) during 1972, 1973, and 1974 to the losses in 1975 and 1976. Although the exact figures are in dispute (Honn, 1975) there is no question that fewer sheep were lost to coyotes during the LiCl trial years than in 1972 and 1973.

Because the loss records are crucial to a determination of effectiveness of LiCl baiting on the Honn Ranch, we re-examined Mr. Honn's data (Table 1) as presented by Stream (1976a). In this re-examination, it became clear that a sufficiently selective review of the data could support any desired conclusion. As reported by Gustavson and Stream, the total kill of lambs and ewes was lower in 1975 and 1976 than in the three previous years. However, if these losses are corrected for variations among years in the length of time that the sheep were exposed to predation, the differences shrink considerably. The differences become even less apparent if one looks only at the number of lambs killed per week. The percentage of lambs killed, a standard measure of losses, increased each year from 1970 through 1976 as the herd size declined.

Table 1. Sheep and coyote kill data from the Honn Ranch, Whitman County, Washinton[1].

Year	No. of lambs	Weeks in field	% of lambs killed	Lambs killed	Lambs and ewes killed	No. of lambs killed per week	No. of lambs and ewes killed per week	Coyotes killed (January-May) by trapper
shed lambed								
1970	1025	10	1.95	20	28	2.0	2.8	23
1971	1120	8	1.34	15	20	1.9	2.5	20
1972	1010	9	5.94	60	75	6.7	8.3	9
1973	820	12	7.56	62	76	5.2	6.3	13
range lambed								
1974	540	12	8.52	46	61	3.8	5.1	10
1975	450	11	8.66	39	47	3.5	4.3	16
1976	330	8	8.78	29	38	3.6	4.8	8

[1]Data from Stream (1976a).

The reader may decide which of these results are most pertinent. If one concludes that losses were significantly lower when lithium was used, he must then consider whether the reduction was due to the lithium. One obvious point that was not made by Gustavson or Stream is the apparent, inverse correlation between the numbers of coyotes killed and the rate of coyote predation in different years. Correlation analysis of the data in Table 1 suggests that 59% of the year-to-year variation in the number of lambs and ewes killed per week was associated with variations in the coyote kill by the trapper. In 1975 and 1976, coyotes on the Honn Ranch were subjected to trapping, shooting, and strychnine baits in addition to the lithium baits. A new perimeter fence of "hog wire" was installed in 1976. Because of these confounding influences it is difficult to assess the role of lithium in the predation history of the Honn Ranch.

Antelope Valley, California

During the fall and winter of 1975-76, S.R. Ell ins and his colleagues injected sheep carcasses with an aqueous solution of 40 g/1 of LiCl or 20 g/1 of NaCl at 10 sheep carcass dumps frequented by coyotes in Antelope Valley, California, to test the effectiveness of the conditioned bait aversion method for reducing coyote predation on sheep. The study lasted approximately 18 weeks starting in October 1975. Losses in four sheep herds were monitored (Ellins, 1976) but only two herds which suffered significant predation were described in the published report (Ellins et al., 1977).

The LiCl and NaCl baits were taken as long as they were available. Sheep were killed for seven weeks in one herd and three weeks in another. On the basis of these results, El 1 ins (1976) concluded that (1) coyote predation on sheep was a potential problem prior to the onset of this project; (2) coyotes will take baits even when live prey is readily available; (3) the LiCl treatment significantly reduced the number of sheep killed; (4) suppression of coyote attacks on live sheep continued long after the cessation of LiCl baiting; (5) averted coyotes did not re-acquire a taste for live sheep after safe (NaCl) bait was made available; and (6) prebaiting the grazing areas prior to the arrival of the herds may be effective in reducing the kill rate.

In our opinion, these interpretations exceed the documentation. Although the initial high predation rate did not continue throughout the study, lack of comparable loss data from other years or from untreated areas during the same year, makes it difficult to show that LiCl suppressed predation. Additionally, continued bait consumption on one area after lamb predation ceased suggests that coyotes never were averted to the injected carcasses. If LiCl did not suppress carcass feeding, it is difficult to conclude that it caused lamb killing to stop. The coyotes, however, may have fed selectively on the carcasses, avoiding the LiCl as observed by Burns (1977) and Griffiths (1978) in other studies. It is also possible that transient coyotes consumed carcasses after the resident coyotes become averted, but neither explanation for continued carcass feeding was documented during the study. The effects of concurrent lethal control activities were also unknown, although removal of the killer coyotes could have accounted for the observed cessation in predation. The above reasons suggest that the coyote predation reduction reported in this study cannot be unequivocally attributed to the use of LiCl.

Saskatchewan

Early in 1976, J.R. Jowsey and his colleagues in the Saskatchewan Department of Agriculture added LiCl baiting to their coyote predation control program. They placed sheep meat baits containing LiCl on 22 farms and community sheep pastures and supplied the ranchers with materials and instructions for continued baiting. At the end of the year, each cooperator was contacted by mail and asked to report his total flock size and the number of lambs and mature sheep lost in 1976 to (a) coyotes, (b) other predators, (c) disease, and (d) other causes. At the same time he was also asked to estimate how many sheep he lost to coyotes in 1975, the year before LiCl was used.

Although LiCl baits were placed on 22 sites in 1976, comparative data from 1975 (without LiCl) and 1976 (with LiCl) were available for only 17 of these. Fifteen of the 17 ranches reported lower losses to coyotes in 1976 than in 1975. The other two showed an increase. Overall, the 17 cooperators reported 892 kills in 1975 but only 301 in 1976. This apparent 66% reduction was attributed by Gustavson et al. (1977) to the LiCl used in the second year. Such a conclusion depends on the assumption that predation losses would have been equal in 1975 and 1976 if LiCl had not been used in the latter year. In the absence of experimental controls, however, the validity of this assumption cannot be assessed.

The Saskatchewan work is part of an extension program aimed at minimizing coyote predation on sheep. Ranchers are advised not only to use LiCl but also to confine small lambs, remove carrion, and apply lethal control measures (traps, snares, shooting, or 1080 in fresh kills) as needed (Anonymous, n.d.). Therefore, one may question whether all of the observed results are due to the use of LiCl.

The use of LiCl in Saskatchewan was expanded in 1977 to a total of 42 sites, including 14 of the pastures that were baited in 1976. Sheep losses to coyotes were again low in 1977. Regardless of the questions that may be raised about the data, some of the ranchers who baited faithfully with LiCl in 1976 and in 1977 have had minimal losses even when other control measures were not used. Thus, aversive conditioning may have been effective on these farms. These favorable results suggest to us that more tightly designed field trials are warranted.

DISCUSSION

In our opinion, investigators seeking to field test the effectiveness of any technique aimed at reducing coyote predation on sheep are faced with difficult problems in experimental design. They must not only demonstrate that predation would have occurred in the absence of the treatment, but also, that any observed reduction in predation resulted from the experimental treatment and not from other causes. The rate of coyote predation varies from place to place, as well as over time, and it may be impossible to control all the variations in predation other than those due to the method under test. Our attempts to test control methods in southern Idaho during this past winter have met with failure due to a lack of predation on areas where moderate to high coyote losses were expected from past experience. When the incidence of predation varies unpredictably, large numbers of replications are needed to detect significant differences resulting from the experimental control methods being tested. Moreover, the experiments themselves may add extraneous variability in the form of human disturbance incidental to the setting up and monitoring of tests. An example of this occurred in 1975, when we conducted field trials with the sodium cyanide toxic collar on 13 ranches in North Dakota (Table 2). Generally, the number of coyote kills during the initial 10 days of the tests was greater than during the next 10 days when toxic collars were used. For the 13 ranches, the overall predation rate was 62% lower when the collars were used than it was before.

Superficially these results suggest that the toxic collar effectively reduced coyote predation. Such a conclusion is unwarranted; not a single coyote was killed with the collars in any test. The reduced predation must have resulted from other factors such as wariness of the problem coyotes to the

Table 2. Rates of coyote predation on sheep in North Dakota before and during toxic collar field tests in 1975.

Ranch	Total kills during	
	10 nights before test	First 10 nights of test
#1	2	0
#2	4	1
#3	3	2
#4	1	1
#5[1]	0	0
#6[2]	5	0
#7	4	1
#8	5	4
#9	2	1
#10	3	1
#11	7	1
#12	3	5
#13	5	0
Totals	44	17
Averages	3.4	1.3

[1]Two kills occurred 14 days before test.

[2]Lambs tethered without toxic collars.

presence of tethered lambs or extra human activities, or to other factors beyond our knowledge; for example, some of the problem coyotes could have been shot on neighboring farms.

Although it is obvious in this case that the observed results were due to artifacts rather than to the device being tested, one would be hard pressed to make such a distinction if the test device had been a non-lethal method such as LiCl. The only sure way to demonstrate that an aversive chemical reduces predation losses is to show, with concurrent placebo tests, that the baiting and associated procedures fail to reduce predation when the aversive chemical is not present. The variability in predation patterns from one site to another, and from year to year on any given site, may dictate large numbers of trials with and without the chemical. In our opinion, the field studies conducted to date have not had the depth nor the experimental control necessary to evaluate accurately the efficacy of LiCl as a means of controlling coyote depredations on sheep.

We feel that several aspects of the prey aversion approach need further clarification and have designed studies to investigate these aspects. First, there is a need to develop an effective bait; i.e., one that will result in a lasting aversion to the bait rather than to the chemical within it. Our recent studies indicate that the amount of LiCl currently recommended for the baits used in Saskatchewan (Anonymous, n.d.) is excessive. The strong salty taste of high LiCl concentrations results in an aversion to the salt taste rather than the flavor of the bait itself (Burns, 1977; Griffiths, 1978). Our best aversions have been obtained with LiCl amounts approximately 80% below those used in Saskatchewan. Studies with a dye marker show that LiCl solution does not move evenly from injection sites in the muscle tissue of fresh sheep carcasses. Coyotes soon learn to avoid the "hot" spots when feeding on injected carcasses (Burns, 1977; Conover, 1977; Griffiths, 1978). The bait must bear sufficient clues such as odor, taste, texture and/or appearance that coyotes will associate it with the prey species. Next, tests of lithium-induced prey avoidance should include naive as well as experienced killer coyotes to determine the effect of LiCl bait consumption on attacking, killing and feeding latencies in both types of coyotes. The effect of the aversive agent on these latencies must be determined through comparative tests with control coyotes whose baits do not contain the chemical.

Once an aversion to live prey has been established, the averted coyotes need to be exposed to live prey at intervals to establish extinction time for the aversion. The taste aversion concept should logically be developed to this point with captive animals before field tests are undertaken.

In this paper we have identified some of the problems that we believe must be overcome to transform taste aversion from theory into an effective tool for predation control. We are optimistic enough about the concept to devote major effort toward several of the research needs identified here. Until such research is finished and extended to carefully controlled field trials, no valid judgment can be made about the value of lithium in the control of predation.

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