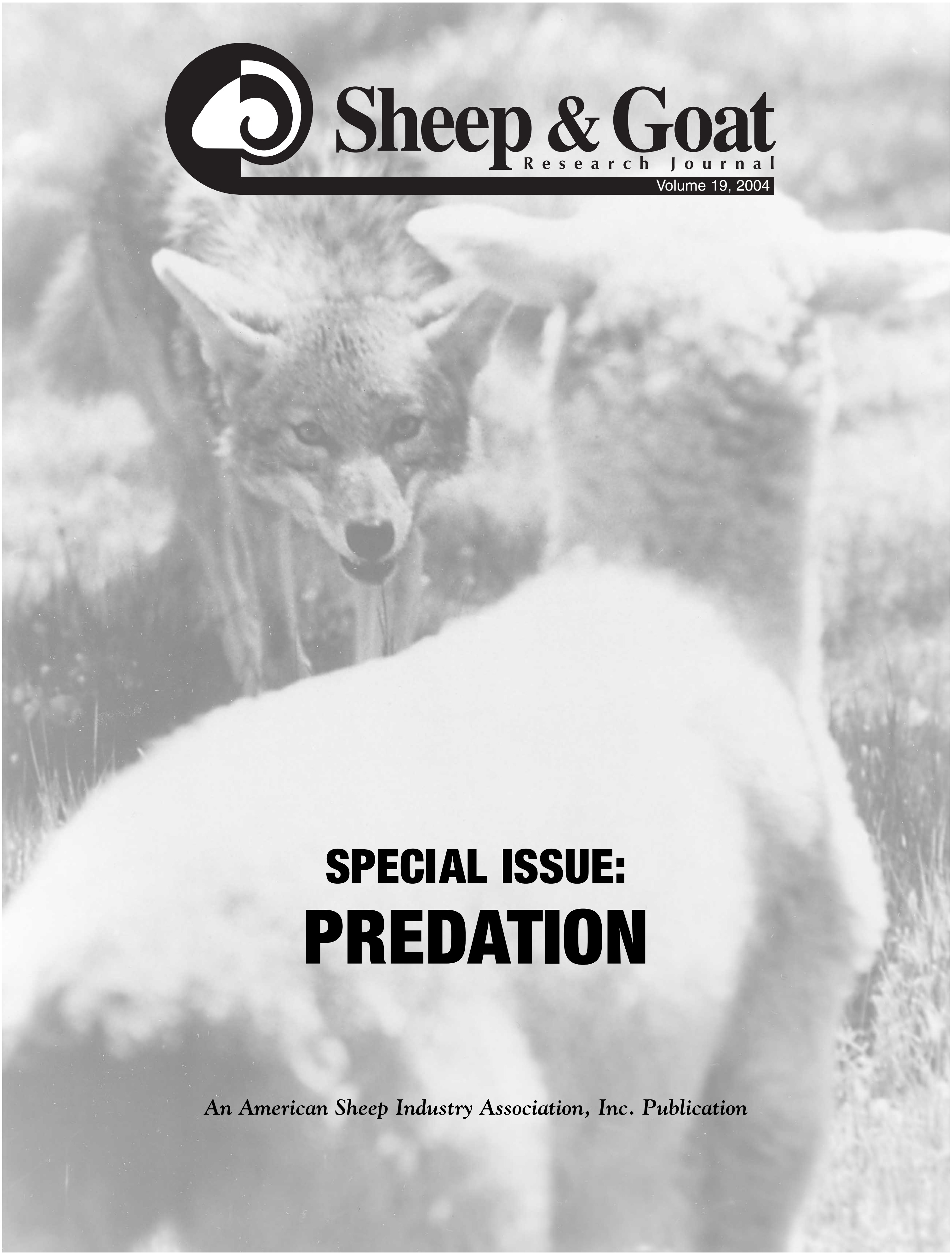

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SPECIAL ISSUE: PREDATION

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SPECIAL ISSUE: PREDATION

Contents:

Predation and Livestock Production Perspective and Overview

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Predation (a mode of life in which food is primarily obtained by killing and consuming other animals) is a purely natural phenomenon, but it is a problem when the predator becomes too abundant or it is unacceptable for humans to share individuals of particular species of prey. Predation has likely been a problem since domestication and continues to be a problem which must be dealt with today. Although much of the focus in this compilation of papers is the livestock industry, predation may also be of concern with respect to wildlife species or household pets. The larger predator species may also constitute a direct threat to man. Some predator species (especially wild or feral swine and coyotes) may also interfere with other agricultural endeavors through destruction of fences, damaging crops, or the threat of spread of disease (Sewart et al., - this issue). Predation management with one goal in mind (i.e., protection of sheep) may also have spin-off benefits for other species as well (Shwiff and Merrell, Allen and Fleming, Shwiff and Bodenchuk, this issue).

To the livestock producer the most serious predator is the one causing trouble at a specific time and place. In the United States, those species which may cause trouble are: bear (grizzly or black), mountain lions, wolf, domestic dog, wild or feral swine, coyote, bobcat, lynx, fox and raptors, such as the golden eagle or black vultures (Avery and Cumings, this issue). Even smaller mammals can at times cause trouble, especially with lambs or kid goats. Some of these species are discussed in the contributing papers to this collection. Overall, the greatest threat to the U.S. livestock industry has been considered to be the coyote due to their wide distribution throughout most of the country (Houben, Nunley, this issue). However, wild and feral swine are rapidly spreading throughout much of the United States and are becoming a serious threat. Also, as grey wolves recolonize the West, they may eventually pose a threat equal or greater than that of the coyote (Breck and Meier this issue), and due to their larger size, wolves are likely to constitute a greater threat to the cattle industry than does the coyote.

Most species of farm or ranch livestock have at times been subject to predation. In the United States, poultry and swine are largely produced in confinement and are thus protected. This is not the case with grazing ruminants, and it is generally recognized that in commercial production of ruminants for meat and fiber production, confinement rearing is not an option. It is reasonably established that in monetary terms, the greatest total loss due to predation is that suffered by the beef cattle industry (Huben, Bruscino and Cleveland; Howery and DeLiberto, this issue) due to their greater value, larger numbers and wider distribution. However, when expressed as a function of the value of the industry, the sheep and goat producers suffer far greater loss (Shelton and Wade, 1979), and it traditionally has been these industries that have born much of the burden of maintaining predation management programs. Predation is one of the chief reasons cited by producers when they leave sheep and goat production (Shelton and Klindt, 1974; Nunley, this issue).

Expressions or evaluations of predator damage usually relate to the numbers or value of livestock killed by predators, but there are serious limitations to the use of this approach alone because it does not consider full costs associated with predators. During the 1970s, a series of studies were conducted to evaluate and document coyote damage to sheep in the absence of management in western states (Huben, Shwiff and Bodenchuk, this issue). With adult sheep, losses range from 1.4 to 8.4 percent and lamb losses range from 6.3 to 29.3 percent. In a similar study conducted with Angora goats in South Texas, Guthrey and Beasom (1978) reported 49% losses of adult does and 64% losses of kid goats due to predators (primarily coyotes). These studies likely represent the most accurate data available, but these reports are specific to the conditions under which the data were collected. The absence of control on study sites likely represents no control on the specific property involved but not necessarily on neighboring properties. The possibility of predator drift from these adjoining areas suggests that the reported loss estimates are likely conservative (Shwiff and Bodenchuk, this issue).

Several contributing authors refer to losses reported by the National Agricultural Statistics Service (NASS) based on producer surveys. These losses were incurred with some type of predation management in place. These data are often reported by states and for years using actual numbers or value of animals killed by predators. They vary by state, region, area, and year but often are on the magnitude of 1% for adult sheep and 3 to 4% for young stock. Similar values are sometimes reported for cattle but are generally lower. Many critics of predator management would suggest that losses of this magnitude could or should be tolerated, but there are additional factors to be considered. First, losses are not uniform, whereas a few producers may absorb the majority of the losses. These producers often go out of business with the result that these losses are transferred to their neighbors, causing them to go out of business creating a "domino effect." This is the case in areas such as the periphery of the Edwards Plateau of Texas. Another qualifying factor is that actual losses often exceed those verified or reported. This fact is implicit in the compensation programs of some states (Bruscino and Cleveland, this issue). Wyoming, for example, pays producers for three sheep in response to each verified kill. Unverified losses may be substantially higher than this. Breck and Meier (this issue) reported an estimated detection rate of 1/8 of the actual losses of calves killed by wolves in a study conducted in Idaho.

An anology can be made that the value of livestock killed by predators represent "the tip of the iceberg" relative to the actual cost of predation. One of the substantial "other costs" is that of control efforts, whether conducted by government (Hawthorne, this issue) or by the individual producer. Producer efforts may include personal attempts to remove predators or altered-management practices to evade losses (night confinement, improved fencing, early weaning, choice of grazing area, etc.). These efforts will almost invariably represent increased costs and/or reduced animal performance (Howery and DeLiberto; Asheim and Mysterud, this issue).

In the final analysis, the greatest loss due to predation is that many farmers or ranchers fail to produce livestock (especially sheep and goats) because their belief that predation losses may be economically unacceptable. This results in the loss of potential income to the producer as well as the community to which they contribute, as well as the loss of rangeland improvement that can result from mixed-species grazing (Merrill, Reardon and Lineweber, 1966).

Lastly, one approach to evaluating the cost (or effect) of predation is through economic modeling. Asheim and Mysterud (this issue) report that the maintenance of genetically viable populations of wild carnivores in Norway will have an adverse effect on the sheep industry of that country. One suggested approach is to consider the entire Scandinavian region in terms of a viable population of wild carnivores. The Jones report (this issue) also indicated a negative effect of predators on the sheep industry in the United States.

Critics of predator control often refute losses reported by individual producers or claims of the impact of predation on the livestock (sheep) industry. Evidence of such an impact can be verified in other ways. There are at least two cases where institutional research flocks have been terminated or greatly curtailed due to predation. One of these was an experimental flock maintained by the Texas Agricultural Experiment Station at McGregor, Texas (Shelton, 1972), and another maintained by the University of California at Hopland, California (Jaeger, this issue; Dally, 2004). Another example of such an effect is the increased losses and decline in sheep numbers as coyotes reinvaded the Edwards Plateau of Texas (Shelton and Klindt, 1974; Nunley, this issue). Perhaps one of the most noted cases of an adverse effect of predation on sheep numbers is the case of the areas adjacent to the Big Bend National Park in Southwest Texas, together with the adjacent Black Gap Wildlife Management Area and the Big Bend Ranch State Park; these areas collectively encompass nearly two million acres on which no predator control is conducted. These areas are contained within, or are adjacent to, Presidio and Brewster counties. At the time the park was established the two counties had a sheep population of close to one-half million (415,266 in 1950). Twenty years later the two counties had only approximately 18% of the 1950 numbers. At present, there are almost none. This serious decline is largely attributed to predation (coyotes and mountain lions migrating outward from the protected areas). Sheep numbers in other southwest Texas counties (e.g., Pecos and Terrell) further removed from the park have also declined, but at a much slower rate and continue to produce a significant number of sheep.

It may be significant that the two countries which now supply much of the U.S. market for lamb and wool are Australia and New Zealand, which were originally almost free of predation. New Zealand continues to be free of predators. Australia currently has significant predation management issues, but also a substantial national effort to manage predation (Allen and Fleming, this issue).

If it is accepted that predation does constitute a serious problem to be dealt with, the logical question is how this is to be done. Common law in the United States (Bruscino and Cleveland, this issue) is that wildlife belongs to the state (public), and thus it might be assumed that because wildlife belongs to everyone, everyone should share in their keep (and management). Currently 14 states and four Canadian provinces have programs to reimburse livestock owners for losses caused by predators. In limited circumstances or under special conditions, wildlife organizations have reimbursed livestock producers for losses caused by the large predators, but not for coyotes which usually cause greater losses. In addition, since 1885, the federal government has taken a position to provide assistance to landowners, farmers or ranchers to manage wildlife damage (Hawthorne, this issue). However, wildlife species, especially predators, do not respect arbitrary property boundaries imposed by humans, and it is difficult or impossible for individual producers acting alone to manage predation when it occurs. This challenge is compounded by increasingly restrictive limitations on tools that can be used and the conditions under which some species can be removed. Thus, it is necessary that some entity with a broader interest participate in this effort. At the present time this role is served by the USDA-APHIS Wildlife Services Programs.

For a period of years, there existed a Western Regional Research Project relating to predation. This was a multidisciplinary group consisting of animal scientists, chemists, economists and wildlife biologists. Much of the effort of this group was directed at coyotes, but at times other species were studied. Studies included sight (e.g. flashing lights or other visual images), sound (high frequency emitters), odor, taste (repellants) and aversive conditioning. Some of these might work for short periods of time or under special conditions but had little or no long-term value.

In addition to previous efforts, ongoing research continues to evaluate other predation management tools and to refine the application of existing methods. These included the selective removal of offending animals, fencing, guardian animals, confinement, partial confinement, night confinement and some management practices, such as early weaning or altering lambing, kidding or calving dates. It is important to point out that none of these provide an adequate or overall solution to this problem. Some of the tools mentioned above are discussed by contributors to this report.

Fencing can be used to discourage coyotes, dogs or wolves, but the expense involved in refencing large areas with low stocking rates has seriously limited this approach. Nunley (quoting Caroline, this issue) mentions that new fencing (when it was originally fenced) was a major tool to control wolf movement and to assist in their control in the Edwards Plateau of Texas. It should be pointed out that fencing would not deter mountain lions, smaller mammals or raptors. Generally, fencing is feasible only in areas of high stocking rates, for night confinement or as barrier fences such as the Australian Dingo fence (see Allen and Fleming, this issue) or where a number of producers cooperatively construct barrier fences. Several reports are available which discuss predator fencing (Gates, et al., 1978; Thompson, 1979; and Shelton, 1984). The possibility of placing barrier fences along major highways (especially new construction) should be considered to reduce predator movement along with the carnage resulting from highway accidents involving wildlife species, especially white-tailed deer.

In some areas, producers are able to remain in business only through aerial hunting of coyotes and feral swine using helicopters and fixed-wing aircraft. However, there are many problems with this approach. The primary problem is the expense. Another is that aerial hunting may not be permitted in certain areas. Finally, aerial hunting is not effective where substantial ground cover exists.

Recently, there has been considerable interest in the development of more efficient methods of selectively removing offending animals. In the intermountain West and California, the available evidence suggests that territorial, breeding coyotes are often responsible for the most loss. Accordingly, efforts are being directed toward the development of more effective methods of calling these territorial animals (Jaeger, this issue). Whether this can be done, and whether territorial coyotes in other areas of the country are those most likely to kill livestock, remains unclear.

The use of guardian animals is relatively new in the United States, although guard dogs were used by Native Americans for many years, and special breed guard dogs have been used in the Middle East and Europe for generations. These special breed guard dogs have only been introduced into the United States in relatively recent times (Andelt, this issue), and they have clear value in many situations. However, the successful use of dogs to protect livestock has been limited with free-ranging flocks in Texas and the Southwest. Dogs require frequent or daily attention, and many ranchers in the Southwest have a number of flocks scattered over large areas which cannot be seen daily and which would require many dogs. Also, dogs may not work well where many people have access to the grazing areas or where the animal populations are frequently changing. Guard dogs cannot be used with some other control measures, such as snares, traps or toxins. Also, it is not known how successful guard dogs are against wolves and grizzly bear. Other guardian animals, such as donkeys and llamas, have been used, and while there are reported successes with coyotes in some situations like fenced pastures, they may not be useful with larger predators.

Some Conclusions and Recommendations

1. Predation is a more serious problem for the livestock industry than most people realize unless they are somehow involved. This problem is almost certain to increase due to the dispersal of feral or wild hogs throughout the country and the expanding range of the reintroduced grey wolf.

2. Because predator species do not respect property or political boundaries, it is important that control efforts be conducted on a national, state or regional basis. At present, these efforts are carried out by the USDA-APHIS Wildlife Service Programs in cooperation with state agencies and livestock producers. Possibly some type of zoning could permit adapting management methods to the unique area being served. An appropriate approach for free ranging (fenced pastures) in the Southwest may be quite different from herded flocks or for farm flocks dispersed throughout the country.

3. Research relating to predation management should be a continuing effort, but should be a multidisciplinary effort involving those knowledgeable and close to the industries being served. Further, more research is needed to make existing management methods more effective, efficient and economical.

4. There is a need for more effective predator management tools including the limited use of effective and environmentally safe toxicants (see Fagerstone et al., this issue).

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Economic Impact of Sheep Predation in the United States

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Abstract

Though accounting for less than 1 percent of U.S. livestock industry receipts, sheep and goat operations are still important to the economies of several states in the Southern Plains, Mountain States and Pacific regions. Revenues from sales of lambs and culled ewes amount to more than three-fourths of the total receipts in the sheep industry. However, nearly 4 percent of the animals in the sheep industry are lost each year. Most of this loss is from predation. Predators include coyotes, domestic dogs, big cats, foxes and bears, and eagles. Predator losses are concentrated in the Southern Plains, Pacific States and Mountain regions, due to a high concentration of both sheep and predators in these regions.

Most previous studies have looked at the direct loss from predation. We used the Impact Analysis for Planning (IMPLAN) procedure to construct an input-output (I-O) model of the 10 USDA farm production regions to look at some of the indirect effects associated with predation. The direct value of all sheep and lambs lost due to predation for 1999 was simulated using this I-O model and the regional economic impact evaluated. The simulated impact of predator losses on the U.S. sheep industry showed that a $16 million direct loss in sheep and lambs due to predation results in a more than $12 million additional income loss over the rest of the economy. The economies of the Mountain States, Southern Plains and Pacific were most affected.

Keywords: sheep, lamb, predators, economic impact

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Introduction

In 1999, the U.S. sheep and goat sector employed 14 thousand people (Bureau of Labor Statistics, Covered Employment and Wages) and generated $495 million in gross income.[1] Although accounting for less than 1 percent of U.S. livestock industry receipts[2], sheep and goat operations are important to the economies of several states in the Southern Plains, Mountain States and Pacific regions. Revenues from sales of lambs and culled ewes amount to more than three-fourths of the total receipts in the sheep industry.

Predation is an important management decision for ranchers. Knowlton, F., E.M. Gese and M.M. Jaeger note that when organized depredation controls exist, losses to coyotes typically range between 1.0 and 6.0 percent for lambs and 0.1 and 2.0 percent for ewes. When producers were reimbursed for their losses in lieu of predator-control efforts, losses to coyotes were typically higher, ranging from 12 to 29 percent in lambs and 1 to 8 percent in ewes. Similar magnitudes were reported by Bodenchuk, M.J., J.R. Mason and W.C. Pitt, (2002). The General Accounting Office (GAO) reports a benefit cost ratio of 3:1 to 27:1 for the range of Wildlife Service activities analyzed (GAO, 2001). The range management literature reviewed by the GAO focuses primarily on the direct costs and benefits of predation-control options.

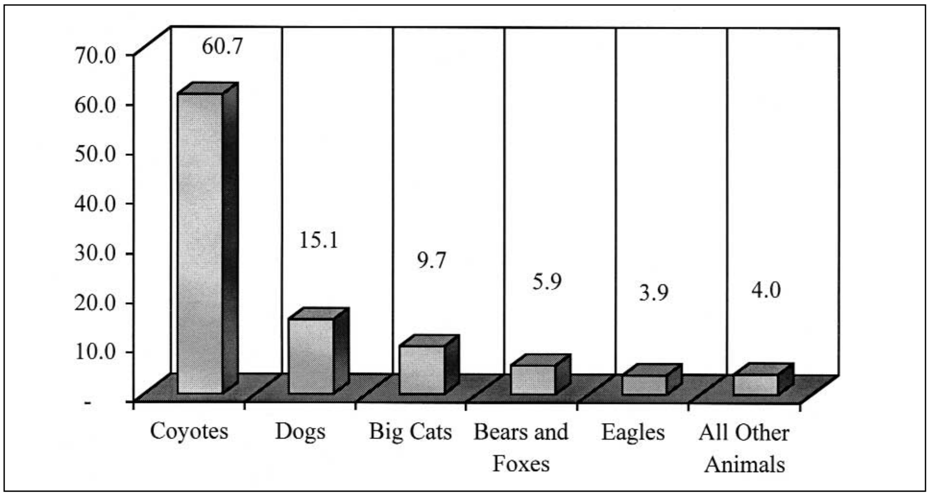
The primary objective of this study is to examine sheep predation and assess its economic impact on regional economies in the United States by examining the *indirect* as well as the direct effects. I discuss the effects of predation on sheep production in section 2. The measurement techniques, assumptions and data are described in section 3. I present the simulation and results in section 4. The conclusions are presented in the last section.

Impact of Predation on Production

Predator losses seriously deplete stock sheep inventory, especially in larger-scale herds that are not intensively managed. Theoretically, if predation reduces the number of lambs and sheep marketed, slaughter prices should be expected to increase. The degree of the price increase will depend on the elasticity of demand. Because of the large market share of imported lamb meat in the U.S. market, the demand for U.S. lamb meat is highly elastic. Nearly half of the lamb sold at retail institutions in the United States is of foreign origin. As such, U.S. suppliers are probably price takers. Thus domestic predation rates are unlikely to influence domestic retail prices. The net effect of predation is a reduction in annual gross sales. Gee et al (1977) report that in 1974 coyote predation alone may have reduced gross U.S. sales of sheep and lamb by 27 million dollars, 9 percent under what sales would otherwise have been. USDA's National Agricultural Statistic Service (NASS) reported that in 1999, sheep and lamb losses from animal predators in

[1] Includes $477.1 million in gross income from sheep, lambs and lamb and mutton and $17.9 million from the value of wool produced.
[2] The Economic Research Service Farm Income Statistics reports 1999 livestock cash receipts of $95.5 billion.

Figure 1. Percent of all sheep and goat losses from predators, 1999.



the United States totaled 273,000 head. This represented 36.7 percent of the total losses from all causes and resulted in a direct loss of $16.5 million, just over 3 percent of gross sales.

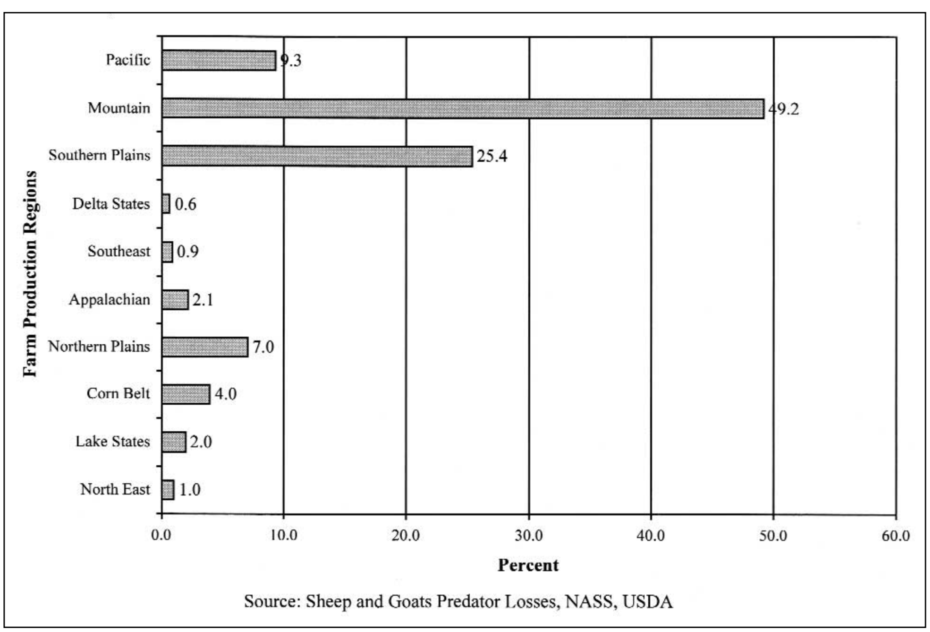
Predators also increase production costs. Gee et al (1977) reports that in 1975, U.S. sheep and lamb producers spent $11 million, or 4 percent of gross sales, on animal damage control measures. In 1999, farmers and ranchers throughout the United States spent $8.8 million on non-lethal methods to prevent predator loss of sheep and lambs, alone — 2 percent of gross sales. Predators include coyotes, domestic dogs, mountain lions, bobcats, foxes and eagles (Fig. 1).

Nearly 4 percent of the animals in the sheep industry were lost to predators in 1999 (USDA, Sheep and Goats Predator Loss, 2000). In 1974, 61 percent of all sheep predation losses were from coyotes (Gee et al., 1977). According to NASS, in 1999, the share of all predator losses attributed to coyotes was the same. Predator losses contribute to declines in inventories, leading to declines in total revenues. Losses are concentrated in the Southern Plains, Pacific States and Mountain regions due to overlapping high concentrations of both sheep and predators.

The Mountain States Region registers almost half of all predator losses (Fig. 2). It is the largest sheep-producing region with just over 37 percent of all U.S. sheep. The Southern Plains experiences a higher proportion of predator losses in relation to the number of sheep in that region. This is expected since larger operations are based in these areas, and there is likely more grazing of animals on open range where exposure to predation is greater.

Lambs are often more vulnerable to predators than mature sheep (Fig 3). In the Mountain States and Southern Plains, more than three-quarters of the animals lost to predators are lambs. Since lambs are usually marketed within one year of birth, large predator losses tend to affect producer cash flows.

Figure 2. Regional distribution of sheep and lamb losses due to predation, United States, 1999.



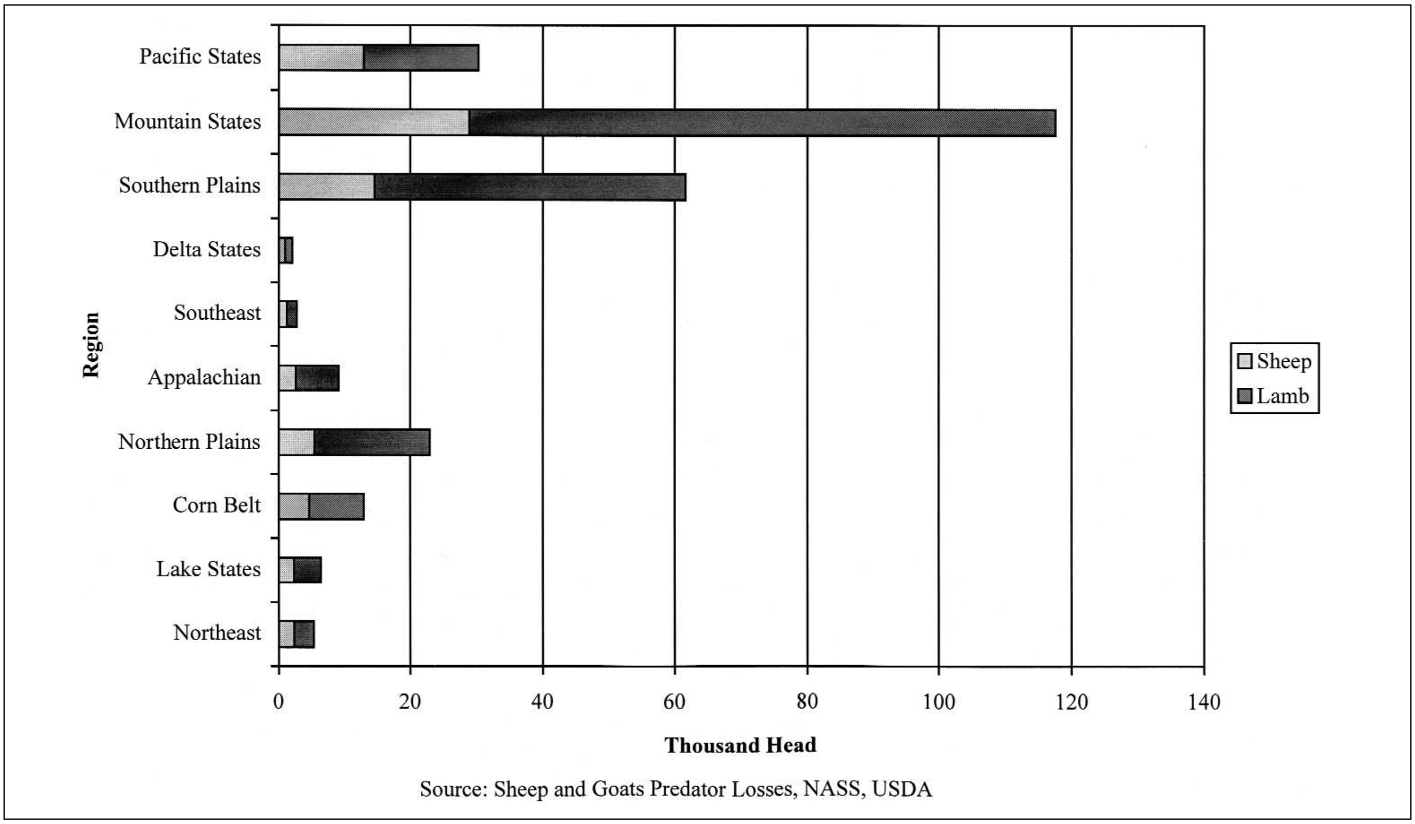
Measurement Techniques, Assumptions and Data

This analysis focuses on predation in sheep only. The Impact Analysis for Planning (IMPLAN) procedure was used to construct a preliminary Input Output (I-O) model (MIG Inc. 1997) of the United States and the 10 USDA farm production regions (Fig. 4). USDA-NASS sheep predation data is incorporated into the model to assess the regional economic impact of losses from predation on the U.S. sheep industry.

Measurement Techniques

Input-output (I-O) analysis portrays economic linkages deterministically, and requires that a sector use inputs in fixed proportions (Miller and Blair, 1985). The IMPLAN model-building procedure (Alward and Lindall, 1996) is used to construct the I-O models for the U.S. economy and its regional economies. Input-Output analysis is typically demand driven and examines the relationships within an economy, both within sectors and between sectors and final consumers. As such, the resulting simulation output model, from which multipliers are derived, is expressed as: $X = [I-A]^{-1} F$ which shows that output, X, depends on final demand, F. The multiplier matrix, $[I-A]^{-1}$ translates the given level of final demand into direct and indirect outputs for each sector. Similarly, the resulting simulation of value added (TVA) is expressed as $TVA = V[I-A]^{-1} F$ where V is the diagonal (v_i), which is the ratio of value added to industry output. Employment (l) is simulated as $l = L[I-A]^{-1} F$ where L is the diagonal (l_i), which is the ratio of number of people employed to million dollars of industry output.

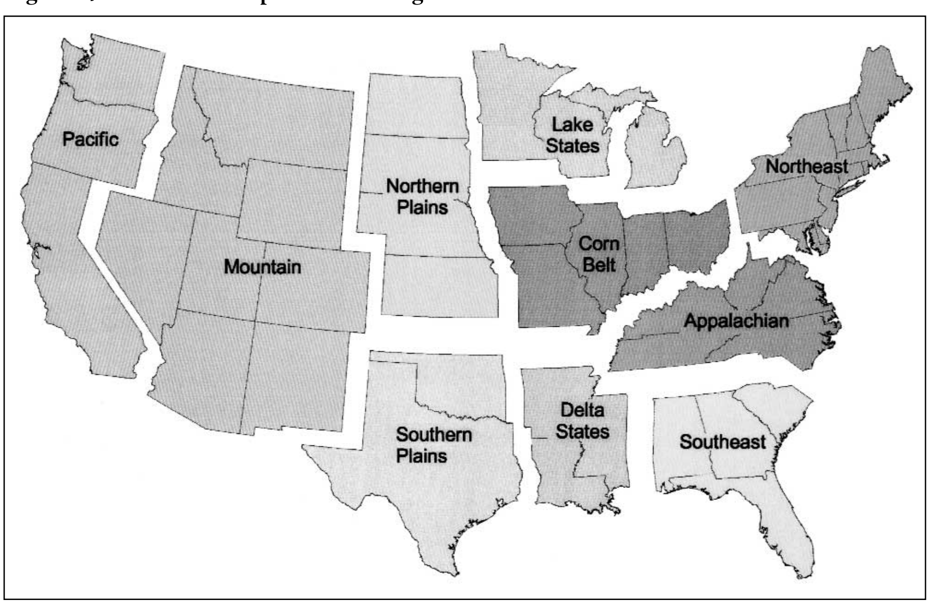
Figure 3. Regional losses of sheep and lambs to predators, number by regions, 1999.



The economic contribution of the sheep sector extends far beyond the farm. Because sheep producers buy inputs from other regional producers, and sell their products for further processing, sheep production contributes to the vitality of regional economies. As a result of extensive linkages, fully understanding the impact of sheep predation to the regional economy requires a close examination of its direct and indirect effects of these linkages.

Input-output analysis is a straightforward tool for examining the relationship between the predation in the regional sheep industries and the rest of the regional economies. This can best be analyzed by examining the region-wide loss to the regional economies from sheep predation. Using IMPLAN to construct the regional models, we can approximate how the entire local economy would be affected if the cost associated with predation is subtracted from the sheep sector. The value of losses due to predation for each region for 1999 is used to simulate changes in the sheep industry. The value of sheep losses is deflated to correspond with the 1996 IMPLAN data, then re-inflated, after simulation, to 1999, for reporting of results.

Figure 4. USDA farm production regions.



Input-output multiplier models distribute the impacts of a shock among two components: a direct effect, and indirect effect. The direct effect shows the direct (first round) impact of a change in output due to predation on final demand. The indirect effect shows the indirect impact in subsequent rounds resulting from increased or decreased purchases from other industries in the economy.

Key Assumptions

The relationships forming the I-O analysis are based on a demand-driven modeling framework employing production equations governed by certain simplifying assumptions. First, it is assumed that no errors of aggregation exist in each of the n industries in the I-O model; that industries or firms aggregated to form a particular industrial sector are homogeneous; and that at least some part of the output of industry A required by industry B will vary with the level of activity in industry A.

Second, it is assumed that factors of production of intermediate goods are used in fixed proportions in the production process. This implies that there are no possibilities for input substitution and no economies of scale or, in other words, the production function for each sector is a fixed technical relationship. In practice, depending on the size of the shock and given that production and the economy are dynamic systems, the assumption of constant coefficients may not always be appropriate. But in our case this assumption is justified given the small magnitude of our shock.

Third, in I-O analysis, changes in final demand are not translated into price changes. In such a framework, a perfectly elastic supply response is assumed. Changes in final demand are reflected in changing output levels for all industries and causes supply to adjust to a shift in demand along a horizontal supply curve. As such, an increase in final demand for a given industry results in a rightward shift in the demand function for that industry, meaning that those industries producing inputs will supply additional inputs, that will in turn result in corresponding increases in the output of other sectors. Such increases are as a result of a direct technical relationship with the increase in inputs, and imply changes in output, not changes in price.

Last, in estimating the value of sheep and lamb predation losses, it is assumed that all the animals are lost to predators while on range, and prior to entering the feedlot. While we are aware that lambs may be lost to predators at varying sizes and weights, it is reasonable to estimate the value of these animals at a weight of transferring them to the feedlot. Warnock and Carkner (1995) indicate that feed represents 80 percent of the total annual cash operating cost to raise sheep, but a significant portion of this cost is associated with the feed grain fed during finishing. Animal loss prior to finishing causes negligible change in cost of production associated with any given farm, since the operating costs associated with labor, hay, and grazing will change little with losses due to predators.

The Data

The regional IMPLAN database for 1996 was used as the base for analysis. The IMPLAN database provides annual, county-level data for final demand by commodity, sales by sector, transfers to households and other institutional elements and commodity transshipments. Input-output models were constructed for each of the 10 USDA farm production regions. Our simulation models were developed for these regions using the 2-digit standard industry classification (see table 4 for industries included in the analysis). The sheep and goats sector was separated from other livestock and other farm sectors for the purpose of this study. Data for the value of all sheep and lambs lost to predation was obtained from NASS, Sheep and Goats Predator Loss bulletin.

Since 1990, NASS has reported the number of sheep and lambs lost to predators and the total value of these losses. Predator losses are estimated as a percentage of total losses from all causes. Sheep value per head is based on two-year average value of ewes reported in the January 1 sheep survey. The value of lambs per head is based on the average market price. An average lamb weight of 60 to 90 pounds was used. Lambs are taken to the feedlots for finishing at between 60 and 90 pounds. Feeder lambs are fed for approximately 2 to 3 months before attaining a finishing weight of 110 to 120 pounds.

Simulation and Results

The direct value of all sheep and lambs lost due to predation is for 1999 is shown in table 1. Sheep and lambs lost to predators are valued at $16.5 million. Two-thirds of the value of all losses was seen in the Mountain States and Southern Plains combined. The Mountain States realized $7 million in losses and the Southern Plains realized $3.2 million in losses. The Northern Plains and Pacific states were the other regions realizing over $1 million in losses.

The economic impacts presented in table 2 show the effect of predation in the sheep industry on the regional economies. The multiplier model quantifies the additional activity in terms of industry output, value added, and employment generated throughout the economy as a result of direct losses due to predators. Industry output is a measure of the total outlay of the industry as a result of a direct income change in the economy. Value added is a measure of the total payments made to factors of production (labor, land, and capital) used by the industry. Value added consists of employment compensation, other property type income and indirect business taxes. Employment is expressed as the number of full- and part-time jobs needed to produce the new industry output.

Table 2 shows overall economic losses of sheep and lambs due to predation — $28.97 million dollars to the U.S. economy. Large sheep producing regions with high predator losses had less than proportional impacts on industry income, value added, and employment.

Table 1. Direct value of sheep and lambs lost from predation, 1999.

Region	Total Value ($ thousand)	Percent U.S. Losses
Southeast	-272.64	1.7
Appalachian	-611.42	3.7
Northeast	-477.50	2.9
Lake States	-398.12	2.4
Corn Belt	-931.29	5.6
Delta States	-204.48	1.2
Southern Plains	-3,221.00	19.5
Northern Plains	-1,313.00	8.0
Mountain	-7,013.17	42.5
Pacific	-1,995.62	12.1
United States	**-16,438.85**	**100**

Source: Sheep and Goats Predator Losses. NASS-USDA

Table 2. Regional economic impact of losses (direct, indirect) due to predation, United States, 1999.

Region	Industry Output	%	Value Added	%	Employment Number	%
Southeast	-380,845	1.3	-176,466	1.9	-24	2.5
Appalachian	-972,021	3.4	-344,103	3.7	-68	7.2
Northeast	-701,446	2.4	-256,874	2.8	-42	4.4
Lake States	-658,031	2.3	-220,550	2.4	-32	3.4
Corn Belt	-1,514,435	5.2	-610,713	6.5	-56	5.9
Delta States	-286,200	1.0	-123,325	1.3	-14	1.5
Southern Plains	-6,244,828	21.6	-1,133,000	12.1	-114	12.0
Northern Plains	-2,295,446	7.9	-863,491	9.3	-55	5.8
Mountain	-12,679,099	43.8	-4,214,513	45.2	-387	40.7
Pacific	-3,236,911	11.2	-1,390,473	14.9	-159	16.7
United States	**-28,969,262***	**100***	**-9,333,508***	**100***	**-951***	**100**

*Additive and assumes no inter-regional impacts.

For example, 49 percent of all U.S. sheep and lambs lost from predation were in the Mountain States (see fig. 2), but only just above 43 percent of the output lost in the United States from predation were lost in the Mountain States regional economy. The movement of goods within and outside the region could explain this. Because more than 7 percent of the intermediate inputs in the sheep industry are imported from outside the Mountain States region, a portion of the regional loss may be felt in other regions, thus causing a less than proportional loss.

A similar situation occurs in the Southern Plains, which imports nearly 19 percent of the intermediate inputs for the sheep industry from other regions. The Southern Plains region had 25 percent of the U.S. sheep and lamb predation losses, but less than 22 percent of the U.S. total-output loss due to predation, 12 percent of the U.S. value-added loss, and 12.3 percent of the U.S. employment loss. By contrast, smaller sheep producing regions with low percentages of the U.S. sheep and lamb predation losses experienced more than proportional losses in industry output, value added, employment due to the fact that they absorb losses from other regions. For example, the Northern Plains had 7 percent of all U.S. sheep and lambs lost from predation but experienced 8.1 percent of the U.S. total income loss due to predation, 9.3 percent of the U.S. value-added loss and 6.2 percent of the U.S. employment loss. Similar scenarios were seen in the Delta States, Appalachian, Southeast and Northeast.

Table 3 shows the direct and indirect impact of predator losses in output, value added and employment. Here, I highlight the indirect effects. When the sheep industry purchases inputs from other industries, those purchases, in turn, generate indirect demands for additional inputs for the supplying industries. It was evident that regions with a larger proportion of the sheep industry and larger producers suffered greater indirect losses to output, value added, and employment. Larger farms are more likely to demand inputs in large quantities, thus industries supplying inputs to sheep are likely to be located close to where the sheep are located. The loss of indirect demand for additional inputs varies widely among the regions, from 28 percent to 48 percent of a region's total output. Larger indirect effects imply that more capital-intensive inputs from other regional industries are used by the sheep and will be lost as a result of predation. The largest share of indirect output losses was seen in the Southern Plains.

Since value added is the payment to

Table 3. Regional losses due to predation.

	Southeast	Appalachian	Northeast	Lake States	Corn Belt	Delta States	Southern Plains	Northern Plains	Mountain	Pacific
Output										
Direct	-272,644	-611,609	-477,507	-398,123	-931,289	-204,483	-3,220,997	-1,313,406	-7,013,170	-1,995,617
Indirect	-108,201	-360,412	-223,939	-259,908	-583,146	-81,717	-3,023,831	-982,040	-5,665,929	-1,241,294
Total	**-380,845**	**-972,021**	**-701,446**	**-658,031**	**-1,514,435**	**-286,200**	**-6,244,828**	**-2,295,446**	**-12,679,099**	**-3,236,911**
% Indirect	28.4%	37.1%	31.9%	39.5%	38.5%	28.6%	48.4%	42.8%	44.7%	38.3%
Value Added										
Direct	-116,975	-160,366	-133,972	-94,699	-319,135	-82,999	-337,607	-423,672	-1,631,572	-739,410
Indirect	-59,491	-183,737	-122,902	-125,851	-291,578	-40,326	-795,393	-439,819	-2,582,941	-651,063
Total	**-176,466**	**-344,103**	**-256,874**	**-220,550**	**-610,713**	**-123,325**	**-1,133,000**	**-863,491**	**-4,214,513**	**-1,390,473**
% Indirect	33.7%	53.4%	47.8%	57.1%	47.7%	32.7%	70.2%	50.9%	61.3%	46.8%
Employment										
Direct	-23	-61	-39	-27	-47	-13	-73	-41	-286	-130
Indirect	-1	-7	-3	-5	-9	-1	-41	-14	-101	-29
Total	**-24**	**-68**	**-42**	**-32**	**-56**	**-14**	**-114**	**-55**	**-387**	**-159**
% Indirect	4.2%	10.3%	7.1%	15.6%	16.1%	7.1%	36.0%	25.5%	26.1%	18.2%

Table 4. The 2-digit standard industrial classification industries.

Industry	
Other Livestock	Water Transportation
Sheep, Lambs and Goats	Air Transportation
Other Farms	Pipe Lines, Except Natural Gas
Forestry Products	Transportation Services
Commercial Fishing	Communications
Agricultural Services	Utilities
Metal Mining	Wholesale Trade
Coal Mining	Retail Trade
Oil Mining	Banking
Non-metal Mining	Credit Agencies
Construction	Security and Commodity Brokers
Food Processing	Insurance Carriers
Tobacco Manufacturing	Insurance Agents and Brokers
Textiles	Real Estate
Apparel	Hotels and Lodging Places
Wood Products	Personal Services
Furniture	Business Services
Pulp and Paper	Automotive Services
Printing and Publishing	Repair Services
Chemicals and Allied Products	Motion Pictures
Petroleum Products	Recreation Services
Rubber Products	Health Services
Leather Products	Legal Services
Stone, Glass and Clay	Education Services
Primary Metals	Social Services
Fabricated Metal	Non-profit Organizations
Industrial Machinery	Professional Services
Electrical Equipment	State & Local Non-education Government
Transportation Equipment	Federal Non-military
Scientific Instruments	Special Sectors
Miscellaneous Manufacturing.	Federal Government - Military
Railroads and Related Services	State & Local Government - Education
Local, Interurban Passenger Transit	Domestic Services
Motor Freight Transport and Warehousing	

factors of production, the quality of, and the level of compensation paid to, the inputs used determine the indirect effects. Larger indirect value-added effects imply greater compensation paid to the factors of production. Though the proportion of indirect industry output losses was never more than 50 percent for any of the regions, indirect loss in value added ranges from 33 percent in the Delta States to 70 percent in the Southern Plains with five states having value added over 50 percent.

The indirect effect on employment is much smaller and ranged from 4.2 percent in the Southeast to 36 percent in the Southern Plains. Large direct effects imply more labor intensive industries, while small indirect effects imply that the inputs used from other industries were more capital intensive in nature. Losses were greatest in the processing and wholesale trade sectors.

Conclusions

The losses of sheep and lambs due to predation reduce the number of animals available for market each year, creating secondary effects in regional economies. The extent of the impacts depends largely on the number of sectors within the regional economy that supply the sheep industry with inputs.

However, some caution is in order here. The simulated economic impacts suffer from the general weaknesses of static input-output models. As such, simulated economic impacts of a loss in the sheep industry due to predation results in an unidirectional change in all other sectors affected by this loss. This is not necessarily the case in a dynamic setting, since interactions among agents and substitution among factors of production often results in lower magnitudes of impacts than are obtained from an input-output analysis. Also, in the event of a change in one sector, full and immediate change in all other sectors that may be affected is assumed in the input-output framework. However, all sectors do not adjust at the same rate. As such, situations of temporary underemployment of resources may result. This is particularly true with labor resources. A decrease in workload on the farm may result in a decrease in activity for employees in other sectors, but due to temporary disequilibrium conditions in these sectors, the number of employees may not change. The results, therefore, should be viewed as upper bounds or the maximum loss that can be expected to the economy as a result of predation.

The simulated impact of predator losses on the U.S. sheep industry showed that a $16 million direct loss in sheep and lambs due to predation results in a more than $12 million additional output loss in the rest of the economy. However, due to the overlapping effect of regional losses, where direct losses from one region may result in indirect losses from other regions, the overall impact of the indirect losses from predation may be smaller for the entire United States. Economies of the Mountain States, Southern Plains and Pacific were most impacted, largely because most of the sheep and lambs are concentrated in these regions, and as a result, most of the sheep and lambs lost due to predation are in these regions. Also, industries supplying inputs to the sheep industry would be more likely to be located in regions where there is intensive sheep production — near the source of production. As such these intensive sheep-producing regions are likely to experience a higher proportion of indirect loss, while the less-intensive, sheep-producing states are likely to have a lower proportion of the indirect losses.

Finally, it is important, when interpreting these results, to bear in mind the assumptions of the model and to recall that the costs associated with the removal of predators are not included in the analysis. If the costs were explicitly included in the analysis, the overall economic impact of predator removal would be much less than our modeling results indicate.

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The History of Federal and Cooperative Animal Damage Control

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Keywords: ADC, Coyotes, Education, History, Predation, Rodents, Wildlife Services

Introduction

The predecessor of the Wildlife Services program within the U.S. Department of Agriculture, Animal and Plant Health Inspection Service, was founded by C. Hart Merriam in 1885 with a Congressional appropriation of $5,000. These funds were used to organize a Section of Economic Ornithology as part of the Entomology Division of USDA. Merriam immediately hired longtime friend A. K. Fisher to be his assistant and the two shared a clerk. The new Section proved to be so popular with farmers and politicians that the Congress created a separate Division of Economic Ornithology and Mammalogy in 1886. The Commissioner of Agriculture stated that the principal effort of the Division would be to educate farmers about birds and mammals affecting their interests, so that destruction of useful species might be prevented. One of the first publications dealt with the introduction of the English sparrow into the United States.

Merriam and his assistants began to collect data on the geographic distribution of various birds and mammals of economic importance. "Economic" was gradually dropped from the organization's title, and in about 1890, the title of the Division was changed to the Division of Ornithology and Mammalogy. Early studies detailed the life histories and impacts of jack rabbits, ground squirrels of the Mississippi Valley, and pocket gophers. In addition, field experiments on the control of prairie dogs in Texas and New Mexico were initiated. Merriam and others soon promoted another change in the title of the Division to the Biological Survey, arguing that the name was more apt, and in 1896, the Division was renamed. In 1905, the name was changed again to the Bureau of Biological Survey and this title remained as long as the program was with the Department of Agriculture.

Merriam's dedication to field surveys never wavered, even though it brought him into constant conflict with various Congressmen who did not see the practical value of investigating animals in Canada and Mexico. Merriam insisted that the information was needed to help the farmers in the United States. Nevertheless, his agency was known by some as the "Bureau of Extravagant Mammalogy," and in 1907, several Congressmen attempted to abolish the Bureau's appropriation. In the end, the effort failed, thanks in part to President Theodore Roosevelt. Roosevelt expressed his pleasure at the outcome with a characteristic note to Merriam that read "Bully for the Biological Survey."

The Early Twentieth Century

By 1900, livestock interests throughout the West were lobbying against the collection of grazing fees on national forest land and other public domains heavily populated with wolves and coyotes. Between 1905 and 1907, the Forest Service and the Biological Survey both investigated predator/livestock problems, and each had publications that described approved and familiar methods of shooting, trapping, poisoning, the development of den hunting, and wire-fencing to manage predation.

Operational rodent control began in 1913, in order to manage plague on a few national forests in California. The following year, the first of many hundred cooperative agreements with Land Grant Colleges and Universities was signed by the president of the New Mexico College of Agriculture and Mechanic Arts and the Secretary of the Department of Agriculture.

Congress finally appropriated a small amount in 1914 for experiments and demonstrations to control predatory animals. The following year, the first sizeable appropriation was made ($125,000), and the language of the Act called for direct participation by the Biological Survey. This action ended the Forest Service's Predator Control Program. Within the Bureau of Biological Survey, ten districts were formed as Arizona/New Mexico, Colorado, Idaho, Oregon, Montana/North Dakota, Nevada, California, Texas, Utah, and Wyoming/South Dakota.

In 1916, a rising epidemic of rabies in wild animals, particularly in coyotes, increased the appropriation by $75,000. This increased the number of Government hunters primarily in the hardest hit areas of northern California, Oregon, Nevada, and Idaho. Also for the first time, funding for rabies work and predator control exceeded that spent for "food studies." Stanley P. Young wrote, "After a few preliminary contacts with J. Stokley Ligon, mainly through correspondence, I was asked to go to work as a Government hunter in Arizona with a grand salary of $75 a month. This magnificent salary meant that you had to board and take care of your other requisites, such as upkeep of saddle and pack horses, but I was able to do this with cooperators aiding at times because $75 was a lot of money in those days. By the time the employment date came around, on October 1, 1917, I was sent a sack of wolf traps, formula for making wolf scent and stake pins, together with a little packet of official stationery with instructions therein one of which read: 'A man who does his duty well is the man who serves his country best, especially so when the world is being devastated by war (World War 1). Be a clean hunter, keep a clean trapping kit, and leave a clean record. It will be honor to yourself and a credit to your country. To delay reports interferes with all accounts and delays your own pay.' " The instructions went on to inform the hunter how to keep furs and scalps. In 1920, all restrictions were "officially" dropped for work to be done only on national forests and public domain.

Beginning about 1920, tremendous rabbit populations erupted throughout the West, and the Biological Survey coordinated poisoning campaigns and drives. Interest in rabbit control also was stimulated by a commercial demand for rabbit skins for felt hats and other products. In Wyoming, farmers and ranchers sold 100,000 skins, netting them $12,000-15,000. One year, the Idaho ADC program killed 600,000 rabbits and sold 61,000 pounds of skins.

The placing of toxicants had become a fine art for both predators and rodents, and in 1920, a laboratory for experimentation with toxicants was established in Albuquerque, New Mexico. It was called the Eradication Methods Laboratory and was under the direction of Stanley E. Piper. In 1921, it was moved to Denver, Colorado, and in 1928, it was renamed the Control Methods Research Laboratory. In 1940, the Control Methods Research Laboratory was combined with the Division of Food Studies to become the Branch of Wildlife Research. The research facility at Denver was called the Denver Wildlife Research Laboratory. In 1959, it was renamed the Denver Wildlife Research Center. In 1997, after the transfer of the ADC program from the Fish and Wildlife Service to the USDA, the Center was moved to the campus of Colorado State University and renamed the National Wildlife Research Center.

For many years, strychnine had been used as a means of controlling wolves and coyotes. The common practice was to salt any carcass found on the range with raw strychnine. Coyotes and wolves soon learned to avoid the treated carcasses, and so the strychnine was put in tallow baits and these were inserted into a carcass. This practice was soon abandoned in favor of small baits known as "drop baits" placed around a carcass or a draw station. Research later developed methods for putting toxicant into capsules and tablets that would hide the bitter taste of strychnine. Beside strychnine, work was done with thallium sulfate mostly in bird control. For raven control, treated corn was placed on platforms 14 feet tall which afforded the only vantage point for miles.

The Office of Ornithology and Mammalogy within the Bureau of Biological Survey was upgraded to a division in 1928, and the name was changed to the Division of Economic Investigations. But a year later, the name was changed again to the Division of Predatory Animal and Rodent Control. In the Appropriations Act for the Department of Agriculture in that year, Congress called for an investigation as to the feasibility of a definite predatory animal control program over a certain period which would likewise assure a definite amount for expenditures for each succeeding year and upon which to base more efficient control work. The investigation was made, and a report recommending a cooperative program to cover a 10-year period was submitted to the 70th Congress. A number of bills were introduced in both Houses of the 71st Congress to authorize the institution of the 10-year plan. After full Congressional hearings on the matter, the bill that was passed by Congress and signed by the President became known as the National Animal Damage Control Act of March 2, 1931 (Public Law 776).

In the late 1920s and early 1930s, employees of the division would go into communities experiencing problems and organize rodent control campaigns. These campaigns would involve the farmers and ranchers of the area, and also there would be a place set up for mixing bait. Because not all projects were large enough to justify setting up facilities to mix bait, a number of mixing stations were established around the country in locations such as Medford, Oregon, and McCannon, Idaho. The latter was moved to Pocatello and in 1934, Congress approved funds to buy property at Pocatello, build a bait mixing plant, and operate it in cooperation with the Pocatello Chamber of Commerce. In 1936, the mixing plant was completed and the Pocatello Supply Depot was opened for business and remains an important part of the Wildlife Services program.

In 1934, the Division of Predatory Animal and Rodent Control was combined with law enforcement to form the Division of Game Management with a Section of Predator and Rodent Control. However, only four years later, the Section was again separated and named the Division of Predator and Rodent Control. In 1939, the Bureau of Biological Survey of USDA and the Bureau of Fisheries in the Department of Commerce were transferred to the Department of the Interior to form the Fish and Wildlife Service.

The Mid-Twentieth Century

In the fall of 1941, the Humane Fur Getter, later renamed the Humane Coyote Getter, became operationally used in Wyoming, Colorado, New Mexico, and on a wildlife research project in Texas. The following year, this tool became operational West wide. The coyote getter was especially valuable in freezing weather that impeded other control efforts. From the beginning, there was concern throughout the Fish and Wildlife Service about the hazard of this device. Reflecting this concern, an agreement and release form was developed, which required the signatures of the landowner and the agent of the Fish and Wildlife Service, as well as the signature of a third party witness. A form very much like the original is still used by the Wildlife Services operational program, but now it is called Agreement for the Control of Animal Damage on Private Property.

In August of 1945, the Fish and Wildlife Service announced the discovery and demonstration of a new rodenticide known as compound 1080 (sodium monoflouroacetate). Later that year, a policy statement was issued on its use. Unlike strychnine, 1080 is tasteless, soluble in water, and could be applied to bait more easily, and it only took a small amount to be effective.

In 1946, Assistant District Agent, J. R. Alcorn of Fallon, Nevada, published an article in the May issue of the Journal of Mammalogy that described decoying coyotes. Shortly thereafter, predator calling became widely used by the ADC program. Mr. Alcorn also described how to use a howl or a siren to locate coyotes before using the call.

Also in the 1940s, research also was being conducted on thallium sulfate and compound 1080 for coyote control. By 1948, Compound 1080 was being used on a limited basis for coyote control. A year later, Weldon B. Robinson published an article that described the use of thallium and Compound 1080 impregnated stations in coyote control. Robinson reported that while both poisons were equally effective, Compound 1080 was preferable because it was cheaper, more readily available, somewhat more selective, and easier to apply.

The use of aircraft in predator control by private individuals dates back to the 1930s. However, the Fish and Wildlife Service did not start using them until the late 1940s, primarily to distribute strychnine drop baits. It soon became apparent that an airplane could be used effectively to shoot coyotes from the air, and their use has evolved from that time. Today's Wildlife Services program often employs the Aviat Husky or less frequently, the Piper PA-18 Super Cub. Both aircraft have a modified shooting window, extended wings fitted with drooped wing tips, and oversized props and tires. Some have larger horse powered engines to cope with the higher altitudes of the inter-mountain West.

In 1948, the Division was renamed the Branch of Predator and Rodent Control. Reflecting a worldwide shortage of cereal foods, Congress created the Clean Grain Program, and appropriated $1,000,000 to USDA to combine forces with USDI on rat control. This funding resulted in a significant expansion in the program, and helped to establish ADC efforts in the eastern United States.

Transformation of the Program in the 1960s-1970s

In 1963, because of concerns expressed by environmental organizations, Secretary of the Interior Stewart Udall appointed an Advisory Group on Wildlife and Game Management to review the activities of the Branch of Predator and Rodent Control. This group was chaired by Starker Leopold, a professor at the University of California. The review, titled, "Predator and Rodent Control in the United States" and better known as the Leopold Report, was delivered to Secretary Udall in 1964. There were six recommendations: (a) appoint an advisory board; (b) reassess the goals of the predator and rodent program; (c) revise the predator and rodent control guidelines; (d) amplify the research program; (e) establish legal control over the use of certain pesticides; (f) change the name of the organization.

On June 16, 1965, Secretary Udall adopted the report. He changed the name of the Branch to the Division of Wildlife Services and created two branches within the Division, the Branch of Wildlife Enhancement and the Branch of Pesticide Monitoring and Surveillance. Jack Berryman, a professor at Utah State University and a former Fish and Wildlife Service employee, was named Chief of the Division. These changes were insufficient to quell the controversy surrounding the program, and on March 16, 1971, the Defenders of Wildlife and the Sierra Club sued the Department of the Interior demanding an end to the use of toxicants in predator control. A month later, the Humane Society of the United States filed a similar lawsuit. The Department of Interior reacted by forming an Advisory Committee on Predator Control, better known as the Cain Committee. The committee report was rapidly prepared, and critical of the ADC program. As a result, President Nixon signed Executive Order 11643 banning the use of toxicants for the control of predators by a Federal program or on Federal lands. The United States Environmental Protection Agency then canceled the registrations for Compound 1080, strychnine, and sodium cyanide.

To offset the loss of the toxicants, several feasibility studies using helicopters were initiated. The best known of these was conducted on the Bridger National Forest in Wyoming, and it showed that the helicopter could be used effectively, particularly in the mountains and in areas with dense cover where fixed-wing aircraft were ineffective. The helicopter remains an important tool for the Wildlife Services program in the West. The most commonly used are the Bell 47 (Soloy Conversion), the Bell Jet Ranger, and the Hughes 500.

The Division of Wildlife Services was dissolved in 1975. The Enhancement and Pesticide Branches were moved to another Fish and Wildlife Service division, and the branch of Animal Damage Control was reduced to a Washington, D.C. office. Nonetheless, President Ford amended Executive Order 11643 to allow the experimental use of sodium cyanide in the M-44 device for one year. The following year, Ford amended the order again to allow for the operational use of sodium cyanide.

In 1978, again reflecting controversy generated by the environmental community, Interior Secretary Cecil Andrus appointed an Animal Damage Control Policy Study Committee to review the ADC program. This resulted in a policy statement by Andrus on November 8, 1979, which stopped the practice of den hunting of predators and discontinued research on the use of Compound 1080. However, at a breakfast prior to a predator control symposium in Austin, Texas, Guy Connolly provided the Secretary with data that he said had not been given to him before, and during his talk at the symposium, he reversed his ruling on 1080 research for predator control. In 1981, Interior Secretary James Watt rescinded the Andrus policy statement and on January 27, 1982, President Reagan issued Executive Order 12342, revoking Executive Order 11643 and the two amendments by President Ford.

Return to the USDA and Conclusion

On December 19, 1985, Congress amended the appropriation bill for FY 1986 to transfer the Animal Damage Control program from the U. S. Fish and Wildlife Service to the Animal and Plant Health Inspection Service of USDA. On March 1, 1986, this transfer officially took place. On August 1, 1997, the name of the ADC program was changed to Wildlife Services. Today, the Wildlife Services program remains dedicated to the protection of American agriculture, the protection of human health and safety, and the resolution of other human wildlife conflicts. Wildlife damage management has become an inexorable component of modern wildlife and wildland conservation. Despite continuing reservations expressed by animal rights and environmental activists, the increasing need for sound, safe, efficient, and economical damage management is apparent everywhere. The Wildlife Services program is involved in a greater variety of wildlife issues than at any time in the history of the agency, and reflecting its historical commitment to research, the Wildlife Services National Wildlife Research Center has become the leading wildlife damage and disease research and development laboratory in the world.

Status and Management of Coyote Depredations in the Eastern United States

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Introduction

The populations of coyotes (*Canis latrans*) have increased dramatically in the eastern United States since the early 1900s (Hilton, 1978; Chambers, 1987; Hill et al., 1987; Witmer and Hayden 1992). The expansion of the coyote range into eastern North America has been summarized by Parker (1995) and characterized as two distinct geographical events: 1) the northern front moving across southern Ontario and the Great Lakes region and 2) the southern front colonizing the southeastern United States from Arkansas and Louisiana. These two fronts expanded throughout the northeastern and southeastern United States during the 1960s and 1970s, finally converging during the mid 1980s in the central Appalachian mountains of Virginia and West Virginia. Upon their arrival, eastern coyotes, like their western counterparts, began killing livestock. There has been concern that coyote depredations in the eastern United States could cause significant impacts on sheep and other livestock industries (Slate, 1987; Witmer and Hayden, 1992; Witmer et al., 1995). Other authors have suggested that coyote predation is an important contributing factor in the decline of the American sheep industry (Terrill, 1986; Hilton, 1992).

Coyote depredations on livestock in the eastern United States have been documented by several authors (Witmer and Hayden, 1992; Witmer et al., 1995; Tomsa and Forbes, 1989). The USDA National Agricultural Statistics Service (NASS) completed surveys of "Sheep and Goat Predator Loss" during the years 1990, 1994, and 1999. Similar surveys of "Cattle Predator Loss" were made in 1991, 1995, and 2000. These nationwide surveys were completed during the final phases of coyote range expansion in the eastern United States and as coyote depredations in the east began to increase. During the 1990s, the USDA APHIS Wildlife Services (WS) programs in Virginia, West Virginia, and Ohio initiated programs designed to assist producers experiencing livestock depredations by coyotes. The WS program documents livestock losses, requests for assistance, and management activities through its Management Information System (MIS). WS uses the MIS system to produce annual reports on coyote depredation management activities. The NASS surveys and WS reports have not been analyzed on a regional basis or in the context of the range expansion of the coyote in the eastern United States. This paper reviews these data and examines the effectiveness of WS programs aimed at managing coyote depredation on livestock in the eastern United States.

Materials and Methods

NASS Reports

The "Sheep and Goat Predator Loss" and "Cattle Predator Loss" NASS surveys for 1991, 1995, 2000 and 1992, 1996, and 2001, respectively, were analyzed to determine quantities and trends in coyote depredation on sheep and cattle in the eastern United States. These data were compared with national averages and within eastern U.S. sub-regions based on livestock production and range expansion by coyotes. To account for changes in livestock inventories between survey years, coyote depredation was expressed as percent loss of inventory. NASS annual state sheep and cattle inventories corresponding to each predator loss survey were used to determine percent loss of inventory. NASS divides its survey results into three regions including the Mountain/Western region, Mid-west region, and Southern/Eastern region. The southern/eastern United States, as delineated by NASS, includes: Alabama, Georgia, Maryland, New Jersey, Rhode Island, Virginia, Connecticut, Kentucky, Massachusetts, New York, South Carolina, West Virginia, Delaware, Louisiana, Mississippi, North Carolina, Tennessee, Florida, Maine, New Hampshire, Pennsylvania, and Vermont.

For the purposes of this paper, the southern/eastern states defined by NASS were grouped to reflect major areas of livestock production. The majority of sheep production east of the Mississippi River is concentrated in New York, Pennsylvania, Virginia, West Virginia, and Ohio. Ohio is the top ranking state in sheep inventory numbers east of the Mississippi River. Additionally, Ohio, Virginia, and West Virginia have each had coyote depredation management programs during the 1990s. Coyote depredations on sheep in the remaining southern/eastern states were excluded from this analysis due to low inventories. Cattle depredations were calculated by dividing the southern/eastern states into three sub-regions: New England (Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island), Mid-Atlantic (New York, Pennsylvania, West Virginia, Virginia, New Jersey, Maryland, Delaware, North Carolina, South Carolina), and Southeast (Alabama, Georgia, Kentucky, Louisiana, Mississippi, Florida, Tennessee).

USDA APHIS Wildlife Services Reports

Wildlife Services annual tables were used to determine trends in requests by the public to provide technical assistance with coyote depredation problems. The number of coyotes removed annually by WS programs in the eastern United States was employed as an indicator of program field activities and coyote population growth. The number of technical assistance requests and the number of coyotes removed by WS in the southern/eastern states described above was reported for fiscal years (FY) 1991, 1995, and 2000.

During the 1990s, WS had Integrated Wildlife Damage Management (IWDM) programs (sometimes referred to as Integrated Pest Management or IPM) to assist livestock producers in managing coyote depredations in Virginia and West Virginia. IWDM is described in Chapter 1, pages 1-7 of the *Animal Damage Control Program Final Environmental Impact Statement* (USDA 1994). The Virginia WS IWDM program has provided service from 1990 to present and the West Virginia WS IWDM program from 1996 to present. In Ohio, WS has provided extension assistance (rather than technical assistance). These extension activities are coupled with an indemnity program administered by the Ohio Department of Agriculture. The WS programs in Virginia and West Virginia have produced annual reports for their respective state departments of agriculture summarizing program activities. These annual reports were used to determine the effectiveness of IWDM programs in managing livestock depredations in the East. Trends in the number of operations, producers requiring assistance, sheep depredations per operation, and cost effectiveness of these programs were investigated.

Results and Discussion

A review of existing literature documenting coyote depredations in the eastern United States over the past decade reveals a picture which is not unlike those problems historically faced by livestock producers throughout the West. Coyote depredations on sheep and cattle in the eastern United States have risen sharply over the past decade, and those states which implemented IWDM programs have managed depredation in a cost-effective manner.

Sheep/Lamb Losses

Predation is the leading cause of sheep and lamb mortality. Coyote depredations account for 60.7% of the total sheep/lamb losses to predators (NASS 1999). Coyote depredation of sheep/lambs in New York, Pennsylvania, Virginia, West Virginia, and Ohio markedly increased between 1990 and 1999 (Fig. 1). Between 1990 and 1999, the percent inventory loss to coyote depredations of sheep/lambs in New York, Pennsylvania, Virginia, West Virginia, and Ohio nearly doubled, increasing from 0.53% of the inventory in 1990 to 0.97% of the inventory in 1999. In 1999, these losses were valued at $404,948. Sheep/lamb losses in the remaining southern/eastern states were valued at $205,496, amounting to a total sheep/lamb loss in the eastern United States of $610,444. According to NASS (1991-2000) inventories of sheep and lambs in these eastern states declined during the 1990s. The sheep inventory in the New York, Pennsylvania, Virginia, West Virginia, Ohio region, declined 14% faster than the reduction in sheep numbers nationwide (50% vs. 36%).

Coyotes typically prey more heavily on lambs than adult sheep. Coyote depredations on lambs were not uniformly distributed throughout New York, Pennsylvania, Virginia, West Virginia, and Ohio. New York and Pennsylvania were impacted the least with 0.1%, 0.6%, and 0.8% loss of the annual lamb crop during 1990, 1994, and 1999, respectively (Figure 2). In Virginia, West Virginia and Ohio, coyote depredations accounted for 1.5% to 1.9% loss of the annual lamb crop between 1990 and 1999. A number of factors could have contributed to the relatively greater severity of coyote depredation in these states. These factors include coyote population densities, relative lower abundance of natural prey, differences in flock size, terrain, and livestock management. During the 1990s, New York and Pennsylvania flock sizes were typically smaller (2% to 25%) than flocks in Ohio, West Virginia, and Virginia. In Pennsylvania, it has been noted anecdotally that large flocks appear to suffer more coyote depredations than smaller, more intensively managed flocks (J. Suckow, USDA-APHIS-WS, personal communication). It is quite typical in Virginia and West Virginia to graze sheep on semi-isolated mountain pastures without human or animal guardians. Regardless, coyote depredations on lambs in New York and Pennsylvania have increased 88% between 1990 and 1999. This is a fourfold increase compared to the 21% increase in lamb losses in Virginia, West Virginia, and Ohio during the same

Figure 1. Sheep/lamb inventory and percent inventory lost to coyote depredations in New York, Pennsylvania, Virginia, West Virginia, and Ohio.

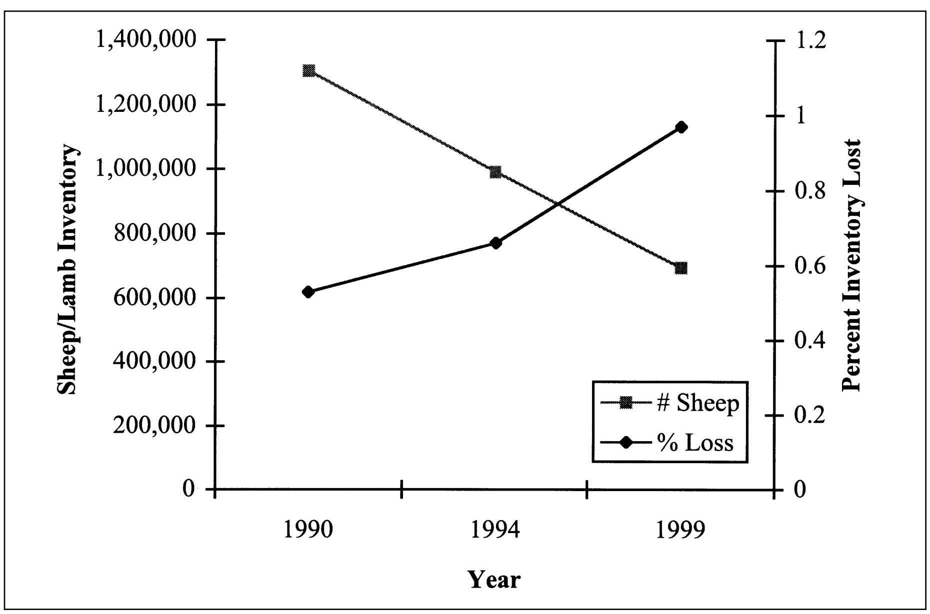
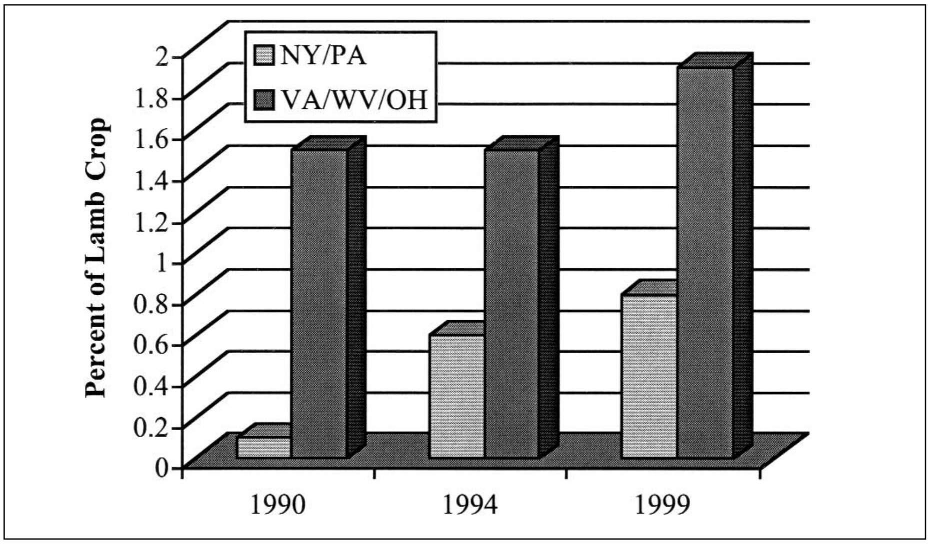


Figure 2. Percent of lamb crop killed by coyotes in New York and Pennsylvania compared to Virginia, West Virginia, and Ohio.



period (Fig. 2). This greater rate of loss is the motivation behind current attempts to establish an IWDM program in Pennsylvania (J. Suckow, USDA-APHIS-WS, personal communication).

Cattle/Calf Losses

Cattle losses to coyotes are generally restricted to calves during the first several months of life. Occasionally, adult cows also are killed when movements are restricted (e.g., when giving birth). Nonetheless, NASS (1999) estimates that coyotes account for 70.1% of cattle losses to predation. The inventory of cattle and calves in the eastern United States remained steady during the 1990s (Fig. 3). During this period, however, there was an overall rise in both the number of cattle/calves killed by coyotes and the percent of the inventory those depredations represent in the eastern United States (Fig. 3, Fig. 4). Between 1991 and 2000, the percent inventory loss of cattle/calves in the southern/eastern United States increased from 0.05% in 1991 to 0.11% in 2000. In 2000, these losses were valued at $10,101,000.

The increase in coyote depredations on cattle in the eastern United States correlates with coyote range expansion and population growth during the past 20 years. The southern front of coyote range expansion swept across the southeastern states during the 1960s (Parker, 1995). This front then expanded further north and east through Tennessee and Kentucky during the 1970s and 1980s. Finally, during the late 1980s and early 1990s, coyotes colonized Virginia, West Virginia and the Carolinas. Coastal areas in the mid-Atlantic region have only recently seen large numbers of coyotes. Once established, coyote populations have increased. For example, coyote harvest data in Mississippi, increased from 1,200 in 1980 to 40,000 in 1989 (Bourne, 1991). Harvest of coyotes by hunters and trappers in Pennsylvania and Virginia suggests exponential growth in coyote populations in these states during the 1980s and 1990s (Witmer and Hayden, 1992; Wright et al., 1999). These increases in coyote populations correlate with the increase in cattle/calf depredation reported by NASS. By 1991, cattle/calf depredations by coyotes in the southeast United States were already equivalent to the national average (Figure 4). These losses continued to increase dramatically during the 1990s, exceeding the national average by 2000. In the mid-Atlantic region, cattle/calf depredation increased from almost immeasurable numbers to equal the national average between 1991 and 2000, reflecting the increase of coyote populations in this sub-region during the 1990s. Cattle/calf losses in the New England states were minimal.

Within the mid-Atlantic region, the relationship among coyote range expansion, coyote population growth, and cattle depredation is further illustrated. As coyote numbers increased within central Appalachia, coyote depredations increased three-fold (Fig. 5). Measurable levels of coyote depredations on cattle/calves in the Carolinas were not detected until the NASS survey in 2000 and the coastal states of New Jersey, Maryland and Delaware have yet to experience noticeably increased levels of coyote depredation (Figure 5). There are anecdotal reports in the western United States that coyote depredation on cattle is increasing as sheep numbers decline (sheep being relatively preferred prey); the Utah WS program recorded a 700-percent increase in requests for protection from cattle producers between 1998 and 2001 (M. Bodenchuk, USDA-APHIS-WS, personal communication). Evaluation of depredation by coyotes on cattle in the

Figure 3. Cattle/calf inventory and percent inventory lost to coyote depredations in the southern/eastern United States.

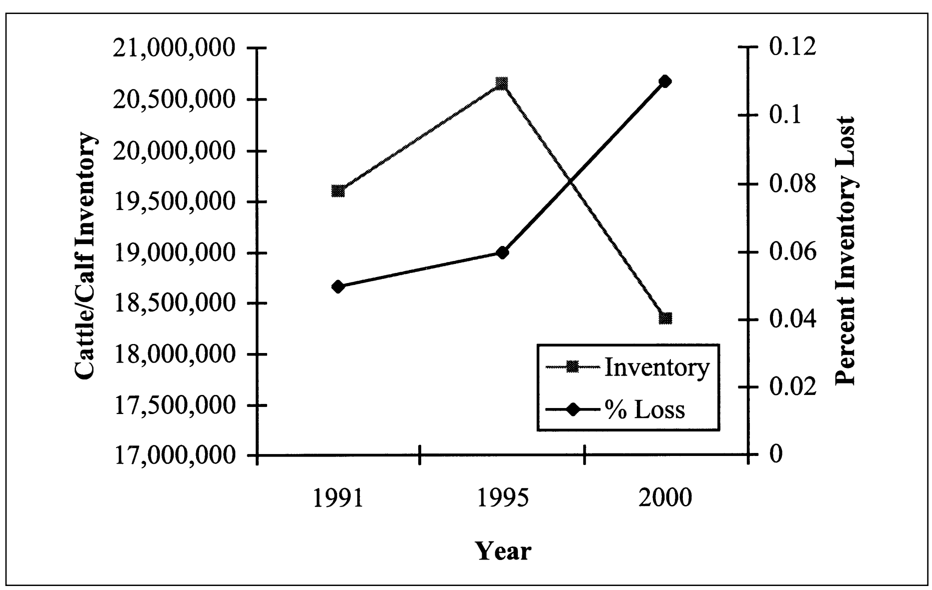


Figure 4. Number of cattle/calves killed by coyotes in the New England, Mid-Atlantic, and Southeast sub-regions of the eastern United States.

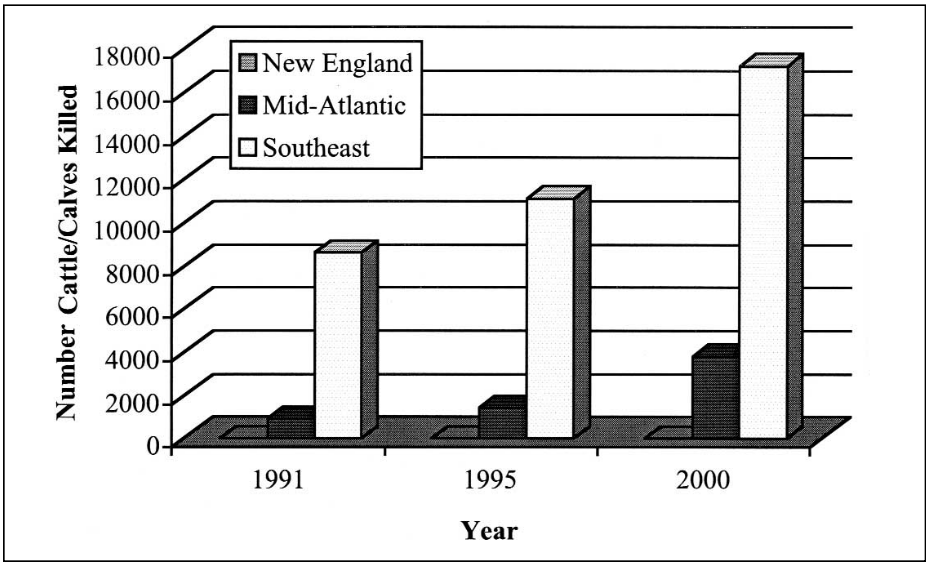


Figure 5. Number of cattle/calves killed by coyotes within the Mid-Atlantic sub-region.

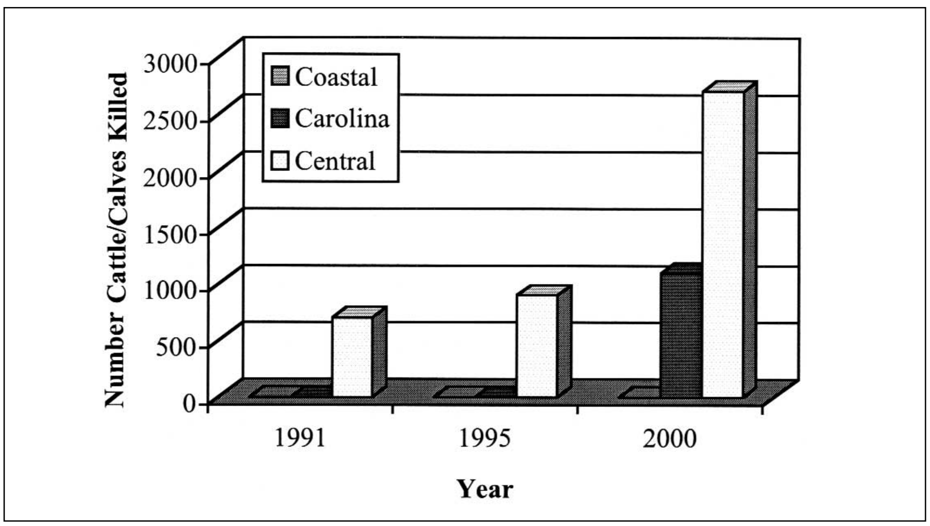
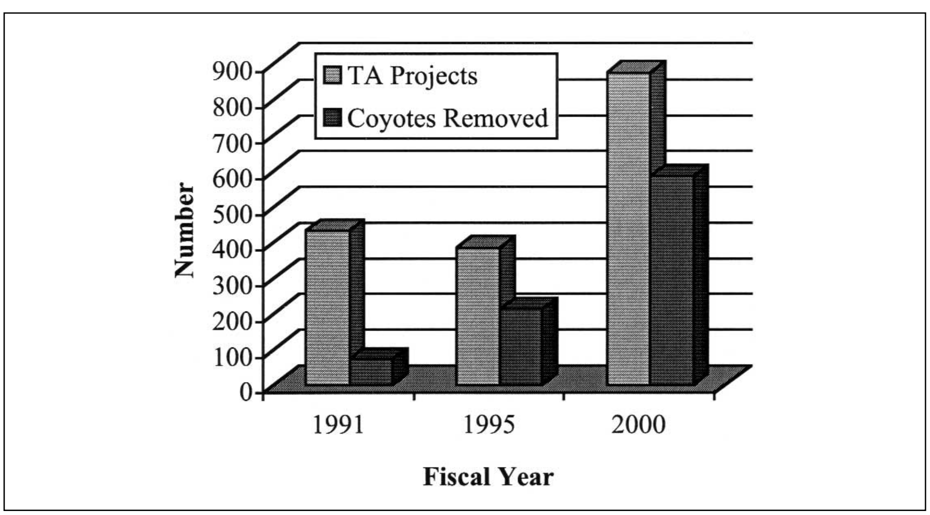


Figure 6. Technical assistance requests and number of coyotes removed by WS in the eastern United States.



eastern United States is complicated by the possibility the eastern coyote has developed behavioral and morphological modifications that enhance its ability to successfully prey on larger animals (Parker, 1995).

The impact of coyotes on livestock in the eastern United States is also reflected in the number of requests for assistance WS Eastern Region receives annually from the public. The number of technical assistance projects and the number of coyotes removed by WS Eastern Region programs increased during the 1990s (Fig. 6). During 2000, WS Eastern Region programs received 874 requests from the public for technical assistance over coyote damage. The number of coyotes removed by WS Eastern Region programs increased from 72 in 1991 to 585 in 2000. This increased take of coyotes is reflective of both increased program field efforts and increases in coyote populations in the East. These two parameters further illustrate the increasing concern by the public over coyote depredations and need for assistance.

Integrated Predation Management Programs

IWDM programs were established in Virginia and West Virginia to protect sheep, goats, and cattle in 1990 and 1996, respectively. These programs, administered by WS, involve the implementation of non-lethal (e.g., improved husbandry practices, predator resistant fencing, predator frightening devices, livestock guarding animals) and lethal (e.g., calling and shooting, traps, snares, M-44s, livestock protection collars) management techniques. Up to 14% (range 1.1% to 14.2%) of the sheep producers in these states use WS IWDM programs each year (Table 1). The number (percent) of sheep producers availing themselves of the WS program is somewhat dependent on the ability of the program to respond. In Virginia, between 1990 and 1997, approximately 1.5 employees were funded to provide service. This level of staffing was able to provide assistance to 1.1% to 2.0% of the sheep producers. The number of sheep producers utilizing the IWDM program increased (4.8% to 7.5%) in Virginia after 1998 as the number of Wildlife Specialists increased to 2.5 to

Table 1. **Number of sheep operations receiving assistance from the WS IWDM programs in Virginia and West Virginia, 1990-2002.**

	VIRGINIA			WEST VIRGINIA		
Year	Number of Sheep Operations*	Number Producers Assisted (%)	Number WS Specialists	Number of Sheep Operations*	Number Producers Assisted (%)	Number WS Specialists
1990	2,500	44 (1.8)	1.0	2,000	___	___
1991	2,400	50 (2.1)	1.0	1,900	___	___
1992	2,200	35 (1.6)	1.0	1,800	___	___
1993	2,100	24 (1.1)	1.0	1,700	___	___
1994	2,000	41 (2.1)	1.0	1,500	___	___
1995	1,900	28 (1.5)	1.5	1,600	___	___
1996	1,900	56 (2.9)	1.5	1,400	40 (2.9)	3.0
1997	1,800	49 (2.7)	2.0	1,300	56 (4.3)	3.0
1998	1,500	72 (4.8)	2.5	1,100	85 (7.7)	3.0
1999	1,300	84 (6.5)	2.5	1,000	104 (10.4)	3.5
2000	1,300	67 (5.2)	3.5	1,000	110 (11.0)	3.5
2001	1,400	83 (5.9)	3.5	1,000	142 (14.2)	4.0
2002	1,500	113 (7.5)	3.5	1,100	124 (11.3)	4.0

*Source: National Agricultural Statistics Service state livestock inventories for Virginia and West Virginia, 1990-2002.

3.5 employees. A similar pattern occurred in the West Virginia IWDM program. Sheep producers receiving assistance from the West Virginia IWDM program increased from 2.9% to 14.2% as the number of Wildlife Specialists increased. These numbers likely reflect both the ability of WS to respond to demand for service and the growing need for coyote depredation management.

Both Virginia and West Virginia WS programs have reduced the number of sheep lost per producer on farms receiving IWDM services (Table 2). The number of sheep lost per farm is lower than would be expected if predation management programs were not in place. The rate of predator losses in the absence of a predation management program ranged from 1.4% to 8.1% for adult sheep and from 6.3% to 29.3% for lambs in several studies (Table 3). Based on the NASS (1999) report, predation losses averaged 1.6% of adult sheep and 6.0% of the calculated lamb crop when a blend of non-lethal and lethal control strategies were used.

Savings attributed to WS IWDM programs to protect sheep in Virginia and West Virginia can be calculated using the NASS (1999) predation loss survey and state sheep inventory data (Table 4). The Virginia and West Virginia WS expenditure for predator damage management to protect sheep in FY

Table 2. Average number of sheep killed by coyotes per sheep producer receiving assistance from the Virginia and West Virginia IWDM programs, 1990-2002.

	VIRGINIA			WEST VIRGINIA		
Year	Sheep Killed	Producers Assisted	Sheep Killed/Farm	Sheep Killed	Producers Assisted	Sheep Killed/Farm
1990	555	44	12.6	___	___	___
1991	569	50	11.4	___	___	___
1992	623	35	17.8	___	___	___
1993	404	24	16.8	___	___	___
1994	363	41	8.8	___	___	___
1995	191	28	6.8	1,111*	40*	27.8
1996	402	56	7.2	101	40	2.5
1997	250	49	5.1	240	56	4.3
1998	229	72	3.2	460	85	5.4
1999	448	84	5.3	385	104	3.7
2000	337	67	5.0	288	110	2.7
2001	187	83	2.3	490	142	3.5
2002	234	113	2.1	129	124	1.0

* Represents the number of livestock producers contacted from April through September, 1996, and their reports of livestock lost for predations in the twelve months prior to April, 1996, before WS initiated predation management.

Table 3. Predator losses in the absence of a predation management program.

Source	Location	Year	Sheep lost %	Lambs lost %
Henne (1977)	Montana	1974	8.4	29.3
Munoz (1977)	Montana	1975	3.7	24.4
McAdoo and Klebenow (1978)	California	1976	1.4	6.3
Delorenzo and Howard (1976)	New Mexico	1974	not reported	12.1
Delorenzo and Howard (1976)	New Mexico	1975	not reported	15.6

Table 4. Savings attributed to USDA-APHIS-Wildlife Services (WS) predation management programs in Virginia and West Virginia, calculated from statistics compiled by the National Agricultural Statistics Services (1999).

Sheep and lambs	NASS Inventory	NASS Actual losses with WS program (%)	NASS Projected losses without WS program (%)	Difference	Average 1999 $ value/head	Total saved
VA Sheep	65,000	400 (0.6)	3,705 (5.7)	3,305		$ 274,315
VA Lambs	50,000	1,500 (3.0)	8,750 (17.5)	7,250		601,750
WV Sheep	40,000	300 (0.7)	2,280 (5.7)	1,980	$83	164,340
WV Lambs	36,000	1,800 (5.0)	6,300 (17.5)	4,500		373,500
TOTAL	**191,000**	**4,000**	**21,035**	**17,035**		**$1,413,905**

1999 was $532,000. The total benefit ($1,413,905) of these programs would indicate a 2.66:1 benefit cost ratio. This benefit is conservative, since the cost savings do not include projected losses to cattle and goats. Both Virginia and West Virginia provide assistance to cattle and goat operations, which were not included in this analysis. The marketing of the animals saved as a result of predation management benefits many segments of the rural economy, and not just individuals involved in direct production. Jahnke et al. (1987) reported a three-fold economic multiplier effect for the benefits of predation management in Wyoming. If this multiplier is applied to the total value of sheep saved in Virginia and West Virginia, then the value of predation management to businesses not involved in direct agricultural production would be $4,241,715. The gross total benefit to all segments of the Virginia and West Virginia economy would be $5,655,620.

Conclusions

NASS surveys of sheep and cattle predator loss during the 1990s and WS program records provide insight into the impact of coyotes on livestock in the eastern United States. Earlier concerns that coyote depredations in the eastern United States would increase and have an economically meaningful impact on sheep and other livestock industries (Slate, 1987; Witmer and Hayden, 1992; Witmer et al., 1995) were well-founded. Coyote depredations on livestock increased significantly between 1990 and 2000. In Virginia and West Virginia, coyote depredations on sheep increased to the point that IWDM programs have been established to manage damage. The available evidence suggests that these programs are both efficient and economical for the producers served. In Ohio, New York, Pennsylvania, North Carolina, and South Carolina both sheep and cattle losses to coyotes appear to be reaching levels that will justify the creation of IWDM programs. The increase in coyote depredations on cattle in the mid-Atlantic region may be related to decreasing sheep inventories and increasing coyote populations as appears to be the case in some western states. Cattle losses to coyotes in the southeastern United States have exceeded the national average. These trends are likely to continue in the future. Coyote depredation on livestock in the eastern United States may eventually become a problem for producers on par with losses traditionally experienced by producers in the western United States.

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Coyote in the Edwards Plateau of Texas — an Update

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Introduction

In the early 1900s, organized predator control was initiated to remove coyotes and wolves from the sheep- and goat-producing areas of Texas. Operations were begun in the Edwards Plateau, the largest area of sheep concentration. The Edwards Plateau and, to a lesser extent, portions of other adjoining ecological areas presently account for 18% (1.2 million head) of the sheep and lambs and 85% (1.2 million head) of the goats in the United States (Texas Agriculture Statistics Service, 2004). These numbers are down in both actual numbers and as a percent of the national flocks. It is important that the industries be protected and preserved. The inventory and distribution of sheep and goats by counties in 2003 is reflected in Figures 1 and 2. The Edwards Plateau itself encompasses about 24 million acres of "Hill Country" in West-Central Texas comprising all or portions of 37 counties (Fig. 3). By the 1920s, many of the interior Edwards Plateau counties were considered to be free of coyotes and wolves.

In 1950, there were 33 counties covering nearly 24,000,000 acres, which were considered to be coyote free (Fig. 4). This area remained virtually void of coyotes for several decades until their encroachment began in the 1960s. This process has been described by several authors (Caroline, 1973; Shelton and Klindt, 1974; Hawthorne, 1980; Nunley, 1985; Nunley, 1995a). The purpose of this paper is to review and update the progress of the re-establishment of coyotes into the Edwards Plateau of Texas, since that reported by Nunley (1995a). This area is historically and currently unique due to its unsurpassed intensive level of coyote control over an extensive area.

Organized Predator Control

The predecessors of what is currently known as the cooperative Texas Wildlife Services Program have been involved in providing predatory animal control services for the last eighty years. This cooperative wildlife damage management agency is comprised of the Wildlife Services Program of USDA's Animal and Plant Health Inspection Service, the Texas Cooperative Extension Service of the Texas A&M University System, and the Texas Wildlife Damage Management Association.

Figure 1. Distribution of sheep and lambs in Texas (Texas Agricultural Statistics Service 2003).

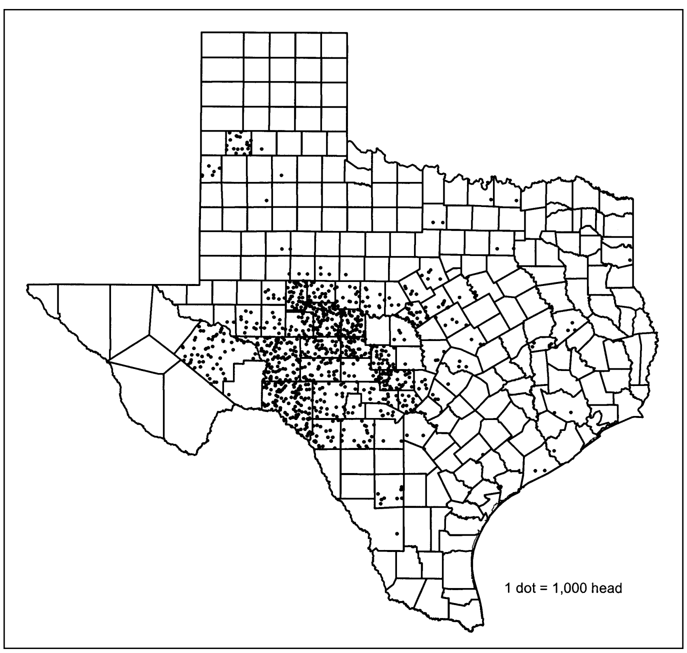
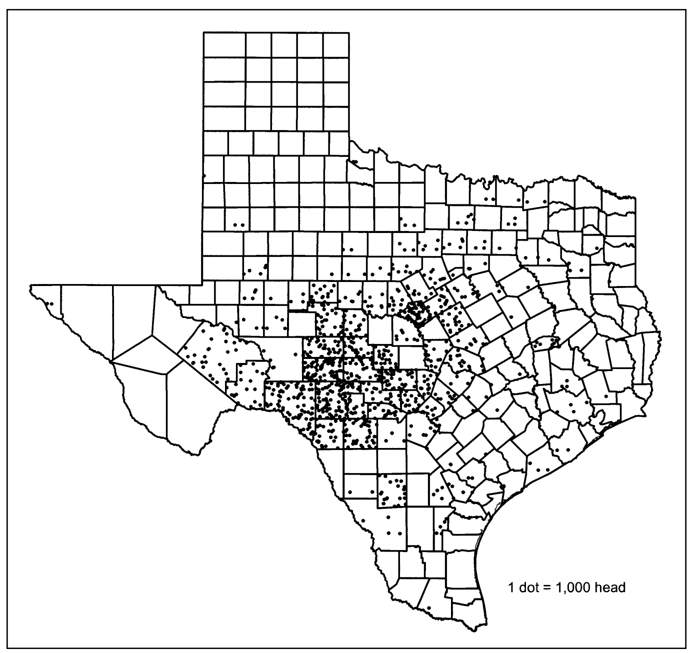


Figure 2. Distribution of all goats in Texas (Texas Agricultural Statistics Service 2003).



Extirpation of Coyotes

The coyote and wolf take by county of the organized control program during fiscal year 1950 is reflected in Figure 5 (Landon, 1950). This categorized illustration of the number of animals taken per county provides a relatively representative picture of the re-establishment of coyotes into the Edwards Plateau when examined every tenth year. Those counties within the sheep and goat production areas, which indicate no "take," either had no program or had a program and did not take any coyotes. In either case, this usually indicated that few coyotes, if any, were present in those counties at that time.

In the predatory animal control agency's 1958 annual report, the status of coyotes and wolves in the Edwards Plateau in the 1950s was reported as follows (Landon, 1958):

In those counties where the sheep and goat industry is a major importance the coyotes have been practically eradicated, and they were well under control even in the border counties. The gray or lobo wolf is no longer found in Texas. The Texas red wolf of central and east Texas is no longer numerous where the hog, turkey and cattle raisers show much more interest in control than formerly.

Caroline (1973) cited several reasons why this early control work in the

Figure 3. Texas ecological regions.

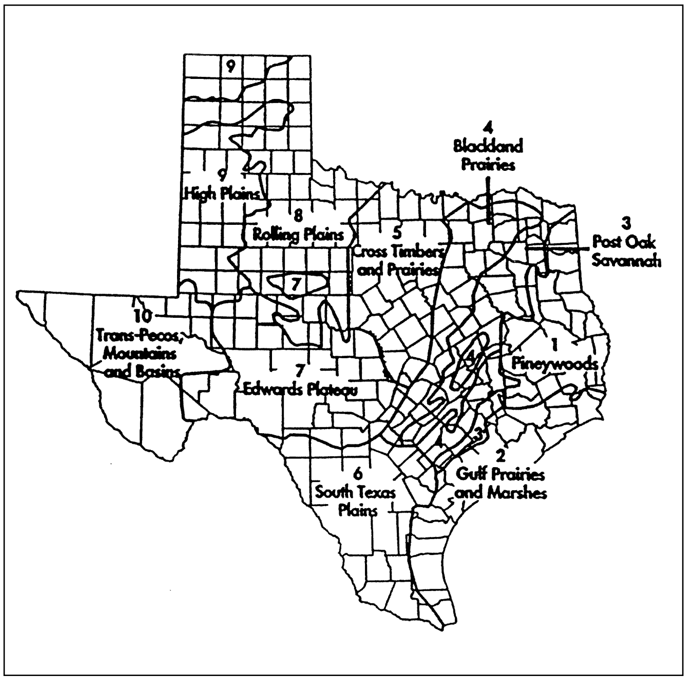


Figure 4. Coyote-free Texas counties in 1950 (about 24 million acres).

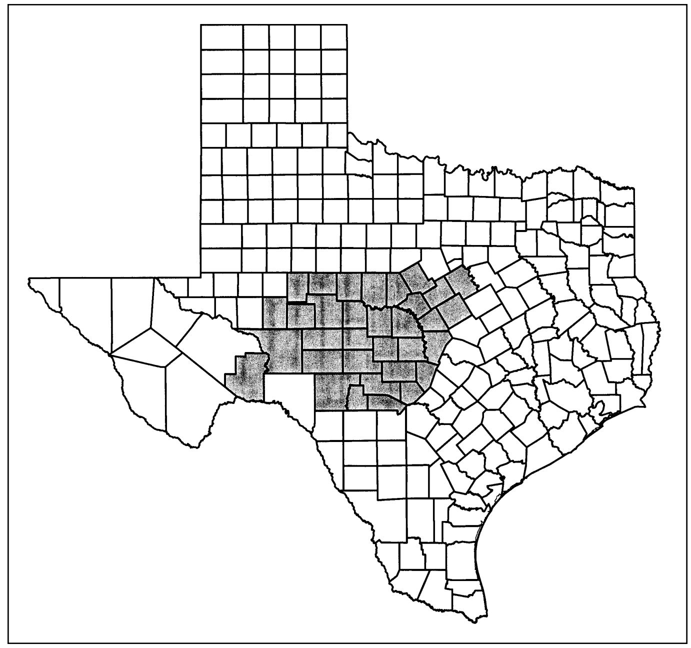


Figure 5. Coyote and wolf take of the Texas cooperative damage management program in 1950.

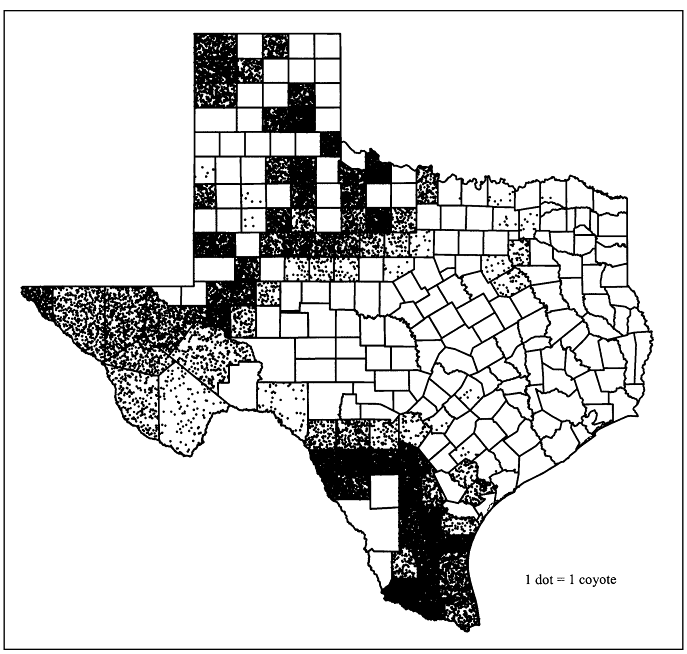
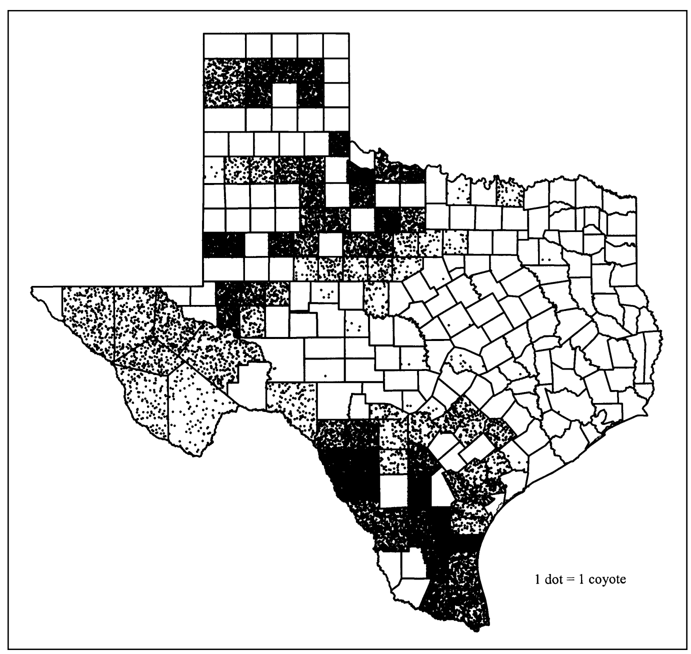


Figure 6. Coyote and wolf take of the Texas cooperative wildlife damage management program in 1960.



Edwards Plateau was successful: (1) the wild canid population contained a large proportion of red wolves or hybrids, which were relatively easy to capture; (2) many ranchers participated with professional animal damage control staff; (3) the increased use of net-wire fencing; (4) many ranchers kept hounds to remove coyotes; (5) economic incentives to ranchers; and (6) extensive use of traps. Shelton and Klindt (1974) suggested that the success of early control work resulted from a "massive human effort using all of the tools and techniques which could be brought to bear."

Re-Establishment of Coyotes

In fiscal year 1960, 118 coyotes were taken from within the former coyote-free area. Nearly 31,000 coyotes were taken from throughout the coyote's range in Texas during that same year, double the number taken in 1958. The explanation for this very conspicuous upswing in coyote numbers is not fully understood, but may have been in response to the drought-breaking rains of the late 1950s, which resulted in a dramatic increase in available prey. These rains provided an exceptional environment of food, water and cover, which was relatively absent during the drought, for the coyote's prey species. Populations of one prey species in particular, the Hispid cotton rat, erupted to unbelievable numbers with estimates as high as several hundred rats per hectare (W. B. Davis and D.J. Schmidly, 1994). In years of high rodent density, it is known that coyote liter sizes increase and more females, especially yearlings, breed. This relative coyote population increase, in response to an increasing food supply, was probably a major factor when an unprecedented 34,754 coyotes were taken in 1962. Coupled with this increase in the coyote population was the effect that the drought had on the sheep and goat industry itself. Shelton (2004) observed that the drought of the '50s caused a marked reduction in the number of sheep and goats, livestock producers, as well as the number of ranch hands involved in livestock care. Livestock producers also worked off the property or were involved in other pursuits resulting in fewer people living on range lands or involved in sheep and goat production (Shelton, 2004). Thus, many factors came together to facilitate the movement of coyotes back into the principal sheep and goat production area of the Edwards Plateau. The relative intensity and distribution of the coyote and wolf taken by the organized control program during fiscal year is reflected in Figure 6 (Caroline, 1960). It has been shown (Shelton and Klindt, 1974) that livestock losses (especially lambs) is greater in areas of coyote encroachment and that the decline in number of sheep and goats are accelerated.

In fiscal year 1970, 420 coyotes were taken from within the former coyote-free area, and the distribution of coyotes within the Edwards Plateau area continued to expand (Caroline, 1970) (Fig. 7). In 1972, the use of chemical toxicants for predator control, such as strychnine and 1080 (sodium monofluroacetate) were canceled by EPA. The use of 1080 on the periphery of the major sheep- and goat-production areas was successfully utilized to prevent or reduce the infiltration of coyotes into these regions. The protection of sheep and goats from predators has since been limited to more manpower-intensive control tools, which include traps, snares, shooting, calling, aerial hunting and M-44 devices utilizing sodium cyanide.

Caroline (1973) described the status of the coyote within the Edwards Plateau in 1973 as follows:

In 1950 coyotes were a rarity in the heart of the Hill Country. On occasion a single animal would appear in the western part of the area but it was soon removed. Along the South Pacific tracks west of San Antonio ranchers to the north were interested in control south of the tracks, and for many years this was sufficient. Although much land improvement took place, "wolf-proof" fences were allowed to deteriorate.

Figure 7. Coyote and wolf take of the Texas cooperative wildlife damage management program in 1970.

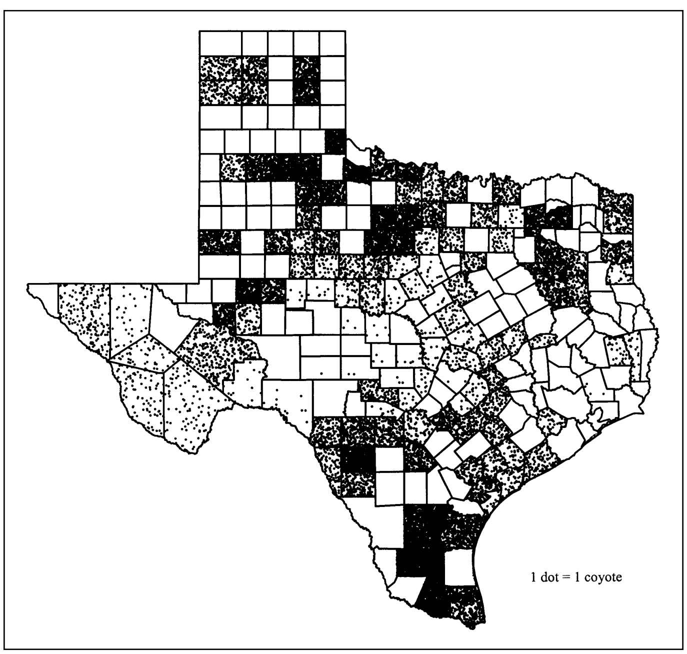
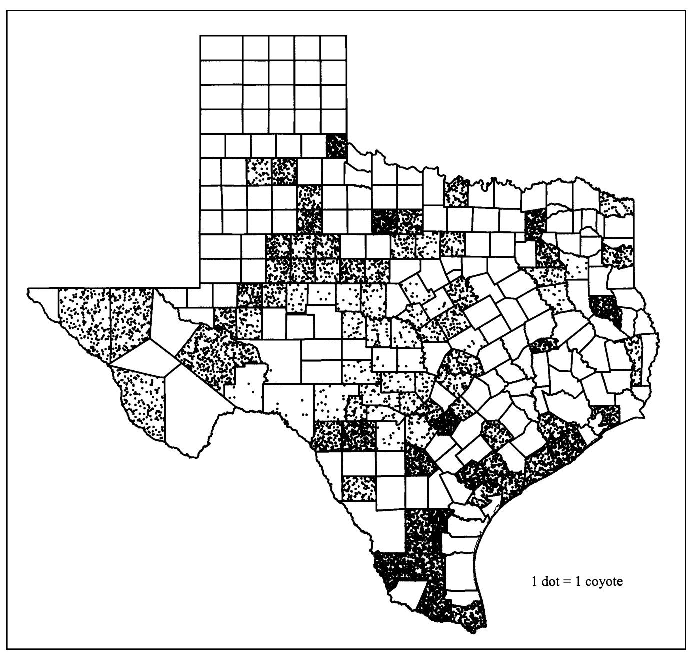


Figure 8. Coyote take of the Texas cooperative wildlife damage management program in 1980.



Coyotes could enter any pasture. (This is an important part because removal of the wolves was half due to fencing and half to organized control). For some time there was no one who recognized this fact. Losses were light and what were found were usually attributed to bobcats, foxes, and raccoons. By the time it was known that coyotes were present, there were far more of them than anyone expected. Consequently, today and in some cases as late as this year, there are coyotes in every formerly coyote-free county in the heart of sheep and goat country.

The re-establishment of coyotes within the Edwards Plateau had further progressed by fiscal year 1980 as reflected by Figure 8 (Hawthorne, 1980). A total of 637 coyotes were taken from within the former coyote-free area. This continued encroachment of coyotes into the sheep- and goat-production areas had become a serious concern. In 1981, a request for the emergency use of Compound 1088 bait stations as per Section 18 of FIFRA was prepared and submitted to EPA for consideration (Nunley, 1981). The request was eventually denied by EPA after a lengthy administrative hearings process. In fiscal year 1990, 2,168 coyotes were taken from within the former coyote-free area (Nunley, 1990) (Fig. 9). In fiscal year 1994, the cooperative program provided

Figure 9. Coyote take of the Texas cooperative wildlife damage management program in 1990.

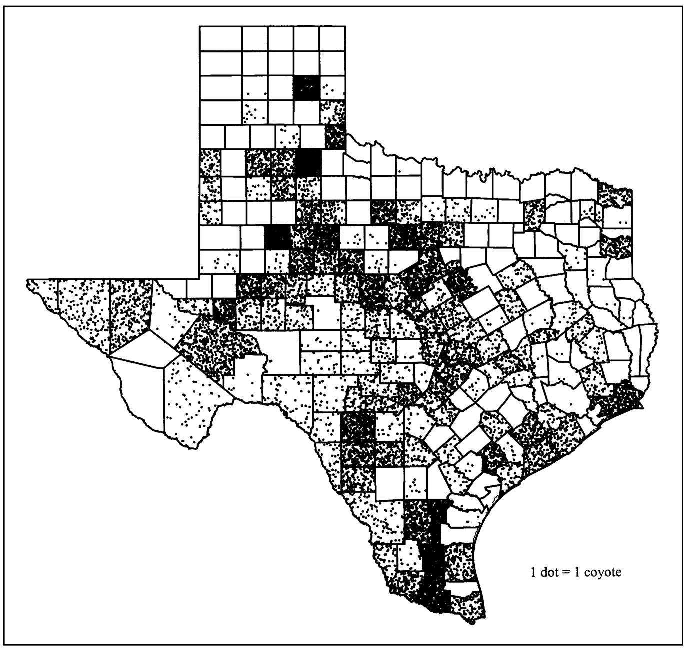


Figure 10. Coyote take of the Texas cooperative wildlife damage management program in 2000.

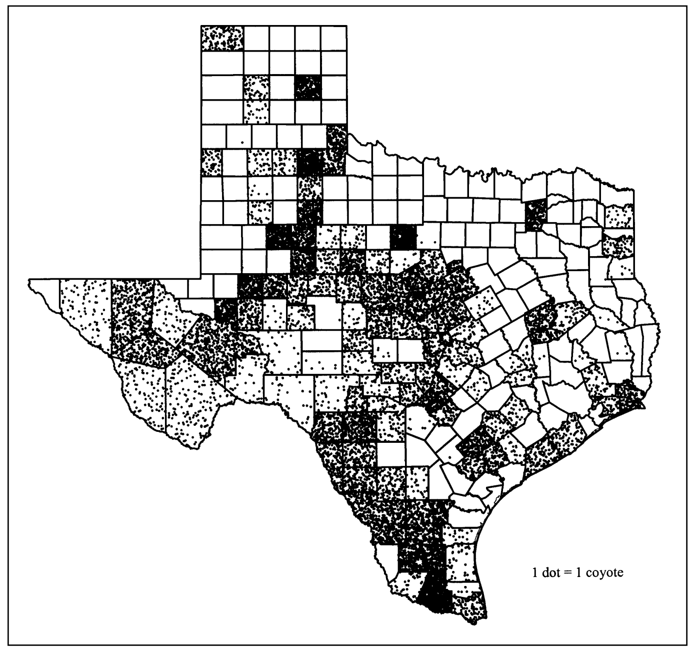


Figure 11. Coyote take of the Texas cooperative wildlife damage management program in 2003.

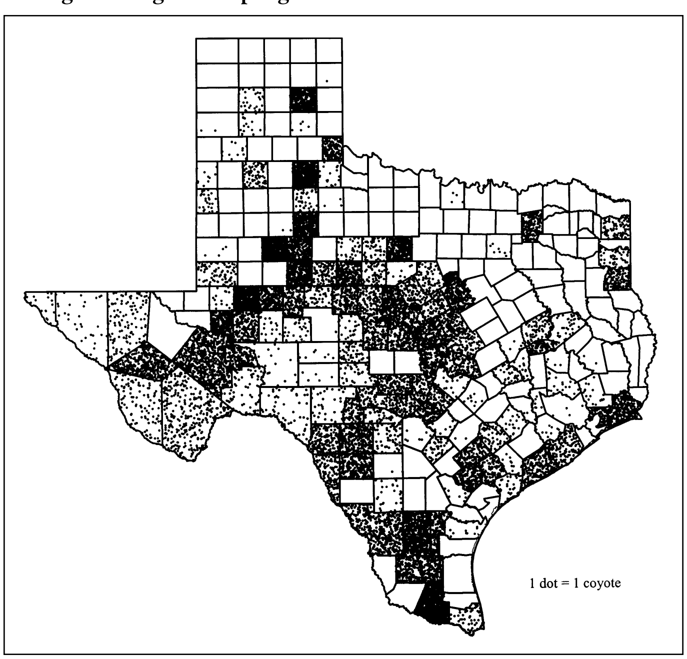
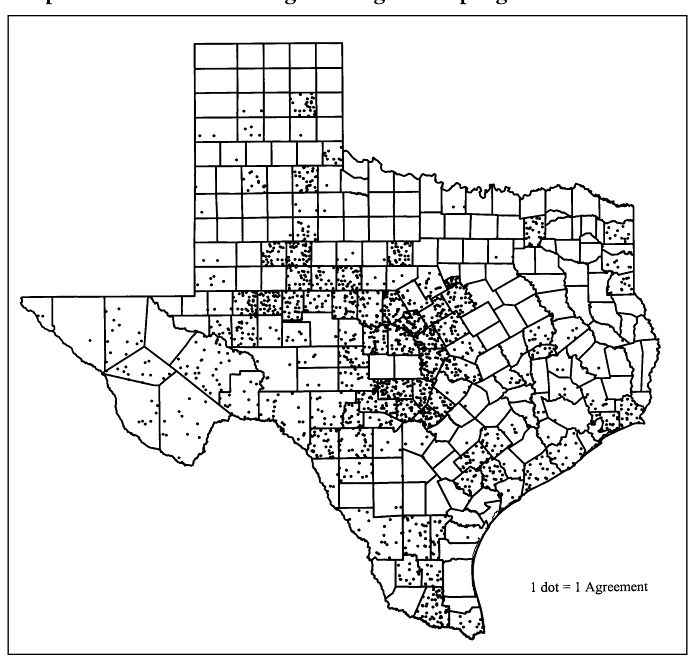


Figure 12. Properties where coyotes were taken by the Texas cooperative wildlife damage management program in 2003.



predator damage management services on 7.5 million acres within the former coyote-free area. This was a 64% increase over the acreage worked in fiscal year 1984. The primary reason behind this additional control effort was related to the increasing exposure of additional livestock to coyote predation. This exposure is directly related to the relative degree and geographical distribution of the coyote's movement into the Edwards Plateau.

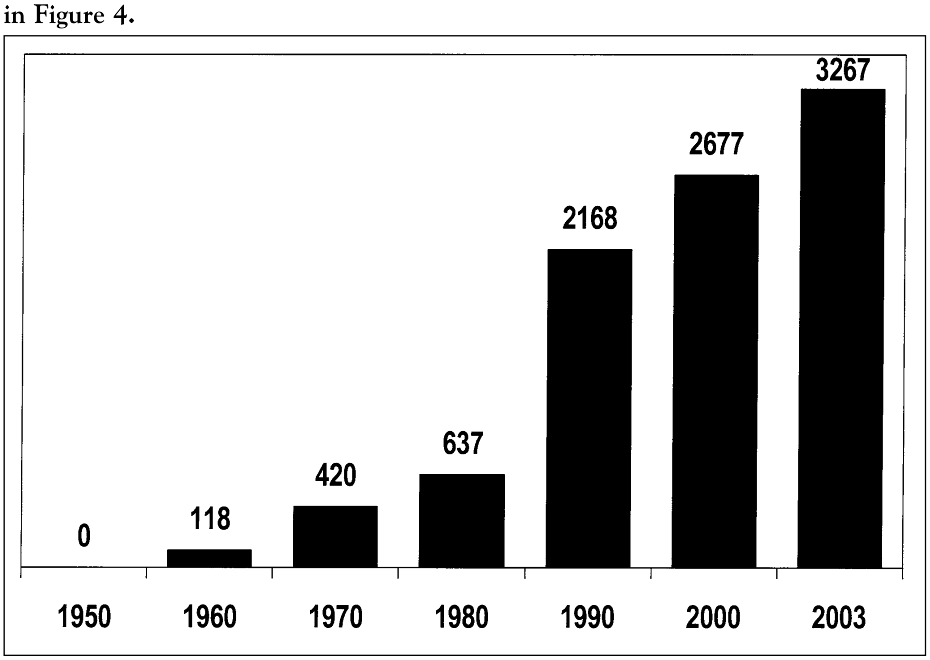
Present Status of Coyotes

Coyote take within this area continues to increase, as reflected by the take of 2,677 coyotes in fiscal year 2000 (Fig. 10) and 3,267 in fiscal year 2003 (Fig. 11). The distribution of properties worked, where coyotes were taken in fiscal year 2003, is also reflective of the presence of coyotes throughout the area (Fig. 12). While the take of coyotes in the area has increased for the past fifty years (Fig. 13), the acres worked by the cooperative program in FY 2003 reflected a reduction of 10% from the area worked in fiscal 1994. This is primarily related to fewer numbers of sheep and Angora goats within each county. Eighteen of the 33 counties in the area had decreased acreages worked, and the remainder had increased acreages worked. All of which is reflective of the further movement of coyotes into sheep and goat areas, which is facilitated by a combination of factors as described below.

Factors Responsible for Coyote Re-Establishment

The range expansion of coyotes within the Edwards Plateau is directly related to the presence, viability, and geographical distribution of the sheep and goat industry as previously indicated. Gee, et al. (1977) also surveyed former sheep producers in Colorado, Texas, Utah, and Wyoming who had terminated sheep production. Factors which they rated of greatest importance in their decisions to discontinue sheep production were (1) high predation losses, (2) low lamb and wool prices, (3) shortage of good hired labor, (4) the sale of their land, and (5) their own age. Predation losses due to the limitations and cost of the application of current predator-control techniques has also contributed to the decline in the number of sheep and goats in Texas (Nunley, 1995b). The loss of toxicants in 1972 greatly reduced the efficiency and effectiveness of coyote control over large areas. However, in more recent years, the loss of the wool- and mohair-incentive program greatly influenced and accelerated the inventory decline of sheep and Angora goats.

Figure 13. Trends in the number of coyotes taken by the Texas cooperative wildlife damage management program within the formerly coyote-free area shown in Figure 4.



Another major factor for declining sheep and goat production on the eastern periphery, and increasingly in all areas of the Edwards Plateau, has been the changing land use away from sheep and goat production. This occurs through the sale of properties due to economic pressures, especially near urban centers and recreational areas. This results in the fragmentation of rural lands into smaller parcels, which generally are too small to maintain the economy of scale for traditional farming and ranching (Wilkins et al., 2000). It often follows that the new land managers and absentee landowners do not pasture sheep or goats, or in many cases, do not allow coyote-control activities on their properties. Consequently, sheep and goat producers who border, or are surrounded by properties where coyote control is not conducted, bear the brunt of the coyote predation. These producers on the fringe of the sheep- and goat-production area find that it is very difficult to control losses to predators on their ranges (Nunley, 1995).

Prognosis for the Future

Since the majority of the factors, especially in regards to land use, will continue and most likely accelerate in the future, coyote damage management options will become increasingly challenging. Additional sheep and goat producers who have not had any or little problems with coyote predation in the past will have in the future, as the distribution and abundance of coyotes within the Edwards Plateau continues to increase.

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Coyote Predation Management: An Economic Analysis of Increased Antelope Recruitment and Cattle Production in South Central Wyoming

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Keywords: Antelope, Coyote, Cost-Benefits, Economics, Predation Management

Introduction

In 1999, a project was implemented for the protection of antelope fawns in two areas of Carbon County, Wyoming. The project was funded by the Wyoming Animal Damage Management Board (ADMB) for the benefit of two antelope areas that were having trouble rebounding to their normal population levels after the severe winters of 1991 and 1992. While the Wyoming ADMB project's main focus was on enhancing pronghorn antelope fawn recruitment, the benefits of coyote population management could have "spillover" benefits to cow/calf producers in the coyote removal areas.

With the decline of the value of coyote fur in the late 1980s, coyote populations have increased in many areas of Wyoming, including ADMB area 63 and ADMB area 55, the two geographic areas in the study (Merrell and Shwiff, in review). ADMB area 61, another geographic area, was the control site. At the ADMB two predator management sites, there are, on average, 4,095 cows giving birth every spring. Since the decline of the sheep industry in these areas in the mid-1970s, no significant coyote management had been conducted. A study on the relationship of coyotes to mule deer fawn recruitment, done on and around area 63 in 1976-79, estimated the area's coyote population at 1 coyote/20.6 square miles (Springer and Wenger, 1981). Population data from the ADMB project for pre-treatment coyote populations in 1999 were 1 coyote/2.2 square mile, a nine-fold increase (Merrell and Shwiff, in review).

Prior to 1972, coyote populations had been suppressed by the use of broad-based poisons such as 1080, thallium and strychnine. After the ban on poisons, coyote populations continued to be suppressed by people hunting and trapping for fur. Many cow/calf producers who historically had been operating in low-coyote population densities, felt that coyote predation on calves was not at a level to cause concern. Our study suggests that these coyote populations should be a serious economic concern to both the producer and the consumer.

Methods — Study Areas

ADMB area 61 is the geographic control area. It is in west-central Carbon County and generally comprises Wyoming Game and Fish antelope hunt unit 61. Hunt unit 61 differs on the south end from ADMB area 61 because of ongoing predator control for livestock protection south of Mineral X Road (Carbon County Road 63). Area 61 is bordered on the south by Mineral X Road, the west by the Jeffery City/Wammsutter Road (Carbon County Road 23-N), the north by the Bairoil Road (Carbon County Road 22) and the east by Wyoming Highway 289. There are 90,133 ha (348 mi^2) in area 61, including 5,892 ha (22 mi^2) of patented land, 3,528 ha (13 mi^2) of state land and 80,712 ha (311 mi^2) of public land administered by the BLM. The area is predominately used for grazing cattle. There are some mineral uses, especially in the northeast corner of the unit, and one human habitation.

Area 61 was chosen for its similarity to the treatment units in habitat, weather and grazing patterns. There had been almost a total lack of predator control within its boundaries during the previous 10 years due to the lack of lambing and calving in the area. There had been some selective coyote control done in the previous five years along a 24-km stretch of Wyoming Highway 287 for the removal of depredating coyotes on sheep that grazed east of the highway.

ADMB area 55 is the southern treatment unit and corresponds with Wyoming Game and Fish antelope hunt unit 55. It is bordered on the north by Interstate 15, the east by the drainage divide of Atlantic Rim, the south by Muddy Creek and on the west by Wyoming Highway 789. There are a total of 92,982 ha (359 mi^2), including 46,556 ha (179 mi^2) of patented lands, 7,964 ha (30 mi^2) of state lands and 38,462 ha (148 mi^2) of public land administered by the Bureau of Land Management (BLM). Lands within area 55 are predominantly grazing lands used by cattle. Portions of area 55 are oil and gas leases and are currently under use. Three human habitations (seasonal cow camps) exist in the area.

ADMB area 63 is the northern treatment unit. It is the northern portion of Wyoming Game and Fish antelope hunt unit 63. It also encompasses a small portion of antelope hunt unit 68 on the north side of Wyoming Highway 220. It is bordered on the north by the Sweetwater River, on the east by the banks of Pathfinder Reservoir and the North Platte River, on the south by the drainage divide of that portion of the Seminole Mountains located on the west side of the North Platte River and Ferris Mountain, and on the west by Muddy Creek, at Muddy Gap Junction north to the Sweetwater River. There are a total of 95,184 ha (367 mi^2) in area 63, consisting of 14,504 ha (56 mi^2) of patented lands, 8,935 ha (34 mi^2) of state land and 71,744 ha (277 mi^2) of public land administered by the BLM. Lands within area 63 are used for grazing cattle. There are no mineral leases in operation. There are eight inhabited locations, including six cattle-ranch headquarters and two historical sites.

There are many similarities between the two treatment areas, including size and ecological composition, which is partially why they were chosen as treatment areas. The average budget allocated to coyote removal over the two years in each area is also similar, with area 63 having an average budget that is 7 percent greater than area 55. The average number of coyotes removed in both areas over the two-year period is similar (130 in area 55 and 126.5 in area 63).

Baseline data on coyote abundance was established prior to treatment. Merrell and Shwiff (in review) surveyed many census techniques and after assessing each method the siren-elicited-response method was chosen. This method required minimum personnel, could be accomplished in a short amount of time, and one of the authors (Merrell) had experience in estimating the numbers of individuals involved in a group howl.

Coyotes were removed from area 55 and area 63 each year of treatment primarily by aerial hunting from fixed winged aircraft. Some M-44's were placed in area 63 for livestock protection. During 2002, some denning was used in each treatment area to supplement aerial operations. Aerial operations were conducted beginning in January, 2001 and continued until May, 2001 the first year. Post-treatment coyote populations remaining in the treatment areas were estimated using a formula comprised of the known number of coyotes seen versus estimated population expressed as a percentage, (first year of treatment), extrapolated over to the second year of treatment. We assume that the same amount of effort expended over the same amount of area would result in the same percentage of the coyote population being viewed. Using data supplied by the pilots during aerial operations, we were able to estimate the coyote population each year after treatment had begun.

Economic Analysis

The economic analysis for pronghorn antelope indicated that coyote management for the protection of antelope increased recruitment and led to a positive net benefit for Wyoming (Merrell and Shwiff, in review). For this economic analysis, we applied a benefit-cost model, which attempted to determine the net benefit to Wyoming in monetary terms, based on the gross benefits and costs given coyote predation management on cattle in both treatment areas and cattle and antelope in one of the treatment areas. The benefit-cost analysis (BCA) follows the framework outlined in Engeman et al. (2002).

The BCA of coyote management involves estimating the monetary value of the benefits measured in the dollar value of cattle saved by reduced coyote predation versus the costs measured in the amount spent to remove coyotes. The determination of the monetary values of pronghorn antelope was assumed to fall within the civil penalties, which can range from $400 to $10,000 for an illegal take. In particular, the Wyoming Game and Fish Department estimates the economic value of each antelope to the state at $3,000 in 2003 dollars (Wyoming Game and Fish Department, personal correspondence). We used four different antelope values ($400, $1,500, $3,000 and $10,000) to estimate the benefits and costs of coyote management, allowing for an economic sensitivity analysis (Bodenchuk, et al, 2003). The dollar value was considered consistent across time periods and was not adjusted for inflation given the lack of normal market characteristics unique to wildlife species (see Engeman et al., 2002).

The economic value of cattle is also reflected by a range of values. The minimum value of cattle is assumed to be the market value of $425 at the time of the study. This reflects the minimum value because it is assumed that at the very least, the value of a single head of cattle is what it can bring in the market. A range of values is used to calculate the economic contribution of cattle to reflect the idea that economic value of cattle to the state exceeds what each head can bring on the market. This is due to the fact that market values do not always reflect the actual value of each individual head, and dollars generated from the agricultural sector of the economy tend to have a greater multiplier effect in the local economy. Given this, we used a range of values ($425, $600, $800 and $1,000) to estimate the benefits and costs of coyote management.

Estimates of Cattle Saved from Coyote Predation

In years prior to the study years, cattle production was stable in the study areas, showing no increase in subsequent years. Ranchers also reported that there were no changes in husbandry practices, ranching practices (i.e. new fencing, scare devices, and protection animals), or number of head stocked during the study years. Therefore, at the end of the treatment year, the number of additional calves taken to market was attributed to coyote predation management. Table 1 shows the increased number of calves attributed to coyote predation management. Area 55, which has fewer calves than area 63, produced a consistent 32 additional calves in each treatment year, while area 63 also produced an average of 152 additional calves per year.

In this study, the number of cattle saved each year represents the benefits (B) of the coyote predation management program. It is important to note that the increase in calf production could reflect not just decreased calf predation, but also increased calf production because cows were less stressed, were able to forage without harassment and other contributing factors that led to an environment more conducive to calf production. Antelope were also saved from predation in area 63 during the study period. In 2001, 366 antelope were saved from predation while in 2002, 434 were saved (Merrell and Shwiff, in review).

Calculating Benefits, Costs and Benefit-Cost Ratios (BCRs)

The benefits that accrued each year were measured in terms of the number of

Table 1. Number of cattle saved.

Year	Area 55	Area 63
2001	32	150
2002	32	154

cattle saved each year. Benefits were calculated by multiplying the number of cattle saved each year by the value of each individual head. Annual total cost of coyote removal represents the costs (C). In 2001, at area 55 the annual program costs for coyote predation management was $8,899.58, and in 2002, the program costs were $9,537.37. At area 63, program costs were $9,991 in 2001 and $10,079.20 in 2002. In order to compare costs across years, 2001 costs were adjusted for inflation to reflect their actual costs in 2002 dollars. The BCRs are calculated using the standard format of the ratio of benefits to costs (Loomis and Walsh, 1997; Boardman et al., 1996; Nas, 1996; Zerbe and Dively, 1994; and Loomis, 1993). In general, the BCRs for this analysis were calculated from the equation:

$$BCR = \frac{\textit{Total Value of Calves Saved}}{\textit{Coyote Management Costs}}$$

A value of 1.0 is indicative of no net benefit (dollar savings in recruited calves). For example, the basic BCR for the year 2001 is calculated from the equation:

$$BCR^{\$425}_{2001} = \frac{Benefits(B)}{Costs(C)} = \frac{\$13,600}{\$8,899.58} = 1.53$$

In other words, in 2001, the benefit of saving 32 calves at $425 per calf is 1.53 times greater than the annual cost of predation management for that year.

Keep in mind that only 25 percent of the total area involved in the treatment on area 55 is utilized for calf production. The cost figure represents the total costs for predator management over 100 percent of the area, which implies that the BCR is conservative.

The coyote predation management program in area 63 benefited both cattle and pronghorn antelope. Merrell and Shwiff (in review) examined the benefits and costs associated with coyote predation management for antelope. It is important to examine the cumulative benefit-cost ratio when both species are considered together. The benefits (B) are calculated by multiplying the number of antelope saved by the dollar value per antelope and adding that to the value of cattle saved. The net benefits (NB) of coyote removal are determined by the total value of antelope and cattle saved minus the program costs, which is given in the equation:

$$NB^{\$antelope,\#cattle}_{2001} = [(\$antelope * \#\ of\ antelope\ saved) + (\$cattle * \#\ of\ cattle\ saved)] - annual\ program\ costs.$$

Equation (3) can be rewritten as,

$$NB^{\$antelope,\#cattle}_{year} = [(B^{\$antelope}_{year}) + (B^{\$cattle)}_{year}] - C_{year}$$

Adding the benefits together in Equation (4) represents the total value (benefit) of antelope and cattle saved.

Calculating the cumulative (antelope plus cattle) benefits and costs that accrue to area 63 as a result of coyote management allows for the calculation of the benefit-cost ratios. The benefit-cost ratios are calculated for each area by Equation (1), except for the numerator changes to total value of cattle and antelope saved:

$$BCR_{year} = \frac{[(B^{\$antelope}_{year}) + (B^{\$cattle}_{year})]}{C_{year}}$$

This equation more accurately describes the benefits and costs that accrue to each area. Under this equation, if the BCR exceeds 1, then the total benefits to that area exceed the costs.

Results and Discussion

Area 55

Data provided by livestock producers indicated that in the two years of coyote removal in the treatment areas, there were an additional 368 calves sent to market, a 5.4-percent increase per year. This increase occurred despite one of the most severe droughts in south-central Wyoming in recent history and no changes in cow/calf management practices or number of head stocked.

Area 55 had a minimum total population of 169 coyotes prior to treatment. There were 108 coyotes removed, or 63.9 percent of the population in 2001. At the beginning of treatment in 2002, there was an estimated minimum population of 163 coyotes and a total of 130 coyotes removed, or 79.7 percent of the minimum estimated population. The cattle population at area 55 in 2002 consisted of 715 cows and 643 calves. The value of calves saved or the benefit of each calf saved is calculated by multiplying the calves saved by the dollar value of a calf. For example, Table 2 illustrates that in 2001, 32 calves were saved at a dollar value of $425, which resulted in $13,600 worth of calves saved. Substituting the appropriate values into Equation (2) yields the benefit-cost ratios in parenthesis in Table 2.

Lower costs in 2001 resulted in higher BCRs for that year in comparison to 2002. All of the BCRs were greater than 1, indicating that at any calf value, the benefits of the program exceed the costs.

Area 63

Area 63 had an estimated minimum total population of 195 coyotes in 2001. During treatment in 2001, 172 coyotes were removed, or 88.2 percent of the estimated population. In 2002, there was an estimated population of 115 coyotes, with 97 being removed, or 84 percent of the population. The cattle production at this site was 3,380 cows and 2,872 calves in 2002. Calculating the value of calves saved and substituting the appropriate values into equation (2) yields the results in Table 3.

A higher number of calves saved in this treatment unit resulted in higher BCRs. At the very minimum, the benefits exceed the costs by at least six times.

Table 2. Value of calves saved by coyote predation management in Area 55 (Benefit-Cost Ratios).

Year	No. of calves saved	Value of Calf $425	$600	$800	$1,000
2001	32	$13, 600 (1.53)	$19,200 (2.16)	$25,600 (2.88)	$32,000 (3.60)
2002	32	$13, 600 (1.43)	$19,200 (2.01)	$25,600 (2.68)	$32,000 (3.36)

Table 3. Value of calves saved by coyote predation management in Area 63 (Benefit-Cost Ratios).

Year	No. of calves saved	Value of Calf $425	$600	$800	$1,000
2001	150	$63,750	$90,000	$120,000	$150,000
		(6.38)	(9.01)	(12.01)	(15.01)
2002	154	$65,450	$92,400	$123,200	$154,000
		(6.49)	(9.17)	(12.22)	(15.28)

3.3 Cumulative Benefit-Cost Ratio for ADMB 63

Substituting the appropriate values into Equation (3) yields,

$$NB_{2001}^{\$400,\#425} = [(\$400*366) + (\$425*150)] - \$9,991 = \$200,159$$

Completing this process for all of the values of antelope and cattle yields the numbers provided in Table 4. Even at the lowest value for both antelope and cattle, the net benefit to the Wyoming economy is approximately $200,000 for each year. Using the Wyoming Game and Fish value of $3,000 for antelope and the conservative value of $600 for cattle, the cumulative net benefits of this program are $1,178,009 for 2001 and $1,384,321 for 2002. These values represent the additional benefit to the Wyoming economy of this program, through expenditures on the hunting of antelope and the market sale of cattle and additional revenues generated by cattle production.

The BCRs for area 63 lend further support to the success of this program. BCRs greater than 1 indicate that the program benefits exceed the costs. Examining the BCRs that result from the coyote predation management program in area 63 in Table 5, it shows that at the minimum, the benefits are over 20 times the costs in both years.

Using the Wyoming Game and Fish value of $3,000 for antelope and the conservative value of $600 for cattle, the BCRs indicate that in 2001 the benefits were 122 times the costs and in 2002 the benefits were 138 times the costs. These BCRs show the extraordinary success of this program.

Conclusions

Determination of the economics of predator control has been valuable to formulation of management strategies elsewhere (e.g., Engeman et al., 2002). The results of this benefit-cost analysis demonstrate that, from Wyoming's perspective, a coyote predation management for the protection of antelope and cattle is a cost-beneficial program with the potential to increase revenue to Wyoming in the range of $200,000 to $4,000,000. Benefits would most likely continue to accrue for each year thereafter; however, the model used does not predict benefits beyond the short-term horizon.

Using a range of values for antelope and cattle allows for the examination of the program from the most conservative scenarios (lowest animal values) to the maximum potential benefits (highest animal values). This analysis shows that under any value scenario, the efforts of this program result in economic efficiency.

Table 4. Cumulative net benefits for cattle and antelope saved by coyote predation management in Area 63 for the period 2001-2002.

2001

Value of Cattle	Value of Antelope $400	$1,500	$3,000	$10,000
$425	$200,159	$602,759	$1,151,759	$3,713,759
$600	$226,409	$629,009	$1,178,009	$3,740,009
$800	$256,409	$659,009	$1,208,009	$3,770,009
$1,000	$286,409	$689,009	$1,238,009	$3,800,009

2002

Value of Cattle	Value of Antelope $400	$1,500	$3,000	$10,000
$425	$228,971	$706,371	$1,357,371	$4,395,371
$600	$255,921	$733,321	$1,384,321	$4,422,321
$800	$286,721	$764,121	$1,415,121	$4,453,121
$1,000	$317,521	$794,921	$1,445,921	$4,483,921

Table 5. Cumulative Benefit-Cost Ratios (BCRs) for cattle and antelope saved by coyote predation management in Area 63 for the period 2001-2002.

2001

Value of Cattle	Value of Antelope $400	$1,500	$3,000	$10,000
$425	21.66	63.17	119.77	383.89
$600	24.37	65.88	122.47	386.60
$800	27.46	68.97	125.57	389.69
$1,000	30.56	72.06	128.66	392.78

2002

Value of Cattle	Value of Antelope $400	$1,500	$3,000	$10,000
$425	23.72	71.08	135.67	437.08
$600	26.39	73.76	138.34	439.76
$800	29.45	76.81	141.40	442.81
$1,000	32.50	79.87	144.46	445.87

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Feral Swine Impacts on Agriculture and the Environment

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Introduction

More than 30 species of exotic free-ranging mammals have become established in the United States since European colonization (De Vos et al., 1956; McKnight, 1964; Roots, 1976). These species often become serious economic pests and can have grave consequences on their host environments (Cottam, 1956; De Vos et al., 1956; Mayer and Brisbin, 1991). True wild pigs (*Suidae*) are not native to the United States. Only the collared peccary (*Tayassu tajacu*; Tayassuidae) that inhabits the southwestern and south-central parts of the United States is native (Mayer and Brandt, 1982; Mayer and Wetzel, 1986). Feral swine (*Sus scrofa*) in the United States have originated from varieties of domestic swine, Eurasian wild boar, and their hybrids (Jones, 1959; Wood and Lynn, 1977; Rary et al., 1968; Mayer and Brisbin, 1991). Domestic swine were introduced to the United States as early as 750-1000 A.D. during the settlement of the Hawaiian Islands (Towne and Wentworth, 1950; Joesting, 1972; Smith and Diong, 1977). Christopher Columbus introduced domestic swine to the West Indies during the 1400s, where they proliferated and became pests. In the 1500s, Spanish explorers, such as DeSoto and Cortez, were the first to bring domestic swine to the United States mainland (Towne and Wentworth, 1950; Beldon and Frankenberger, 1977). By the 1960s, domestic swine and Eurasian wild boar were established in >20 states (McKnight, 1964). Swine introductions have intentionally or accidentally occurred by a variety of means, including: 1) translocation to establish populations for hunting, 2) escapees from shooting preserves or confinement operations, 3) avoidance of capture by domestic pigs in free-ranging livestock operations, 4) abandonment by their owners, and 5) dispersal from established feral populations (Gipson et al., 1997; Witmer et al., 2004).

Feral swine are the most abundant free-ranging, exotic ungulate in the United States (McKnight, 1964; Decker, 1978) and have become widespread because of their reproductive potential and adaptability to a wide range of habitats. Like domestic swine, litter size depends on the sow's age, nutrition, and time of year. Feral swine are capable of producing two litters per year with average litter size varying from 4.2 to 7.5 piglets (Taylor et al., 1998), but up to 10 piglets can be born during ideal conditions (Conquenot et al., 1996). Mayer and Brisbin (1991) and Mackey (1992) report feral swine populations in 23 states. A Southeastern Cooperative Disease Study (1994) and Nettles (1997) point out an additional 16 states with feral swine populations. An estimated population of 4 million feral swine currently occur in the United States (Pimentel et al., 2000) with the largest populations inhabiting Texas (1 to 1.5 million; Pimentel et al., 2000), Florida (>500,000; Layne, 1997), Hawaii (80,000; Mayer and Brisbin, 1991), and California (70,000; Barrett, 1993). Since 1965, feral swine have expanded their range from 15 (26%) to 45 (78%) of the 58 California counties (Frederick, 1998). Feral swine populations continue to increase (Gipson et al., 1997) because they possess the greatest reproductive potential of all free-ranging, large mammals in the United States (Wood and Barrett, 1979; Hellgren, 1999) and because of the absence of large native predators (e.g., mountain lion (*Felis concolor*) and wolves (*Canis lupus*) over much of the area occupied by feral swine. In southwest Florida where feral swine and a large predator coexist, feral swine is the most common food item (42%) in Florida panther (*F. c. coryi*) scats (Maehr et al., 1990), which may suggest that the presence of a large predator helps regulate feral swine density and associated damage.

Environmental Damage and Wildlife Depredation

Environmental Damage

Feral swine are generalists. Their omnivorous diet allows them to utilize a variety of food sources and to thrive in a wide range of environments. The majority of their diet consists of grasses, forbs, and soft and hard mast such as shoots, roots, tubers, fruit, and seeds. Acorn (*Quercus* spp.) and hickory (*Carya* spp.) nuts are two important food items that feral swine use seasonally (Mungall 2001) and may lead to competition with other wildlife (Yarrow and Kroll, 1989). Feral swine also eat a variety of invertebrates including earthworms, leeches, grasshoppers, centipedes, beetles, and other arthropods. As a predator, feral swine eat salamanders, frogs, fish, crabs, snakes, turtles, rodents, muskrats (*Ondatra zibethicus*), eggs and chicks of ground-nesting birds, white-tailed deer fawns (*Odocoileus virginianus*) (Hellgren, 1993), and livestock. Feral swine must forage almost continuously because their simple stomach is not as efficient as a ruminant's multi-chambered digestive system — hence the expressions "as greedy as a pig" and "eats like a pig."

Feral swine negatively impact natural plant communities (Bratton, 1975; Wood and Barrett, 1979; Stone and Keith, 1987) and may seriously impact agricultural ecosystems (Singer et al., 1982). Feral swine rooting activity, digging for food with their snout, loosens the soil and accelerates erosion, sets back plant succession, reduces earthworm activity, and exacerbates exotic plant invasion (Mungall, 2001). Damage from rooting, trampling, and compaction directly and indirectly impacts plant regeneration, plant community structure (Bratton, 1975), soil properties (Lacki and Lancia, 1983), nutrient cycling (Tate, 1984), and water infiltration (Mungall, 2001). Rooting and incidental damage may give exotic plants an ecological advantage over native plants (Howe and Bratton, 1976) because exotic plants are typically better adapted at colonizing disturbed areas. Additionally, feral swine may help spread root-rot fungus (*Phytophthora cinnamomi*), which causes disease in native vegetation (Kliejunas and Ko, 1976).

Habitat damage by feral swine is most pronounced in wet environments (e.g., Choquenot et al., 1996; Engeman et al., 2004). Exposed marsh shoreline is particularly susceptible to damage because the shoreline and shallower water is typically dominated by shrubs and herbs, which are attractive forage (Engeman et al., 2003). Feral swine also use upland habitats and have been documented impacting longleaf pine (*Pinus palustris*) regeneration (Lipscomb, 1989) and southern hardwood forest composition (Wood and Lynn, 1977; Lacki and Lancia, 1986).

Wildlife Depredation

Feral swine impact native wildlife in a variety of ways, depending upon the habitat, density of feral swine, and other extraneous factors. About 400 of the 958 wildlife species listed as threatened or endangered under the Endangered Species Act are considered to be at risk primarily because of competition or predation by non-indigenous species (Nature Conservancy, 1996; Wilcove et al., 1998; Pimentel et al., 2002). In Florida, feral swine have contributed to the decline of at least 22 plant species and 4 species of amphibians listed as rare, threatened, endangered, or of special concern (USDA, 2002). In the southern United States, feral swine predation may negatively affect bobwhite quail (*Colinus virginianus*) and wild turkey (*Meleagris gallopavo*) nest success (Synatzske, 1979). Tolleson et al. (1993) constructed 192 simulated quail nests in Texas and reported that feral swine was the most common predator (28%) of simulated nests. They concluded feral swine could have detrimental effects on bobwhite quail populations depending upon the density of quail and feral swine, quail nesting cover, and quantity and diversity of other swine food sources.

On some southeastern U.S. beaches, feral swine have become significant predators of marine turtle nests by excavating and feeding on the eggs (Stancyk, 1982; Lewis et al., 1996). Feral swine seriously threaten the nesting success of several threatened and endangered marine turtles including: the loggerhead (*Caretta caretta*) (federal; threatened); green (*Chelonia mydas*) (federal; endangered); leatherback (*Dermochelys coriacea*) (federal; endangered); hawksbill (*Eretmochelys imbricata*) (federal; endangered); and the Kemp's ridley (*Lepidochelys kempii*) (federal; endangered), destroying up to 80% of nests in some regions of Florida (USDA, 2002). It has become critical to monitor and manage nest predation to ensure the existence of these threatened and endangered turtles. USDA/Wildlife Services (WS) is working with various state and federal agencies to reduce turtle nest predation by protecting nests with portable fences and reducing feral swine densities through cage trapping and culling.

Livestock Depredation and Agricultural Crop Damage

Shortly after Christopher Columbus introduced swine to the West Indies, feral swine depredated cattle (Ensminger, 1961) and consumed agricultural crops such as maize and sugar cane (Donkin, 1985). Frederick (1998) surveyed all 58 county agricultural commissioners in California and reported $1,731,920 in feral swine damage. This figure is likely underestimated because only 69% of county agricultural commissioners responded, and the exact number and monetary value of damaged resources was conservatively estimated (Frederick, 1998). Livestock and wildlife depredation and agricultural and environmental damage will likely continue to increase as feral swine flourish and humans encroach wildlife habitat.

Livestock Depredation

Feral swine are well documented as significant predators of lambs (*Ovis aries*) in Australia (Moule, 1954; Rowley, 1970, Pavlov et al., 1981, Choquenot et al., 1997) where 4 to 20 million feral swine exist (Emmerson and McCulloch, 1994; Pimentel et al., 2000). Feral swine prey on a variety of other livestock including goats (*Capra hircus*), newborn cattle (*Bos taurus*), and exotic game. Animal matter typically makes up only a small percentage of their diet, but considerable economic loss can occur from livestock depredation. In Australia, the greatest losses occur in sheep (wool and meat loss) and cattle production (Tisdell, 1991). In the semi-arid rangelands of Australia, losses of newborn lambs from feral swine predation have been as high as 32% (Plant et al., 1978), with a multiple-year average loss of 19% (Pavlov et al., 1981). Choquenot et al. (1997) found that the rate of lamb predation increased with feral swine density, until reaching a maximum of 29% at a density of 4 to 8 pigs/km^2. Predation typically occurs on lambing or calving grounds, possibly because of the attraction of afterbirth and fetal tissue (Wade and Bowns 1985; Beach, 1993). Occasionally, livestock giving birth are killed and fed upon (Wade and Bowns, 1985). Predation occurs throughout the age classes for sheep and goats, but newborn or immature animals are usually targeted (Beach, 1993). In fact, feral swine preyed upon twin lambs on average 5 to 6 times more than single lambs (Choquenot et al., 1997). This is likely attributed to twin lambs being smaller and weaker than their single counterparts (Alexander, 1984) and the divided vigilance of their mother. Feral swine have been observed to disrupt flocks 78% of the occasions when within 100 m and caught lambs during 24% of chases (Pavlov and Hone, 1982). Feral swine predation may be difficult to document because the entire carcass is typically consumed, leaving little evidence. Additionally, feral swine will scavenge dead animals including other swine carcasses (Hanson and Karstad, 1959; Nichols, 1962). Therefore, predation may be mistaken as low productivity in the herd, or vice-versa, when scavenged stillborns and aborted fetuses are mistaken as cases of depredation.

Feral swine usually follow a characteristic feeding pattern that makes identification of depredation possible if the entire carcass is not consumed (Pavlov and Hone, 1982). Death typically occurs by biting and crushing the skull or neck (Frederick, 1998). A good indicator of feral swine predation is that the prey's carcass will be skinned out with the rumen or stomach contents consumed (Wade and Bowns, 1985). Feral swine tracks are distinct and may help decipher cause of mortality when the soil and nearby vegetation have been disturbed.

Feral swine cause serious economic loss to the livestock industry, although exact numbers and values are largely unknown. This may be caused by misidentification of the cause of predation. For example, signs of coyote (*Canis latrans*) and feral swine predation appear very similar; therefore cases reported as coyote predation may actually be feral swine. This is especially plausible in Texas, where high densities of coyotes and feral swine exist and target newborn animals. Coyotes typically attack sheep and goats with a bite to the throat, causing death from suffocation and shock, then feed on their prey (Wade and Bowns, 1985) starting at the flank or just behind the ribcage. Coyotes typically leave splintered bones, chewed ribs, and scattered pieces of skin, fur, tendons, and bones (Wade and Bowns, 1985). Conversely, black bear (*Ursus americanus*) normally do not consume the rumen and its contents, but the carcass will appear skinned out (Wade and Bowns, 1985). Black bears usually do not scatter their prey, and the hide and skeleton will be mostly intact. Large claw marks across the shoulders and back may provide additional clues.

The annual economic loss from feral swine predation in the United States is unknown; however feral swine predation on livestock in the United States does not appear to be as prevalent as in Australia, where >$80 million is lost annually (Emmerson and McCulloch, 1994). In Texas, Rollins (1993) reported that 33% of county agricultural agents listed livestock depredation by feral swine as a problem with losses directed towards sheep and goats. In 1990, 1,243 sheep and goats were documented as being lost to feral swine in Texas, with an estimated value of $63,000 (Rollins, 1993). Barrett and Birmingham (1994) reported 1,473 sheep, goats, and exotic game animals were killed by feral swine in Texas and California in 1991. In a more recent survey, 23% of county agricultural commissioners in California reported livestock depredation by feral swine (Frederick, 1998); total economic loss was not estimated. Texas produces 1.1 million goats annually, about 90% of the goats raised in the United States (Scrivner et al., 1985), and Pearson (1986) reported that predators killed 18% of adults and 34% of kids. The number of goats lost to feral swine predation is unknown, but is likely substantial (>$1 million) considering $5.7 million was lost to coyotes in the United States in 1990 (NASS 1991). Additionally in 1990, combined sheep and lamb losses from coyotes were valued at $18.3 million in the United States (NASS, 1991). Where practical, ranchers should closely monitor livestock and confine pregnant animals to protected areas during calving and lambing seasons to reduce susceptibility to predation. An understanding of field sign and different behavioral cues can help determine cause of mortality and the impact of feral swine predation.

Feral Swine and Disease

Annual pork sales in the United States exceed $11 billion with retail sales exceeding $34 billion (Witmer et al., 2004). Therefore, there is concern relative to the role feral swine could pose to the pork industry as a reservoir for disease. However, only 26% of Texas agricultural extension agents were concerned about disease transmission to livestock (Rollins, 1993). Feral swine can harbor at least 30 significant viral and bacteriological diseases (Williams and Barker, 2001) and feral swine in Florida have been documented to have as many as 45 different parasites and infectious diseases (Forrester, 1991). These include 37 parasites (12 protozoans, 17 nematodes, 1 acanthocephalan, 1 sucking louse, 4 ticks, and 2 mites), 7 bacteria, and 1 virus. Eight of these parasitic and infectious diseases can infect humans (brucellosis, leptospirosis, salmonellosis, toxoplasmosis, balantidiasis, trichinosis, trichostrongylosis, and sarcoptic mange). All four species of ticks opportunistically infect and feed on humans. The diseases of most concern to the livestock industry include pseudorabies, swine brucellosis, bovine tuberculosis, leptospirosis, and vesicular stomatitis (Becker et al., 1978; Williams and Barker, 2001). These and the possibility of an exotic disease outbreak, such as foot-and-mouth disease, a contagious viral disease of ungulates (e.g., pigs, sheep, cattle, goats, and deer) (Pech and McIlroy, 1990), or classic swine fever (a contagious viral disease of wild and domestic swine), could have serious repercussions for livestock industries (Hone et al., 1992). On the other hand, feral swine may serve as a surveillance tool for the early detection of exotic diseases (Mason and Fleming, 1999; Witmer et al., 2004). These potential health aspects should be kept in mind when considering feral swine range expansion, translocation (Forrester, 1991), and tolerance around livestock operations.

Crop Damage

Feral swine damage pasture and agricultural crops by consumption, rooting, digging, and trampling. In Australia, feral swine cause considerable agricultural crop damage with >$100 million lost annually (Choquenot et al., 1996). The greatest losses occurred in wheat, sorghum, barley, oilseeds, sugar cane, oats, and maize, in that order (Tisdell, 1991). In the United States, feral swine damage $800 million in agricultural crops each year, assuming that 4 million feral swine inhabit the United States and cause $200 worth of damage per pig (Pimentel et al., 2002). This estimate is likely very conservative because it does not consider livestock predation, disease transmission, or environmental degradation.

In Texas, the most common complaint or concern (75%) in a survey conducted by Rollins (1993) was damage to agricultural crops including hay, small grains (milo, rice, and wheat), corn, and peanuts. Other crops affected were vegetables, watermelons, soybeans, cotton, orchards, horticultural crops, and conifer seedlings. Seventy-two percent of surveyed extension agents reported additional damage to ranch facilities (e.g., fences, water supply, irrigation ditches, and guzzlers).

Population Control and Management

No panacea for feral swine control, management, or eradication currently exists (Choquenot et al., 1996). In most states feral swine are unprotected or classified as an agricultural pest, therefore hunting methods are liberal and swine can be harvested throughout the year. States where feral swine are classified as game animals rely on hunter harvest to control or regulate swine populations; however, sport hunting has had negligible effects on swine population management (Barrett and Stone, 1993). Feral swine can be controlled by several techniques including shooting, trapping, and, in overseas locations, with toxicant baiting (Tisdell, 1982). In Australia, toxicant baiting [e.g., sodium monofluoroacetate (Compound 1080), warfarin] has been used to reduce feral swine populations in some areas by 58 to 73% depending upon the length of the poisoning campaign (Hone and Pederson, 1980; Hone, 1983; Pech and Hone, 1988). Careful consideration and monitoring must be applied when using toxicants because other non-target species may be harmed (Stone et al., 1988). Frightening devices are ineffective and no repellents or toxicants are registered for feral swine use in the United States (Barrett and Birmingham, 1994). Other lethal means for eradication include aerial hunting with helicopters, hunting with dogs, or shooting at night over bait. Saunders and Bryant (1987) used aerial shooting over five days to reduce a population by 80%. Hunting with dogs can also be effective at reducing feral swine populations in local areas (Barrett and Birmingham, 1994). Trapping and snaring followed by euthanasia can also help reduce swine density and nuisance animals. Trapping with corral traps and portable drop-gate traps can be effective, but efficacy varies seasonally with production of natural food sources (e.g., acorns) (Barrett and Birmingham, 1994). Leg snares can be effective, but should be implemented with caution in areas where livestock, deer, or other non-target animals may be present. Access points such as fence under-passes or pen entrances not used by non-target animals are ideal. Other control measures to alleviate damage include excluding feral swine with wire mesh fencing or electric fence. No fence design is completely pig-proof, but they can significantly reduce feral swine movement into protected areas. Wire mesh fencing or adding an electrified wire to an established fence 15 to 20 cm off the ground appear to be the most effective means of excluding feral swine (Hone and Atkinson, 1983). However, due to the associated cost of these control measures, agricultural producers must weigh the cost of taking precaution to their expected loss to determine if action is cost-effective. An integrated approach may be more feasible and may help alleviate feral swine recognition and avoidance of specific control practices (Choquenot et al., 1996).

One of the greatest needs for feral swine management is a practical means for indexing populations (Choquenot et al., 1996). Knowledge of relative swine population abundance and spatial distribution is valuable for timing control programs, optimally locating control sites, and evaluating control efficacy. A variety of methods have been applied to estimate absolute abundance of feral swine, though they often require many resources and produce mixed results (Choquenot et al., 1996). Assessments of populations can be done by directly estimating population density through line-transect (e.g., Burnham et al., 1980) or mark-recapture estimation (e.g., Otis et al., 1978). An alternative is to calculate an index reflective of population abundance (e.g., Caughley, 1977). Engeman et al. (2001) recently evaluated a passive-tracking method in Florida to index the relative abundance and distribution of feral swine in an area and to evaluate the impact of control programs. The technique is easy to use and allows managers to index feral swine density around agricultural operations. Knowledge of feral swine density will aid in making decisions about whether control measures are warranted. If density is low, then the associated risk of depredation may be acceptable and no control measures may be necessary. However, if feral swine density is high, then it may be beneficial to take precaution and reduce the threat of damage.

Discussion

Despite the negative impacts feral swine have on agriculture and the environment, humans continue to introduce feral swine to new areas (Howells and Edwards-Jones, 1997; Leaper et al., 1999) and allow range expansion. Some individuals, mostly feral swine hunters and landowners that generate revenue from hunting leases, encourage feral swine and consider them a desirable big game species. In most states with large populations (e.g., Texas, Florida, California, and Hawaii), feral swine are considered a big game species and year-long hunting seasons have been established to "control" numbers. In Texas, Rollins (1993) regarded feral swine hunting as a sport for locals more so than nonresidents with an average cost of $169 per hunter. However, this may be changing; in 1998 the Texas Parks and Wildlife Department generated over $1 million from the sale of 30,512 hog permits to nonresidents (Chambers, 1999). Hunting may serve to alleviate disease transmission and predation by reducing the number of feral swine at the livestock interface. Ranchers and farmers should be encouraged to hunt feral swine, grant hunting permission, and participate in state hunter access programs.

Although feral swine hunting generates income for some, the damage to private and public property and natural resources is hardly justifiable. Ranchers and farmers should understand the potential risks and have cost-effective means available to them for feral swine control. In areas where feral swine pose a threat to natural resources, most conservation organizations promote the eradication or reduction of feral swine populations. Until a paradigm shift occurs and society understands that the negative impacts feral swine cause outweigh any immediate or potential benefits, some current conservation strategies for native wildlife and maintenance of disease-free, domestic-swine populations will be at risk.

In the United States, ranchers and farmers operating in feral swine-occupied areas need more information regarding feral swine damage and means to alleviate potential losses. Research is needed to determine the rate of predation relative to feral swine density, assess the economic loss caused by feral swine predation, quantify the rate of disease transmission to domesticated livestock, and to develop economical means to alleviate feral swine damage. Current damage management techniques in the United States include fencing, snares, cage traps, and various methods of hunting. In Australia, the use of aerially delivered toxic bait is legal, and it is the most efficient means of quickly reducing feral swine numbers. Resource management agencies in the United States should consider following Australia's lead and manifesting a management plan for the eradication of feral swine in areas that have the potential to be exposed to exotic livestock diseases. This would likely require the registration and approval of a toxicant and bait delivery system that targets feral swine with minimal impact on non-target species and the environment. As Tisdell (1991:168) stated, "the question has been raised whether feral swine should be managed on a sustainable yield basis, with an eradication strategy pursued only if an exotic livestock disease, such as foot-and-mouth, be accidentally introduced." This statement is very reactionary; we must remember that feral swine are an exotic species and pose a significant threat to agriculture and the environment. Strict control of feral swine populations is responsible management. Until state agencies address feral swine populations and their expansion, the damage they cause will likely continue to increase.

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Managing Wolf Depredation in the United States: Past, Present, and Future

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Introduction

With the successful recolonization and reintroduction of wolves (*Canis lupus*) in parts of the western United States (Bangs and Fritts, 1996; Bangs et al., 1998) and the natural expansion of wolves in the upper Midwest (Fuller et al., 1992; Thiel, 2001), managing conflicts between wolves and livestock is a growing issue for livestock producers, resource professionals, and the general public (Mech, 1996). Unlike the coyote, (*Canis latrans*) where a great deal is known regarding the biology and ecology of depredation and methods for managing it (Knowlton et al., 1999), very little is known regarding patterns and processes of wolves preying on livestock and effective ways to mitigate this conflict. Understanding the ramifications of growing wolf populations for livestock production and successfully managing these problems will require knowledge of depredation patterns, wolf ecology, livestock husbandry, and the effectiveness of different tools and techniques to manage wolves. As wolf populations expand into more agricultural areas (Mech et al., 2000) such knowledge will become increasingly important.

Here historic records were compared to current data on wolf depredation rates and wolf management techniques relative to the wolf's status on the endangered species list. The objectives were to synthesize the history of wolf depredation and management, present current data of wolf impacts on livestock, and speculate on the future management of wolves so that producers can consider the ramifications of a growing wolf population and possible mechanisms for decreasing the threat.

Methods

A Web of Science search was performed for articles published on wolf depredation in the United States and manually searched bibliographies of relevant published articles. The literature search included all relevant combinations of the following keywords: *wolf, livestock, depredation, predation, and domestic animals*. From this literature, data were compiled for the following parameters: wolf population status, depredation rates, amount of compensation paid, and control actions taken. Depredation rates are presented as the number of livestock killed by wolves divided by the total livestock available within wolf range.

Data were compiled for the years 2000 to 2002 on the same parameters mentioned above. Statistics on cattle and sheep distribution (*http://www.usda.gov/nass/*) were used to estimate the number of cattle and sheep within wolf range. Annual USDA-Wildlife Services annual reports from each state were employed to determine the number of cattle and sheep killed by wolves each year. Kills were verified by specialists trained in doing field necropsies to determine cause of death and do not reflect those animals that were determined to be probable or possible kills. Accordingly, the data are conservative. Estimates of wolf population size, number of wolves killed each year, and number of wolves moved each year were gathered from one of the following sources: US Fish and Wildlife Service, Interagency Rocky Mountain wolf recovery reports (USFWS et al., 2003); Wisconsin Department of Natural Resources annual reports (Wydeven et al., 2003); Michigan Department of Natural Resources (Michigan DNR, 1997); and USDA Wildlife Services-Minnesota annual reports (Paul, 2002). The amount of compensation paid in each state was determined for wolf kills through one of the following sources: Minnesota Department of Agriculture, Wisconsin Department of Natural Resources, or Defenders of Wildlife.

Results and Discussion

Wolf Depredation and Wolf Management Prior to the Endangered Species Act

There was very little reliable information regarding the impact of wolves on livestock and factors that affected this interaction before the 1970s. Wolves certainly killed domestic animals and apparently caused considerable damage in certain areas (Bailey, 1907; Young and Goldman, 1944; Brown, 1983). But the accounts were generally anecdotal, possibly exaggerated, and usually did not consider ecological and biological aspects that may have influenced wolf-livestock relationships. The paradigm during this period was that wolves should be eradicated in part because they killed livestock (Lopez, 1978; Fritts, 1982; McIntyre, 1995). Eradication was accomplished primarily through the broad use of poison (e.g., strychnine, thallium sulfate, sodium monofluoroacetate-compound 1080, and cyanide) in conjunction with trapping (e.g., pitfalls, snares, steel traps), denning (finding dens and killing all animals associated with the den), aerial shooting, and sport hunting (Brown, 1983; Cluff and Murray, 1995; McIntyre, 1995). Initially the eradication efforts were financed by livestock producers and state bounty programs that supported professional "wolfers" but because of inefficiency and

Table 1. Mean values for 2000 to 2002 of wolf population, number of wolves killed or moved annually, and compensation paid annually in states with wolves.

	Wolf population	# Wolves killed annually	# Wolves moved annually	Annual compensation
MN	2,600	134	0	$ 75,251
WI	305	0	9	$ 52,280
MI	283	0	5	$ 1,323
MT	134	14	8	$ 23,093
WY	188	4	0	$ 15,224
ID	234	11	4	$ 12,141
NM/AZ	29	0	4	$ 6,251
Sum	**3,773**	**163**	**30**	**$185,563**

fraud, the U.S. Biological Survey hired professional trappers in the early 20th century to remove wolves primarily in the western United States (Lopez, 1978; Brown, 1983; McIntyre, 1995.). By the early 1970s, wolf eradication was nearly complete in the United States except for a small population that remained in remote wilderness of northern Minnesota. Throughout this period other methods occasionally employed to decrease depredation were fencing, shepherding, and improved husbandry (Brown, 1983).

During the 1800s and early 1900s, densities of native ungulates (deer, *Odocoileus* sp.; elk, *Cervus elaphus*; bison, *Bison bison*; and antelope, *Antilocapra americana*) were dramatically reduced through unregulated hunting. Concomitantly, densities of domestic livestock were dramatically increased throughout much of the United States. These changes in ungulate composition and density very likely increased the rate at which wolves killed livestock and contributed to the wolf's reputation as a livestock killer (Brown, 1983). By the time ungulate populations began to rebound in the later 20th century, most wolves had been eradicated. Because large populations of native ungulates and abundant livestock have never been studied in relationship to wolves, there is little known about the impacts that wolves might have on these simultaneously present native game and livestock populations.

Recovering Wolf Populations (1974-2002)

In 1974, wolves were placed on the Endangered Species List, and, as such, lethal control of wolves subsided. In 1978 the wolf's status was changed to threatened in Minnesota to allow federal biologists more flexibility with controlling problem individuals (Fritts, 1982). Otherwise, wolves remained endangered in the lower 48 states. As a result of protection, and despite the 1978 change in this state, the Minnesota wolf population grew steadily from approximately 1000 in 1974 to 2500 in 1998 (Fuller et al., 1992; Berg and Benson, 1999). In the late 1970s and early 1980s, dispersing wolves from Minnesota began colonizing parts of Wisconsin (Wydeven et al., 1995; Thiel, 2001) and Michigan (Michigan DNR, 1997). Populations grew steadily in each state and numbered approximately 330 in each state in 2002.

In the western United States, wolves dispersed from Canada in the late 1970s and began to naturally colonize northwestern Montana (Ream et al., 1989; Pletscher et al., 1997). In 1995 and 1996, wolves from Canada were reintroduced into Yellowstone National Park and central Idaho as experimental non-essential populations. This designation allowed greater flexibility to manage problem wolves despite their status as endangered species. Wolf populations grew steadily in Idaho, Wyoming, and Montana through 2002, to where they occupied most remote areas in these states and were becoming more common in agricultural areas (USFWS et al., 2003).

Depredation Rates

The first studies of the impact of wolves on livestock began in Minnesota and are detailed in Fritts (1982) and Fritts et al. (1992). Mack et al. (1992) summarized data from this work and found that in Minnesota from 1979 to 1991, annual depredation rates averaged 0.12 cattle/1,000 available (range: 0.04 to 0.18) and 2.37 sheep/1000 available (range: 0.03 to 7.04) (Table 2). Our data for Minnesota from 2000 to 2002 showed a mean depredation rate of 0.22 cattle/1000 available (range: 0.17 to 0.26) and 1.81 sheep/1000 available (range: 0.33 to 3.84) (Table 3).

In Montana, Mack et al. (1992)

Table 2. Wolf depredation on cattle and sheep in northern Minnesota, 1979 to 1991 (from Mack et al., 1992 and Paul, 2001.)

	Number of Livestock				Losses/1000 Available	
	Available		Killed			
Year	Cattle	Sheep	Cattle	Sheep	Cattle	Sheep
1979	220,970	30,839	17	1	0.08	0.03
1980	225,244	32,950	16	56	0.07	1.70
1981	241,291	39,569	30	110	0.12	2.78
1982	241,742	34,698	24	12	0.10	0.35
1983	242,156	29,827	35	29	0.15	0.97
1984	242,589	24,956	10	92	0.04	3.69
1985	243,021	20,085	23	75	0.10	3.73
1986	220,141	15,904	26	13	0.12	0.82
1987	220,141	15,904	24	9	0.11	0.57
1988	220,141	15,904	31	68	0.14	4.28
1989	220,141	15,904	40	47	0.18	2.96
1990	220,141	15,904	37	112	0.17	7.04
1991	220,141	15,904	35	31	0.16	1.95
Mean	**229,066**	**23,719**	**27**	**50**	**0.12**	**2.37**

Table 3. Number of livestock available and killed by wolves and depredation rate in Minnesota, Wisconsin, and Michigan for calendar years 2000 to 2002.

	Number of Livestock				Losses/1000 Available	
	Available		Killed			
State/Year	Cattle	Sheep	Cattle	Sheep	Cattle	Sheep
MN 2000	380,000	15,100	95	19	0.25	1.26
MN 2001	380,000	15,100	64	5	0.17	0.33
MN 2002	380,000	15,100	97	58	0.26	3.84
MN Mean	380,000	15,100	85.33	27.33	0.22	1.81
WI 2000	360,000	15,699	6	0	0.02	0.00
WI 2001	360,000	15,699	11	0	0.03	0.00
WI 2002	360,000	15,699	37	7	0.10	0.45
WI Mean	360,000	15,699	18.00	2.33	0.05	0.15
MI 2000	54,000	2,600	2	1	0.04	0.38
MI 2001	54,000	2,600	3	0	0.06	0.00
MI 2002	54,000	2,600	3	0	0.06	0.00
MI Mean	54,000	2,600	2.67	0.33	0.05	0.13

summarized depredation rates of colonizing wolves from 1987 to 1991 and calculated a mean depredation rate of 0.04 cattle/1000 available (range: 0.0 to 0.08) and 0.21 sheep/1000 available (range: 0.0 to 0.88) (Table 4). From 2000 to 2002, we calculated a mean depredation rate of 0.02 cattle/1000 available (range: 0.02 to 0.03) and 0.59 sheep/1000 available (range: 0.09 to 1.05) (Table 5). Overall, from 2000 to 2002, wolf range in the lower 48 states exposed approximately 1,894,000 cattle and 208,649 sheep to the presence of wolves. There were about 3,773 wolves that killed an average of 153 cattle and 136 sheep per year.

The losses we report were those verified by USDA/APHIS/Wildlife Services; actual losses were greater by an unknown amount. This is an important area of research because compensation programs were primarily based on the number of verified losses. From 2000 to 2002, an average of $185,564 per year was paid in compensation for livestock losses by state governments and Defenders of Wildlife (Table 1). Oakleaf et al. (2003) estimated that the detection rate of cattle killed by predators reflected one-eighth of the actual losses to wolves within their study system in Idaho. They also speculated that the detection rate varied depending on the type of terrain and vegetation characteristics of the grazing allotment (i.e., less rugged and less timbered country would have higher detection rates).

Several patterns emerge from these results. First, the overall impact of wolves on the livestock industry was small relative to other factors, such as disease, coyote depredation, birthing problems, weather, and accidents. However, our analysis does not consider specific spatial location of kills and the degree to which kills were clustered for particular producers. Often it is found that kills are relegated to a few ranches (i.e., hot spots) and that wolves can have a significant economic impact on these individual operations. A number of studies of livestock losses to carnivores demonstrate the presence of hot spots, or small areas that have recurring attacks on livestock by carnivores (Fritts et al., 1992; Cozza et al., 1996). For example, Stahl et al. (2001) studied lynx attacks on sheep in France and found that certain geographical areas that covered only 0.3 to 4.5% of the total area where attacks occurred accounted for 33 to 69% of the attacks. A number of factors are hypothesized for causing hot spots, including individual problem predators, herding techniques, the abundance and availability of wild and domestic prey, habitat characteristics, and the abundance of predators. Mech et al. (2000) compared Minnesota farms that experience chronic depredation by wolves killing cattle to nearby farms without chronic problems. Of 11 farm characteristics measured they found that chronic losses occurred on larger farms, farms that had more cattle, and farms that had herds farther from human dwellings. No other habitat or husbandry practices were found to differ significantly between depredated and non-depredated farms; whether or not these are general patterns that hold true for wolves in other geographical areas is unknown.

Second, the rate of depredation remained relatively constant for Minnesota (1979 to 2002) and Montana (1987 to 2002). These data should be interpreted cautiously because of the uncertainty associated with the estimate of the number of cattle "available" to wolves. But assuming depredation rates were fairly accurate, these data indicate that the size of the wolf population did not affect the rate at which they killed livestock. It is possible that this rate may increase in the future as wolf populations continue to grow and expand into agricultural areas where the availability of livestock and natural prey are different than in more remote wilderness areas. Mech (1998) analyzed this issue and recommended consideration of pre-emptive control to reduce economic cost of controlling wolf populations that are growing into agricultural areas.

Table 4. Wolf depredation on cattle and sheep in northwestern Montana, 1987 to 1991 (from Mack et al., 1992 and U.S. Fish and Wildlife Service et al., 2003)

	Number of Livestock				Losses/1000 Available	
	Available		Killed			
Year	Cattle	Sheep	Cattle	Sheep	Cattle	Sheep
1987	75,067	11,338	6	10	0.08	0.88
1988	75,067	11,338	0	0	0.00	0.00
1989	75,067	11,338	3	0	0.04	0.00
1990	75,067	11,338	5	0	0.07	0.00
1991	75,067	11,338	2	2	0.03	0.18
Mean	75,067	11,338	3	2	0.04	0.21

Table 5. Number of livestock available and killed by wolves and depredation rate in Montana, Wyoming, and Idaho for calendar years 2000 to 2002.

	Number of Livestock				Losses/1000 Available	
	Available		Killed			
State/Year	Cattle	Sheep	Cattle	Sheep	Cattle	Sheep
MT 2000	750,000	80,000	14	7	0.02	0.09
MT 2001	750,000	80,000	12	50	0.02	0.63
MT 2002	750,000	80,000	20	84	0.03	1.05
MT Mean	750,000	80,000	15.33	47.00	0.02	0.59
WY 2000	80,000	50,000	3	25	0.04	0.50
WY 2001	80,000	50,000	18	34	0.23	0.68
WY2002	80,000	50,000	23	0	0.29	0.00
WY Mean	80,000	50,000	14.67	19.67	0.18	0.39
ID 2000	210,000	25,000	15	48	0.07	1.92
ID 2001	210,000	25,000	10	54	0.05	2.16
ID 2002	210,000	25,000	9	15	0.04	0.60
ID Mean	210,000	25,000	11.33	39.00	0.05	1.56

Last, our data demonstrate that sheep were more vulnerable to attack by wolves than cattle (sheep depredation rates were 2 to 30 times higher than cattle depredation rates; Tables 2, 3, 4, and 5). The reasons for higher depredation rates on sheep were unknown but may be associated with the generally higher vulnerability of sheep to predators or the fact that sheep flocks tend to be less dispersed than cattle herds, possibly facilitating surplus killing. Of interest is the observation that surplus killing by wolves is commonly associated with sheep but not cattle. Because a single depredation incident, or series of incidents, may cause the death of many sheep, sheep depredation numbers show more erratic, unpredictable variation from year to year than cattle depredation numbers.

Depredation Management Techniques

From a management context, the listing of wolves brought about the development and use of new non-lethal tools and techniques to manage wolves (see Smith et al., 2000a and Smith et al., 2000b for a comprehensive review). These included: translocating problem animals (Fritts, 1982, 1985; U. S. Fish and Wildlife Service et al., 2003) utilizing scare devices (Shivik and Martin, 2001; Shivik et al., 2003; Breck et al., 2002), dogs (Coppinger and Coppinger, 1995), barriers (Musiani and Visalberghi, 2001; Musiani et al., 2003), and improving livestock husbandry (Fritts et al., 1992; Mech et al. 2000). Translocation was fairly effective at stopping depredation problems but was expensive and time consuming and relied upon there being vacant areas available to release captured animals. This practice was phased out in all recovery areas as populations grew. The effectiveness of non-lethal tools, such as scare devices and fladry, varied but in general worked for short periods (a few weeks to a few months) and only in small areas. In many situations with problem wolves, non-lethal techniques were initially utilized until they failed at which time lethal control was implemented.

Little is known about how altering livestock husbandry would affect depredation patterns, but it offers promise as to a long-term, non-lethal solution in some situations, especially in areas where livestock are grazed on open range with little management. Alteration to husbandry might include aggregating livestock, managing birthing dates so young are not born on the open range, and herding vulnerable animals at night. Robel et al. (1981) evaluated the effectiveness of several husbandry methods for reducing sheep losses to coyotes by correlating the number of sheep killed to a number of factors that varied among 109 sheep producers in Kansas. Producers experienced less predation loss when they hauled away sheep carcasses, lambed during particular seasons, confined flocks of sheep to corrals, and maintained larger flock sizes. Evidence from Europe also suggests the importance of husbandry. Greater losses of livestock to carnivores occurred in Norway, where sheep were entirely free-ranging and unattended, than in France, where livestock were constantly herded or confined at night (Stahl et al., 2002). Though these and other studies suggest husbandry can be effective for reducing conflict with carnivores, our knowledge regarding husbandry and its effectiveness with different carnivore species, especially wolves, is very limited (Knowlton et al., 1999). It is also important to consider the increased costs and possible deleterious consequences associated with altering husbandry practices (e.g., confinement of livestock may lead to overgrazing) but little research has been done on this topic.

Lethal control of problem individuals and packs became more common in all recovery areas as wolf populations grew. Lethal removal usually was implemented when non-lethal procedures were impractical or ineffective. During 2000 to 2002, an average of 163 wolves were killed annually in the contiguous United States (primarily through trapping) in contrast to none or a few during the earlier years of recovery. It is likely that as wolf populations continue to grow, lethal control will be used more often to control problem wolves. Lethal control of wolves was primarily carried out by federal biologists and managers, and this is likely to remain the paradigm for some time, even after wolves are delisted. Depredation management from 1974 to 2002 was related to the size of a recovering population. At small population sizes, much time and effort was devoted towards minimizing depredation problems through non-lethal management, but as populations grew, lethal removal of selected individuals or packs became more prevalent.

After Delisting

The initial listing of wolves as endangered species in 1974 delineated a critical juncture for the way wolves were managed in the United States. It is likely that the impending delisting of wolves from the endangered species list will present another critical period in that lethal management will become more common in areas where recovered wolf populations are at sustainable levels.

The amount of lethal control allowed, how it is carried out and by whom will likely vary depending upon how individual states set up their individual management plans. In the short term, most wolf control is likely to continue to be done by USDA Wildlife Services, under arrangements with the states similar to those for coyote control. When delisting occurs, it is likely that greater authority will be given to the local communities that have to interact most closely with wolves. Non-lethal control will likely be de-emphasized because of the high costs and limited effectiveness, although research into long-term, non-lethal solutions will likely continue because of the strong interest in alternative management strategies.

Future research regarding lethal control will focus on determining if problem individuals exist and figuring out ways to selectively remove these animals. Problem animals are those individuals that kill more livestock per encounter than other individuals within the population (Linnell et al., 1999). Problem individuals are known to exist for a wide range of carnivores including grizzly bears (Anderson et al., 2002), coyotes (Till and Knowlton, 1983; Conner et al., 1998; Sacks et al., 1999), lynx (Stahl et al., 2002), wolverine (Landa et al., 1999), and jaguars (Rabinowitz, 1986). However for wolves it is difficult to determine whether or not problem individuals exist because of the social nature of packs. Thus it may be more realistic to investigate whether or not problem packs develop. If so, the causal mechanism leading to the development of problem packs would be important to investigate. Understanding what influences carnivores to attack and kill livestock will aid in the development of tools and techniques that managers can use to mitigate problems. It is likely that the most significant advances will unite knowledge of livestock husbandry, technology, and carnivore behavior and ecology.

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Compensation Programs in Wyoming for Livestock Depredation by Large Carnivores

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Introduction

Common law in America, which has been continually reinforced in the courts of the United States, holds that the people of the state own the wildlife within its boundaries. No person or entity holds absolute property rights to wildlife regardless of the ownership of the land on which the animal is found. The courts have construed that since wildlife belongs to everyone, everyone must share in its keep. As a result of this interpretation, courts have ruled the government, both state and federal, is immune from liability for damage caused by wild animals, unless the government waives its sovereign immunity and voluntarily assumes liability.

The federal government has long invoked its sovereign immunity from liability for damage caused by species managed under federal law, such as migratory waterfowl, passerine birds, and those species listed as threatened or endangered, such as grizzly bears and gray wolves. In addition, many states have traditionally invoked their sovereign immunity from liability for damage caused by wild animals. As an example, the state of South Dakota does not accept monetary liability for damage done by wildlife. Conversely, some states, such as Wyoming, Utah, Washington and Idaho, have waived their sovereign immunity to a limited degree and assumed liability for some types of damage caused by some types of wild animals.

After a century of persecution that resulted in large scale population reductions, large predator numbers have increased over much of their former ranges in North America. Predators such as wolves, cougars and grizzly bears are making a comeback in parts of the West. The comeback is largely due to a variety of changing societal values about predators that have resulted in reduced control campaigns. Along with the increase in predators, predator compensation programs have evolved in some jurisdictions. Currently, fourteen states and four Canadian provinces have government administered programs to reimburse livestock owners for losses caused by some predators. In addition, Defenders of Wildlife, a private conservation group, reimburses livestock producers for losses caused by grizzly bears in two western states and wolves in three western states. Most programs pay for losses caused by only the large predators (black bears, grizzly bears, cougars, and wolves) even though in most states smaller predators, such as coyotes or golden eagles, cause a far more significant monetary loss to the livestock industry. This industry is important, and in some instances critical, to the rural infrastructure and local economies of Wyoming.

Discussion

The question begs to be asked, "Why would government waive sovereign immunity and assume liability for damage to livestock that is the result of depredation by animals, such as black bears, grizzly bears, and cougars?"

Let's look at the Wyoming example. In Wyoming, Title 23, the Game and Fish Act states, "all wildlife in Wyoming is property of the state. It is the purpose of the act and the policy of the state to provide for an adequate and flexible system for control, propagation, management, protection, and regulation of all Wyoming wildlife." The livestock producers, and the majority of residents in Wyoming, agree livestock owners should not have to carry the entire financial burden associated with having wildlife in the state and of damage done by wildlife, in this case large predators. For this reason, long ago the Wyoming Legislature enacted laws that waive the State's sovereign immunity to a limited degree and accept responsibility for damage done to livestock by bears and cougars (and will do so to a limited degree for wolves in geographic locations where they are classified as trophy game animals when wolves are removed from Endangered Species Act protection). In addition, Wyoming statutes allow any black bear or cougar doing damage to private property may be immediately taken and killed by the owner of the property, employee of the owner or lessee of the property. The statutes also provide for reimbursement to producers for the value of the livestock killed or damaged, which includes bees, honey and hives. How reimbursement is to be administered was left vague by the legislature, so interpreting how compensation programs should be structured is left to the Wyoming Game and Fish Commission.

Revenues collected from application fees for limited draw big game and wild bison hunting licenses fund the current damage-claim program in Wyoming. While the entire public enjoys the benefits of healthy wildlife populations, in the case of carnivores, the management costs, including damage payments, are largely borne by sportsmen and the livestock industry. A recent study conducted by Jessica Montag et al at the University of Montana entitled, "Political and Social Viability of Predator Compensation Programs in the West," concluded that a large percentage of the public and livestock producers endorsed a compensation program that was funded by sources derived from not only hunters and fishermen, but also from a more representative section of the public. How this can be accomplished is a matter of debate. There is currently no system in place to equitably distribute the costs of depredations between all wildlife consumptive and non-consumptive user groups.

Compensation for dead livestock is only one facet of managing predator-livestock conflicts. Most chronic livestock damage problems result in management challenges that cannot be solely mitigated by monetary compensation. Livestock that are routinely preyed upon by large carnivores are often difficult to distribute for ideal range utilization, may tear down fences while escaping predators, and generally are more problematic to manage. Costs associated with finding dead livestock, managing livestock distribution, and those costs associated with filing and defending damage claims all add to the costs of predator damage. Most damage reimbursement programs pay for the value of the livestock at the time of death and not for indirect costs associated with depredations, so managing the conflicts in addition to compensating for losses is often the desired action for both the agencies and the producer. Management of the conflict may come in several forms: 1) the producer may be asked to relocate or remove the livestock from the grazing lands; 2) the producer may be allowed to control the offending predators; 3) the wildlife agency or the producer may initiate a livestock protection action; 4) steps may be taken to deter the predator; or, 5) the agency may implement control actions.

The Wyoming Game and Fish Commission has long recognized that neither the producer nor Department personnel detect every sheep or calf killed by large carnivores. It is recognized that when a bear or cougar kills a sheep, the entire sheep carcass is routinely moved and may be hidden, making it difficult to locate or decomposition may make it impossible to determine the cause of death. Since 1985, in a portion of the state where cougar numbers are high, the Commission has reimbursed owners of livestock for up to the value of three missing sheep believed to have been killed by a cougar for every one sheep confirmed by the Department as having been killed by a cougar. Until recently black bear-caused losses had no multiplier. Due to the difficulty in finding losses in mountainous terrain where calves have been killed by grizzly bears, the Commission has for several years utilized a formula based on the value of a confirmed loss to pay for missing calves, never detected, but believed to have been killed by bears. In order for these formulas to be applied for missing sheep or calves, Department or USDA/APHIS-Wildlife Services personnel are required to confirm at least one calf or one sheep as having been killed by a bear or lion. Total reimbursement for missing livestock never exceeds the total number of sheep or calves placed on the grazing allotment minus livestock lost to non-predator reasons. Formulas do not apply to yearling or adult cattle since experience indicates that losses occur at a much lower rate and when such animals are killed, often times sufficient evidence exists to find a portion of the dead animal for evaluation purposes.

From the broad perspective of the entire livestock industry, livestock lost to depredation by large carnivores, such as black bears, grizzly bears, cougars, and gray wolves may be argued as insignificant, yet these large predators can cause significant livestock losses and resulting financial hardship to individual livestock operators in the West. In fiscal year 2003 (July 1, 2002 through June 30, 2003), Wyoming Game and Fish Department or Wildlife Services personnel confirmed livestock lost to black bear, grizzly bear or cougar predation as 83 lambs, 78 ewes, 35 calves, 11 adult cows, and 1 bull. In addition, during 2002 Wildlife Services or U.S. Fish and Wildlife Service personnel confirmed 23 cattle killed by wolves. The depredations resulted in the Wyoming Game and Fish Commission reimbursing livestock operators $16,417.91 for sheep losses and $48,770.52 for cattle. In addition, the Department expended $28,221.99 to compensate beekeepers for damage inflicted on bees, honey, and hives by black bears and grizzly bears. Defenders of Wildlife paid producers in Wyoming $13,751.21 for wolf-caused losses in 2002. The addition of gray wolves to the list of predator losses for which the State of Wyoming pays compensation may result in a substantial increase in damage payments and associated management costs for both the wildlife agency and the producer. Under the current system, compensation for wolf-caused losses will be paid from hunters' license dollars.

Implications

As a result of increasing concern by livestock producers to be paid for losses that remained undiscovered, the 2003 Wyoming Legislature enacted legislation enabling the Wyoming Game and Fish Commission to, "establish through rule making methods, factors and formulas to be used for determining the amount to compensate any landowner, lessee or agent for livestock damaged as a result of, missing as a result of, or killed by trophy game animals". In July 2003, the Commission adopted formulas in rule and regulation to guide the Wyoming Game and Fish Department in offering reimbursement for missing sheep or calves killed by trophy game animals.

"Any claimant whose verified claim is for missing sheep or calves believed to have been damaged as a result of a trophy game animal, shall include on his verified claim the total known death loss, including missing animals, for the sheep or calves for the grazing season together with the number of such losses known to be due to causes other than damage by a trophy game animal.

Not withstanding the use of the formulas, the Department shall not offer compensation for more than the total known death loss less the number of such losses known to be due to causes other than damage by a black bear, grizzly bear or cougar. In order to utilize any formula, the Department or its representative must have confirmed the claimant had at least one (1) calf or one (1) sheep injured or killed by a trophy game animal.

Veterinary costs for the treatment of individual livestock that have been injured by a trophy game animal shall be considered up to a maximum amount that is not to exceed the value of the livestock injured, only in cases where a licensed veterinarian believes the individual livestock in question had a reasonable chance to survive and return to a productive state. If the individual livestock died as a result of an injury inflicted by a trophy game animal, even though the livestock received veterinary care, payment shall only be made up to a maximum of the value of the livestock."

The factors and formulas contained in the Department's rule and regulation are based upon a combination of analysis of data collected by the Department; historic use of similar formulas to pay producers for sheep missing as a result of cougar depredation in the Big Horn Mountains; and cattle and sheep death loss data compiled by a livestock producers association in the Upper Green River area near Pinedale, Wyoming that has frequently experienced missing livestock that are believed to be the result of grizzly and black bear depredation.

In Wyoming, a second solution has been for the Wyoming Game and Fish Department to develop a program to deal with conflicts that occur between large carnivores and livestock. The program consists of depredation evaluation training for all district game wardens, so that losses can be investigated and documented quickly. In addition, a specialized staff has been formed in the northwest portion of the state to prevent, investigate, and manage damage caused by black and grizzly bears in chronic damage areas. Also, a statewide agreement with specialists at the Wildlife Services to control offending animals at the Department's direction has been adopted. This multifaceted approach seeks to conserve large carnivore populations while managing the impacts to local livestock producers.

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Direct, Spillover, and Intangible Benefits of Predation Management

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Introduction

Predation management is a controversial and often misunderstood reality of livestock management. Few on either side of the argument would believe that some sort of management is not necessary to limit livestock losses. Opposition to the lethal removal of predators characterizes most debates. While most of the opposition reflects a moral opinion about the manner in which people relate to the natural world, opponents of lethal control often argue that control is not economically justified.

Simple economic justification would require that benefits of predation management outweigh the costs. If the only goal of predation management were to be economically efficient, minimization of costs would be one of the primary objectives; however, current predation management philosophies focus on minimum disruption to natural processes. These include focusing lethal management of offending individuals and populations, and using methods (such as aerial hunting) that are expensive but highly selective and humane. Boardman et al. (1996) discuss that the objective of minimizing costs is the same as maximizing net benefits. The costs of management, while important, play a minor role in the selection of management strategies.

Costs of management include direct expenditures by producers for management programs, governmental expenditures for management and compensation programs, producer and governmental costs associated with preventing predation, and societal values associated with the predators removed. Costs of predation management programs are usually easier to quantify, can have significant variance and typically are concentrated to a few individuals, while the benefits are dispersed among many. For this reason, the authors intend to focus on the benefits of predation management programs.

Benefits

Consideration of the benefits of predation management should include an examination of different types of benefits that accrue as a result of a management program. Benefits can be classified as *direct* benefits, which accrue to the primary recipient of the program; *spillover* benefits, which accrue to secondary entities that were not the intended beneficiaries of the program; and *intangible* benefits that are difficult to quantify but nonetheless exist.

Direct Benefits

Direct benefits in the case of predation management typically are calculated as the number of individual animals saved from predation (Engeman et al., 2002; Engeman et al., 2003; Merrell and Shwiff, in review). Therefore, benefits represent a cost saving, in that with predation management a certain amount of losses or costs can be avoided. The dollar value of the species saved represents the direct benefit of the program, and the losses avoided by producers. Determination of monetary values for different species is not a straight-forward process (Shwiff et al., 2003). In the case of livestock, the market price is often used to determine the value of the animal. This, however, often represents a conservative estimate of the true value of the animal (see Shwiff and Merrell, this issue). For wildlife, civil values are often used to recognize the benefit they have within society. Civil values range from \$10 to \$50 each for upland game birds to \$250 to \$450 for mule deer, up to \$2,000 for bighorn sheep, and \$400 to \$10,000 for antelope.

Reducing loss rates is the primary focus of all livestock predation management programs, and in this sense, all programs seek to prevent losses. To calculate the benefits of predation management programs, losses in the absence of management must be determined. Measuring what did not occur is obviously a difficult task and does not require special discussion. Research conducted in the 1970s attempted to detail livestock losses where no predator control was practiced. These studies focused on coyote predation on sheep following the ban on predicides and provide conservative estimates of losses in the absence of management. The authors consider these loss rates to be conservative estimates because: (1) they were designed to estimate coyote loss rates and do not generally reflect losses to bears and cougars (which can be substantial in some areas); (2) some degree of predation management occurred on or near the study sites thus potentially mitigating some of the losses; and (3) despite the best study protocol, some predation losses are never discovered or are so completely consumed to preclude determination based on forensic evidence. Table 1 summarizes these studies.

Like sheep, goats appear more vulnerable to predation and studies to determine predation rates in the absence of management have been few. In a two-year study in Texas, Guthery and Beasom (1978) reported that 49% of adult goats and 64% (range 33 to 95%) of goat kids were killed by predators. The

National Agricultural Statistical Service (NASS) reported that in 1999 calf losses averaged 3% (for those producers experiencing losses).

At some point, discussions of predation rates in the absence of management become an academic exercise. Profit margins in livestock production do not allow a 20% loss rate, and the absence of predation management would likely result in the loss of the livestock enterprise. However, the theoretical calculation of benefits would be the difference between losses in the absence of management and the losses experienced with management in place. Engeman et al. (2002) compared the benefits and costs of four different predation management programs to protect endangered sea turtles to determine which program provided the greatest benefits measured by the number of turtles saved under each program versus the others. One of the programs involved no management and represented the historical rates of predation in the absence of management.

Bodenchuk et al. (2002) reported loss rates (to all predators) where predation management was in place averaging 1.6% of adult sheep and 6% of the calculated lamb crop. Loss of goats where predation management was in place was 12%. Calf losses where predation management was in place averaged 0.8% of the calves protected. The difference, based on the number of sheep, goats and calves protected in 1999 and the 1999 market value, indicated that over $62.6 million was saved by predation management programs. The direct benefits of a predation management program are often the easiest to calculate; however, they fail to capture all of the benefits that accrue to a program.

Spillover Benefits

Spillover benefits are also referred to as secondary, indirect or incidental benefits (Boardman et al., 1996). These benefits are usually an unintentional side effect of the primary purpose of the predation management program, and in some cases are viewed as multiplier effects from primary benefits. Shwiff and Merrell (this issue) examine the spillover benefits to cattle as a result of a coyote predation management program implemented in south central Wyoming to increase antelope recruitment. Cattle producers in the area where coyotes were managed also benefited from the program even though this was not the primary intention of the program.

The value of these benefits depends on the quantity and variety of species affected by predators. In many cases, the spillover benefit of livestock protection in increased wildlife numbers (and value) may equal or exceed the direct benefit in livestock saved. Additional spillover benefits can accrue to the communities that depend on the livestock industry as a primary source of revenue. For example, Shwiff and Merrell (this issue) calculated that the spillover effects to cattle of coyote predation management for antelope ranged from approximately $75,000 to $180,000 in 2001 and $78,000 to $185,000 in 2002. This includes the possibility of additional benefits to the community as a result of agricultural dollars having a larger multiplier effect in the local community. If the livestock industry is a significant employer in the community, the spillover effects could be even greater.

Livestock protection programs often provide benefits to wildlife resources in the same geographic area. For example, Bodenchuk et al. (2002) reported case studies in Utah where mule deer populations responded following a winter die off. Deer numbers were evaluated two years following the die-off and were compared to the state-established population objective. In units where intensive control for sheep protection was provided to summer range (coinciding with the deer-fawning range), the deer numbers averaged 74.4% of the state's management objective and increased an average 6.4% over the previous year. In units where extensive sheep protection was performed on winter range (but not fawning range) the deer numbers were 50.3% of objective and increased an average of 2.3% over the previous year. On units where no predation management was applied, the deer herd averaged 39.7% of objective and decreased an average 1.1% from the previous year.

Spillover benefits can accrue where multiple resources, such as wildlife species or habitat, are in need of protection. The Utah WS predation management Environmental Assessments detail how integrated predation management for multiple resources is conducted. Once a predation program is requested, information from all affected resource managers is obtained. Control intensity, timing, area to be treated and target species are adjusted to optimize direct and spillover benefits.

Intangible Benefits

Intangible benefits from predation management programs exist, but in most cases they are impossible to quantify. Such benefits include things like increased cooperation from landowners as a result of the implementation of a predation management program. For example, while predation management may be controversial in urban areas, in many rural areas it is an accepted and expected practice, and the presence of an effective predation management program has facilitated landowner participation in other sage grouse conservation efforts in Utah (D. Mitchell, 2003; Utah Division of Wildlife Resources, Personal

Table 1. Available information concerning losses to predators in the absence of predation management.

Source	Location	Year	Sheep Lost (%)	Lambs Lost (%)
Henne (1977)	Montana	1974	7.5	29.3
Munoz (1977)	Montana	1975	8.1	24.4
McAdoo & Klebenow (1978)	California	1976	1.4	6.3
Delorenzo & Howard (1976)	New Mexico	1974	Not Reported	12.1
Delorenzo & Howard (1976)	New Mexico	1975	Not Reported	15.6
Average			**5.67**	**17.5**

Communication). Additional intangible benefits include potentially abating amateur efforts to control predators, which are not as selective or humane, or even legal. There are no studies to document the environmental damage caused by the lack of a program, but numerous law enforcement cases exist where landowners attempted control on their own with significant environmental damage as a result. The prevention of environmentally damaging programs is an undeniable benefit of an effective predation program. In many cases, decreased stress on the producer as a result of an effective predation management program provides a significant benefit that can not be calculated.

Conclusion

Predation management has been shown to have many benefits to livestock production. The primary goal of predation management is to reduce livestock losses. It is desirable but not necessary to achieve economic efficiency in predation management programs. In order to achieve efficiency the benefits of a program must exceed the costs, which requires the accurate measurement of benefits and costs. In this paper we identified, *direct, spillover* and *intangible* benefits in relation to the protection of livestock from predation. This will provide a template for the quantification of these benefits, which will lead to a more accurate evaluation of predation management programs. *Direct* benefits usually can be calculated, and in most benefits-cost analyses of predation management these are the only benefits that are reported. *Spillover* benefits are more difficult to quantify, however, they reflect the indirect benefits of a particular program. *Intangible* benefits are almost impossible to quantify but recognition of their importance in a predation management program is vital to provide an accurate description of the contribution of a predation management program. Unless economic assessments of livestock predation management programs include all of these benefits, programs are significantly understating the value of livestock predation management.

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Indirect Effects of Carnivores on Livestock Foraging Behavior and Production

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Introduction

Direct effects of predation (i.e., killing of animals) can result in significant economic losses to livestock producers. A recent publication by the USDA, Wildlife Services (2002) identified the following losses: (1) livestock losses attributed to predators, predominantly coyotes (*Canis latrans*), reach about $71 million annually; (2) cattle and calf losses to predators in the United States totaled 147,000 head during 2000. A National Agricultural Statistics Service (NASS) study valued these losses at $51.6 million; (3) sheep and lamb losses to predators in the United States totaled 273,000 in 1999. A NASS study valued these losses at $16.5 million; (4) In Arizona, New Mexico, and Texas, the three major goat-producing states, 61,000 goats and kids were lost to predators in 1999. A NASS study valued these losses at $3.4 million. Although direct losses of livestock due to depredation are often conspicuous and economically significant, they likely underestimate the total loss to producers because they do not consider indirect effects of carnivores as a result of livestock being exposed to the threat of predation without being killed.

Laundré et al. (2001) suggested that behavioral responses by prey species to impending predation might have more far-reaching consequences for ungulate behavioral ecology than the actual killing of individuals by predators. Potential negative, *indirect* impacts associated with the mere presence of predators include, but are not limited to, increased vigilance and reduced foraging efficiency by prey species, and being forced by predators to forage in suboptimal habitats that contain lower quality or quantity of nutrients, and higher levels of toxins. Moreover, overuse of and lowered carrying capacity in suboptimal habitats could contribute to resource degradation (e.g., overgrazing in marginal habitats, increased erosion and sedimentation) and lower producer profits due to declines in livestock production (e.g., weight gain, body condition, lamb or calf crop). Thus, indirect impacts of predation may have negative impacts on the ecological integrity of the land, as well as negative impacts on personal, local, and regional economies that depend on livestock production. However, there is little or no published information that addresses indirect effects of carnivores on domestic ungulates.

The purpose of this paper is to discuss how the mere threat of predation might influence foraging efficiency and vigilance, diet and habitat selection, skin-gut responses, and social behavior in wild and domestic ungulate prey species. Because there is little or no published information on domestic ungulates concerning these subjects, we rely heavily on wild ungulate studies that have attempted to quantify or qualify the indirect effects of predation. Our aim is to use the wildlife literature as a springboard to stimulate discussion among producers, wildlife damage management professionals, and researchers regarding ways to quantify and address the indirect effects of carnivores on domestic ungulates. We first discuss the evidence from the wildlife literature that supports indirect effects of carnivores on wild ungulates, and then relate that evidence to its potential implications for domestic livestock foraging behavior and production.

Evidence From The Wildlife Literature

Foraging Efficiency and Vigilance

Foraging efficiency is generally higher in the absence of predators because ungulates are not hindered from selecting diets from habitats that contain high nutrient densities and low toxin levels (Laundré et al., 2001). Foraging in high-quality, predator-free habitats affords prey species the opportunity to exhibit maximum selectivity among nutritious plants and plant parts. Conversely, when herbivores sense or encounter predators, foraging efficiency may decrease due to increased vigilance and corresponding lower intake in high-quality habitats, increased energy expenditures caused by avoidance or escape maneuvers, or by being forced into lower-quality habitats where nutrients are less available and less digestible (Lima and Dill, 1990). Decreased animal production could result due to any of these scenarios.

Vigilance has been defined in previous studies as when an animal stands with its head raised while looking around, and is not lying, feeding, moving to another feeding spot, or engaged in a maintenance behavior like grooming or nursing (Hunter and Skinner, 1998; Laundré et al., 2001). Wild ungulates and other prey species increase vigilance while foraging in or near risky habitat (e.g., dense vegetation or water holes), while occupying more hazardous areas within a social group (e.g., group periphery), or while foraging during more hazardous times of the day (Underwood, 1982; Lagory, 1986; Scheel, 1993; Bednekoff and Ritter, 1994; Molvar and Bowyer, 1994). Predation risk and corresponding vigilance levels vary across space and time, with species of predator, and with predator:prey ratios (Brown and Alkon, 1990; Brown, 1992, 1999; Brown et al., 1999; Gese and Knowlton, 2001; Kotler et al., 1994). Increased vigilance by prey species generally comes at the expense of lower foraging efficiency. For example, female elk (*Cervus elaphus*) with calves increased their vigilance rates from 20 to 48% in the presence of wolves, which meant they sacrificed nearly half their foraging effort (Laundré et al., 2001).

Diet and Habitat Selection

When predation risk is high, prey species may move to lower-quality foraging areas that have higher-security value (Brown, 1999), or may choose to occupy the periphery of a predator's territory that may be safer. This, in turn, may negatively influence a prey species' ability to preferentially select high-quality habitats and diets that meet their physiological and nutritional needs. Caribou (*Rangifer tarandus*) resided on Pic Island in Lake Superior to escape wolf (*Canis lupus*) predation on the mainland even though the mainland provided a higher quantity and quality of forage (Ferguson et al., 1988). Mech (1977) found higher densities and survival rates for white-tailed deer (*Odocoileus virginianus*) with home ranges located along the edge of wolf pack territories, suggesting that wolf predation was greater for deer whose home ranges significantly overlapped wolf territories. Mule deer (*Odocoileus hemionus*) subject to predation by mountain lions (*Puma concolor*) reduced use of patches where predation risk was high and increased use of similar quality food patches located in safer areas (Altendorf et al., 2001).

Predators directly affect prey numbers by killing offspring, but also indirectly influence production of female ungulates by altering their preferred diet and habitat selection patterns (Edwards, 1983). This is significant because adequate nutrition is widely recognized as a key component necessary for recruitment, especially for females that must consume adequate diets to conceive, carry a fetus to term, nurse and protect their offspring from predators until weaning. Female ungulates carrying fetuses or traveling with offspring at heel frequently sacrifice their own foraging efficiency to protect their progeny from predators. For example, female caribou dispersed into mountainous areas giving up better quality forage in the lowlands, apparently to avoid wolves during the calving season (Bergerud et al., 1984). Similarly, pregnant bighorn ewes (*Ovis canadensis*) migrated from low-elevation winter range to high-elevation lambing areas before plant growth had commenced, ostensibly to avoid predation during lambing (Festa-Bianchet, 1988). Elk and bison (*Bison bison*) cows were more vigilant in areas with wolves than in wolf-free areas in Yellowstone National Park (Laundré et al., 2001). Lactating moose with active juveniles were more vigilant (i.e., spent less time foraging) than those with inactive young, and spent more time near protective cover than nonlactating cows when subjected to grizzly bear (*Ursus arctos*) and wolf predation (White and Berger, 2001).

Skin-Gut Defense System

In natural systems where predation plays a significant role, safe and unsafe areas of the landscape can rapidly change across space and time because predators move across the landscape in response to their prey (Lima, 2002). Nutrient and toxin contents of plants also change seasonally and across landscapes but at a much slower rate when compared to predation and other potential external threats. To cope with these challenges, animals have evolved the skin-gut defense system to protect themselves from risks in their foraging environment (Garcia and Holder, 1985; Garcia et al., 1985). The skin and gut defense systems are neurologically and physiologically interlinked but produce fundamentally different responses in animals (e.g., place aversions via skin defense versus flavor aversions via gut defense), and operate across dissimilar time scales ranging from seconds (skin defense) to hours (gut defense). The skin-defense system protects animals from danger in their external environment (e.g., predators, electric shock), while the gut-defense system mediates hazards associated with an animal's internal environment (e.g., overingestion of plant toxins or nutrients).

Social Group Responses

Some wild ungulate prey species form social groups in response to impending predation. The formation of social groups is believed to increase protection from predators by enhancing sensory capabilities, confusing the search image of predators, increasing predator:prey ratios, and allowing herd members located within the group's core to dedicate more time to foraging and ruminating (Lagory, 1986; Benekoff and Ritter, 1994; Hunter and Skinner, 1998).

An oft-cited example of how ungulates cooperate socially to mitigate imminent predation is how musk ox (*Ovibos moschatus*) change herd conformation, density, and shape (i.e., perimeter size) in response to an imminent wolf attack (Miller and Gunn, 1984). Similarly, male bighorn sheep form a "musk ring" to protect the herd from carnivores (Shank, 1977). Mule deer form large cohesive groups and make a stand to fight off coyote attacks, as opposed to white-tailed deer that use their speed to outrun coyotes (Lingle, 2001). Risenhoover and Bailey (1985) reported that foraging efficiency of mountain sheep was positively related to group size, and that foraging groups of more than ten animals appeared to be a behavioral adaptation enabling sheep to use less secure habitats. Frid (1997) reported that Dall sheep (*Ovis dalli*) became less vigilant as group size increased, while California bighorn sheep groups consisting of five or less individuals had lower foraging efficiency than larger groups because of more interruptions to scan the environment, i.e., increased vigilance (Berger, 1978).

Some ungulates have been observed to form "nurseries" to cooperatively guard offspring while mother forages. For example, lactating Nubian ibexes (*Capra ibex*) selected richer feeding areas, spent more time feeding per day, and foraged further from escape cover when their young were cached in a "nursery" compared to lactating females with young at heel (Kohlmann et al., 1996). The establishment of nurseries apparently allowed lactating ibex to select and consume more nutritious diets while other herd members protected their young from predators.

Potential Implications for Domestic Livestock

Foraging Efficiency and Vigilance

Productivity of wild and domestic ungulates is largely a function of forage intake (I = g/minute or kg/day), which has been characterized as the product of bite rate (BR = bites/minute), bite size (BS = g/bite), and foraging time (FT = time foraging/day), i.e., BR * BS * FT = I (Stuth, 1991). Ungulates increase, decrease, or maintain forage intake by adjusting any of these three variables in response to changing foraging conditions. Animals that consume more food in relation to energy expended traveling and searching for food are said to forage more efficiently, and typically gain more weight and produce more young than animals with lower intake levels and higher energy outputs (Osugi, 1974; Sevi et al., 1999).

The term "feeding station" describes when an ungulate stops walking, plants its two front feet, lowers its head, and bites a plant (Stuth, 1991). When forage quality is high (e.g., high levels of cell contents, low levels of cell wall and plant toxins), animals learn to select plants and plant parts that offer higher BS than what is available on average within the feeding station. Under these conditions, BR and FT may decrease because of the compensatory response of animals to select plants and plant parts that offer higher BS. On the other hand, when forage quality is low, animals may spend more time harvesting the forage within a feeding station, but less time searching for high-quality forage when walking between feeding stations. Under this scenario, BR may increase as animals try to compensate for lower BS and reduced FT because they require longer rumination times to digest low-quality diets.

As discussed earlier, wild ungulates increase vigilance when in the presence of predators at the expense of forage intake due to a reduction in BR, BS, FT, or all three of these factors. Predators may also force prey species to abandon high-quality habitat for lower-quality habitat, which can reduce ingestion of nutrients for the reasons described above (i.e., increased BR of lower quality forage to compensate for lower BS and FT). Moreover, when prey are forced by predators to utilize unfamiliar habitats in which they have little or no experience they may eat less, suffer more from malnutrition, and spend more time walking than animals foraging in familiar environments. All of these factors may weaken animals and further increase their risk to predation (Provenza and Balph, 1990). Domestic ungulates that are restricted to smaller foraging areas due to the presence of predators could also overgraze and decrease forage and animal productivity. Any of these scenarios would have a negative impact on individual animal productivity in the short-term and overall profitability of livestock operations in the long-term.

Diet and Habitat Selection

Domestic ungulates learn to avoid or select foods on the basis of post-ingestive feedback (Howery et al., 1998a). Animals learn to ingest nutritious foods by associating a food's flavor (taste and smell) with its post-ingestive consequences (reviewed by Provenza et al., 1992; Provenza, 1995). If ingestion of a food is followed by satiety or nutritional benefit (or, internal malaise or illness), preference for the food increases (decreases) and the animal will seek (avoid) the food when it is encountered in the future. If toxicity of a food decreases (or, if its nutrient content increases), the food is no longer paired with negative feedback and intake may increase. Conversely, intake of a food may decrease when its toxicity increases or nutrient content decreases. Animals learn which foods to eat or avoid through constant sampling and updating flavor:post-ingestive associations of foods that change in toxin or nutrient content across space and time. Any change in liking of a food (typically quantified as a change in intake) is known as a "hedonic shift."

As with dietary preferences, animals develop habitat preferences as a result of prior experience. Bailey et al. (1996) proposed the concept of a "site value rating" where lower ratings or expectations are assigned to foraging habitats or sites that contain high levels of plant toxins. According to this model, domestic ungulates learn to rarely revisit sites that contain plants with high levels of toxins, or habitats associated with abiotic constraints that limit access to forage by domestic herbivores (e.g., distance from water, percent slope). Hence, Bailey et al's site value ratings in habitat selection are analogous to hedonic values assigned to foods in the parlance of conditioned flavor preferences or aversions (Provenza, 1995).

Although no field studies have been conducted to determine if site value ratings (or hedonic values) can be estimated for habitats or sites based on the probability of predation attacks, it is widely recognized that domestic ungulates learn to avoid handling facilities if the movement through these facilities is associated with pain and fear (Grandin and Deesing, 1998). Alternatively, animals form place preferences and easily move through handling facilities that are associated with a food reward (Hutson, 1980). It therefore seems reasonable to hypothesize that domestic animals learn to form aversions and avoid locations or habitats associated with predators (e.g., dense vegetation or other forms of stalking cover), although this needs to be tested in the field (Launchbaugh and Howery, 2004).

Skin-Gut Defense System

In controlled experiments where electric shock is used to mimic nonlethal insults to the skin-defense system (Garcia and Holder, 1985), livestock were trained to completely avoid a high-quality habitat associated with visual cues and electric shock (Cibils et al., submitted). Cattle instead foraged near lower-quality habitat that was "safe". The tendency for cattle to shun high-quality habitat following an insult to the skin-defense system is analogous to wild ungulates avoiding high-quality food patches associated with predators (Brown, 1999; Altendorf et al., 2001; Laundré et al., 2001; Lingle, 2001; White et al., 2001; Miller, 2002). Avoidance of high-quality habitats occupied by predators could negatively impact livestock weight gain, animal condition, and overall performance for reasons described earlier.

Social Responses

The phrase "strength in numbers" characterizes how wild and domestic ungulates frequently use group behavior to respond to impending predation. The following anecdotal examples need experimental confirmation, but indicate how domestic herbivores respond to and are impacted by impending predation.

Cattle production suffered in Wyoming when cows and calves were stalked and killed by grizzly bears (Terry Schramn, Grazing Behavior Symposium presentation, Univ. of Idaho, Moscow, 1999). Cattle formed groups to ward off grizzly bear attacks and restricted themselves to areas where predation risk was reduced which resulted in overuse of the range.

In eastern Arizona, where calf losses to wolves on one ranch were estimated to be 50% in 2002, cattle were observed to huddle and move together in smaller groups (Darcy Ely, personal communication). Cattle "were always on the move and never in the same area during a 24-hour period" while grazing an 8,000-acre pasture in wolf country (Darcy Ely, personal communication). Other behaviors observed included increased vigilance, cows running through fence lines, cows fighting wolves to protect their calves, diarrhea, increased stillborns and abortions, and cows and calves running from domestic cow dogs after being exposed to wolves. By fall roundup, cow dogs could no longer control cattle movements. Cows that lost their calves to wolf predation had spoiled teats due to lack of suckling, and new calves had to be bottle-fed the following year. Cows with spoiled teats eventually had to be culled. Incessant wolf predation resulted in the decision to truck cows to a wolf-free allotment that did not have adequate forage quantity and quality. Cows were not observed to rebreed while on this allotment (Darcy Ely, personal communication).

When sheep are herded they are apparently afforded more protection from predators than cattle because herders can move sheep out of areas with predator problems. However, predator attacks still occur at night when sheep are bedded (Mark Pedersen, personal communication). Sheep pursued by predators at night likely suffer from exhaustion and weight loss, which can negatively influence forage intake and reproductive performance of both males and females. Rams need food and rest to service 50 to 60 ewes, and ewes that lose weight may not cycle or carry lambs to term compared to rested animals (Mark Pedersen, personal communication). When a band of 2,000 sheep are chased by predators they move "shoulder to shoulder like an amoeba" which can damage soils and vegetation, especially when wet (Mark Pedersen, personal communication). In addition to increased energy expenditure as a result of being harassed by predators at night, animals also have less time to ruminate, which can reduce digestibility of plant material harvested earlier in the day. Thus, harassment by predators may directly cause weight loss due to increased energy expenditure associated with running and loss of sleep, but may also indirectly reduce the ability of ruminants to convert plant nutrients into weight gain due to decreased rumination time.

Conclusions

More research is needed to better understand the potential impacts of indirect, nonlethal predation on domestic livestock behavior and production. Increased understanding could allow managers to manipulate animals, forage, and habitats in ways that lower both the direct and indirect effects of predation, increase livestock production, and that prevent herbivore distribution problems that may cause resource degradation (Howery et al., 1996, 1998b). Additionally, increased understanding will provide for the development of long-term, sustainable, profitable, and environmentally sound, pest-management systems for agriculture, promotion of reduced risk pest-management practices, and protection and conservation of ecosystem quality and diversity.

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Livestock Depredations by Black Vultures and Golden Eagles

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Black Vulture Biology

Black Vulture

There are two species of vultures common in North America, the turkey vulture (*Cathartes aura*) and black vulture (*Coragyps atratus*). In many localities in the United States, vultures are called "buzzards." The turkey vulture specializes in locating and eating carrion. Black vultures also subsist principally on carrion, but at times this species is predatory. Thus, for livestock producers, the black vulture is the species of concern.

Black vultures have a 1.3 to 1.5 m wing span and weigh about 2 kg (Peterson, 1980; Avery unpub. data). Adult and juvenile black vultures have a dark grey head, black body, the underside of the wings are dark grey to black with a white patch at the end of each wing, and a relatively short tail feathers (Peterson, 1980). In flight, black vultures have the appearance of large bats. Black vultures have been reported to live to 25 years of age (Henny, 1990).

The mode of flight differs between black and turkey vultures due to different wing lengths supporting about the same body mass (Rabenold and Decker, 1989). Turkey vultures flap the wings a few times and glide when at low altitudes, whereas black vultures flap frequently interspersed with brief glides when at low altitudes unless a strong wind blows. At high altitudes both vultures fly primarily by gliding and riding thermal wind currents. While soaring or gliding, turkey vultures generally hold their wings at a steeper angle than do black vultures.

The range of the black vulture includes south-central Arizona, the southern and eastern two-thirds of Texas, and the entire southeastern United States north to the southern portions of Missouri, Illinois, Indiana, Ohio, Pennsylvania, Connecticut and New York (Buckley, 1999). The species' distribution has expanded to the north and east in recent years (Rabenold and Decker, 1989), and the black vulture population on trend is increasing, as measured by the annual Breeding Bird Survey (Sauer et al., vers. 20031).

The black vulture has a very broad diet (Buckley, 1999). Unlike most other vultures, it will subdue, capture and eat live prey, including birds (Baynard, 1909), skunks and opossums (McIhenny, 1939; Dickerson, 1983), turtle hatchlings (Mrosovsky, 1971) and fish (Jackson et al., 1978), and livestock (Lowney, 1999).

The black vulture does not depend upon olfaction to find food (Stager, 1964). Instead, it frequently locates food by sight, sometimes cueing on behavior of turkey vultures (Buckley, 1996). When a turkey vulture finds a carcass, black vultures often arrive in large numbers and dominate or displace the turkey vulture at the feeding site (Stewart, 1978; personal observations). Black vultures roost communally and appear to have a well-developed social structure with long-term, family-based relationships (Rabenold, 1986). Communal vulture roosts probably are important to efficient foraging by black vultures in that information regarding the locations of food resources can be transferred among birds roosting together (Buckley, 1996).

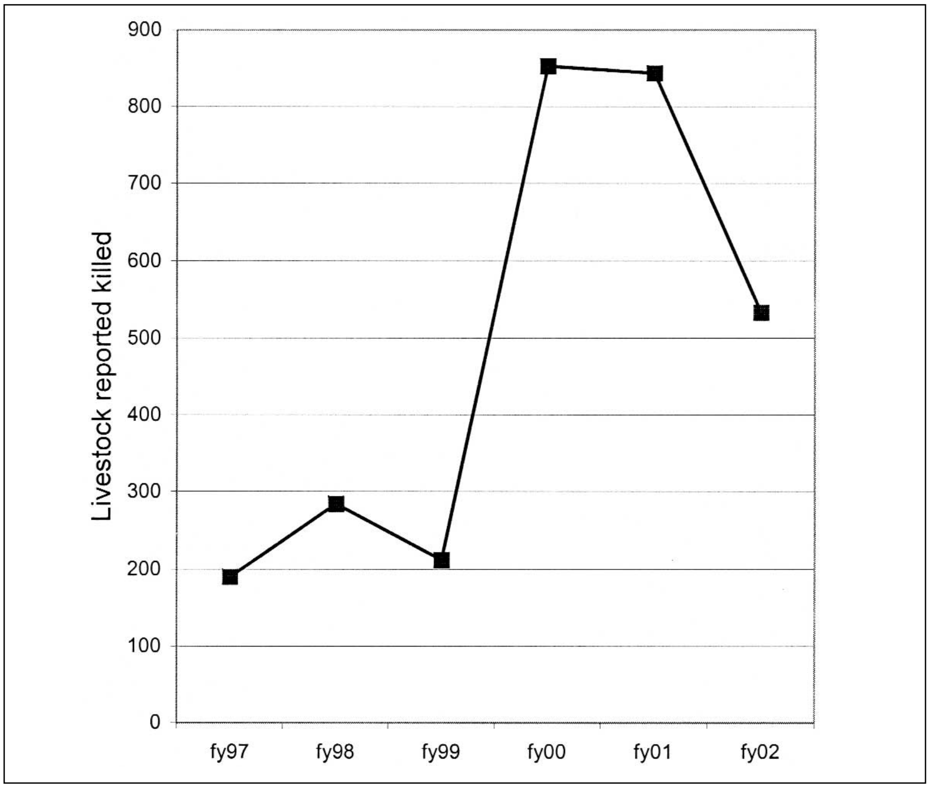
Golden Eagle

The golden eagle (*Aquila chrysaetos*) is North America's largest predatory bird. Its length averages 75 to 100 cm, wingspan is from 2.2 to 2.5 m and weighs between 4 to 6 kg. Males and females are similar in appearance, except the female is much larger than the male. Adult plumage, gained at 4 to 6 years, is largely brown, darkening nearer the wings. The tail is grayish brown. The feathers at the head and nape of adult birds are a golden brown (Reilly, 1968; Terres, 1980). It is federally protected under the Bald Eagle Protection Act of 1962. Breeding populations in states, such as California, Colorado, Wyoming and Montana, indicate positive growth ((USG Sauer et al., vers. 20032).

Golden eagles are skilled and efficient predators. Their diet comprises primarily small mammals such as cottontail rabbits (*Sylvilagus spp.*), black-tailed jackrabbits (*Lepus californicus*), rock squirrels (*Spermophilus variegates*), greater sage grouse (*Centrocercus urophasianus*), and other small birds and reptiles. However, golden eagles have been documented taking larger prey, such as mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), coyotes (*Canis latrans*), and domestic calves and sheep (Arnold, 1954; McEneaney and Jenkins, 1983; Phillips et al., 1996). They have also been observed eating carrion (R. Phillips, personal communication). One bird can carry up to 8 kg (17 pounds) in flight (Terres, 1980).

Golden eagles mate for life, and a pair may need up to 35 square miles of territory in which to hunt. Breeding season generally begins in mid-January and continues into mid-September, though it can vary according to geographic region. Nests have measured up to 3 m across and 1 m deep and pairs may have multiple nests with their territory. The female is responsible for most of the incubation and will lay 1 to 4 eggs. Incubation lasts about 35 to 45 days, and nestlings fledge at 9 to 12 weeks (Terres, 1980).

Figure 1. Reports of black vulture attacks to livestock have increased in recent years.



Livestock Depredations

Black Vulture

The black vulture's dietary breadth, social behavior and foraging skills contribute to its role as a problem species for many livestock producers. Damage by black vultures to livestock and poultry has been reported for decades (e.g. Roads, 1936; Sprunt, 1946; Lovell, 1947). In Florida, Baynard (1909) stated that "Hundreds of young pigs, lambs, etc., are annually devoured by them… I have had them come into my yard and catch young chickens."

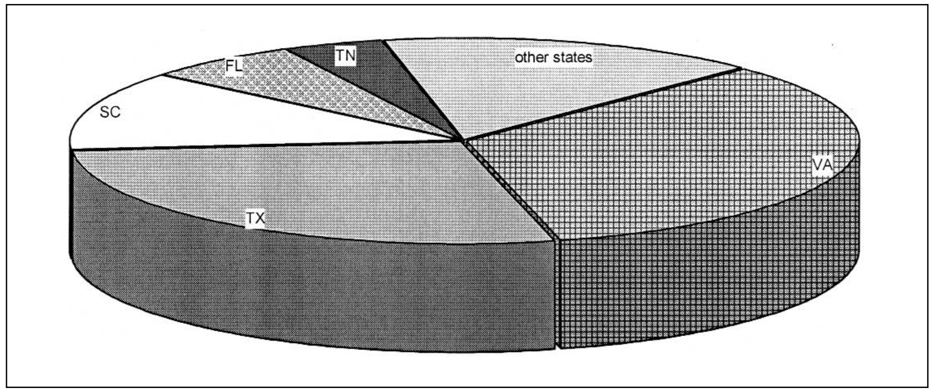
There is no doubt that black vultures continue to attack, kill, and eat domestic animals, but at this time there is little information on the frequency and extent of such occurrences. Data compiled by the USDA's Wildlife Services Program suggest an increasing trend in the numbers of domestic animals attacked by black vultures since 1997 (Fig. 1). These data are compiled from reports to USDA Wildlife Services personnel. We do not know what proportion of the total number of depredations is reported, so at best these data might represent minimal estimates of the extent of the vulture damage problem. Alternatively, these data might overestimate actual vulture-caused mortality because some of the deaths attributed to black vultures could have been due to other factors.

During 1997 to 2002, reports of depredations on domestic animals by black vultures were received from 18 states. Virginia, Florida, Texas, South Carolina, and Tennessee accounted for 84% of the reported incidents (Fig. 2). Depredations to cattle were reported from each of the 18 states, and overall more than half of the livestock depredation reports involved cattle (Fig. 3). Overwhelmingly, black vulture damage to livestock was to young animals (Fig. 4). This apparent preference for young animals is consistent with the birds' ability to identify and then subdue weak and vulnerable individuals.

In Virginia, 115 incidents of black vulture interactions with 1037 livestock animals were recorded during 1990-1996 (Lowney, 1999). Vultures disabled young lambs and calves by first pecking out their eyes and then attacking vulnerable soft parts (rectum, genitals, nose). Cows giving birth were attacked in a similar manner. The prey animals were attacked by groups of 20 to 60 vultures.

At a cattle ranch in central Florida, our investigations showed that both black and turkey vultures focused their activities in pastures where active calving was occurring. Both species of vulture were frequently observed feeding on afterbirth as well as on fresh droppings from calves. At this ranch, we also observed two depredation incidents, four months apart, and one attempted depredation. In each depredation event, the calf was dead and the heifer was alive. There were 20 to 40 black vultures feeding on the dead calves and attacking the heifers when we arrived. Possibly, the calves were stillborn, but it is also possible that black vultures killed them. Each of the heifers was unable to stand and each was euthanized by the rancher because of injuries inflicted by the vultures. During the attempted depredation, we videotaped three black vultures as they repeatedly pecked at the hooves of a calf as it was being born. This cow was able to get up and chase the birds off, however, and she later gave birth without incident.

Figure 2. Although 18 states have reported depredations to livestock by black vultures, most reports come from Texas, Virginia, Florida, Tennessee, and South Carolina.



Golden Eagle

Golden eagle predation on livestock has been documented in many areas of the western United States. Most depredations involve golden eagles preying on young lambs and goats; depredations on domestic calves occur occasionally. A eagle damage survey (Phillips and Blom, 1988) suggested that, in many cases, resident golden eagles were responsible for chronic losses of young domestic lambs (*Ovis aries*), particularly in parts of Colorado, Wyoming, Montana and Utah, where relatively dense breeding eagle populations overlap with lambing areas (Boeker, 1974).

Serious golden eagle depredations in the United States are usually infrequent and localized (Matchett and O'Gara, 1991). The most severe problems are acute, short-term conflicts during lambing and kidding periods. Most researchers have found low levels of golden eagle depredation on livestock (McGahan, 1967; Bolen, 1975; Olendroff, 1976).

Most depredation complaints involve eagles preying on young lambs and goats (Fig. 5; U.S. Dep. Agric. 1991). In 1999, 10,700 head of sheep and lambs were preyed on by golden eagles, representing about 4% of overall predation losses at a cost of $522,000 (National Agriculture Statistical Service 2000). In Wyoming, of 3,600 lamb carcasses examined, 878 were killed by predators (Tigner and Larson, 1977; 1981); 70 had been killed by golden eagles and another 19 were suspected eagle kills. Foster and Crisler (1978, 1979), found golden eagles responsible for up to 15 percent of the lamb losses they examined in the late 1970s in Oregon's Hells Canyon National Recreation Area. During the same period, the Wyoming wool growers estimated losses at 8,600 lambs or $500,000 (Matchett and O'Gara, 1991). In addition, a survey conducted from 1997 to 2002 by Wyoming Agriculture and presented in the Wyoming Agriculture Statistics, indicated that eagles, specifically golden eagles, took over 40,000 sheep/lambs during this period. In Texas, U.S. Department of Agriculture's Wildlife Services verified 98 sheep/lambs taken by golden eagles from 1995 to 2003 (M. Rendon, USDA, Wildlife Services,. Management Information System, November 2003).

Figure 3. Of the reported black vulture depredation incidents, 52% have involved cattle.

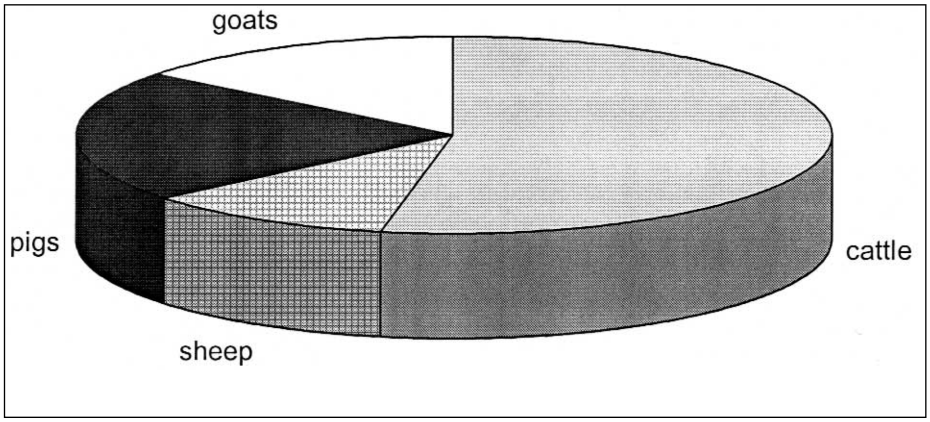


Figure 4. Black vultures overwhelmingly prey on young animals.

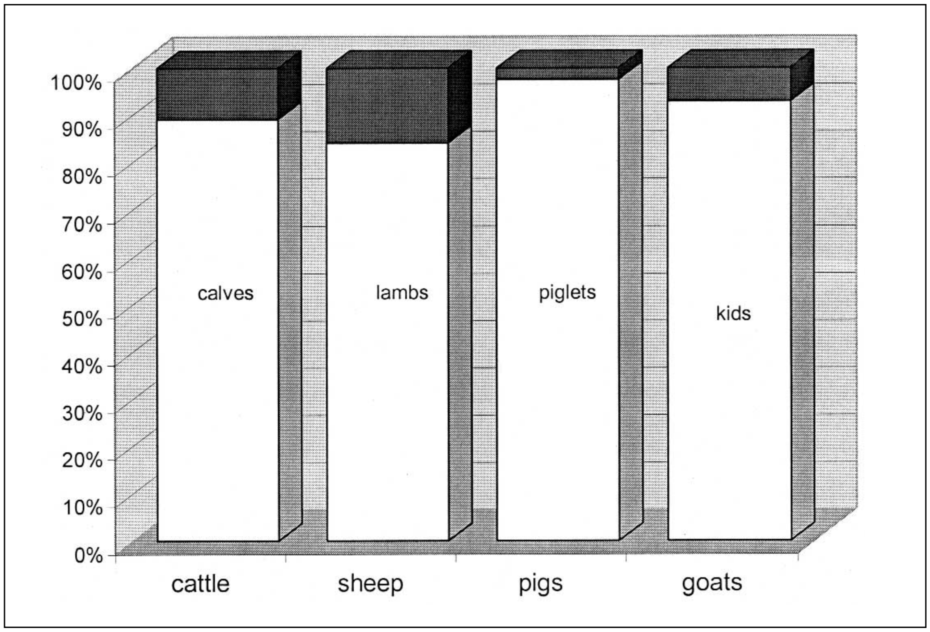
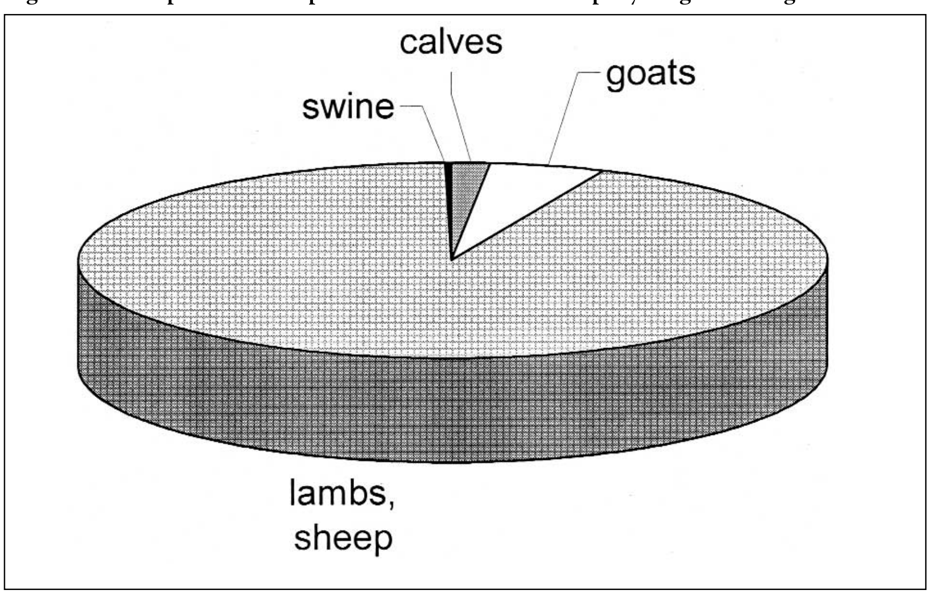


Figure 5. Sheep and lambs predominate as livestock prey of golden eagles.



Depredations on domestic calves occur occasionally. Wood's (1946) observed a golden eagle killing a calf. The most severe calf depredation by golden eagles occurred on the Tigner Ranch in New Mexico, where eagles killed 12 calves and injured 61 between 1987 and 1989. Calves weighed between 41 to 114 kg and represented a $20,000 loss (Phillips et al., 1996).

Vulture Management Methods

Black Vulture

Harassment. Reportedly, vultures can be dispersed from pastures by firing .22 caliber or larger rifle ammunition near loafing vultures. Pyrotechnics or shotguns can also be used. Such harassment often has short-term benefit only, as vultures will return to the site within a few hours. It is illegal to kill or wound a vulture without a Migratory Bird Depredation permit issued by the U.S. Fish and Wildlife Service (USFWS).

Cultural. Removal of food sources, such as dead livestock and road-killed animals, reduces food availability and could lessen the likelihood of vultures being attracted to an area. Vulture depredations can be prevented by locating lambing, pigging, and calving activities in sheds or buildings, or by using paddocks close to barns or buildings with human activity so that birthing animals can be monitored closely.

Effigies. Dispersal of vulture roosts near a livestock operation can help reduce the likelihood that depredations will occur (Tillman et al., 2002; W. Bonwell, personal communication). Dispersal is often best accomplished by suspending a vulture carcass or a taxidermic effigy of a vulture in the roost, but other roost dispersal options, such as pyrotechnics, could produce a similar result. The advantage of using the effigy method is that the vultures will not return once they are dispersed. As long as the effigy remains in place the roost will not reform.

At this time, we do not know the fate of vultures that formerly occupied a dispersed roost site. They must occupy alternate roost sites, but definitive studies on where they go and what they do subsequently have yet to be done.

Trapping, relocating. Vultures are readily trapped in large, baited, walk-in pens (Parmalee and Parmalee, 1967; Davis, 1998; Humphrey et al., 2000). The benefits of relocating trapped vultures are dubious, however. In Texas, relocating trapped birds did not reduce problems at industrial facilities where the birds were trapped. Furthermore, there were increased complaints regarding vultures at the release sites (Davis, 1988). In Florida, four of eight transmitter-equipped vultures released >250 km from the trap site eventually were tracked to within 16 km of their original roost (Humphrey et al., 2000). It was concluded that unless trapping and relocation are combined with habitat modification and harassment to render the original site less attractive to vultures, problems at the original site will persist. At this time there is no evidence that trapping and relocation is an effective vulture management tool.

Lethal control. Given increasing population trends for the black vulture (Sauer et al., vers. 20013), selective lethal control would appear to have limited potential for impacting the overall health and viability of the species. Selective removal of problem vultures could, however, potentially contribute to resolving local vulture management conflicts. Additional documentation of the effectiveness of selective, direct lethal control for vulture management is needed as is quantification of the assertion that removal of a few vultures from a local population increases the efficacy of harassment programs and prevents habituation to harassment (Kadlec, 1968). A Migratory Bird Depredation Permit issued by the USFWS is required before vultures can be killed.

Golden Eagle

Depredation management techniques for golden eagles include trapping and relocation, harassment, alarm/distress calls, and human-like scarecrows. Relocation of non-breeding and breeding golden eagles from lambing or calving grounds offers only a short-term solution. Scarecrows combined with harassment and increased human activity has proved to be the best lamb protection with minimal expense.

Trapping, relocation. Two research studies evaluating the response of golden eagles to trapping and relocation showed that of 14 resident golden eagles relocated over 400 km from their capture sites in Wyoming, 12 returned to their capture sites within 11 to 316 days. Phillips et al. (1991) concluded that relocation of breeding adult golden eagles, at best, offered only a short-term solution to the problem of eagle depredation on livestock. Niemeyer (1975-1983) showed that relocation of 432 golden eagles at a cost of $112,771 had little demonstrated effect on reducing depredations.

Scaring, harassment. Alarm/distress calls and harassment with a helicopter or airplane did not reduce depredations, number of birds present or alter their distribution (O'Gara et al., 1984; Matchett and O'Gara, 1987).

Human-like scarecrows suspended on high knobs and ridges where sheep typically bed for the night seemed to cause golden eagles to avoid those areas. When coupled with harassment (shooting explosive shotgun shells), the effects seemed to be effective in keeping eagles away from lambing bands (O'Gara et al., 1984).

Lethal control. Golden eagles are protected under the Migratory Treaty Act and the Bald and Golden Eagle Act. Since the 1990s, no lethal-take permits have been issued by the Director of the U.S. Fish and Wildlife Service (USFWS) in the western United States. However, the USFWS has issued limited permits for trapping golden eagles that are causing livestock depredations. Golden eagles that are trapped are either given to a Native American Indian Tribe, a master falconer, or are relocated.

Conclusions

Black Vulture

The available evidence suggests that black vultures act as typical predators by seeking and disabling vulnerable animals prior to overwhelming and killing them (Gluesing et al., 1980). These birds take the path of least resistance and eat carrion when it is available. Black vultures are opportunists, however, and when the chance arises, they will attack and eat defenseless live animals. Defenseless does not necessarily mean sick or injured. Healthy newborn livestock are defenseless, especially if the mother is exhausted or otherwise not able to care for and protect the offspring.

In assessing the role of black vultures as livestock predators, it is difficult to obtain objective, unbiased information because direct observations of black vulture attacks on livestock are uncommon. Usually, the investigator arrives at the feeding site after the prey animal is dead and the chain of events leading to the demise of the animal is speculative. The fact that black vultures are feeding on a carcass is not evidence that the birds killed the animal. Some animals are stillborn and others die for reasons unrelated to black vultures. Female livestock, especially young and inexperienced ones, sometimes suffer mortal injuries while giving birth. If vultures attack and kill such mortally injured animals, they are eliminating individuals that are already doomed.

As the black vulture population increases and its range continues to expand, depredations to livestock are likely to increase. To resolve these conflicts, research is needed to understand more fully the population dynamics of this species and to determine factors that contribute to the birds' preying on livestock. In particular, it will be important to know why some livestock operations incur vulture damage while other ranches are not affected. Research is currently underway specifically to address these data gaps.

Golden Eagle

Golden eagle populations are increasing in western states with sheep production. It is unknown whether increased eagle numbers translates into increases in livestock depredations. It is important for livestock producers to understand that management techniques for golden eagles are limited. The combination of human-like scarecrows, harassment and increased human activity is the most feasible means of protecting lambing bands from golden eagles. As potential new avian management techniques evolve, an effort should be made to evaluate their effectiveness to reduce livestock depredation from golden eagles.

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Non-lethal Alternatives for Predation Management

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Introduction

The ethical milieu in which wildlife biologists and livestock producers work continues to change as the concepts of environmentalism and animal rights and welfare have become introduced and normalized (Singer, 1975). The American public, including livestock producers, are mired within a typically human psychological quagmire of having a high demand for benefit, but a low tolerance for cost — that is, economic forces. Americans tend to demand a cheap, reliable food supply, while simultaneously demanding the existence of animals that, through predation activities, drive up production costs. Ironically, members of the urban public who may find fault with food and fiber production practices are also the customers on which livestock producers are dependent.

In the United States, predation management has evolved from an attempt to eradicate or limit predator populations to the application of focused approaches for minimizing the damage done by predators. For coyotes, very large scale population suppression (using 1080), was restricted and sometimes apparently ineffective (Wagner, 1988). Other authors could find little correlation between the number of coyotes removed and the number of sheep kills at a California ranch (Conner et al., 1998). Further studies suggested that at least in some areas, dominant territorial coyotes are responsible for most sheep predation but typical lethal control methods tend to bias capture toward coyotes that are less likely to be livestock killers, thus, typical lethal methods such as trapping, snaring, and using M-44s are sometimes inefficient for solving depredation problems (Sacks et al. 1999, Blejwas et al. 2002).

Lethal control methods are also often at odds with conservation needs (Shivik et al., 2003; Haber, 1996) and the general public favors the use of non-lethal methods of predation management in many situations (Reiter et al., 1999). Non-lethal methods provide a means of keeping predators established, while protecting livestock from predation and thus, a great amount of effort has been spent identifying and evaluating non-lethal predation-management options (Linnell et al., 1996).

Effects of territoriality may improve efficiency of non-lethal methods relative to lethal control. Because predators, such as coyotes and wolves, are territorial and relatively long-lived, multi-year effects of management actions are possible, in contrast to lethal control which tends to be required annually (Bromely and Gese, 2001a,b). One goal of non-lethal methods with territorial species is to develop a bioexclusive effect such that resident predators do not kill livestock themselves, but further prevent losses by excluding other predators from the area.

The field and body of knowledge on non-lethal techniques is growing, and a need exists to categorize and understand the plethora of methods that are being advertised by both scientists and charlatans. The objective of this paper is to provide a descriptive outline of non-lethal methods for predation management and to identify hindrances to their use and future development. I have performed a basic search of non-lethal methods that are available. These methods have been categorized and then discussed. Note that inclusion of a method in this paper is not an endorsement or guarantee of effectiveness of the technique; the effective application of any management method will depend upon the particulars of the management situation. Many methods that are applicable in small pasture situations, for instance, may have little or no applicability in large, open-range situations.

Materials and Methods

Categories of Non-lethal Methods

Conflicts between humans and predators occur when food-acquisition behaviors of predators vie with food-production behaviors of humans. Thus, decreasing the level of conflict is largely a matter of altering specific behaviors of either humans or predators (or both).

Humans can alter food-production behavior (e.g., husbandry) to prevent conflict. However, human conflicts with wildlife also have a psychological (i.e., the degree of conflict is a matter of perception and personal opinion) and/or economic component. Therefore, some non-lethal methods of resolving predation problems can alter human behavior by assuaging the perception of the conflict. If the source of conflict is economic loss, other methods can address economic concerns.

Altering Human Behavior

Niche marketing. In some circumstances, it may be possible to influence what level of loss is economically and socially acceptable. For livestock producers, aggressive and innovative marketing through value-added products may help to shift the costs of damage onto the members of the public that prefer the use of non-lethal methods of damage control. For instance, prices of "wolf-friendly" goods could capitalize on a niche market that will support non-lethal wolf management practices.

Compensation. Individuals may be able to take advantage of subsidized compensation programs. Various governments and non-governmental organizations approach systems of compensation differently, and the use of compensation for losses remains controversial, with a requirement to proactively understand the agrarian system where compensation is to be applied (Angst et al., 2003; Montag, 2003). Surveys indicate that although non-lethal methods of predation management are preferred by the general public, government compensation for damages is not (Wagner et al., 1997). Some private organizations have been willing to fund compensation programs and encourage public support where damage due to predation is linked to particularly valued species such as wolves. However, the economic logic of compensation programs is limited because they do not actually address the cause of the problem and may be much more expensive (including administrative, predation culpability evaluation, and actual payment costs) than the impact of the damage that they are designed to reduce (Wagner et al., 1997). Two points that should be understood when considering implementing a compensation program are that compensation does nothing to manage or reduce the level of predation, but that it may help to increase public acceptance of predation while acknowledging the economic hardships caused by predators. The topic of compensation is complex and is therefore addressed more completely elsewhere in this issue.

Insurance. Some insurance companies will insure against livestock losses. Problems associated with instituting insurance programs include the need to find and positively identify predator damage, and agreeing on real market value of dead livestock. Insurance programs are most easily instituted when the threat of damage is low, but spatially extensive; however, in most current predator-damage situations, the threat of damage is high on small areas. but minor at the industry scale. The basic administrative needs of an insurance program require significant amounts of capital investment with only a small pool of livestock owners from which to draw insurance premiums. Without subsidies, the associated premiums of insurance may be too costly for programs to be financially solvent. The topic of insurance is complex and is therefore addressed more completely elsewhere in this issue.

Zoning lands. A concept that has recently been examined is the physical separation of predators and livestock by zoning lands for livestock use or predator conservation (Linnell et al., 1996). This concept acknowledges the need for different management goals and priorities in different areas and adapts methods, rules, and recommendations to vary within individual geographic zones. For example, some areas would be managed to be free of predators and designated for livestock, but other areas would be designated as wild places where predators roam with minimal human disturbance. Success of zoning would depend on identifying the appropriate size of zones and buffers such that conservation needs are met (Linnell et al., 1996). However, changing the use of large tracts of land after a long history of one use (e.g., changing grazing lands into a predator zone) may be politically intractable.

Altering Husbandry

Animal armor. A fairly new and untested method of livestock protection uses plastic collars to prevent canids from being able to grasp and kill sheep. The King Collar (Gray King, South Africa [046] 685 0645) is a brand of animal armor developed in South Africa for protection from jackals, a species that closely resembles coyotes in appearance and behavior. The manufacturer claims that the collar prevents jackals from gripping the cheek and biting the trachea. Its application to wolves or bears, which have different killing patterns than jackals, is unknown. It is possible that the novelty of protective collars may deter predation for some period of time, but because predators are very adaptable and quick to learn alternative methods of killing, animal armor that is both practical and effective in the long term will be difficult to develop. However, more research and development is required for a more thorough evaluation of its potential.

Herding/vigilance. North American predators tend to be wary of human presence, and a good herder who is able to stay with and monitor livestock can be an effective method of protection (Linnell et al., 1996). Furthermore, humans are able to observe when predators enter an area, employ aversive or disruptive stimuli, and identify the characteristics and timing of predators and predation. It is possible to maintain a human guard that walks through the pasture throughout the day and night watching for and chasing away wildlife. In most situations, hiring a human guard may be cost prohibitive; however in situations with sponsors, e.g., the Wildlife Guardian program (Defenders of Wildlife), outside parties can assist private producers by providing a free service of human guards for livestock.

Fencing. Fencing is a predation mitigation method that involves constructing a physical barrier that will keep human resources and predators apart and has been studied for centuries (Jardine, 1908). Because of previous thorough reviews, discussion of fencing is limited in this paper (Wade, 1982), but the topic is an important concept for consideration. Exclusionary devices can be as simple as an easily-strung, electric-energized temporary corral, or as complex and expensive as a dingo-proof fence stretching from one side of Australia to the other. Barriers can be extremely expensive to construct and maintain, and attention to detail in barrier construction and maintenance is extremely important. The general assessment is that fences can be very effective, but due to construction and maintenance costs fences are most practical for small night-time enclosures (Dorrance and Bourne, 1980; Linhart et. al., 1982; Linnell et al., 1996).

Night and seasonal enclosures. Robel et al. (1981) suggested that night penning is effective for minimizing losses to predators. Some producers herd animals back to corrals in the evening, and a few have proposed training beef cattle to return to barns at night by feeding them regularly in the evening, similarly to how dairy operations bring cattle in for milking. Shed lambing, i.e. keeping ewes inside a shed when they are giving birth to lambs, can reduce lamb losses due to predators and other factors. It is also common to calve near human habituations to assist cows with parturition.

Clearly, this technique is most possible in small operations, especially near human habitation, when small- to medium-sized flocks and herds can be grouped tightly and enclosed by a human herder. However, corralling livestock tightly can likely lead to localized damage to the range, and increase disease transmission and stress for the animals. Furthermore, this intensive husbandry may require additional labor costs that are prohibitive.

Timing of breeding. Predators are often more likely to kill livestock at specific times of year, e.g. coyote-killing of lambs often coincides with the need to provision their pups (Till and Knowlton, 1983; Bromely and Gese, 2001a). If livestock are bred earlier in the season, they are larger earlier and may be less vulnerable to predation, thus Robel et al. (1981) concluded that fall lambing reduces sheep losses. Altering breeding may allow for optimization of market price and predator-damage economics, but market and range conditions may be more important economically, making altering reproduction for predation management economically unfeasible. Other limitations include the biological limits to the alteration of lambing seasons and the increased husbandry and veterinary costs involved with altering reproductive cycles.

Selective pasturing, lambing, and calving. Certain pastures and range areas may have a record of high predation, i.e., be "hot spots" of predation (Linnell et al., 1996). Spatially intense predation may be due to some intrinsic aspect of the land, e.g., it may have a nearby rendezvous site with cover and prey that attracts predators, or the land may be near a source population of wolves. Coyote predation on livestock tends to be associated with the availability of stalking cover and land features (Pearson and Caroline, 1981). Sometimes, it may be possible to not use an area for grazing, and it may be economically advantageous to do so if predation pressures are high. In rotational grazing schemes, incorporating probability of predation into the management plan may be useful. Of course, when grazing areas are most beneficial to livestock, they may also be most attractive to predators, so simply altering timing or use of land may not be feasible economically or logistically. Also, moving livestock around repeatedly can cause additional stress and affect weight gain.

Altering herd composition. The composition of herds may influence the degree of depredation. For instance, sheep are generally much more vulnerable to predation than cattle (Fritts, 1982; Gee, 1979). An interesting husbandry practice employs a combined livestock operation. Mixing cattle with sheep (i.e., forming a "flerd") may lead to a better use of the landscape, with the added benefit that cattle may be more aggressive toward small predators, thus providing some degree of livestock protection (Hulet and Anderson, 1991). However, cattle and sheep operations are different in terms of market conditions, timing, and land use, and switching to raising both animals may be difficult or impossible for some producers. Furthermore, cattle and sheep do not stay together naturally and efforts at bonding the two must be made, for instance by raising young heifers with lambs for 30 to 60 days. Mixed composition livestock operations, however, have yet to be thoroughly investigated for their degree of protection from predators, and because cattle too are subject to predation, the effectiveness of using cattle for deterring predation by large predators is questionable.

Sanitation. Eliminating food resources in the form of bone yards or carcasses can reduce the attractiveness of an area to predators and other species of wildlife. Some research suggests that regular carcass removal and sanitation around livestock operations may help to lessen the severity of canid predation (Robel et al., 1981), while other research is less clear on the benefits of carcass disposal as a method to reduce wolf predation (Mech et al., 2000). As with most non-lethal methods, the degree of effectiveness using carcass removal is mostly unknown. Destroying carcasses may be beneficial indirectly, for instance, by limiting food supplies for predators, thus limiting their attraction to an area where livestock reside. Thus, many experts recommend removing carcasses and food sources when possible. However, in large livestock operations, logistical constraints on the ability to remove or destroy carcasses can be formidable, thus limiting the application of this management technique.

Altering predator behavior

Humans can reason paths away from conflict, but with other animals, the only options are to alter or prohibit specific predatory behaviors. Two broad behavioral modification approaches have been widely used, confused, and misused for depredation management (Bangs and Shivik, 2001). First, primary repellents use disruptive stimuli, which are stimuli that disrupt predatory behaviors by causing a "fright" or "startle" response. The limitation of primary repellents is that predators will quickly habituate to, i.e. learn to ignore, the stimuli, which leads to a loss of effectiveness. Second, secondary repellents use aversive stimuli, which are paired with a behavior in order to condition a predator against the behavior. The difficulty with using aversive stimuli is that achieving effective and specific conditioning against behaviors such as attacking cattle may be extremely difficult under natural conditions (Shivik et al., 2003; Shivik et al., in press). It is important to understand that putting flashing lights in a pasture will not aversively condition wolves to not enter the pasture; to the contrary, wolves will learn to ignore the stimulus. Similarly, shooting wolves with rubber bullets when they enter a pasture will not necessarily condition the wolves to generalize and avoid the area or to avoid killing calves; rather, they are more likely to learn to avoid the person shooting at them.

Primary Repellents: Disruptive Stimuli

Simple Visual Stimuli. One of the most ancient disruptive stimulus techniques is a scarecrow. The concept can be extended to almost anything out of the ordinary that is placed in a pasture or area and startles or frightens predators away. A light in a field or a vehicle or some other large object in a pasture may keep some predators from entering, at least for a short time. As with scarecrows, of course, animals quickly become accustomed and habituated to passive disruptive stimuli. Moving the object or light around intermittently and randomly may slow the habituation process (Shivik and Martin, 2001). Simple disruptive stimuli are beneficial because they are fairly inexpensive and easy to apply. However, they are usually useful in small pens or pastures only. It is presumable that a bigger object may be more of a deterrent, but some pastures may not be accessible with vehicles. If protection is needed for a very short time, then simple stimuli may be useful. Because rapid habituation by predators is likely, other methods will probably be required to achieve a significant degree of protection.

Noise. As with visual disruptive stimuli, sounds can frighten or startle a predator and limit access to an area. Radios, ultrasonic devices, and other noise placed in a pasture or pen and played loudly during the night will likely frighten intruding predators for a limited time (Blackshaw et al., 1990; Bombford and O'Brien, 1990; Koehler et al., 1990). Exploder cannons are propane-powered disruptive stimulus devices that intermittently fire, producing a loud boom that may deter coyote predation for about 31 days (Pfeifer and Goos, 1982; Andelt, 1996). Ultrasound is often touted as an animal-damage panacea for everything from mice to large ungulates, but as with any other simple stimuli, animals are likely to habituate to it very quickly (Bombford and O'Brien, 1990). Noise-generating devices, especially ones with sirens or other emergency sounds, require the notification of neighbors and law-enforcement personnel in order to prevent worry and confusion. As with other simple auditory stimuli, predators will habituate to sounds quickly; moving them frequently may increase longevity of effectiveness.

Flashing lights, Electronic Guards. Linhart et al. (1992), in an operational study of a strobe light/siren device (Electronic Guard), determined that Electronic Guards reduced sheep losses by 60%. Electronic Guards are randomly activating light and siren disruptive stimulus devices. According to APHIS guidelines, more than two units must be used in small fenced pastures, or one unit per 10 acres in larger areas. The devices may be purchased from the United States Department of Agriculture, Wildlife Service's Pocatello Supply Depot. They appear to be beneficial in areas, such as bed grounds, and are small, portable and flexible for various-sized areas. Electronic Guards are limited, however, in that their noise and lights can annoy people, and habituation by predators is likely at about 91 days for coyotes (Linhart et al. 1984). Use of Electronic Guards requires notification of neighbors and law-enforcement personnel to prevent undue alarm. Other researchers have extended the Electronic Guard concept to Radio Activated Guards for wolves, which activate in response to the presence of a radio-collared animal and may delay habituation (Breck et al., 2003).

Fladry. An ancient Eastern European technique used to capture wolves is to drive them along a narrowing boundary constructed of flags hung beneath a rope. Wolves tend to not cross the human-constructed line and can be driven into a corral or net-trap. Some research indicates effectiveness of fladry with captive wolves, but reports of effectiveness under field situations with other predators have varied (Musiani and Visalberghi, 2001; Shivik et al., 2003; Musiani et al., 2003). Fladry is likely to be limited to small- and medium-sized fenced areas because the flags require maintenance, especially in places with high winds. One study estimated longevity of effectiveness with wolves of 1 to 60 days (Musiani et al., 2003).

Chemical Repellents. Although applying chemicals over a wide area can be less expensive and easier than using other methods, there are a number of difficulties associated with using chemical repellents in the environment. First, there are no selective chemical repellents that affect only individual species (Lehner, 1987). The sensory physiology of all mammals is similar, and thus a selective chemical repellent which will repel predators, but not affect livestock or humans has not been identified. However, some manufactures claim efficacy of their predator repellents. Renardine, for example, is bone tar oil that is claimed to be a repellent for coyotes. The product is used to coat fence-lines and posts. Like any novel stimulus, strange smells posted around a pasture may deter predators from entering and predating on livestock. It may be applied to small- to large-sized pastures, but is costly and messy to apply and, due to habituation, its effectiveness may be limited.

Burns et al. (1984) determined that non-lethal amounts of chemicals in collars did not stop predation, but new chemical-filled collars are available. The Vichos anti-predator collar, for example, incorporates a chemical repellent in its construction. When punctured, a formulation of 3% capsaicin oleo resin is dispensed. In one study, researchers determined that the Vichos collar was ineffective for deterring predation because the collars did not prevent a second attack, which was usually launched at the hind-quarters of lambs instead of at the neck (Burns and Mason, 1996).

Biological odor repellents. Predators, such as wolves and coyotes, use scent marking to delimit territories, and although territoriality does not ensure complete exclusion of conspecifics (Shivik et al., 1996), it may be possible to mimic territorial behaviors by surrounding pastures with artificial scent marks that could repel intrusions. This technique can be used on areas of various sizes, but it has not been thoroughly evaluated and its effectiveness is in question. For example, other behavioral (e.g., howling) cues may be necessary to effectively prevent intrusions, and maintenance of scent stations may require frequent (i.e., daily) visits around the protected area's perimeter. Individual scent marks are also attractants for coyotes and wolves (e.g., scat and urine are used as lures to selectively capture them), and the method of applying artificial scent marks such that they repel predators has not been determined.

Disruptive harassment. In some situations, it may be possible to guard an area and then, if a predator enters a livestock area, use rubber bullets or other non-lethal projectiles to prevent a predation event. This technique may be beneficial because it is selective for predators presenting an immediate threat of depredation, but is limited due to logistics and cost of the required effort — a trained person must be nearby to observe and harass the predator. Clarkson (1989) reviewed shotgun weapons and Hunt (1985) examined multiple methods for bears. A variety of weapons exist, and newly developed devices for crowd control include paint-ball type weapons which use rounds filled with capsicum powder (the active ingredient in hot pepper). Low power lasers have been developed for military and law-enforcement applications. Some tests indicate that lasers are effective for dispersing some birds, but may not be effective on many mammals. Further testing is required, however, to determine types of lasers that may be used to repel predators such as wolves.

Guarding animals. The use of guard animals is an interesting avenue for research in that guard animals exhibit all of the attributes required of primary repellents for delaying habituation: multi-sensory stimuli and behavior contingent activation (Shivik and Martin 2001). The use of guard dogs originated in Europe and Asia thousands of years ago, and Americans have been using guard dogs and other guard animals since the mid-1970s. Some studies have shown that producers who use dogs are pleased with their effectiveness, and that guard dogs are a cost-effective means of reducing predation for coyotes and other predators (Andelt, 1992). The use of other guard animals has also been investigated (Meadows and Knowlton, 2000). Smith et al. (2000) produced a comprehensive review on the subject of guardian animals, and there is another discussion of this topic in this volume by Andelt.

Secondary Repellents: Aversive Stimuli

Aversive Harassment. Harassment, if performed very intensively, may condition predators to avoid livestock. The projectiles or other aversive stimuli must occur whenever predators are threatening the resource so that they do not identify conditions when they may obtain the prey without receiving a negative experience.

Conditioned Taste Aversion. Conditioned taste aversion (CTA) is a powerful training technique. CTA uses a less-than-lethal poison that is fed to a predator after it has consumed a type of food; the poison causes illness and the illness causes an intense aversion to the flavor of the food. The method was championed as an effective technique by Gustavson et al. (1974), and CTA seemed promising as an effective means of minimizing predation. However, due to a variety of logistical and biological constraints, the technique does not appear to be effective in field situations, and is thus not used widely (Dorrance and Roy, 1978; Conover and Kessler, 1994). For example, CTA is excellent for deterring eating behaviors, but is not especially effective at modifying killing behaviors, and a strong aversion to a tainted meat baits does not necessarily translate to a strong aversion to killing live prey. Attack and kill behaviors may continue after an animal is successfully conditioned using CTA. Another significant obstacle in the United States is the lack of a proper odorless, tasteless, environmentally safe poison that will cause violent illness, but not injure the predator or a non-target species.

Electronic Training Collars. It is possible to condition some predators to not attack specific prey. Some researchers used training collars (electronic collars used to train domestic dogs) to keep coyotes from attacking sheep (Andelt et al., 1999) and reported promising results, but other researchers were unable to overcome logistical difficulties and show an effective way to use them in actual management situations (Shivik et al., 2003; Shivik et al., 2003). The economic costs of implementing this strategy might also be unacceptably high.

Diversionary feeding, altering prey populations. It may be useful to increase game availability, or place carcasses or other alternative food supplies in areas near livestock and allow predators to consume these resources, so that livestock remain unmolested. Bear damage to trees was limited by alternate feeding (Ziegltrum, 1990), but other authors suggested that alternative feeding may not be effective in the long-term (Boertje et al., 1992). However, even well-fed predators may harass and kill livestock, and multiple years of diversionary feeding may result in increased numbers and concentrations of predators and a larger potential for conflict.

Reproductive inhibition. Reproductive inhibition may be a useful tool for minimizing predation by territorial predators. Earlier work indicated that coyotes without pups killed fewer sheep (Till and Knowlton, 1983), and some researchers investigated the use of surgical sterilization as a means of limiting coyote predation (Bromely and Gese, 2001a,b). Predators that have to provision pups require more food than those that do not have offspring. Thus, predators that have been sterilized are not as likely to damage livestock as intact animals are. It is also most likely to be effective in areas where losses are seasonal and proportional to coyote reproductive activity. Reproductive inhibition, it should be noted, is primarily a means of predation management, and not necessarily for population control, although it could slow population growth if employed on broad spatial and temporal scales. However, appropriate chemical contraceptives and delivery systems have not yet been developed, so no inexpensive and practical methods for reproductive inhibition are currently available.

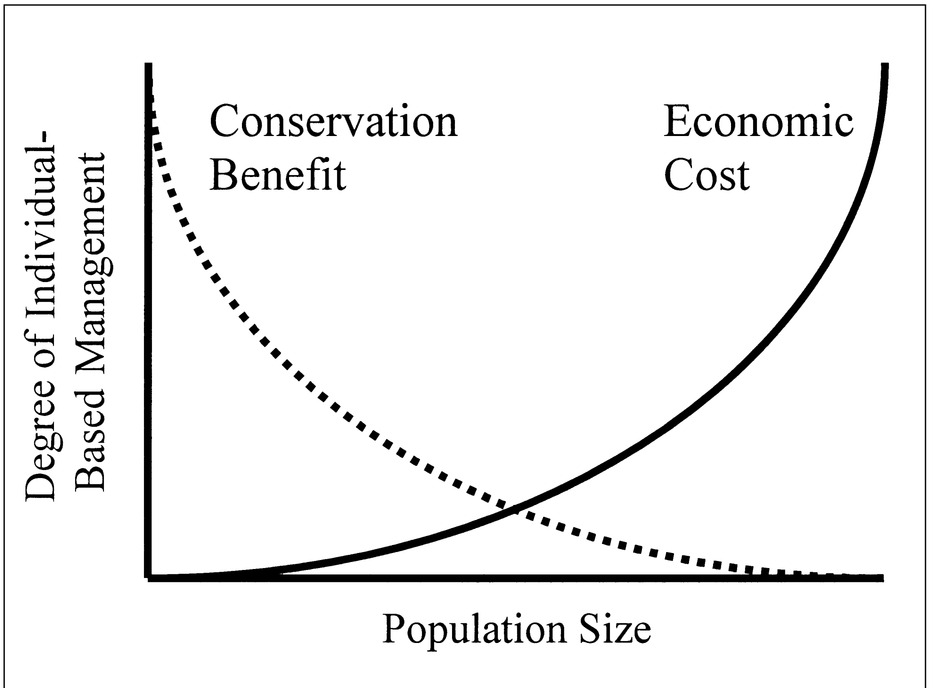
Translocation. If predators and livestock do not occupy the same place, they cannot interact, and thus translocation is sometimes advocated as a damage management strategy. Some studies reported a decline in killing after predators were removed (Armistad et al., 1994; Waite and Phillips, 1994; Stander, 1990). Moving a predator can be effective and more acceptable to many people since the predator is not immediately or apparently killed. However, translocated predators will often attempt to return, cause similar or worse conflicts, or die (Linnell et al., 1996).

Discussion

What non-lethal methods should be used? The answer depends on the circumstances of the predator, livestock, economics, and the social and political context in which methods are applied (Primm and Clark, 1996). In general, however, primary repellents tend to be logistically more simple and easier to apply than secondary repellents (Shivik et al., in press), but their drawback is an often short duration of effectiveness. Habituation can be decreased as the complexity of primary repellents increases, but increasing stimulus complexity tends to increase cost and decrease ease of use. Finding an appropriate primary repellent requires simultaneously trying to lessen the effect of habituation while minimizing costs and logistical difficulties associated with a device or technique.

Non-lethal methods tend to be selective toward particular predators, especially toward particular behaviors of predators. From an endangered species point of view, a high-degree of individual-based management is worth the cost of elaborate non-lethal techniques, but when predators are abundant, the simple economic model pressures toward population-based methods (Fig. 1).

Figure 1. **Conceptual cost-benefit model of individual-based predator management by conservation need. When predators are rare and highly valuable (in terms of genetics and conservation), the cost-benefit ratio favors the use of individual-based, non-lethal methods. When predators are abundant and not as valuable individually, the costs of individual-based management approaches rises dramatically, altering the cost:benefit ratio away from efficiency of individual-based management techniques.**



Most methods described in this paper are most appropriate at small scales, such as a pasture, and new non-lethal methods are needed that work on a larger scale (e.g. within a region or across allotments).

In reviewing the previous list of techniques, it is possible to conclude that non-lethal techniques are expensive, impractical, have a limited degree of effectiveness, and are sometimes controversial. However, due to socio-political constraints, the most appropriate method may not be the least expensive or logistically easiest one. That is, due to the changing world view of the American public, it may be important to understand that although non-lethal techniques may not be the most efficient, they are certainly necessary to develop, understand, and apply, especially as a part of an Integrated Pest Management (IPM) strategy.

Conclusion

Because of the varying quality of information and research about non-lethal techniques, the future of development and application is dependent upon good science in a complex social and political environment. Given the preceding list of methods, a producer or scientist may inquire which method is the best, but there is no one best solution to all animal damage situations. The type and degree of damage is important to realize before choosing the most appropriate method. In order for management methods to be effective, the mechanism by which they work must be considered and understood (Linnell et al., 1996). Future efforts in research must not only realize effectiveness or ineffectiveness of a given technique, but must provide knowledge and detail that shows why a method did or did not work. Efforts must be made to understand and limit habituation, to produce non-lethal techniques that work at the landscape and population scale, and to devise methods with maximal effectiveness but minimal cost and complexity. Producers should be educated about techniques available and in development, not only to take advantage of new methods that may reduce losses, but also to prevent the waste of time and money on inappropriate applications.

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Use of Livestock Guarding Animals to Reduce Predation on Livestock

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Introduction

Predation by coyotes (*Canis latrans*), domestic dogs, mountain lions (*Felis concolor*), black bears (*Ursus americanus*), red foxes (*Vulpes vulpes*), golden eagles (*Aquila chrysaetos*), and bobcats (*Felis rufus*) has been a major problem faced by domestic sheep, goat (NASS, 2000), and cattle (NASS, 2001) producers. Predators were reported to kill 273,000 sheep and lambs (NASS, 2000) and 147,000 cattle and calves (NASS, 2001) in the United States, and 61,000 goats in Arizona, New Mexico, and Texas (NASS, 2000) during either 1999 or 2000. Several methods, including the use of livestock guarding dogs, llamas, and donkeys, have been used to reduce these mortalities (Andelt, 1996, 2001). In this paper, I summarize use and effectiveness of livestock guarding animals for reducing predation on domestic sheep and goats. Recent reviews of livestock guarding animals are provided by Smith et al. (2000) and Rigg (2001).

Livestock guarding dogs

Livestock guarding dogs have been used in the United States since the early 1970s to protect sheep and goats from predators. Most guarding dog breeds have been selectively developed in Europe and Asia to protect livestock from bears (*Ursus* spp.) and wolves (*Canis lupus*). The most common breeds used in the United States are Great Pyrenees, Akbash, and Komondor (Green and Woodruff, 1988; Andelt and Hopper, 2000), whereas the Anatolian Shepherd, Maremma, Shar Planinetz, and mixed breed dogs are used less frequently. Most guarding dogs weigh 75-100 pounds and are ≥ 25 inches at the shoulders. Successful guarding dogs are trustworthy (will not harm sheep), attentive to sheep, and aggressive toward predators (Coppinger et al., 1983). These traits are "instinctive;" they develop in most dogs with proper handling and minor training.

Guarding dog pups cost an average of \$240 in Kansas (Andelt 1985), \$176 in North Dakota (Bergman et al., 1998), and \$331 and \$458 (depending on breed) in the western United States (Green et al., 1984). Annual maintenance fees (food, veterinary care, miscellaneous costs) averaged \$235-\$250 (Green et al., 1984; Andelt, 1985).

About 28% of sheep producers in the United States used guarding dogs to protect sheep during 1999 (NASS, 2000). Andelt and Hopper (2000) reported that the percentage of sheep with guarding dogs in fenced pastures and on open range in Colorado increased from 7% in 1986 to 65% in 1993. They also indicated that primarily producers with large flocks of sheep have incorporated guarding dogs.

Sheep producers in Colorado who did not use livestock guarding dogs lost 5.9 and 2.1 times greater proportions of lambs to predators than producers who had dogs in 1986 and 1993 (Andelt and Hopper, 2000). Predation on ewes and lambs decreased more from 1986 to 1993 for producers who obtained dogs between these years compared to producers who did not have dogs. A total of 125 producers in Colorado estimated that their 392 dogs reduced predation losses by \$891,440 in 1993. Thirty-six producers in North Dakota reported guarding dogs reduced predation on sheep by 93% (Pfeifer and Goos, 1982). Producers in Colorado indicated that guarding dogs greater than 9 months of age saved more time in sheep management than the amount of time spent feeding and working with each dog (Andelt, 1992). Overall, guarding dogs are a cost effective means of reducing predation (Green et al., 1984; Andelt and Hopper, 2000).

Livestock guarding dogs have been successful in reducing predation by coyotes on domestic sheep (Pfeifer and Goos, 1982; Coppinger et al. 1983; Andelt and Hopper, 2000). Producers with guarding dogs, compared to producers without guarding dogs, also sustained fewer ewe and lamb mortalities to black bears and mountain lions (Andelt and Hopper, 2000). Guarding dogs repelled black bears and grizzly bears (**Ursus arctos**) during most encounters (Green and Woodruff, 1989; Green et al., 1993; Hansen and Bakken, 1999). Guard dogs, at least in North America, may not be effective against wolves. There are documented cases of wolves killing dogs, and some reports of dogs pair-bonding with wolves and assisting in livestock depredation (M. Collinge, USDA/APHIS Wildlife Services; personal communication).

Disadvantages of guarding dogs include some dogs not staying with or harassing sheep, some dogs, especially Komondors, being overly aggressive toward people (Green and Woodruff, 1988; Andelt, 1992), and the dogs can be subject to injury and premature death. Many of the disadvantages are relatively uncommon. Most producers surveyed feel strongly that the advantages of their dogs far outweigh the disadvantages.

Green and Woodruff (1988) reported that the rate of success in protecting livestock from predators did not vary among several breeds of guarding dogs, nor was the rate of success different among males and females or intact and neutered dogs. Dogs that were reared with livestock from ≤ 2 months old had a significantly higher rate of success than dogs that were > 2 months old when placed with livestock. Ratings of effectiveness of guarding dogs by producers using one breed of dog in Colorado did not differ among breeds, but producers who used multiple breeds rated Akbash more effective than Great Pyrenees and Komondors (Andelt, 1999).

Guarding dog pups should be raised, preferably with a few head of bum lambs in a small pen in a barn or isolated area away from the flock, starting at 6 to 8 weeks of age when they develop a strong bond with sheep (Andelt, 1995). A pup should be treated like a working dog in the operation from the beginning. Pups should not be allowed to play with children or herd dogs or hang around the house. As a pup gets older, it should be introduced to equipment, machinery, other livestock (horses, cattle, chickens), and herding dog(s) so later it will not guard the sheep from them. A producer should spend some time with a pup so that it is not afraid of them and can be captured later on. A pup should not be rewarded when it wanders away from the sheep.

A pup should be raised, preferably with lambs that will be incorporated into the main flock. Once one group of sheep accepts the dog, other sheep unaccustomed to guarding dogs tend to accept it more quickly. High-quality dog food should be provided in a self feeder near the sheep at all times. A barrier should be placed around the feeder to exclude the sheep, or the dog may remain near the feeder, guarding it from the sheep.

When a dog matures and begins to work, it will stay with sheep willingly, and its barking and scent marking with urine will increase. These behaviors notify predators that a dog is present and help deter them from approaching the sheep. Coyotes and other predators usually remain in the area but are prevented from killing sheep.

Most producers who have <200 sheep, or graze sheep in <200-acre fields, usually use one or two guarding dogs. Producers who graze 1,000 ewes and their lambs on open range often use two to five dogs. The number of dogs used usually depends on the extent of predation, dispersion of sheep, and amount of brushy cover on the range.

Llamas

Llamas have been used to deter predation primarily by coyotes, red foxes, and dogs since the early 1980s. About 13% of sheep producers in the United States used llamas to protect sheep from predators during 1999 (NASS, 2000). Llamas are naturally aggressive toward coyotes and dogs. Typical responses of llamas to coyotes and dogs are being alert, alarm calling, walking to or running toward the predator, chasing, kicking, or pawing the predator, herding the sheep, or positioning themselves between the sheep and predator.

Franklin and Powell (1993) surveyed 145 producers who used llamas, primarily in Montana, Wyoming, Colorado, California, and Oregon. Most producers used one gelded male with 250 to 300 sheep in 250- to 300-acre pastures. Nearly all llamas were not raised with sheep and were not trained to guard sheep. One llama was more effective than multiple llamas for deterring predation; the effectiveness of gelded males, intact males, and females was similar. However, producers reported more problems with intact (25% of 61 intact males) than gelded males (5% of 135 gelded males) attempting to breed ewes. Sheep that were introduced to llamas in corrals initially sustained lower mortalities than those introduced in pastures. The success of llamas was not related to age when the llama was introduced, age of llama (after 1 or 2 years old) when guarding, if lambs were present or absent when the llama was introduced, or between open and covered (forested, shrub lands, gullies, ravines, etc.) habitat. However, Cavalcanti and Knowlton (1998) reported that weight, alertness, and leadership of llamas were correlated with aggressiveness toward dogs and should be considered when selecting potential guardians.

Franklin and Powell (1993) reported that gelded male llamas cost $700 to $800 and intact males were about $100 cheaper, whereas Bergman et al. (1998) reported that llamas cost an average of $450 in North Dakota. Most producers reported that daily care for llamas was the same as for sheep and that no special feeds were provided. Average annual expense was $90 for feed (not including pasture) and veterinary costs were about $15.

Franklin and Powell (1993) reported that 21% of ewes and lambs were killed annually before acquiring a llama and 7% afterwards. Meadows and Knowlton (2000) reported that producers with llamas lost significantly fewer sheep to predators than producers without llamas during the first year of use, but mortalities did not differ during the second year in Utah.

Donkeys

About 9% of sheep producers in the United States used donkeys to protect sheep from predators during 1999 (NASS, 2000). Donkeys apparently have an inherent dislike for dogs and other canids. They will bray, bear their teeth, run and chase, and attempt to bite and kick an intruder (Green, 1989).

Donkeys apparently are most effective in small open pastures or where sheep graze together. Green (1989) and Walton and Feild (1989) recommended using only one jenny or gelded jack per pasture because two or more donkeys often stay together instead of being with the sheep. Intact jacks generally are too aggressive around sheep. Donkeys generally should be allowed 4 to 6 weeks for bonding with sheep before they are used to deter predators. Donkeys should be removed during lambing because they might trample lambs or disrupt the ewe-lamb bond. Green (1990) recommended challenging a donkey with a dog to test its response to canids; donkeys that are not aggressive should not be used.

The average purchase price per donkey was $144 in Texas (Walton and Feild,1989) and $236 in North Dakota (Bergman et al., 1998). Walton and Feild (1989) reported that average annual upkeep per donkey was $66.

Bonding sheep and goats to cattle

Bonding young sheep to cattle (Anderson et al., 1987; Hulet et al., 1987) and goats to sheep which have been bonded to cattle (Hulet et al., 1989) has reduced predation by coyotes. This technique has not been readily adopted by sheep producers, possibly because of the additional labor, expense, and practicality involved with bonding sheep and goats to cattle, or perhaps ineffectiveness; cattle, and calves in particular, have been killed by predators (NASS, 2001).

Relative effectiveness of guarding animals

Benefits of using guarding animals include a decrease or elimination of predation, reduced labor to confine sheep and goats at night, more efficient use of pastures for grazing, reduced reliance on other predator control techniques, and a greater peace of mind. A comparison of surveys where producers reported the average annual value of sheep saved per guarding animal suggests guarding dogs, compared to llamas, saved more sheep from predators (Table 1). Guarding dogs and llamas have been rated as more effective than donkeys for deterring predation (Table 1; NAHMS 1996a,b [cited by Connolly and Wagner, 1998]).

Advantages of donkeys and llamas over guarding dogs include less prone to accidental death, longer-lived, do not require special feeds, stay in the same pasture as sheep, apparently do not need to be raised with sheep, more compatible with other depredation control techniques, such as traps, snares, M-44s (sodium cyanide injectors), and livestock protection collars, and donkeys are cheaper than guarding dogs. Alternately, guarding dogs deter predators in fenced pastures and on open range, whereas llamas and donkeys appear most effective in fenced pastures < 300 acres. Guarding dogs are effective in deterring bear and mountain lion predation (Green and Woodruff, 1989; Andelt and Hopper, 2000), whereas some donkeys (Green, 1989) and possibly llamas are afraid of bears and mountain lions. Although one early report indicated that guarding dogs could protect cattle from wolf predation (Coppinger et al., 1988), and were fairly effective in keeping wolves and black bears from carrion feeding sites in Minnesota (Coppinger et al., 1987), wolves have killed some domestic dogs (Fritts and Paul, 1989; Bangs et al., 1998), and dogs may serve to attract wolves to livestock under some circumstances.

Table 1. Average annual value of sheep saved from predation by each livestock guarding animal and ratings of effectiveness of guarding animals as reported in various studies.

Factor	Guarding dogs	Llamas	Donkeys
Value of sheep saved	\$3,836[a]	\$1,253[b]	
	\$2,506[c], \$3,733[c]		
Ratings of effectiveness			
Very effective	71%[d]		
Excellent and good	95%[e], 84%[c]		
Very effective and effective		80%[b], 90%[f]	
Good and fair			59%[g]
Excellent and good			20%[g]

[a]Green et al. (1984)
[b]Franklin and Powell (1993)
[c]Andelt and Hopper (2000)
[d]Green and Woodruff (1988)
[e]Andelt (1992)
[f]Meadows and Knowlton (2000)
[g]Walton and Feild (1989)

Several methods, including livestock confinement, disposal of livestock carcasses, herders, fencing, frightening devices, trapping, snaring, M-44s, denning (locating the dens of depredating coyotes and killing the pups and/or adults), aerial hunting, ground shooting, hunting with decoy dogs, livestock protection collars, and poison baits have been used to reduce predation on livestock (Andelt, 1996). Poison baits were withdrawn from use in 1972 (Andelt, 1996) and use of some methods such as trapping, snaring, M-44s, gas cartridges for denning coyotes, and livestock protection collars have been restricted or eliminated by ballot initiatives in some states such as Arizona, California, Colorado, and Massachusetts (Manfredo et al., 1999). The public also has rated guarding animals as more acceptable than most other techniques for reducing predation (Arthur, 1981; Reiter et al., 1999). Thus, guarding animals are one of the few remaining successful techniques, in some states, that livestock producers can use to mitigate predation. However, guarding animals are not a cure for all problems with predators. Their effectiveness is influenced by a variety of factors and their use requires a commitment by their owners. Some livestock producers continue to require other animal damage-control measures in addition to guarding animals.

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Predacides for Canid Predation Management

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Keywords: Coyote, Compound 1080, Cyanide, Livestock Predation, Predacide, Toxicant

Introduction

Throughout the livestock industry in the western United States, control of canid predators was considered to be of considerable importance to the livestock industry, especially to sheep producers, who suffered high losses from coyotes and wolves. In the 19th century, the demand for predator control was communicated to Congress and the western state assemblies, with the result that predator control was provided in western states by the Federal Bureau of Biological Survey in cooperation with state agencies, and by trappers hired by stockmen. Steel traps and poisons were the principal methods used for predator control during the early years of the program. Historically, predacides have been used in the United States primarily to control wolves, coyotes, and red foxes that prey on livestock. Strychnine was employed in the late 1800s and early 1900s to collect wolf carcasses (Quaife, 1973). Strychnine drop baits were employed for coyote and fox control through the 1960s. Drop baits consisted of strychnine tablets put in small pieces of perishable fats then placed around unpoisoned decoy carcasses (Robinson, 1962). Meat baits impregnated with a lethal agent, either thallium sulfate or Compound 1080, were used between 1937 and 1972 (Robinson, 1942). Currently, three predacides are available for use in controlling coyotes, foxes, wild dogs, and arctic fox. This paper will provide a description of these toxicants and the current status of their use in predator control in the United States.

Gas Cartridge

Gas cartridges were developed by the former Bureau of Biological Survey more than 40 years ago and have been used since then to control burrowing rodents and canid predators in dens. The USDA/Animal and Plant Health Protection Service (APHIS) currently registers the Large Gas Cartridge with the EPA. The gas cartridge is a fumigant for control of coyotes, red foxes, and striped skunks (*Mephitis mephitis*) in dens. It is not classified as a restricted-use pesticide, so no special training is required for its use. The APHIS gas cartridge contains two active ingredients, sodium nitrate and charcoal. The gas cartridge is placed in a den, ignited, and the entrance to the den is sealed. The main combustion product is carbon monoxide, which kills the animals quickly and humanely (Savarie et al., 1980; Savarie, 2002).

Gas cartridges are used primarily during the spring, when coyotes are rearing young and predation on livestock is highest (Till and Knowlton, 1983). The gas cartridge poses few non-target risks because the dens of target animals can be identified by tracks, scat, and animal observations and dens selectively fumigated. Because the cartridge contains only sodium nitrate and charcoal, the EPA has no concerns regarding the environmental fate of the cartridge ingredients. The nitrate is very mobile, and in soil and water serves as a plant nutrient source. The charcoal is immobile and is slowly degraded by microorganisms in soil, whereas in water it floats and disperses. Bioaccumulation in animal tissues does not occur.

Gas cartridges are available through the APHIS Wildlife Services Pocatello Supply Depot and can be purchased from Wildlife Services state directors or hardware stores.

Sodium Cyanide (M-44)

Sodium cyanide (NaCN) ejectors have been used in predator damage control programs since the late 1930s. The first device developed was called the Humane Coyote Getter, commonly known as the Coyote Getter (Blom and Connolly, 2003). When the coyote pulled on the top of the ejector, a .38 Special cartridge was fired that ejected sodium cyanide into the coyote's mouth from a case containing the toxicant. A scent attractant was used to draw the coyote to the device. The Coyote Getter was used in federal predator control programs until the 1970s. All predacidal uses of sodium cyanide were canceled by the EPA in 1972 because of non-target hazards.

In 1975, sodium cyanide was registered by the U. S. Fish and Wildlife Service (now transferred to APHIS) for use in the M-44, a device similar to the Coyote Getter. The M-44 consists of a base that is placed in the ground to contain the ejector, the capsule holder, a capsule containing sodium cyanide, and an ejector mechanism with a spring-driven plunger that expels the sodium cyanide capsule contents. The capsule holder is wrapped with absorbent material that contains an attractant scent and protrudes above the ground. As with the Coyote Getter, the attractant draws the coyote to the device; when the coyote pulls on the top of the M-44, the ejector is triggered and sodium cyanide is ejected into the animal's mouth. APHIS currently holds two registrations of the M-44 device with the EPA. One label is registered for control of coyotes, foxes and feral dogs that prey upon livestock and poultry, threatened or endangered species, or are vectors of communicable disease. The second label is for control of arctic foxes that prey on threatened or endangered species in the Aleutian Islands, Alaska.

Sodium cyanide is a white granular solid that, when in contact with carbon dioxide or fluids, such as in an animal's mouth, forms toxic hydrogen cyanide (HCN) gas, which is colorless. HCN poisons the cytochrome-oxidase system of cells and lethal doses are rapidly fatal. HCN is immediately dangerous at 150 ppm and a concentration of 200 ppm will quickly kill a human. Amyl nitrate is an effective antidote if used quickly after exposure. Non-target animals can be poisoned if drawn to the device, but few of these animals are killed. This reflects the use of specialized lures that selectively attract canids.

Sodium cyanide used in the M-44 does not pose an environmental risk to soil or water. It is moderately stable in light, is degraded by soil microorganisms to non-detectable levels in about 24 hours, and has low mobility. It is rapidly hydrolyzed in water and slowly degraded by aquatic organisms. Bioaccumulation in animal tissue does not occur because cyanide has low-fat solubility.

Compound 1080

Monofluoroacetic acid (Compound 1080) was first prepared in Belgium in 1896 but was not seriously investigated as a pesticide until World War II, when toxicants, such as strychnine and thallium sulfate, were not readily available from overseas sources. Compound 1080 was developed during the 1940s for use as a rodenticide. It proved to be highly toxic to canids as well, so 1080 was used for both rodent and predator control in the United States beginning in the mid-1940s. Compound 1080 replaced thallium sulfate (used beginning in 1937) as the preferred toxicant in meat bait stations used in Western states to reduce coyote populations that preyed on domestic livestock. While the two compounds were considered to be equally effective in controlling coyotes, 1080 was preferred because it was cheaper, more readily available, and somewhat more selective for target animals (Robinson, 1942). Use of bait stations increased until 1964, when approximately 16,000 toxic bait stations were placed by the U.S. Fish and Wildlife Service's Predator & Rodent Control program (Connolly, in press). After 1964, use of Compound 1080 declined until 1972, when an Executive Order banned use of 1080, sodium cyanide, and other predacides from use on Federal lands and in Federal programs.

Beginning in 1977, Compound 1080 use was allowed for experimental use in livestock protection collars. It was also allowed for use in single-dose coyote baits between 1983 and 1985 (Connolly, in press). In 1985, APHIS received a conditional registration from the EPA for technical Compound 1080 for use only in the Livestock Protection Collar (LPC). The collar has two rubber reservoirs containing a 1080 solution and is attached around the neck of sheep or goat in areas where coyotes are killing livestock. When the coyote attacks the collared sheep, it bites the collar and receives a lethal dose of the toxicant. The LPC is highly regulated. It can only be placed on livestock in fenced pastures by trained and certified applicators. Use of the LPC is highly selective because it targets only those coyotes doing the killing. However, successful implementation requires a high level of livestock management to direct the coyotes to the collared sheep, and its use is therefore not appropriate for many depredation situations.

Sodium monofluoroacetate is a white, tasteless compound that is soluble in water. It is absorbed in the gastrointestinal tract, where it is metabolized to fluorocitrate, blocking the Krebs cycle. Death results within 24 hours from cardiac arrest and/or central nervous system failure. A wide variation in toxicity exists between different species, with greater toxicity to mammals than to birds, and with very low toxicity to fish. Canids are among the most sensitive species. The use of 1080 in the Livestock Protection Collar allows little exposure to nontarget species; therefore, the potential for primary or secondary hazards to non-target species is low. Environmental hazards of 1080 are also minimal, both because of its limited and selective use and because of its chemical characteristics. Compound 1080 is degraded by soil microorganisms within one to two weeks. It is not hydrolyzed in water but undergoes a slow degradation by aquatic organisms; mobility is high because of its solubility.

Predacide Risks

Most pesticides hold some potential for risk to wildlife, but currently registered canid predacides are generally very safe, especially when compared to other pesticides. Several factors limit risks to wildlife, including: (1) safeguards provided by the registration process; (2) the low volume of use of these pesticides; (3) the limited area of application; (4) specificity in the action of these pesticides; and (5) the fact that the pesticides are targeted to specific animals or situations. Considering the first point, the EPA registration process lends a large degree of safety to pesticide products by requiring extensive data on product chemistry, human health hazards, environmental fate, and toxicity to nontarget birds, fish, and invertebrates. In addition, for vertebrate pesticides, the EPA frequently requires efficacy and non-target hazards data not generally required for other types of pesticides (Fagerstone et al., 1990; Ramey et al., 1994).

The second characteristic that provides a margin of safety for vertebrate pesticides is the low volume of use compared to insecticides, fungicides, and herbicides. The total use of pesticides in the United States (for residential, agricultural, and other uses) averages 1.2 billion pounds (Fagerstone, 2002). Use of canid predacides is an insignificant portion of pesticide use. To illustrate, in 2000, the Wildlife Services program used only 352 pounds of sodium nitrate in canid fumigants and less than one pound of Compound 1080 in the LPC. Wildlife Services and state cooperators used less than 200 pounds of sodium cyanide in the M-44 (compared to about 215 million pounds of sodium cyanide used each year in mining operations). Another factor limiting risk from canid predacides is the use pattern of the vertebrate pesticides. Most are used in very limited areas, such as the gas cartridge (placed in dens), the M-44 (placed on paths frequented by predators), and the LPC (placed around the neck of a few sheep in pastures where livestock depredation is occurring).

Future of Predacides in the United States

Sodium cyanide, Compound 1080 and the Large Gas Cartridge are the only predator toxicants legally available in the United States. However, several states have banned use of sodium cyanide and Compound 1080. As toxicants are an essential component of nearly all integrated pest-management programs, these bans severely restrict the ability of ranchers and pest-control operators to limit livestock losses caused by predators, such as coyotes. As development and U.S. Environmental Protection Agency (EPA) registration of new toxicants typically takes at least five to ten years, it behooves the agricultural community to proactively develop new predator toxicants that are compatible with existing delivery systems (M-44 and Livestock Protection Collar) and are safer to humans, non-target wildlife and the environment.

Because the USDA/APHIS/Wildlife Services is committed to supporting the U.S. livestock industry, the Wildlife Service's National Wildlife Research Center (NWRC) is actively investigating new candidate predacides. Criteria for the selection and development of these new substances were outlined by Savarie and Connolly (1983). These include effectiveness, taste and odor, speed of action, hazard to humans, antidote, environmental safety, regulatory concerns, cost and availability. Candidate predacides currently under study include theobromine and caffeine. Both of these materials are selectively toxic to canids and are present in high concentration in extracts of tea, coffee and cocoa plants. Evaluating plant extracts that are rich in theobromine and caffeine against the predacide selection criteria provides insight into the advantages, disadvantages, and likely success of this research project.

Effectiveness. The propensity for canids to overdose on methylxanthines via ingestion of chocolate is well documented in the veterinary literature (Farbman, 2001; Gwaltney-Grant, 2001; Pittenger, 2002). While theobromine doses as low as 100 mg/kg have been acutely toxic to dogs (Paul, 1984) the median oral lethal dose (LD50) for caffeine and theobromine to domestic dogs is estimated at 140 and 300 mg/kg, respectively (RTEC, 2002). For most compounds, a dose of three times the LD50 is usually lethal to 100 percent of the population. Assuming that the toxicity of these compounds is similar in dogs and coyotes, we need to develop a product that is capable of administering oral doses of 420 to 900 mg/kg.

Taste and odor. Substances with noxious taste or odors are likely to be rejected by coyotes. Such substances are poor choices for predacides, even if they exhibit a high degree of toxicity to the target species (Savarie and Connolly, 1983). As indicated by statistics from the National Animal Poison Control Center and numerous articles in the veterinary literature, chocolate is readily consumed by canids (Farbman, 2001; Gwaltney-Grant, 2001; Pittenger, 2002). As such, we are hoping theobromine-rich chocolate extracts will likely be palatable to canid predators.

Speed of action. The speed of action of effective pesticides varies greatly. Some pesticides (i.e. zinc phosphide) exert their toxic effects on the target species within minutes of exposure. Other pesticides (i.e. diphacinone) may require several days post ingestion to effect acute toxicity (Connolly et al, 1976; Connolly, 1980). While a quick acting predacide may be preferable to some ranchers and pest-control personnel, a slower-acting predacide offers a higher margin of safety with respect to non-target pets and wildlife. This is because a gradual onset of toxicosis provides opportunities for veterinary intervention to assist accidentally exposed animals. As acute toxicity resulting from methylxanthine ingestion typically occurs 6 to 24 hours post ingestion, accidentally exposed canids may be successfully treated at a veterinary clinic.

Antidote. The availability of an antidote or effective medical treatment to reverse the toxic effects of a pesticide increases the safety associated with its use. Given the frequent exposure of dogs to chocolate, veterinary supportive therapy procedures to minimize the effects of the ingested methylxanthines are well known: (1) induced vomiting eliminates unabsorbed methylxanthines from the gastrointestinal tract; (2) multiple oral doses of activated charcoal accelerate depletion of methylxanthines from blood; and (3) an orally administered saline solution is beneficial to maintain electrolyte concentrations (Hornfeldt, 1987; Farbman, 2001). For humans and many other species, no antidote is generally required.

Hazard to humans. All currently registered predacides are extremely toxic to humans. Sodium cyanide is a well-known human toxicant. As Compound 1080 is a broad spectrum mammalian toxicant, it too is very toxic to humans. While the exact lethal doses for humans are unknown, the rat oral LD50s for sodium cyanide and Compound 1080 are 15 mg/kg (Budavari, 1996) and 0.2 mg/kg (Meister, 1998), respectively. For theobromine, the rat oral LD50 is 1,250 mg/kg. It is likely that humans are even more tolerant of caffeine and theobromine. Despite high consumption of caffeine and theobromine in coffee, tea, cola beverages and chocolate, there is no documented human mortality associated with consumption of these products (New York, 1979). Put another way, while a dose of just three ounces of baker's chocolate can be toxic to a 10 kg dog, an equivalent dose of 21 ounces of chocolate to a 70 kg human is essentially harmless (Kreiser and Martin, 1980; Blauch and Tarka, 1983; Winston and Nguyen, 1984).

Environmental safety. Selective toxicity is extremely desirable to minimize accidental poisoning of non-target animals. The available evidence suggests that methylxanthines are selectively toxic to canids, as reports of accidental poisonings due to the consumption of methylxanthines appear to be limited to these species. The enhanced toxicity of methylxanthines to canids is believed to be due to their inability to efficiently metabolize methylxanthines (particularly theobromine) via enzymatic N-demethylation to compounds which are readily excreted via urine. In a theobromine metabolism study of rats, mice, hamsters, rabbits, and dogs, dogs were unique in their near inability to demethylate theobromine at the N-3 position (Miller et al., 1984).

As stated previously, mode of application increases the selectivity of predacides. Most likely, methylxanthines would be most effectively delivered in devices such as the LPC, and thus, only livestock killing canids would be exposed. While non-target species may be exposed to low levels of methylxanthines on carcasses of predator-killed sheep wearing punctured livestock protection collars, the selective toxicity of methylxanthines to canids should minimize secondary hazard concerns. Environmental concerns associated with the contamination of soil and plant materials from punctured livestock protection collars should be insignificant as the methylxanthines will be composed of biodegradable, natural plant extracts.

Cost and availability. Pure analytical grade methylxanthines, such as caffeine, theobromine, and theophylline, are widely available through chemical supply sources. The livestock protection collar will likely need to contain approximately six grams of active ingredient. For the pure active ingredient, this would cost approximately $0.25 per collar. However, if the predacide is prepared as a crude extract of natural plant materials, the cost will likely be significantly less.

Regulatory concerns. All pesticides including predacides, must be approved for use by the U.S. Environmental Protection Agency. Acceptance criteria include efficacy, safety, and environmental hazards. As previously discussed, plant-derived methylxanthines, such as theobromine, should display high levels of efficacy and selectivity toward canid predators while being environmentally benign. Based on these characteristics, it is reasonable to infer that a methylxanthine-based predacide should fare well with respect to U.S. EPA pesticide-registration criteria.

Societal acceptance. Historically, the fear associated with the use of predacides has limited societal acceptance of these compounds. Groups which oppose predator control in the United States have successfully capitalized on this fear to garner support for anti-predator control initiatives. Development of a predacide based on the active ingredients in substances that the general population embrace daily (chocolate, tea, coffee) could permit society to evaluate these compounds based on realistic benefits and risks rather than emotion.

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Selective Targeting of Alpha Coyotes to Stop Sheep Depredation

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Introduction

Research to find more effective and socially acceptable solutions of managing coyote (*Canis latrans*) depredation has been ongoing for many years. The primary objective is to develop strategies that effectively reduce losses, not simply reduce coyote numbers. An important step in solving such conflicts is to clearly define the problem. In this case, it is important to know which coyotes are most likely to kill sheep and when and where their depredation is greatest. For a control strategy to be effective, it must be appropriate to these three defining characteristics. The hardest of these questions to resolve has been determining if some coyotes are more likely to kill livestock than others and, if so, whether these animals can be relatively more difficult to remove than the others. While the conventional wisdom of trappers supports the existence of particular sheep-killing coyotes, it is another matter to demonstrate that they in fact occur and to explain why.

This paper is a review of our current state of knowledge about the coyotes that kill livestock, particularly sheep, and methods that can be used to target them. The important research findings upon which this is based will be discussed. The main thrust of the paper will deal with a series of studies done in California between 1993 and 2002. These were undertaken jointly by the National Wildlife Research Center (USDA/Wildlife Services) and the University of California at Berkeley. These studies represent the most intensive investigation to date of predation ecology of coyotes in the presence of sheep. In addition, future research needs will be discussed. This review will illustrate the importance of first developing an understanding of the problem before testing methods to alleviate it, that may be inappropriate.

Coyote Territoriality and Social Structure

It has long been recognized that removal of a single coyote from an area can stop depredation (Sampson and Nagel, 1948 from Gier, 1968). However, it was not known whether sheep-killing could be attributed to a particular class of coyotes. A key research finding that helped to better frame questions regarding sheep-killing coyotes was showing that coyotes are territorial (Camenzind, 1978; Windberg and Knowlton, 1988). Territories in an area are contiguous with little overlap (e.g., Windberg and Knowlton, 1988; Gese et al., 1996) and coyotes do not tend to occur where they cannot be territorial year-round (Ganz, 1990; Shivik et al., 1996). In addition, territoriality is maintained even in the presence of livestock (Sacks et al., 1999a). This implies that coyotes from surrounding territories do not concentrate where livestock are pastured (e.g., a sheep ranch), but rather that sheep-killing coyotes are likely to be residents in the territory where killing occurs. The basic social unit of coyotes occupying a territory is the alpha pair, who are the breeders. Other adult coyotes may also reside in a territory; they are referred to as betas and are usually offspring of the alpha pair from the previous year or two. Therefore, resident coyote packs are family groups controlled by the dominant alphas. Non-territorial coyotes, referred to as transients, have dispersed from their natal territories and are searching for opportunities to become alphas and to breed. Transients have relatively large home ranges that can encompass two or more territories, although they seem to avoid contact with alphas by moving in the corridors between territories. The question becomes: Are alphas, betas, and transients equally likely to kill sheep?

Alphas Implicated

In the inter-mountain west, where sheep are moved to summer grazing allotments, depredation coincides with the time coyotes are rearing pups. Conventional wisdom of government trappers is that coyotes kill lambs to feed their pups and that when pups are removed (referred to as denning) the killing stops. This was confirmed by Till and Knowlton (1983), and it implied that breeding coyotes were the principal killers in this situation. At the time of this study, it was thought that both alphas and betas could breed. Evidence now indicates that alphas are the principal breeders (e.g., Gese et al., 1996; Blejwas et al., 2002) and although beta females occasionally do give birth, their pups have a poor chance of surviving (Knowlton, personal communication). In addition, the primary feeders of pups seem to be the alphas; they can successfully rear pups with or without betas (Sacks and Neale, 2001). Where betas do occur, some of them do help with provisioning pups while others do not (Hatier, 1995). Therefore, denning provides indirect evidence that alphas with pups are the principal killers of lambs on summer grazing allotments. This is supported by the finding that depredation is less in territories with surgically sterilized adults that produced no pups (Bromley and Gese, 2001a,b).

The above findings suggest that provisioning pups is the driving force behind depredation. However, this maybe the case only where sheep are present at that time of year coyotes have pups such as the inter-mountain west. In large areas of California and Texas, sheep are present in the same areas year-round, and coyote depredation occurs throughout the year, including times when pups are not present. Generally, depredation peaks during the lambing season, which overlaps pup-rearing. In north-coastal California, however, the lambing season occurs in winter prior to whelping of pups. In this situation, depredation peaks during the lambing season before the presence of pups and the use of dens (e.g., Conner et al. 1998). As a consequence, it was not known whether betas and transients also killed lambs at this time of year, when naturally occurring prey can be relatively scarce.

Do All Coyotes Kill Livestock?

Attempts have been made to get at the question by looking at sheep-killing behavior of captive coyotes. Sterner (1997) tested whether observational learning (e.g., an inexperienced beta coyote watching its experienced alpha parent kill a sheep) was an important factor affecting whether coyotes kill sheep. The results, however, were ambivalent, and the sex, age and social status of test coyotes were not considered in the experimental design. Connolly et al. (1976) exposed captive coyotes to sheep in an enclosure to observe sheep-killing behavior. These coyotes had no previous experience killing sheep. The 2-year-old males and females paired with them (i.e. simulated alpha pair) attacked sheep more frequently than yearling males, while unpaired females did not attack. The conclusion was that most coyotes can kill sheep without previous experience but that some are more likely to do so than others. Another enclosure study found that 18 of 19 pen-raised coyotes killed sheep compared with 38 of 54 wild-caught adult coyotes (p.74, USFWS 1978). This result suggested that wild-caught coyotes may be more cautious of killing sheep, although other factors may account for this difference.

The first field study specifically addressing the question of which coyotes kill livestock was initiated in 1991 by scientists from the USDA Denver Wildlife Research Center (now known as USDA/WS/NWRC). The objective was to determine the age, sex, and territorial status of coyotes that kill livestock and to distinguish these coyotes from those that only feed on carcasses. Alpha coyotes were not distinguished from betas; both were classified as territorial and compared to the non-territorial transients. Goat-killing coyotes were to be determined by the use of radioactive markers in collars around the necks of the goats. Coyotes typically kill sheep and goats by suffocating them with a bite to the throat that crushes the trachea. No coyotes were subsequently found with the radioactive markers and, therefore, the study was unable to determine who the killers were. However, both territorial and non-territorial coyotes had fed on the carcasses of kid goats determined to have been killed by coyotes (Windberg et al., 1997). This does not mean that all of these coyotes had killed goats. Coyotes commonly feed on the carcasses of livestock or game that they did not themselves kill (e.g., Gier, 1968). It was unclear where in relation to territory boundaries the kills were made.

Hopland Studies

It remained to be determined whether alpha coyotes are more likely to kill livestock than betas or transients. This question was addressed in a series of studies undertaken at the UC-Hopland Research and Extension Center (Jaeger et al., 2001), which was the largest sheep ranch remaining in north-coastal California. Depredation had remained high at Hopland despite concerted efforts at control, including annual population reduction of coyotes with traps, snares, and M-44 cyanide ejectors and use of a variety of non-lethal methods (Timm and Connolly, 2001). Sheep were present year-round at Hopland; and coyotes, killed them throughout the year with peak losses during the lambing season (December to May). In general, the strategy for removal of coyotes was non-selective and based on the assumptions that all coyotes in the vicinity of sheep were equally likely to kill them and, if not, that the sheep-killers were as likely to be removed by control as were the non-killers. These assumptions were tested.

Several lines of evidence indicated that the principal killers at Hopland were the alphas whose territories overlapped sheep. First, radio-telemetry of coyotes of known social status located alphas near sheep kills within their own territories close to the time kills were made (Sacks et al., 1999a). While betas and transients were found at sheep carcasses hours or days after the kill had been made, they were not nearby around the time of the kill. Alphas, on the other hand, appeared to feed on sheep at the time they made the kill and did not later return to the carcass. Second, there was a single kill site within a territory during any one night suggesting that multiple, independent killers were not active in the same area (Sacks et al., 1999a). Third, killing within a territory stopped when a resident alpha was removed (Blejwas et al., 2002). Fourth, coyotes killed in the act of attacking a sheep were known alphas (Blejwas et al., 2002). One way that this was determined was to swab the site of the wound (i.e. throat) of a recent coyote-killed sheep and match the DNA from the saliva of the coyote that had made the wound to that from a tissue sample of the coyote taken at the time it was originally captured and radio-collared (Williams et al., 2003).

These findings are likely to be applicable to a wide set of circumstances and not unique to the Hopland study site. They are supported by evidence that alphas are the principal killers of wild ungulates (Gese and Grothe, 1995; Gese, 1999). As previously noted, coyotes have been found to be territorial virtually everywhere they have been studied. This implies that the territorial dominant animals (i.e. alphas) defend their space from intrusion by other coyotes and are the individuals most likely to kill sheep within its boundaries. But why betas in a territory do not seem to kill livestock, particularly small lambs, independently of alphas is unknown. Two factors may influence this. First, the energy demands of betas are probably less than those of alphas. Greater energy needed to maintain a pair of coyotes (i.e. alphas) as opposed to an individual (i.e. beta) and to provision pups may be the impetus for alphas to begin killing larger prey (e.g., Harrison and Harrison, 1984). Second, small mammals, such as rabbits and rodents are, in addition to carrion, the main prey-base of coyotes in many areas of the western United States where sheep and deer are common, suggesting a preference for this general size of prey (e.g., Sperry, 1941; Ferrel et al., 1953; Ellis, 1959; Gier, 1968; Wagner and Stoddart, 1972). This preference may be due, at least in part, to the difficulty in handling larger prey. Coyotes are known to prey principally upon lambs and fawns indicating that handling more fully grown animals may be difficult, particularly by individual coyotes. Furthermore, lambs are usually in the presence of their mothers, who may effectively deter betas. Connolly et al. (1976) noted that defensive behavior by ewes was often effective at deterring an attack, and coyotes, were never seen to attack rams. An alpha is more likely to be assisted by its mate who distracts the ewe while its lamb is killed. Blejwas et al. (2002) review the literature supporting the use of cooperative hunting by coyotes (alpha pairs or alphas and betas) for killing ungulates.

Efficacy of Selective Removal

Next it was important to determine whether a control strategy of selective removal of alphas effectively reduces depredation and, if so, for how long. Removal of one or both alphas from a territory could result in an influx of neighboring alphas and betas or transients and rapid resumption of the killing. This possibility was supported by radio-tracking data from Hopland showing movement into a territory by these other perspective territory holders within days following removal of the resident alphas (Blejwas, 2002). Nevertheless, when both alphas were removed from a territory, killing did not resume before a new alpha pair became established, which usually took three to four months (Blejwas et al., 2003; Gese, personal communication). In some cases, territories were divided among established alphas from surrounding territories (Blejwas et al., 2002). The time period over which this process occurred was not established. When only one alpha of a pair was removed, the average time to replace the mate was two months, which corresponded to the average time to resumption of killing. In a few cases, a lone alpha with pups resumed killing lambs within a few days or weeks of the removal of its mate. The presence of lambs in a territory affected a faster resumption of the killing than did the presence of ewes only, averaging 43 days as compared with 184 days (Blejwas et al., 2002). Notwithstanding, killing during the lambing season was significantly reduced or eliminated in a territory during the three-month period following removal of one or both alphas (Blejwas et al., 2002).The overall result of this control strategy (i.e. selective removal of alpha coyotes whose territories overlapped lambing pastures where depredation was occurring) was to effectively reduce depredation losses during the lambing season at Hopland. In contrast, non-selective removal was ineffective (Conner et al., 1998; Blejwas et al., 2002). This control strategy requires annual application.

Vulnerability of Alphas to Capture

The ineffectiveness of non-selective population reduction at Hopland suggests that either too few coyotes were being removed to show an effect or that the alpha coyotes were less vulnerable to the capture methods used than were other coyotes. Available evidence supports the second option. Sacks et al. (1999b) found that juvenile and yearling coyotes at Hopland were more vulnerable than were older coyotes (i.e. alphas) to capture by traps, snares, and M-44s. This was particularly true during the winter, prior to whelping, when lambs were present and depredation was at its annual peak. Following whelping, the need to provision pups likely requires that alphas take risks that make them more vulnerable to capture. Interestingly, alpha coyotes at Hopland were not vulnerable to M-44s at any time during the study. In contrast to these findings, Windberg and Knowlton (1990) reported no differences between juveniles and adults in vulnerability to capture with traps or M-44s. However, unlike Hopland, this study was done where coyotes had not been previously exposed to intensive removal. That coyotes, particularly alphas, can learn to avoid M-44s after brief exposure to their use is supported by the findings of Brand et al. (1995) with closely related black-backed jackals (*C. mesomeles*) in sheep producing areas of South Africa.

How can prior experience with control reduce a coyote's vulnerability to capture, particularly with a lethal method such as the M-44, which usually kills any coyote that activates the device? Would a coyote have to see another member of its pack killed in order to know to subsequently avoid the device? Probably not, as coyotes seem sensitive to missing pack members or neighbors (Blejwas, 2002) and may associate their removal with human activity in the area, and as a consequence become cautious toward any novel object associated with human odor.

Furthermore, alpha coyotes are harder to capture within their own territory than they are on its periphery or outside of it (Sacks et al., 1999b; Séquin et al., 2004). How are alpha coyotes better at avoiding capture? It has been argued that resident coyotes (i.e. alphas and betas) become very familiar with their territories as opposed to transients that range over much larger areas. As a consequence of this experience, residents are more likely to recognize unfamiliar objects or smells (e.g., trap set) when in their own familiar space than when outside of it and be cautious toward them (Lehner et al., 1976; Windberg, 1996; Harris and Knowlton, 2001). Alphas and betas, however, were not distinguished in these studies. Séquin et al. (2004) investigated the vulnerability of coyotes of different social status toward photo-capture and how this was affected by the location of camera stations relative to territorial boundaries. Alphas from five contiguous territories were exposed to cameras (two territories at a time) in eight, six-week sessions. Each territory was tested in at least two sessions at different times of year. All coyotes, except pups, avoided photo-capture during the day but at night the alphas were least vulnerable. They were never photo-captured within their own territories, whereas betas were. Transients were photo-captured along territorial boundaries. Radio-telemetry and direct observation indicated that the alphas avoided photo-capture within their territories by tracking human presence and evidently learning the locations of camera stations at the time they were set-up. This suggests that alphas are territorial while betas are simply resident within the territory and that there can be a fundamental difference between the two social classes in how each attends to the threat of capture.

Methods that Selectively Target Alphas

The Livestock Protection Collar (LPC) is the only method currently in use that targets a coyote that is in the act of killing a sheep (Burns et al., 1996). The collars contain the toxicant 1080, which the coyote ingests when it bites down on the sheep's throat and punctures the bladder containing the poison. Coyotes usually kill sheep in this way, although sometimes they avoid the collars. Despite its selectivity, the LPC is not widely used. One reason for this is that relatively few sheep in a flock can be collared. It is often necessary to substitute a smaller lure flock with collars.

Denning is another lethal method currently in use that is selective in that it targets alphas and/or their pups in the vicinity of depredation. The use of this method and its limitations were described previously.

Calling coyotes by imitating their vocalizations or those of injured prey has long been used as a way to attract coyotes within rifle range. "Calling-and-shooting" has the potential to be selective to alphas. This assumes that a particular type of call can be identified that imitates an intruder in a territory and will provoke a resident alpha to approach the source of the call. A study of responses of coyotes of different social status to a variety of playback calls, used at different times of year and at different times of night, has recently been completed and the data are now being analyzed (Mitchell, in prep.).

Traps and snares can also be used selectively by those with sufficient experience and the time to pursue individual coyotes. Other methods such as aerial gunning, while not selective to alpha coyotes, may be as likely to remove alphas as betas or transients. Aerial gunning may be more selective to alphas when used in combination with calling by ground crews. This should be tested.

Methods now exist that can be used to test whether particular methods are removing the problem coyotes. This is particularly true in the case of corrective control where coyotes are removed in response to depredation. Williams et al. (2003) demonstrated that coyote DNA can be swabbed from the throat area of a recently killed sheep and matched to that from tissue of coyotes removed by control. Initial findings from this work suggest that alpha males may be the principal killers of sheep. This needs further investigation. If true, the most effective methods should be those that take adult males, or at least, are not biased against them. This could be easily tested by collecting dead coyotes removed by a particular control method and determining their age, sex, and reproductive condition.

The one, non-lethal method that targets coyotes attempting to kill sheep is use of guard animals (e.g., Green et al., 1984; Andelt and Hopper, 2000). This is probably the most commonly used non-lethal method. However, coyotes are known to kill sheep in the presence of guard animals (e.g., Timm and Schmidt, 1989), although the relative incidence of this is unknown. This may reflect a flaw in the behavior of the guard animal (e.g., breed, age, training) or a lack of human supervision. Objective studies of the behavior of coyotes toward sheep, guard animals, and humans attending them is lacking. Do alpha coyotes learn to work around guard animals, and if so, under what conditions (e.g., dense cover together with rough terrain)? Non-lethal techniques are probably most effective when (1) they are interactive with the coyote, in other words respond when the coyote is present; and (2) are unpredictable in terms of when and where they are likely to be. This is to suggest that guard animals and shepherds are more effective deterrents when they are more interactive and less predictable. The article by Shivik in this issue addresses some of these concerns.

Surgical sterilization *in lieu* of denning has potential as a non-lethal means directed at alpha breeders (Bromley and Gese, 2001 a,b). This is not intended as a means of local population reduction but rather as a way to stop depredation by those alphas whose territories overlap sheep by affecting their motivation to kill for provisioning pups. A potential advantage of this approach is that a sterilized pair can remain together for years and defend their territory, thus eliminating the need for annual capture and sterilization. On the other hand, the major disadvantage is the difficulty in capturing and identifying the alphas. In the original study, the attempt was made to capture and surgically sterilize all adults in the area. This was facilitated by helicopter capture. Confirmation that alphas were in fact captured was done through subsequent radio-tracking. This process is impractical to do in a control operation. However, this method could be made more practical and cost-effective if a way was found to identify the likely alphas at the time of capture.

Conclusion

Alphas whose territories overlap sheep were the primary killers of sheep in a series of studies done in California. Betas and transients fed on sheep carcasses. These findings are supported by studies from elsewhere in the West. A control strategy that selectively targets alphas can be more effective at reducing depredation losses than a strategy of non-selective population reduction. Alphas were relatively less vulnerable to capture with traps, snares, and M-44s than were betas and transients. This was particularly true during winter prior to whelping and the need to provision pups. There is a need to develop additional control methods, both lethal and non-lethal, that selectively target alphas.

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Using Genetic Analyses to Identify Predators

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Introduction

Coyote and dog depredation account for much of the economic losses to livestock in the United States (National Agricultural Statistical Service, 2000, 2001). However, depredation by other species (such as members of reintroduced wolf populations) can be more socially and politically contentious. Predators are often elusive and attacks on livestock are not often witnessed but the species of predator causing stock losses can sometimes be ascertained from evidence near the carcass (such as scat or hair), the attack pattern, or size and spacing of bite wounds. However, these species assignments can be subjective and may be influenced by the experience level of personnel, the condition of the carcass, and knowledge of previous predation history at the site. Variation among conspecific predators in attack pattern, and inter-specific overlap in those patterns, may be another complication to accurate predator species identifications. There are wide ranges in accuracy of identifying species based on scat morphology (Farrell et al., 2000). Variation in individual feeding preferences (Fedriani and Kohn, 2001) may also complicate accurate species identification from scat. Sociological considerations also may influence results. For example, local or regional compensation schemes may unintentionally result in biases in predator species identification (Cozza et al., 1996). Using common field methods, the accurate identification of the gender of a predator responsible for a specific predation event is unlikely. Likewise, although there may be assumptions about which specific individual was responsible for an attack on livestock, those assumptions may not be based on any concrete data. Clearly, an unambiguous method to determine the predator species would remove identification biases. A method to identify the specific individual responsible for kills would benefit our understanding of predation and would be useful in certain situations. Both methods, even if used strictly in research situations, might ultimately result in improved approaches to minimize livestock losses to predation.

Samples, such as hair, scat, and saliva (referred to as noninvasive samples), contain DNA, although the DNA tends to be in low quantity and degraded (Taberlet et al., 1999). Despite this difficulty, these samples can be analyzed using the polymerase chain reaction (PCR), which allows the analysis of even minute amounts of degraded DNA. Because the mitochondrial (mt) genome is small and is present in multiple copies in most cells, mtDNA lends itself well to PCR analysis. Importantly, certain regions of the mt genome are variable among species (Foran et al., 1997). By analyzing for such mtDNA differences, unknown samples (including noninvasive samples) can be identified to species. For example, Foran et al. (1997) demonstrated the ability to use mtDNA to identify scat samples from a wide range of wildlife species. Likewise, Woods et al. (1999) used mtDNA to differentiate black bear from brown bear hair collected from snares. By using highly variable nuclear DNA regions, such as microsatellite DNA loci, identification of the individual animal responsible for predation is also possible from noninvasive samples. Woods et al. (1999) were also able to differentiate individual bears based on unique multilocus microsatellite DNA genotypes generated from those hair samples. Additionally, the gender of an animal leaving a noninvasive sample can be determined based on analysis of regions of the sex chromosomes that vary between male and female (Woods et al., 1999; Williams et al., 2003b).

Studies that use genetic analysis of noninvasive samples to delineate regions of species overlap, census populations, or track elusive or rare species are becoming more frequent (Woods et al., 1999; Kohn et al., 1999; Palomares et al., 2002). However, the genetic analysis of noninvasive samples also has potential applications in situations involving livestock predation. Predators often leave traces of scat, hair, or saliva at a kill site, and those samples have the potential to allow the unambiguous genetic identification of the predator (Ernest et al., 2002). These noninvasive samples are not identical in utility, however. The usefulness of scat or hair found near a kill site must be carefully considered. Although found physically near a kill site, there may be some ambiguity whether the hair or scat sample was deposited at the exact time of the kill and whether it was deposited by the individual that made the kill. However, saliva left on predation wounds offers the opportunity for direct identification of the predator. Saliva has been increasingly used as a source of DNA in human criminal investigations in recent years. Despite the low quantity and quality of DNA in such samples, multi-locus genotypes have been generated from unintentionally deposited saliva samples that allowed the matching of a sample to a specific suspect (Sweet and Hildebrand, 1999). Analysis of saliva has only recently been applied to investigations of livestock predation. For example, Williams et al. (2003b) used analysis of saliva to identify species and gender of predators killing sheep (*Ovis aries*) at a site in California. At that site the most important predator of sheep was coyotes (*Canis latrans)*; (Neale et al., 1998), but other potential predators were also present (bobcat, *Lynx rufus*; black bears *Ursus americanus*; dogs, *Canis familiaris*; mountain lions, *Puma concolor*). Williams et al. (2003b) demonstrated the ability to generate microsatellite genotypes from those saliva samples. Blejwas et al. (in prep) took the identification of predators at that site further by comparing microsatellite genotypes from coyotes in the area (obtained from tissue samples; Williams et al., 2003a) to microsatellite genotypes obtained from saliva on predation wounds. Blejwas et al. (in prep) successfully identified some of the individual coyotes responsible for specific sheep kills at that study site.

Approaches for sample collection and genetic analysis

Hair samples obtained from kill sites are collected and preserved dry, in an envelope. Scat samples may be frozen or stored at room temperature in ethanol or a buffer solution (Ernest et al., 2000; Frantzen et al., 1998). To collect saliva swabs the carcass should be skinned and attack wounds distinguished from scavenging by the presence of sub-dermal hemorrhaging. Attack wounds are individually sampled using a dry, sterile swab. The swabs are air dried, then stored in an envelope or bag. Care must be taken to minimize potentially cross contaminating samples. The cotton tip of the swabs should not be handled or touched to any surface other than the single bite it is being used to swab. Samples must be stored individually.

DNA from scat or saliva is isolated using a commercially available kit (Qiagen, Valencia, Calif.) and the manufacturer's instructions. The DNA from hair is typically isolated using a commercially available resin (Chelex 100, Bio-Rad, Hercules, Calif.). An aliquot of DNA, or an aliquot of a 1:10 dilution for scat samples, is used as a template for PCR amplifications, which are targeted to amplify specific genetic regions. For species identification, primers are used that amplify a short fragment of the mtDNA, typically the control region (Kocher et al., 1989; Foran et al. 1997; Woods et al., 1999). This genetic region varies among species either in length (so some species result in fragments of different lengths) or in DNA sequence. For example using primers developed by Pilgrim et al. (1998), black bears produce a distinctly different fragment pattern than canids, and the felids show multiple fragments due to heteroplasmy (not shown). Other species, such as the canids, require digestion of the amplification product with restriction enzymes to resolve sequence differences. Determining gender relies on analyzing regions on the sex chromosomes which may require species-specific primers (Woods et al., 1999). Conserved primers for mammalian gender determination would be of particular use for saliva or hair samples (Woods et al., 1999), unless the fragments they amplify are large (Shaw et al., 2003). Determining an individuals' genotype is accomplished by microsatellite DNA analysis. Microsatellite primers, which target these short, highly variable, genetic regions have been developed for most large and many small predators (Ostrander et al., 1993; Paetkau and Strobeck, 1995; Ernest et al., 2000).

Technical Issues

The degraded quality and low quantity of DNA from noninvasive samples makes such samples prone to contamination. Special precautions should be taken to minimize cross contamination, such as handling samples with gloves and packaging individually in the field. Laboratory precautions have been discussed by Taberlet et al. (1999) and include facilities and equipment dedicated for low-template samples, as well as additional negative controls. The nature of noninvasive samples means some samples will yield no information on species identification. However, they should not yield incorrect species identification. The degraded state of DNA from noninvasive samples also means primers targeting large DNA fragments may not result in amplification, and necessitates the use of relatively short DNA regions for all genetic analyses. For example, saliva swabs from livestock carcasses have not yielded amplification using primers that amplify a mtDNA fragment about 600 bases long (H16498 and L15774, Foran et al., 1997), but did result in amplification of an approximately 165 base fragment using other primers (Pilgrim et al., 1998; data not shown). Although markers have been developed to differentiate even closely related species (Paxinos et al., 1997) those markers rely on relatively long genetic regions and so may not be of use with all noninvasive samples.

Although scat may contain degraded DNA from both predator and prey, saliva swab samples will likely contain degraded DNA from the predator in the presence of less degraded prey DNA (from blood), which may interfere with some identifications (Williams et al., 2003b). All types of noninvasive samples can produce erroneous microsatellite genotypes (Taberlet et al., 1999). To ensure the correct microsatellite genotype is obtained for an individual predator, additional special precautions are required. Such precautions include establishing criteria for accepting genotypes, in order to account for allelic drop out and false alleles (Taberlet et al., 1999; Fernando et al., 2003). Generating individual multi-locus microsatellite genotypes will not be practical for all samples identified to the species level, given the additional time and expense required.

Hybridization between species could also be a complicating issue for genetic species identification (Roy et al., 1994; Vila et al., 2003). Hybrids carry the mt genome of their mother, and mt analysis alone would identify a hybrid as being a member of its mothers' species. Individuals that are the descendants of hybrids may also carry a misleading mt genome. For example, a dog mt haplotype was detected in coyotes in the southeastern United States, presumably as a result of a historical hybridization during range expansion into that portion of the country (Adams et al., 2003b). Similarly, wolves in certain regions in North America carry coyote mt genomes due to hybridization (Lehman et al., 1991). For accurate species identification, mt variation among individuals in a population or among species of interest may need to be established.

Discussion

Genetic methods can be successfully applied to evidence left on or near livestock carcasses to identify predator species, gender and individual genotype (Williams et al., 2003b; Ernest et al. 2002). Similar methods are being used to identify predators attacking humans. Genetic identification of predator species can be conclusive and may offer resolution to ambiguous or controversial cases. Clearly, genetic markers have the capacity to easily differentiate more distant species. For example, differentiating canids from felids is readily accomplished, as is differentiating either from ursids. More closely related species may require more thorough analysis and, as mentioned, differentiating among canid species can be more technically challenging (Adams et al., 2003a). One of the greatest logistical difficulties is finding carcasses of missing livestock in a suitable timeframe. On large ranches, where livestock may be most vulnerable to predation, it may not be feasible to search pastures often enough to distinguish predation wounds from scavenging. However in situations where livestock can be checked daily or more frequently, or for research purposes, success in identifying predation wounds and predator species can be high (Williams et al., 2003b; Blejwas et al., in prep). Genetic analysis can be used not only to determine the presence of a particular species at a certain location, but also to determine the identity of prey items in predator scat or stomachs (Scribner and Bowman, 1998; Fedriani and Kohn, 2001). So, for example, a scat containing both coyote and sheep DNA could indicate livestock depredation. However, we have not discussed this approach because predation could not typically be readily differentiated from scavenging using that method.

Genetic analyses offer new approaches to predator identification and can play a part in a better understanding of livestock depredation. Genetic analysis also offers a means to confirm that management programs are targeting the predators responsible for depredation. In addition to identifying predators responsible for individual cases, such data may assist investigations into prey base shifts, and the effects of multiple, overlapping predator species.

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Economic Impact of Protected Large Carnivores on Sheep Farming in Norway

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Introduction

Norway has historically been a stronghold for carnivore predators. Today there are four protected carnivore species, brown bear (*Ursus arctos*), wolverine (*Gulo gulo*), wolf (*Canis lupus*) and lynx (*Lynx lynx*), together with the golden eagle (*Aquila chrysaetos*). The carnivore populations were significantly reduced, and wolves and bears almost eradicated nationally during the end of the 19th and the beginning of the 20th centuries (Ministry of the Environment, 1992; 1996-97). Today, the species are protected, and management calls for restoring demographically and/or genetically viable populations (Ministry of the Environment, 1996-97). Another proposal is to view Norwegian management goals and responsibilities in accordance to the Bern Convention in combination with those of Sweden and Finland, i.e. shared-predator populations for the Nordic countries (Nordic Farmers Central Council, 1988). The principle has recently been introduced by the authorities for management of wolves in Norway, defining viability based on a common Norwegian-Swedish population.

The suitability of the Norwegian environment for large predators is partly due to its extensive land resources and rugged topography. The soil is generally poor and the area of agricultural land limited. However, due to the Gulf Stream, the climate is wet and relatively mild and well suited for production of grass and herbs. Grazing plants are found throughout the country's mountains and forests and constitute the basic forage for wild ungulates, herded domestic reindeer and livestock. The production systems have traditionally been of utmost significance for inland settlement and development of the local economy. In post World War II times, the national agricultural policy has supported the development of the systems by protecting the market from foreign competition and by providing relatively generous direct support.

In the traditional Norwegian production system, lambs are generally born during late winter or early spring while the sheep are fed indoors. During spring, the sheep and lambs are kept for a short period on fenced pastures before they are released onto open ranges. Flocks graze in forested or alpine areas for about 100 days before they are gathered during the latter part of September (Asheim, 1986). After a period of autumn grazing on fenced pasture, the breeding animals are again fed indoors. The most important production of meat is that by lambs and culled adult animals sold in the autumn. On good pasture, slaughter weights of lambs may reach 25 kg, and ideally, lambs suited for slaughter are sent directly from the range. However, 10 to 12 kg is not uncommon on low-quality ranges ("blue lambs") and sometimes strategies with early gathering and/or on-farm feeding programs are needed to improve lamb quality.

Some sheep producers do not have adequate land for spring grazing and release the animals on the open range more or less directly from the barn. Other farmers may have abundant pasture and/or few animals, and can allow them to remain on the fenced pasture for the whole season. Operational details are often the result of local adaptations. In some limited coastal areas the sheep can graze outdoors year-round (more or less like Western Europe or New Zealand), a system only possible without large numbers of predators. The current system of sheep farming is quite different from the milk sheep production systems found for instance in countries around the Mediterranean. In such systems herding or night pens may be natural operational measures, easy to introduce in case of predator attacks. In Norway, keeping sheep for milk ceased to exist at the same time as wolves and bears were eradicated nationally during the end of the 19th and the beginning of the 20th centuries.

Around 25,000 farms in Norway have sheep, averaging 44 winter-fed animals. Sheep production takes place on fairly small farms; in 1989, about 60% of the sheep were on farms with less than 10 hectares of arable land. Due to the seasonal variation in labor input, combining sheep with forestry, and historically fishing in coastal areas, has been common. Today, different combinations of off-farm work for either the farmer or spouse are making sheep farming the most common agricultural activity on part-time farms in the Norwegian grassland areas.

Sheep farming is still based on the use of open ranges, most lamb growth occurs there and it constitutes 40 to 50% of the production system's total forage harvested (Asheim, 1978). The animals are not herded, but tended at regular intervals. This makes the sheep vulnerable to predators, and locally losses are considerable (Mysterud and Mysterud, 1995a). The conflict with sheep farming is the most problematic obstacle to viable carnivore populations. The paper describes the conditions and assesses the economic consequences for sheep farming nationally and regionally of restoring viable carnivore populations in Norway. It is based on premises concerning national agricultural policy and viable carnivore populations in the middle of the 1990s as presented in an environmental impact assessment (EIA) (Mysterud and Mysterud, 1995a). Consideration is also given to the present situation of predators and losses of sheep. However, the paper does not address the national socio-economic (cost and benefit to society) question of balancing agricultural and environmental policies with respect to sheep and large carnivores on Norwegian ranges.

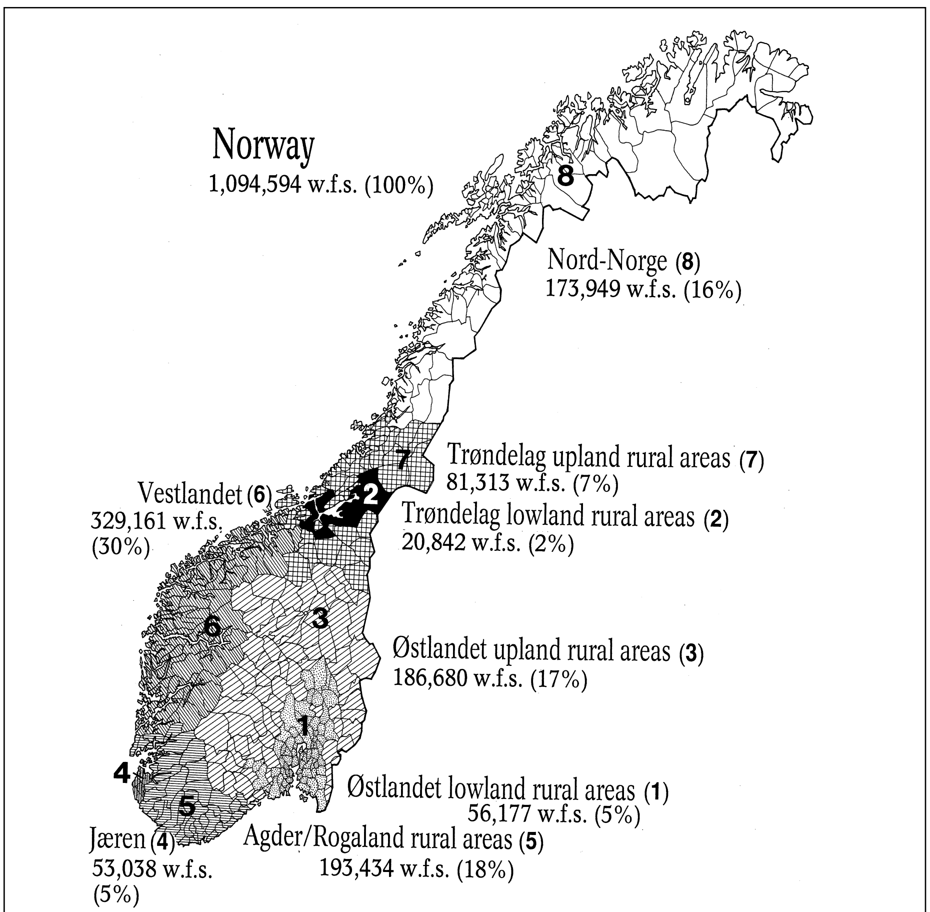
Materials and Methods

The population of ewes and lambs grazing on open ranges in the snow-free period is approximately 2.4 million, unevenly distributed throughout the country. The most important sheep farming regions are in the west and southwest with approximately 53% of the sheep. The greatest losses to predators occur in the upland rural areas in Trøndelag and in northern Norway, as well as in upland rural areas in eastern Norway, all of which contain approx. 40% of the country's sheep population (Fig. 1).

In this study three categories of sheep farming were identified, based on statistics for subsidies as of January 1, 1993 and standard labor input values (Ministry of Agriculture, 1991; 1992). About 52% of the sheep were on specialized sheep farms (including part-time farms) i.e. farms where sheep accounted for more than 85% of the calculated labor input and with total farm labor input of 400 hr or more. On the mixed sheep farms (often with dairy cows) 15 to 85% of the labor input was due to sheep. These farms accounted for another 28%, whereas the remaining 20% of the sheep were found on versatile farms where they accounted for less than 15% of total farming labor input or on small "sheep hobby farms" with less than 400 hr of total farming labor input.

The sheep farming in each region was represented by one, two or three of the categories above, and economical data for each category were computed as average of approximately 30 farm records for 1992 and 1993 (Table 1). The records were drawn from a sample of Norwegian farm accounts (Norwegian Agricultural Economics Research Institute, 1993a; 1994). Stratified-random sampling was used to achieve the same average number of sheep in each sample as in the represented category. As the total meat production of the samples was approximately 10% higher than the national figure, the average incomes were adjusted accordingly. The results were converted into US $ using the average exchange rate for 1992 and 1993[1] (Table 1).

Figure 1. Regional distribution of winter-fed sheep (w.f.s.) in Norway as of January 1, 1993.



The total weighted 1992 to 1993 net farm income from agriculture was estimated to $ 643.5 million (NOK 4.3 billions) for all sheep farms. Based on the share of the specialized sheep farms, the net income from sheep production was estimated to about US $ 133.2 million (NOK 886.1 million), a figure to which the costs of the predators have been related.

Approximately 70% of the sheep farmers are members of centrally organized grazing groups, which report number of released animals, total losses, and labor input (standard man days) to supervise and gather the sheep in each grazing area. Nationwide total losses of sheep and lambs while on open ranges are available from the central organization of the grazing groups (Coordinated Pasturing Database; Norwegian Sheep and Goat Association), showing an average loss of 2.31% for adult sheep and 5.21% for lambs for the period 1988 to 1993. These numbers do not show the share of the total losses caused by protected predators.

The number of lost animals has been calculated as minimum and maximum values. The minimum values are based on the official compensation statistics (County Governors offices; Database Biomys).[2] The minimum, showing an average of 1,962 adult sheep and 8,381 lambs compensated during the period,

[1] US $ 1 = 6.65 Norwegian kroner (NOK).

[2] The minimum or unquestioned losses were collected before the result of the farmer's appeal of the outcome for each area and predator. Losses to protected predators that are unspecified to predator species have been distributed in accordance with losses to specified species in each area. Lynx was not protected during the years 1988 to 1991 and has been attributed 25% losses for sheep and 80% for lambs these years, based on the situation in 1992 to 1994.

Table 1. Sheep per farm model, number of farms represented and net farm income (measured in US $) in 1992-1993 on Norwegian sheep farms; for region specification, see Figure 1.

Region and category of sheep farming	Adult sheep	No. farms	Net Farm Income, US $ Per farm, thousand	Total, million
Lowland r. areas (Østlandet and Trøndelag), versatile	45	1,726	21.2	36.5
Østlandet upland rural areas, specialised	62	1,906	7.6	14.4
Østlandet upland rural areas, versatile	33.5	2,012	29.7	59.8
Agder/Rogaland rural areas, mixed	60	2,937	34.8	102.1
Agder/Rogaland rural areas, versatile	31.5	1,916	46.2	88.6
Vestlandet, specialized	53	3,098	4.8	14.8
Vestlandet, mixed	41.5	2,254	25.8	58.2
Vestlandet, versatile	19	3,853	31.1	120.0
Trøndelag upland r. areas and N-Norge, specialised	95	1,357	15.6	21.2
Trøndelag upland rural areas and N-Norge, versatile	30	3,972	32.2	127.9
Sum		25,031		643.5

represented a small fraction (5 to 10%) of the total losses in the period. The maximum values (50 to 70% of total losses), are based on data from mortality transmitter studies for the period 1988 to 1993 (Mysterud and Warren, 1991; 1994; Warren and Mysterud, 1995), and have been estimated at 14,890 sheep and 37,018 lambs lost to predators. The maximum values have been distributed across area and predator species in accordance with the minimum values.

Since most of the costs of sheep farming are incurred before releasing the animals on the open range and lambs are sent directly or shortly afterwards, we have employed the principle that the loss of income will be the same whether a lamb is killed on the first or the last day on the range. Another principle of the calculations is that there might be economical losses on surviving animals if carcass quality or breeding values are affected. Farmers are paid a substantially lower price per kg for "blue lambs" weighing 10 kg or less and such lambs are unsuited for breeding. This may be the case if lambs loose their mother ewe.

The costs of predators to sheep farming consist first in the value of the meat, wool, and hide of the killed animals. Second, breeding programs are affected when animals are lost and this is taken into account by adding 10% for the life (life value). Third, when ewes are lost they have to be replaced with lambs from the same flock that are adapted to the local range. Consequently, because yearlings have a lower lambing rate than older ewes, there will be lower production the following year and a skewed-age composition of the flock for one or more years after a considerable loss of ewes. In the standard rate of compensation payment the value of 0.86 lambs is added to the value of the meat and wool of the ewe, as the lambing rate has been estimated to be 0.86 lambs lower for yearlings compared to older ewes.

Fourth, there will be consequential costs on lambs having lost their mother ewe. Such lambs may have lower weights, leading to lower breeding value or a lower price for the carcass. In a study of the live weights for lambs (Mysterud and Mysterud, 1995a; Asheim and Mysterud, 1995), the slaughter weight was computed to be 0.55 kg lower for lambs in communities with bear or wolf, while no such effects was reported for communities with other predators. The price effect due to quality deterioration on lambs is estimated to NOK 1.85 a kg and the farm price per kg of lamb meat to NOK 48.48 in Trøndelag upland rural areas and northern Norway and NOK 42.83 elsewhere. In the rounded values, US $ 9.0 (NOK 60) per lamb in bear/wolf communities within Trøndelag upland rural areas and northern Norway and US $ 8.3 (NOK 55) elsewhere, some consideration is also given to effect of depredation on breeding values of surviving lambs.

Fifth, excess fat accumulation and increased risk of mastitis are the main consequential costs to ewes having lost their lambs. The cost due to excess fat accumulation is assumed to be US $ 36.1 (NOK 240) per ewe, based on price grading according to fat content for carcasses of ewes. The effect is most important in areas with predators that apparently specialize in attacking lambs, such as wolverine, lynx, and the golden eagle, and would probably be most pronounced with respect to ewes having lost their lambs early in the grazing season, for instance due to golden eagle depredation. However, some ewes lose only one of two lambs, and some of those having lost all lambs still could perform well for more years. It is estimated that one ewe in three has to be slaughtered after having lost its lambs (Skjevdal, personal communication).

Sixth, extra labor input due to predators has been assessed on the basis of studies of the connection between loss percentage and labor input (standard day's work). Data were derived from the grazing groups (Coordinated Pasturing), with totally 5,982 observations for the period 1981 to 1992 (Mysterud and Mysterud, 1995a; Asheim and Mysterud, 1995). This database has no information about the cause of the losses. However, we have assumed that the extra labor required would be the same no matter what caused the loss. The extra labor input required amounted to 0.00225 standard man days per animal for each extra percent of loss (F-value = 3.82, Standard Error 23.6%) whereas for lambs it amounted to 0.00096 standard man days (F-value = 3.69, Standard Error 27.1%). The value of the extra hours has been determined by using the hourly wage for hired farm labor.

The standard rates of compensation payment for ewes and lambs (Norwegian Agricultural Economics Research Institute, 1993b; 1993c) have been employed to assess the first three kinds of costs. However, the standard rates do not account for consequential costs on lambs having lost their mother ewe or on ewes having lost their lambs as well the extra labor input required to search for lost animals, identifying the cause of loss and

Table 2. General population estimate, distribution and densities of protected carnivores, including golden eagle in Norway, based on official 1994 figures and maps.

Species	Number[1]	Area (Km^2)	Number/Area (1,000 Km^2)
Brown bear	20-25[2]	49,200[3,4]	($\bar{x}$ = 0.45 (0.4-0.5)
Wolverine	200	56,107[3,5]	($\bar{x}$ = 3.6 (3.6-3.6[*2])[9]
Wolf	5-10[7] (20-25)[6]	961[3]	($\bar{x}$ = 7.8 (5.2-10.4)
Lynx	300-400	142,560[3]	($\bar{x}$ = 2.45 (2.1-2.8)
Golden Eagle	700-1,000[8]	273,790	($\bar{x}$ = 3.1 (2.5 - 3.7)

[1] Revised 1994 population estimates from Directorate for Nature Management (1994).
[2] Swenson et al. (1994).
[3] Measured with digital planimeter (PLACOM KP-90) on maps with species distribution (Ministry of Environment 1992).
[4] The sum of three sub-areas; 35,690 km^2 (South- and Middle-Norway), 3,025 km2 (Troms) and 10,485 km^2 (Finnmark).
[5] The sum of two sub-areas; 8,317 km^2 (South-Norway) and 47,790 km^2 (Trøndelag and North Norway).
[6] Population figure for the common 1994 Norwegian-Swedish population (Wabakken et al. 1994) in brackets.
[7] Estimate for Norwegian part of the 1994 Norwegian-Swedish population.
[8] Gjershaug et al. (1994).
[9] No population estimate interval given.

extra supervision due to predators. These costs have been computed separately. Surviving animals may additionally have different kinds of injuries due to predator attack, such as beats, scratches, or torn up udders etc., which have not been considered, and may become difficult to gather and feed and unsuited for breeding. Another basis for assessing the damage of the different predator species, has been the official 1994 statistics, as well as official distribution maps for the four species of large carnivores (Ministry of the Environment, 1992) and the golden eagle (Gjershaug et al., 1994) (Table 2).

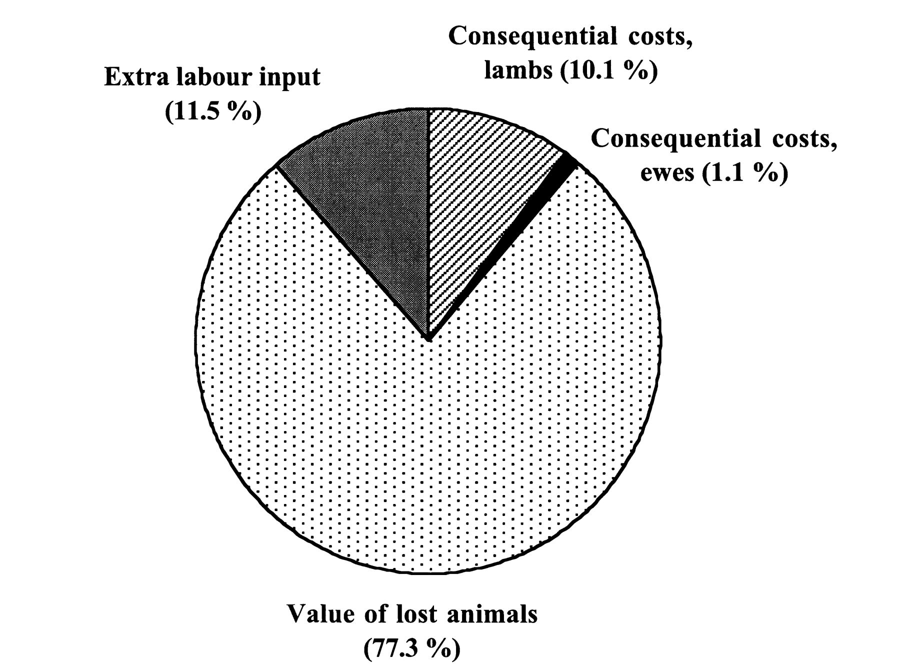
At the time of the EIA, only the Norwegian populations of lynx, wolverine and golden eagle were regarded to be demographically viable[3]. For calculating cost of viable numbers of all predators, the population of bears has been expanded to approximately 70 animals and to approximately 50 animals for wolves. These are regarded as minimum demographically viable numbers in order not to overestimate the costs. The expanded demographically viable populations are distributed geographically by assuming expansion northward, southward, and westward from the core areas of bears and wolves in the Norwegian-Swedish border zone (See Ministry of Environment, 1992).

If the populations of large carnivores should be expanded further in size to genetic viability, bear populations would be roughly 1,250-2,500 individuals (Mysterud and Mysterud, 1995a). As articulated during the Yellowstone reintroduction program, genetic viability would involve at least ten breeding pairs of wolves in three different areas, starting with 210 individuals. Such numbers would, in practice, mean to re-establish the bear and wolf over most of Norway (Mysterud and Mysterud, 1995a).

Results

The main cost of the predators is the value of the lost animals, which constitute more than three quarters of the total cost (Fig. 2). The consequential cost on lambs having lost their mother would be approx. US $ 809,600 (NOK 5.4 million). A total of 6.4% of the sheep graze in bear/wolf communities. The effects on ewes having lost their lambs was smaller, by comparison, ranging from an estimated minimum of US $ 45,000 (NOK 299.2) to a maximum of US $ 123,800 (NOK 823.4). The value of the extra labor input amounted to US $ 268,300 (NOK 1.8 million) (minimum) and US $ 1.6 million (maximum) (NOK 10.4).

Figure 2. Composition of predator costs. Percent



[3] A risk assessment of demographic viability takes into account characteristics relating to number, age and sex distribution in the short-term survival of populations. Genetic viability on the other hand, takes into account the longer-term genetic processes, both systematic (migration, mutation, selection) and dispersive (drift, inbreeding) (see Mysterud and Muus Falck, 1989). The actual carnivore population sizes needed to meet the criteria of viability are discussed (i.e. for bears, see Sæter et al., 1998; and Wiegand et al., 1998).

Measured together, the consequential costs and extra labor input constitute 22.7% of the costs.

The effects of the protected predators on net farm income from the sheep are shown in Table 3. Based on documented losses from the period 1988 to 1993, the five predator species appear to have reduced farm incomes by US $ 3.0 million (NOK 20.2) annually or 2.3% of the total net sheep farm income. These results are in line with estimates by the U.S. Agricultural Statistics Board (1991), showing that $ 22 of $ 895 million or 2.46% of the sheep value was lost to predators. However, such numbers only indicate the magnitude of the problem in a given country, since different predator species and agricultural systems occur nationally and regionally.

Based on loss figures from radio transmitter studies, maximum cost was estimated at US $ 12.9 million (NOK 86.1) in 1992/93 or 9.7% of the net income from sheep farming (Table 3). The cost of the predators is slight in Vestlandet, Jæren and Agder/Rogaland. In the southwest, losses are mainly to lynx and golden eagles, whereas wolverines are also present in parts of Vestlandet. Losses are also moderate (1.7 to 5.5%) in the lowland rural areas around Oslo and Trondheim (grain areas). However, dispersing bears do occasionally cause some damage in lowland rural areas of Trøndelag, and lynx can also be present in the forests of central areas, quite close to the cities of Oslo or Trondheim.

In upland rural areas of Østlandet, losses range from 4.1% (minimum) to 15.0% (maximum) of net income from sheep farming. About 27% of the total losses occur in the region. All predators are present in the area, however bears and wolves (measured together) were most important. Bears and wolves are mainly a problem along the border with Sweden, however dispersing animals can from time to time cause damage in the whole region. The costs of the losses due to lynx are almost as important as costs due to bears/wolves. Lynx prefer forested areas, and no important natural obstacles significantly influence the movement of the lynx in the region. Wolverines on the other hand, prefer alpine areas, and losses to wolverine are therefore reported only in the northern parts of the region. In these areas, losses can become very severe, increasing local conflicts with respect to size of the wolverine population.

Table 3. Economic impact of the present protected predator situation on Norwegian sheep farming in 1992 to 1993.

Region	Net Farm Income from sheep. Million US $	Cost of predation, million US $. Minimum	Maximum
Lowland rural areas	9.3	0.2 (1.7%)	0.5 (5.5%)
Østlandet upland rural areas	23.3	1.0 (4.1%)	3.5 (15.0%)
Jæren and Agder/Rogaland	29.2	0.1 (0.2%)	0.3 (1.0%)
Vestlandet	40.0	0.2 (0.5%)	1.0 (2.4%)
Trøndelag upland rural area and N-Norge	31.4	1.7 (5.3%)	7.7 (24.4%)
Sum	133.2	3.0 (2.3%)	12.9 (9.7%)

By far, the most significant losses are found in the Trøndelag upland rural areas and in northern Norway where they range from 5.3 to 24.4% of net farm income from the sheep. Estimated by region, about 59% of the total losses occur in this region. Lynx, wolverines and bears/wolves cause about equal shares of the maximum costs by predators in the region. Losses to golden eagle are generally small by comparison to the other predators, however in northern Norway damage by golden eagle is also important. The golden eagle clearly prefers lambs (Bergo, 1990). Northern Norway is also the most important region for domestic reindeer herding that causes additional conflicts between predator conservation and reindeer production.

Although the number of bears (and wolves) has been far below that considered viable populations in the period, losses due to these animals have been considerable. An important reason for this is that bears prefer adult ewes, subsequently leading to costs to lambs after having lost their mother. Approximate estimates of the effects of expanding the 1994 wolf and bear populations to demographically viability are shown in Table 4.

Expansion to demographic viable predator populations increases damage sustained by the sheep farms to US $ 5.4-20.9 million (NOK 35.6 to 138.8). The cost associated with further expansions of bear and wolf populations to genetic viability has been estimated by extrapolating today's costs computed for these species to the whole country. This would yield an annual loss for the sheep farms of between US $ 20 and 68 million (NOK 130 and 450), including losses to the three other currently viable predator species. In areas where it is economically difficult to sustain sheep farming under

Table 4. Economic impact (in 1992/93 prices) of the 1994 predator situation on Norwegian sheep farming compared with computed effects from expanded viable Norwegian and Nordic countries predator populations.

Alternative	Predation cost, in million US $. Minimum	Maximum
1994 situation, lynx	0.8	3.9
1994 situation, wolverine	0.6	3.3
1994 situation, golden eagle	0.2	0.9
1994 situation, bears/wolves	1.4	4.8
Demographic viability of bears/wolves	3.8	12.7
Genetic viability of bears/wolves	18	60
Nordic countries shared populations (lower limit) [1]	3.0	12.9

[1] Increased costs for Norway under a Nordic countries management strategy with shared populations are not considered, as they will depend on negotiations and agreements.

the 1994 conditions, it will become virtually impossible to continue profitable production without additional subsidies and/or comprehensive adaptation of operating conditions to the new predator management policy. As for the Nordic countries co-operative alternative, the lower limit might be seen as the total costs of the 1994 situation in Norway (Table 3).

Discussion

The study is based on the official number of carnivore predators in 1994 and losses in the period 1988-93. The overall number of carnivore predators has increased in later years (Ministry of Environment, 1996-97), however so has also the losses of sheep. According to the database, Coordinated Pasturing, the average loss percentage of sheep and lambs increased from 4.17% for the period 1990 to 1993 to 5.38% for the period 1995 to 1997, and to 5.87% for 1998 to 2000. In the same periods, an average of 8,963, 23,365 and 31,704 animals were compensated as killed by a protected predator. In recent years, about one in four lost animals has been compensated. One aspect in the ongoing management conflict (see Blekesaune and Strete 1997) has been the different opinions of the extent of the damage by farmers and Non-Governmental Groups. Some animals will always die from causes other than predators. Obviously, the acceptance of a predator-caused damage by the government can become a budget question. The maximum and minimum values presented here may be a foundation for an agreement.

The experienced losses may cause sheep-farm decline, and if viable populations of all the five predators in Norway are realized, it will undoubtedly have serious consequences for the present sheep farmers and reindeer herders as well as the hunting interests. Perhaps the most serious result of discontinuing sheep operation in many rural communities is the lack of alternative employment in the affected areas. Development of the Norwegian sheep farming has been shaped through a series of agricultural policy decisions designed to make the industry cost-efficient through investments in infrastructure, modern breeding programs, etc., and help to utilize local resources under conditions with few carnivores. The sheep-milk production system was lost early in the process. A new predator regime with viable populations of protected carnivores will greatly affect sheep farming in its present form. As predator populations increase, losses are expected to increase considerably, escalating the conflict between agricultural and environmental policies.

The current conflict probably could be dampened by a Nordic countries predator solution. Since the Fennoscandian (Norway, Sweden and Finland) populations of the four protected large carnivores and the golden eagle are naturally connected across national borders, long-term (genetic) viability and protective efforts might be discussed in a habitat area of 1.1 million km^2 (Mysterud and Mysterud, 1995b). The strategy for such cooperative sharing of carnivore populations across national borders has, as mentioned, been developed (Nordic Farmers Central Council, 1988). Such a solution might allow better consideration of and adaptation to the different problems and conflicts in each country. This is due to, among other things, different habitat conditions including different physiographical features as well as economical, sociological, and other differences in conflict structure in the involved countries.

The potential of a Nordic Countries' management solution lies in its probable ability to dampen national conflicts by presenting solutions that make it easier for the sheep-farming business to adapt even to carnivore populations that will meet any "scientific criteria" of viability. Under a cooperative-predator management, the various countries could take primary responsibility for differing shares and numbers of the different species, securing long-term survival of genetically viable populations. A common management plan does not, however, exempt each individual country from its responsibility to protect all species occurring naturally in its fauna.

The future development of the conflict also depends upon whether efficient loss-preventive measures can be defined and introduced, or the infrastructure of the industry otherwise strengthened. Removing the sheep from the range, either totally or for parts of the grazing season in the most affected areas, seems promising, but will require alternative pastures. Herding the sheep on the ranges seems too expensive under Norwegian conditions (Flaten and Kleppa, 1999). Herding with night pens for small ruminants is probably most competitive in connection with milk production. Reintroduction of sheep milk might be part of a more permanent management strategy. Changes in management practice in one area might, however, lead to damage displacement (external costs) if predators move to another area. A creative-research effort taking these questions into consideration would be highly needed and appreciated. More research is also needed to evaluate and clarify the conditions for the domestic reindeer industry and game users' interests in future carnivore areas without sheep.

Finally, the study does not address the national socio-economic (cost and benefit to society) question of balancing agricultural and environmental policies with respect to sheep and large carnivores on Norwegian ranges. Sheep-industry losses cannot be considered a loss to a country's total economic system (Wagner, 1988), and that advantages of replacing sheep by predators may surpass the costs. In a protected market, increased costs may be passed on to consumers, otherwise national agricultural support and compensation payments are saved by more import of sheep meat. However, free-ranging sheep seems only possible without large numbers of predators wherever production takes place.

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Review of Canid Management in Australia for the Protection of Livestock and Wildlife — Potential Application to Coyote Management

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Introduction

Australia has two introduced canid species — European red foxes (*Vulpes vulpes*) and wild dogs (which include dingoes, *Canis lupus dingo*, feral domestic dogs *C. l. familiaris* and their hybrids). Foxes were introduced into mainland Australia in the 1860s and quickly spread (Rolls, 1984; Jarman 1986). This dispersal and establishment is believed linked with the introduction and spread of European wild rabbits (*Oryctolagus cunniculus*) (Saunders et al., 1995). Except in Tasmania, where previous introductions appear to have been unsuccessful, and in northern Australia, where the climate is unsuitable and rabbits are essentially absent, foxes have become established throughout in virtually all habitats including urban and residential environments (Saunders et al., 1995). Within decades of their introduction, legislation was enacted proclaiming them as pests to agriculture, and more recently, as a key threatening process to endangered small mammals (NSW National Parks & Wildlife Service, 2001). This status has been enshrined in subsequent legislation and strengthened by virtue of foxes being an introduced pest species rather than a native animal.

Dingoes are thought to have arrived in Australia from Southeast Asia about 5000 years before present (Corbett, 1995a). A number of reports have reviewed the origins, ecological significance of dingos, and their morphological and genetic relationship to domestic dogs. Interested readers are referred to Newsome et al. (1980) as one example. Like foxes they are also found in virtually every habitat across the Australian continent and are absent from Tasmania (Fleming et al., 2001). However, because of their longer association with Australia, they are often regarded as a “native” species (Davis, 2001). Wild domestic dogs have been present since the first European settlement in 1788 (Fleming et al., 2001) and hybridization with dingoes has been occurring ever since (Corbett, 1995a, 2001). Despite the native status of dingoes, all wild dogs and foxes are regarded and managed as pests on agricultural lands, i.e. outside of conservation areas. Pure dingoes alone are afforded legislative protection in areas set aside for conservation (Fleming et al., 2001; Davis and Leys, 2001) yet feral dogs and hybrids effectively enjoy the same legislative protection in conservation areas as dingoes, because they cannot be managed separately.

Impact of Canids on Livestock Production: Wild Dogs

Wild dogs cost the grazing industries of Australia millions of dollars annually in production losses and control expenses (Fleming et al., 2001; Whan, 2003). Production losses are highest in the sheep industry, followed by the cattle and the goat industries (Fleming and Korn, 1989), reflecting the relative numbers of the three livestock species nationally (Meat & Livestock Australia Limited, 2000). Sheep and goats are more vulnerable to wild dog predation than cattle. This is primarily due to two factors: (a) the fleeing and mobbing behavior of sheep and goats in response to the presence of wild dogs; and (b) the hunting style of wild dogs and the efficiency at which wild dogs handle sheep and goats.

The movement of prey is an essential stimulus for eliciting predation by canids (Fox, 1969). Big horn and Dall sheep (*Ovis canadiensis* and *O. dalli*) of North America scatter in the presence of wolves (*Canis lupus lupus*), their fleeing behavior eliciting an attack response by wolves (Mech, 1988). Domestic goats and sheep have been selected from wild species and also flee in the presence of wild dogs. However, unlike their wild caprinid relatives that can take refuge from predators amongst the rocky, rough terrain found in their natural habitat (for example Dall sheep, Frid, 1997), domestic sheep and goats have no defensive behaviors of consequence. The instinctive reaction to flee is disastrous for domestic livestock because they seldom have quality refuge available and their fleeing behavior triggers wild dog attacks. In addition, Australian merinos, which comprise approximately 75% of the national flock of 104 million sheep (Meat & Livestock Australia Limited, 2000), are particularly susceptible because their second anti-predator response is to circle and form a mob. As they circle, more of those on the outside of the moving mob are exposed to the predator (Fleming, 2001) and surplus killing, where one dog is responsible for predation in excess of nutritional requirements (for example Andelt et al., 1980), often occurs. Because of surplus killing, the damage experienced by sheep producers is not related to the density of wild dogs, excepting that no damage occurs in the absence of wild dogs (Fleming, 2001).

Thomson (1992) observed that wild dogs easily out-paced sheep subsequently attacking 66% of the sheep they chased. This level of capture efficiency is exceptionally high relative to other prey and at the higher end for other predators (Table 1). In fact, many of the sheep in Thomson's (1992) study were chased and outrun by wild dogs but not attacked, the pursuing wild dog breaking off to pursue another sheep. Thomson concluded that there was no advantage for wild dogs to cooperatively hunt sheep.

Characteristics of wild dog predation include:

- Relatively few of the sheep and goats killed or mauled by wild dogs are eaten;
- Of those sheep and goats that are eaten, generally little is consumed; and
- All wild dogs that enter sheep or goat grazing lands will eventually attack or harass sheep and goats.

This scenario has resulted in respective State and Territory Governments independently developing management policies that regard sheep or goat production as being incompatible with the presence of wild dogs. In contrast, attitudes of beef cattle producers towards wild dog predation are diverse (Allen and Sparkes, 2000). Part of the reason for this diversity is the defensive behavior of cattle in response to the presence of wild dogs — adult cattle cooperatively defend calves and/or charge wild dogs (Thomson, 1992; Corbett, 1995a). This defensive behavior of cattle discourages wild dogs resulting in fewer attacks. Consequently, even though wild dogs are more efficient at chasing and killing calves than preferred natural prey such as kangaroos (Table 1), they infrequently do so.

Studies comparing calf loss, subsequent to confirmed pregnancy diagnosis, in beef cattle herds depastured in 1080 baited and non-baited paddocks (>400 km²) in far north and southwest Queensland showed that in most years wild dogs do not cause detectable predation losses (Table 2). Curiously, this study also found that when wild dog populations were baited on part of the property, annual predation losses increased both in frequency (number of years predation loss is detected) and magnitude (percentage of calves killed by wild dogs). As one naturally assumes reducing pest numbers consequently reduces the impact of that pest, these results were quite unexpected.

The study showed calf losses occurred when prey populations were low, when below-average, annual rainfall had preceded, and most importantly, when baited areas had been re-colonized by wild dogs (Allen, In Preparation). The study concluded that young, dispersing wild dogs were likely to re-colonize after baiting, and were more predisposed to attacking calves than stable wild dog populations. Thus, attempts to reduce predation losses by controlling wild dogs on individual cattle properties may not only be ineffective but counterproductive. For example, for twenty years 1968 to 1987 baiting programs were conducted on Ironhurst station throughout the year yet they continued to see bitten calves (Fig. 1). When wild dog management changed in 1988 to an annual, large-scale, coordinated-baiting program involving multiple properties

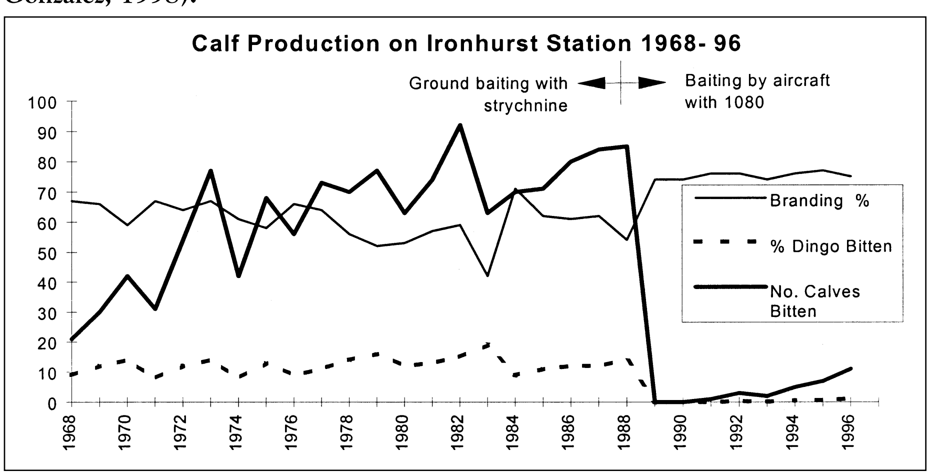
Table 1. Capture Efficiency of Canids Attacking Prey.

Canid	Prey	Capture Efficiency	Reference
Wild Dogs	Sheep	66%	Thomson 1992
Canis lupus dingo,			
C.l. familiaris	Cattle (*Bos* spp)	14%	Thomson 1992
	Kangaroos (*Macropus* spp)	9%	Thomson 1992
Wolves	Elk (*Cervus elephus*)	15-26%	Mech et al. 2001
Canis lupus lupus	White-tailed deer (*Odocoileus virginianus*)	25-63%	Kolonosky 1972
African hunting dogs	Ungulates (mostly *Gazella thompsonii*)	85%	Estes and Goddard 1967

Table 2. Predation loss of calves in baited and non-baited portions (>400 km²) of the same property (from Allen, In Preparation).

Site/Date	Predation Loss Baited Area	Predation Loss Non-Baited Area
Mt Owen/ 1994	Nil Detected	8.8%
Mt Owen / 1995	15%	Nil Detected
Mt Owen 1996	Nil Detected	Nil Detected
Mt Owen / 1997	Nil Detected	Nil Detected
Strathmore/ 1995	11.3%	Nil Detected
Strathmore/ 1996	32.1%	Nil Detected
Strathmore / 1997	Nil Detected	Nil Detected

Figure 1. Changes to the branding rate and number of calves bitten on Ironhurst Station subsequent to major changes to dingo control technique. (From Allen and Gonzalez, 1998).



mean-annual-branding rate increased by 18% simultaneous with a substantial decrease in bitten calves (Table 3). Similarly, in the Brindabella Ranges immediately west of Canberra in the Australian Capital Territory, a cooperative ground baiting and trapping program that included about 850 km^2 of lands managed by government agencies and private owners achieved a 60% reduction on average annual losses of sheep and goats (Hunt and the Brindabella/ Wee Jasper Wild dog/ Fox Working Group, 2002). These are just three examples that demonstrate a strategic advantage from large-scale, coordinated wild dog control that cannot be achieved through control programs having a single property focus.

A recent independent economic assessment valued the impact of wild dogs in Queensland as A$33 million. (Table 4, Whan, 2003). For sheep, most of the direct losses were from mauled and destroyed livestock, whereas in beef cattle, wild dogs cost A$19 million through their roles as vectors for diseases such as hydatidosis (causative agent *Echinococcus granulosus*) as well as predation. A number of economic assessments of sheep predation by wild dogs in other States have been undertaken and these are reviewed in Fleming et al. (2001). It is difficult to obtain data for the costs and benefits of controlling wild dogs in sheep growing areas because few producers are willing to withdraw wild dog control so that damage can be assessed (Fleming et al., 2001). Nevertheless, in four surveys undertaken in New South Wales between 1961 and 1985, losses of sheep in wild dog affected areas ranged from 0.7 to 1.33% in the presence of control (Fleming et al., 2001). Fleming and Korn (1989) found that 6,400 livestock animals were killed or injured annually by wild dogs. These data were reported to eastern New South Wales control authorities by landholders between 1982 and 1985 and probably represented 31% of the actual losses (Fleming and Korn, 1989). A survey of 809 landholders in the State of Victoria in 1985 indicated that the cost of losses and control activities was about A$2.9 million (Backholer, 1986), which is equivalent to A$5 million in 2003.

Neospora caninum is a protozoan that causes abortion in infected beef and dairy cattle herds. The prevalence of *N. caninum* infection in Queensland beef cattle is about 15% and corresponds with the distribution of wild dogs (Landmann and Taylor, 2003). The cost to the Australian dairy and beef industries of abortions caused by *N. caninum* infection has been estimated at A$110 million annually (Reichel 2000). However, the role of wild dogs in *N. caninum* infection has not been investigated but is likely to be important, particularly in north Queensland where prevalence is highest (Landmann and Taylor, 2003).

Table 3. Calf production and dingo control figures from Ironhurst Station in North Queensland from 1978 to 1996. (From Allen and Gonzalez, 1998).

Control Method	Ground Baiting Single property	Aerial Baiting Several Properties
Poison	strychnine	1080
Area Baited	520 km_	>50 000 km^2
Mean Branding	**(1978-87)**	**(1988-96)**
Rate (SE)	57.3% (2.5)	75.3% (0.4)
Mean Calves Branded (SE)	590.8 (39.4)	998.5 (44)
% Calves Bitten	13.3	0.4
Annual Rainfall (SE)	697 mm (102)	608 mm (84)

Impact of Canids on Livestock Production: Foxes

In contrast to wild dogs, foxes are of little consequence to cattle production in Australia except as a source of hydatid infection (Jenkins et al., 2000) and perhaps as a source, along with wild dogs, of *N. caninum* infection. Foxes are known predators of lambs but their impact has

Table 4. Summary of direct costs inflicted on the Queensland's rural economy by wild dogs (Whan, 2003).

Participant	Details of Cost	Amount (A$)
Graziers		
Predation losses - sheep	Direct loss	8,771,000
Predation losses - cattle	Direct loss of calves	9,531,000
Disease losses - cattle	Hydatidosis and Neospora	9,400,000
Prevention costs	Baiting (meat, labour, fuel, etc)	616,000
Other control costs	Trapping, shooting, fencing, surveillance	357,000
Sub-total		**28,675,000**
Local Government (based on 28 shires)		
Barrier Fence in 2001-02	$ for $ matching of State contribution to Barrier	700,000
Check fence (3 shires only)	Tara, Waggamba and Inglewood shires	200,000
Bounties and trapping etc	Bounties range from $10 to $100/ scalp	50,000
Baiting (excluded elsewhere)	Meat, mixing, distribution	1,500,000
Sub-total		**2,450,000**
State & Commonwealth		
Barrier Fence	Staff, materials and vehicles, etc	700,000
1080	30 kg @ $400/kg + freight	13,000
Coordination & bait making	27 NR&M officers directly involved	405,000
NR&M Head Office + Res & Development	Planning coordination and extension $265,000 R&D $400,000	665,000
Other govt departments	QPWS and EPA (estimate only)	200,000
Sub-total		**1,983,000**
State total		**33,108,000**

been little studied. While some studies suggest foxes may take 10 to 30% of lambs in some areas with concurrent negative economic consequences (Lugton, 1993; 1994), fox predation on lambs is often negligible (Greentree et al., 2000) and is regarded as generally insignificant at a national level (Saunders et. al., 1995). Where fox predation is substantial, loss of lambs not only affects the potential income derived from wool and sale sheep but also slows the rate of genetic improvement by reducing the rate of culling for selection.

Impact of Wild Dogs on Wildlife

- The current role of wild dogs in the many Australian ecosystems in which they occur has not been established. Wild dogs probably have a positive impact on wildlife by:
- Suppressing the density of fox populations by limiting the access of foxes to (native) prey resources where the two species coexist (Jarman, 1986; Corbett, 1995a); and
- Preying on feral livestock like goats (Allen et al. 1996, Parkes et al. 1996), pigs and potentially deer (Corbett 1995a), pest species, such as rabbits, feral cats, and hares, and over abundant native animals, such as macropods and emus (Caughley et al., 1980; Shepherd 1981; Robertshaw and Harden, 1987; Newsome et al., 1989; and Corbett 1995a).

Whether wild dogs actually regulate populations of their prey is subject to debate (Corbett, 1995b; Pople et al., 2000). However, the dingo has been implicated as one of the causes of the demise of some endemic marsupials of arid and semi-arid environments prior to cat and fox range expansion into those areas (Corbett, 1995a). Also, the dingo possibly caused the Tasmanian tiger (*Thylacinus cynocephalus*) (Archer, 1974), the Tasmanian devil (*Sarcophilus harrisii*) (Corbett, 1995a) and the Tasmanian woodhen, *Gallinula mortierii* (Baird, 1991) to become extinct on the Australian mainland. The effects of the potential changes in behavior and ecology of wild dogs, caused by increased hybridization, on wildlife is unknown.

Impact of Foxes on Wildlife

In contrast to wild dogs, studies conducted on threatened, vulnerable and endangered wildlife species in the last decade have discovered fox predation is a major cause of mortality threatening biodiversity and species survival (extensively reviewed in Saunders et. al., 1995). In Western Australia, large scale, fox control exercises (e.g. Thomson and Algar, 2000) have been instrumental in the recovery of some threatened mammal species, including numbats (*Mymecobius fasciatus*), woylies (*Bettongia penicillata*), Rothschild's rock wallabies (*Petrogale rothschildi*) and black-footed rock wallabies (*P. lateralis*) (Bailey 1996; Kinnear et al., 1998; Saunders et al., 1995). Fox predation has even been shown to limit recruitment of eastern grey kangaroos (*Macropus giganteus*), the largest and most abundant of the macropods in eastern Australia (Banks et al., 2000).

Canid Management in Australia

Prior to the introduction of the toxicant fluoroacetate (Compound 1080) in the mid-1960s strychnine was extensively used for about a hundred years by graziers to control canids (Rolls, 1984; Allen and Sparkes, 2001). Trapping and fencing were also important methods of wild-dog control. Boundary fences of most sheep-producing properties were constructed of wild-dog-proof netting and the major sheep producing regions were enclosed in a State Government-maintained, Dingo Barrier Fence that stretched thousands of kilometers through Queensland, along the New South Wales border and across South Australia (Fig. 2). The aim of the Dingo Barrier Fence is primarily to prevent the ingress of wild dogs into sheep-production areas from areas where no or less wild-dog control occurs. Its effectiveness is reviewed in Allen and Sparkes (2001).

So intensive was the effort put into wild-dog control and so effective were these methods, that wild dogs were completely removed from core-sheep-production areas of eastern and southern Australia. Nevertheless, the introduction of 1080 brought significant change. Allen and Sparkes (2001) report that within five years from commencing the use of 1080 baiting in Queensland (1968), the use of strychnine baits was suspended because of insufficient demand, and over the decade following 1080 introduction the number of local government-employed wild-dog trappers declined from 57 to four. Similar reductions were evident in the number of trappers employed in northeastern New South Wales (Fleming, 1996a).

For four decades, baits poisoned with 1080 have been extensively used in Australia. They are placed in bait stations or along fence lines and property roads from vehicles, or alternatively,

Figure 2. The Dingo Barrier Fence, a two-meter-high netting fence, stretches thousands of kilometers from Queensland to South Australia and encloses most of Australia's sheep production areas.

dropped from aircraft along inaccessible creeks and ridges — places frequently traveled by wild dogs (Fleming et al., 1996). This practice has been singly the most important canid-control method used in Australia and vast tracts of grazing land have been annually baited. The management of wild dogs relies heavily on 1080 baiting because it delivers a rapid, cost-efficient, and humane reduction in wild-dog populations over areas of sufficient size to prevent re-colonization from uncontrolled populations (Thomson, 1986; Fleming et al., 1996; Fleming et al., 2001). As much of the wild dog control is conducted in remote areas where wildlife is more abundant than in mixed farming and cultivated areas, the reductions in fox abundance that concurrently occur (Fleming, 1996b) are seen as an added benefit.

Trapping for removal is still an essential tool for wild-dog control in the tablelands of southeastern New South Wales and in northern Victoria. Trapping and ground baiting are necessary because the area available to conduct aerial baiting has been reduced over the past 10 years. The perception that spotted-tailed quolls (*Dasyurus maculatus*) might be at risk from canid control (Belcher, 1998) has resulted in a reduction in the area baited by aircraft. However, Körtner et al. (2003) have shown that spotted-tailed quolls are not affected by ground baiting programs for fox control, starvation, disease and predation by foxes and wild dogs being more likely causes of their mortality. Whether baiting for wild dogs endangers spotted-tailed quoll populations has not been determined and is the subject of ongoing research in New South Wales and Queensland.

The control of foxes in conservation areas to protect wildlife resources, in most cases, uses identical methods to those of agricultural areas. Where necessary, large-scale, aerial baiting with 1080 baits is practiced, targeted in those inaccessible areas where vulnerable native species require particular protection from foxes (Bailey, 1996). Recently, foxes were deliberately and maliciously released into Tasmania, which is the largest island refuge for some species, including Tasmanian devils, the Tasmanian woodhen and eastern quolls (*Dasyurus viverrinus*). This led to a widespread and expensive eradication campaign using ground-distributed 1080 baits (Croft et al., 2002). Baiting with 1080-impregnated baits is the cornerstone of fox control for native wildlife protection throughout Australia, and without 1080 most of the recovery and reintroduction programs for threatened species would be impossible to conduct. If 1080 baiting was not available, the consequences for Tasmanian wildlife in the event of further introductions of foxes would be dire. There are no alternative techniques to 1080 baiting that can be applied at equivalent scale and cost, that will reduce fox populations sufficiently to minimize predation on wildlife populations.

Choice of Toxicant

Because native mammals are more tolerant of 1080 than introduced mammals (McIlroy, 1986; McIlroy et al., 1986) and Australia has few medium-sized carnivorous animals that are not introduced pests 1080 is the toxin of choice in Australia. Fluoroacetate occurs naturally in many plants, particularly in Western Australia and northern Australia, and most animals evolved in these areas have consequently developed tolerance to it (McIlroy, 1986). The high tolerance of most native animals and the high sensitivity of canids mean that very small doses are used (3 to 10 mg total per individual) to cause the death of wild canids and hence the hazard to non-targets is limited further. Many Australian plants and soil microbes break down and utilize 1080 (Twigg and Socha, 2001). Laboratory trials have demonstrated that some dasyurid species (for example, the mouse-sized fat-tailed dunnart, *Sminthopsis crassicaudata*, Sinclair and Bird, 1984) are able to detect and avoid 1080. Populations of western quolls (*Dasyurus geoffroii*), which are tolerant to 1080, have been shown to benefit from fox control with 1080 baits, assumedly because competition and direct predation by foxes and wild dogs are removed (Bailey, 1996).

Populations of reptiles (principally goannas *Varanus* spp), birds and rodent-sized mammals (principally dunnarts, *Sminthopsis* spp.), carnivorous species potentially "at risk" from 1080 baiting, were studied in non-baited areas, and adjoining populations located in 1080-baited areas of similar size (400km^2, Allen, in preparation). No immediate or chronic impacts of baiting were seen (Fig. 3). Their populations increased and decreased responding to seasonal conditions but showed identical patterns with and without baiting.

Occasionally, strychnine and cyanide are used under permit for special applications, including the poisoning of trap jaws to prevent the slow death of trapped canids through dehydration or hyperthermia and for research where canid carcasses are required. As these toxins do not have all of the advantages of 1080, their use is uncommon and restricted.

Application to Canid Management in North America

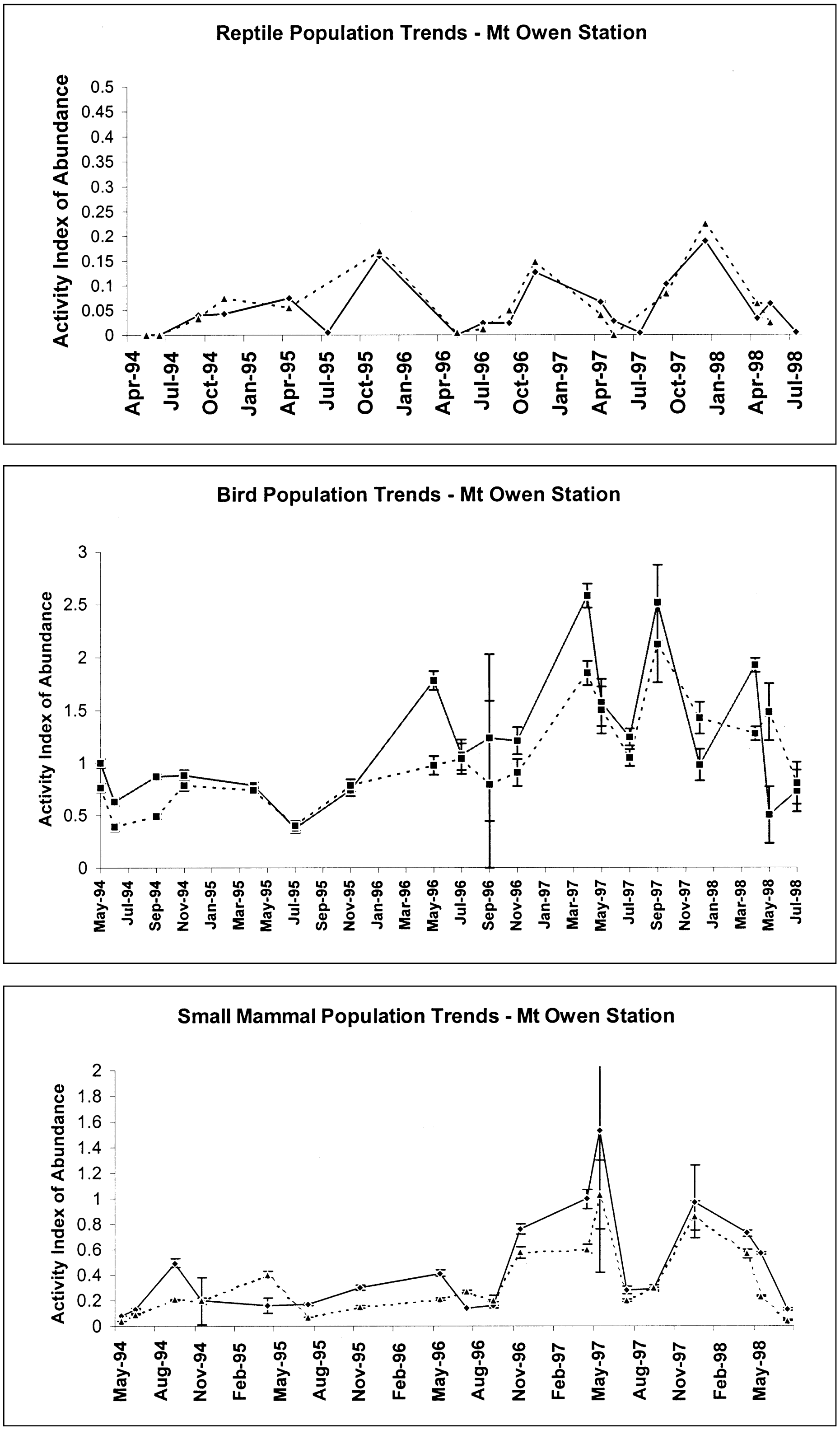
Significant similarities and differences exist between the canids involved in livestock predation, their status, hunting behavior, impact and management in North America and Australia. Similarities include:

- Similar sized canids (wild dogs are several kilograms heavier than coyotes on average) or are similar or identical species (foxes);
- Sheep and goat production are the most vulnerable industries to economic loss from canid predation and harassment;
- Dispersal and rapid re-colonization of controlled populations quickly negates the impacts of canid control on individual properties; and
- Canid control methods are generally identical with the exception of poison baiting in Australia,

Differences in canids and management between North America and Australia include:

- The hunting style of wild dogs coupled with the fleeing and mobbing behavior of sheep results in sheep and goat losses in a higher order of magnitude compared to coyotes;
- Foxes, wild domestic dogs and dingo-domestic dog hybrids are introduced species and regarded as pests to agriculture and conservation in Australia. Their "introduced pest" status ensures greater public support for control programs. In contrast, coyotes and red foxes are native carnivores in North America, although their ranges have

Figure 3. Population trends (including 95% CL) of reptiles (principally goannas, *Varanus spp*), ground foraging birds and small mammals (principally carnivorous dunnarts, *Sminthopsis* spp) in adjoining baited (broken line) and non-baited areas (solid line) illustrating that potentially "at-risk" wildlife are not affected by canid baiting programs. The 400 km^2 baited area was at least annually ground and aerially baited with 800 to 2000 10mg 1080 single-dose meat baits 1994 to 1998. Drought conditions prevailed before 1995 and this was followed by three consecutive years of above-average rainfall.



expanded since European settlement;

- There are no wolves or other large carnivores in Australia; wild dogs are the largest. The largest extant marsupial carnivore is the Tasmanian devil, which is mostly a scavenger and no longer occurs on mainland Australia;
- All Australian canids are proclaimed by legislation as pests to agriculture. Consequently, resource managers are legally obliged to control the abundance and spread of canids;
- Australia's native wildlife is relatively tolerant of 1080, while the target canids are extremely sensitive to 1080. This allows baiting practices to more specifically target pest species in Australia. North America has a relative large number of native carnivores potentially at risk from toxicants;
- Unlike the North American sheep and goat industry, the grazing industry in Australia is a significant contributor to the nation's economy and consequently commands more favorable treatment from resource management agencies;
- In Australia, management of wild canids is population-based with control of individuals occurring opportunistically or in response to predation of livestock that is unresolved by large-scale control; and
- There is a trend in Australia toward cooperative, strategic wild canid management programs that are: large-scale; aimed at preventing impacts rather than reacting to impacts; and jointly funded by all affected stakeholders.

Considering the similarities and differences in canid management between North America and Australia, two key factors seriously compromise the efficiency and economics of sheep and goat production in North America. These are:

1. An absence of an equivalent canid toxicant that has the utility and specificity that 1080 provides in Australia; and
2. The political and legislative support that regulates and protects grazing industries from canid predation in Australia.

Without these key factors Australia could not sustain viable sheep and goat industries, nor could resource managers prevent or mitigate the impacts of canids on threatened or endangered wildlife populations.

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Paul Rodgers
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