Tools for the Edge: What's New for Conserving Carnivores

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The loss of large carnivores at the edges of parks, preserves, and human habitations threatens the conservation of many species. Thus, effective predation management is a conservation issue, and tools to mitigate conflicts between humans and predators are required. Both disruptive-stimulus (e.g., fladry, Electronic Guards, radio-activated guards) and aversive-stimulus (e.g., electronic training collars, less-than-lethal ammunition) approaches are useful, and technological advances have led to many new, commercially available methods. Evaluating the biological and economic efficiency of these methods is important. However, social and psychological effects should also be considered. The management of animal damage to human property is necessary, and methods that allow the coexistence of livestock and large predators must be employed. With further research and development that includes interdisciplinary approaches to management methods, biologists may be better able to conserve large carnivore species by ameliorating human conflicts with them.

Keywords: animal behavior, aversive stimuli, endangered species, disruptive stimuli, predator conservation

The comment that "everyone's complaining about the weather, but no one is doing anything about it" is more a bromide than a joke, but conservationists have a similar refrain: A plaintive cry echoes in ivory towers that too many species are spiraling into oblivion while too little is being done to forestall the losses. If we compare the ecological crisis of species loss to a series of fires, it seems that conservationists tend to race each other, trying to be the first to discover a new conflagration, rather than develop the tools that will extinguish the flames. The grants go to build race cars, when what we need is a squadron of fire engines—or at least a few buckets of water. We need to do more than document extinctions; common sense dictates that we prevent them.

The protection of large carnivores presents a particular challenge because of the conflicts that can arise between human interests—specifically the protection of livestock—and the maintenance of populations of predators. Conflict with people kills wolves (*Canis lupus*), lions (*Panthera leo*), leopards (*Panthera pardus*), cheetahs (*Acinonyx jubatus*), and spotted hyenas (*Crocuta crocuta*) where agricultural areas border these predators' range (Woodroffe and Ginsberg 1998, Ogada et al. 2003), and conflict-mitigation measures are increasingly necessary as it becomes apparent that reserves and legal status are not sufficient for ensuring predators' survival. For rare, large predators, reserves will probably never be big enough, and transgression beyond their edges will continue to lead to the death of individuals and sometimes the decline of species (Woodroffe and Ginsberg 1998, Woodroffe 2001). Indeed, Woodroffe (2001) noted that "reducing the numbers of predators shot, speared, poisoned and trapped by people is the single most pressing need to halt global carnivore declines." Effective management of predator damage is also a conservation issue, and the edges—that is, the intersections of carnivores, people, and livestock—are where efforts need to be focused.

This article provides a brief description of newly developing tools and concepts for scientists, conservationists, and managers. Classical and common techniques of wildlife damage management are described elsewhere (Hyngstrom et al. 1994, Conover 2002), as are surveys of common nonlethal methods (Linnell et al. 1996, Smith et al. 2000, Shivik 2004). However, predation management is a discipline of rapidly growing theory, tools, and technology, necessitating an overview of recent developments. I hope in this article to stimulate new applied and theoretical approaches and to spur the advancement of methods that conserve predators by resolving their conflicts with humans.

Tools and concepts

Broadly, techniques for managing predation can be employed by government agencies and trained professionals in wildlife management, or applied by livestock producers and those directly affected by predation. For example, husbandry practices such as gathering livestock into protected areas during vulnerable times (e.g., shed lambing or night penning) are tools that owners have used for hundreds of years to protect livestock (Robel et al. 1981, Wagner 1988, Ogada et al. 2003).

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Similarly, predator-proof fences have been installed and studied for generations (Jardine 1909). In this article I will concentrate on novel (or less well-known and used) methods that are designed to be used by professional wildlife managers, especially those managing rare or threatened species, to reduce or ameliorate the effects of depredation.

In a theoretical framework, there are two basic conceptual approaches to repelling carnivores (Clark 1997). First are disruptive-stimulus approaches (primary repellents), which act by disrupting appetitive behaviors and "frightening" predators away from resources. Second are aversive-stimulus approaches (secondary repellents), which modify behavior through conditioning.

Disruptive stimuli. Disruptive-stimulus approaches are attractive because of their relatively low cost and simplicity, but it is important to acknowledge that frightening devices are not a panacea for predatory woes (Bomford and O'Brien 1990). Predators will rarely form a conditional response to disruptive stimuli; rather, they normally habituate to the stimuli, which eventually renders the approach ineffective (Shivik and Martin 2001). However, a series of approaches are emerging that may be suitable for high-risk, short-duration predation threats.

Fladry (figure 1) is a tool of ancient derivation for deterring wolves (Fritts 1982, Musiani and Visalberghi 2001) that has recently become commercially available and available by the kilometer (Carol's Creations, Arco, Idaho). Fladry is installed by hanging lines of flags around fields to prevent intrusion; it has some effect of dissuading wolves from entering areas (Musiani et al. 2003), although other predators are not susceptible to it. Its effectiveness on less wary species (e.g., ursid or avian predators) is limited (Shivik et al. 2003a), but initial estimates indicate a 60-day period of effectiveness for wolves. Essentially, anything new or different is likely to elicit avoidance behavior from predators, but this effect disappears over time. For example, fitting livestock with hard plastic collars (figure 2) may provide some protection (King 2004), but eventually predators tend to return to killing, albeit in a different manner that avoids the collar (Burns and Mason 1996).

The Electronic Guard (Linhart et al. 1992) uses a daylight sensor and a 12-volt battery to activate an intermittent siren and strobe light at night. When multiple units were used, and their locations altered, they provided significant protection (8–103 days) to sheep from coyotes (Linhart et al. 1992). However, the Electronic Guard is not currently produced and sold. More recently, however, a programmable light and sound device known as the ScareCall (figure 3; ML Designs, Goleta, California) has been developed, and production of it and other improved devices is likely. Although current versions of electronic repellents have not been rigorously field tested, they may be at least as effective as Electronic Guards for protecting livestock in small areas, and more compact and effective than other noise- or light-making devices (Fritts 1982).

Methods of delaying habituation, such as behavior-contingent activation (Shivik and Martin 2001), are important for increasing the longevity of effectiveness of disruptive stimuli, and modern sensors have been incorporated into some tools. The Model 9000 frightening device (Avian Systems, Louisville, Kentucky), commonly known as the radio-activated guard (RAG; figure 4), employs a scanning radio receiver to monitor the proximity of radio-collared animals (Breck et al. 2003). If a radio-marked predator approaches a protected area, such as a calving pasture, the unit activates a strobe light and a series of sound effects to prevent the predator from advancing. The RAG is complicated because

Figure 1. Fladry, a line of flags hung on the outside of a pasture to dissuade wolves from crossing it and entering the area. Photograph: John Shivik, US Department of Agriculture.

Figure 2. The King Collar, a simple plastic collar designed to be worn by vulnerable livestock. Its intent is to provide armor-like protection to the throat of animals, the area where jackals and coyotes typically target their attacks. Photograph: Fred Knowlton, US Department of Agriculture.

it requires radio-tagging predators, a significant effort. Alternatively, Shivik and colleagues (2003a) used a movement-activated guard (which uses passive infrared sensors to detect approaching predators) in a multiple-predator system and determined that the electronic devices were more effective than passive disruptive stimuli (fladry) or electronic training collars (see below). More sophisticated sensor designs using radar and other technologies may result in sensors that are useful in a wide array of predation management situations.

My lab is continually working with industry and electrical engineers to develop a variety of disruptive stimulus devices, but for biologists in the field, it also may be useful to consider unusual sources for ideas and products. In the United States, a survey of garden catalogs can uncover interesting devices, such as motion-activated Critter Gitters (Amtek Pet Products, San Diego) or motion-activated sprinkler systems (Contech Electronics Inc., Victoria, Canada) designed to protect vegetation from deer. Most electronic frightening devices have shown limited effectiveness for field use on deer (*Odocoileus* spp.) and require improvement in sensor technology to reduce occurrences of false alarms (Gilsdorf et al. 2004), but because large carnivores are usually secretive, the devices may be very useful for them.

Many aspects of electronic disruptive-stimulus devices require more thorough research. The optimum area and duration of effective protection are not known, although a working hypothesis is 10 hectares and 2–3 months per device. The relative (and potentially synergistic) effects of auditory and visual stimuli have not been adequately examined, nor has the effectiveness of incorporating other sensory modalities, such as olfactory stimuli. For simple stimuli, even wary animals such as wolves will eventually habituate completely and even approach the devices (Fritts 1982). Methods of decreasing habituation, such as behavior-contingent activation and randomization of stimulus location and presentation, have been indicated, but electronic devices are relatively new, and their use is probably far from being optimized.

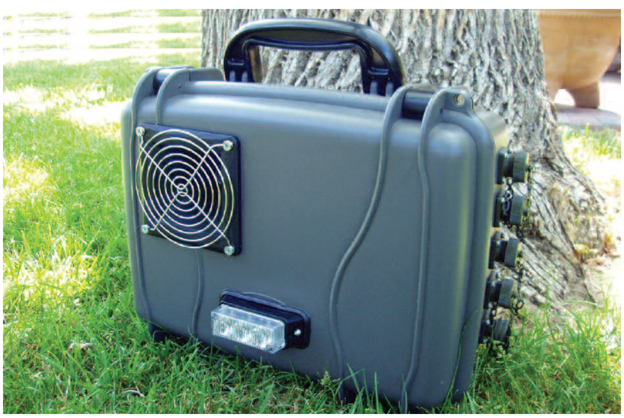

Figure 3. The ScareCall, a fully programmable light and sound device that can be suspended on a fence or tree in a pasture to prevent the advance and intrusion of wary carnivores. The device can use randomly activating lights and repellent sound effects (e.g., gunfire), or can be programmed with attractant calls (e.g., prey distress calls) to draw predators into an area for capture. Photograph: Martin Lilly, ML Designs.

An old technology of special note due to its recent popularity is the use of guard dogs. Guard dogs were investigated in the late 1970s and 1980s in the United States (Linhart et al. 1979, Green et al. 1984) and have been largely incorporated into western US sheep production operations; indeed, by 1993, 65 percent of the sheep producers in Colorado were using guard dogs (Andelt 1999, Andelt and Hopper 2000). Dogs are thought to be effective against wolves in parts of Europe (Rigg 2001, Fritts et al. 2003). In the United States, however, complications arise when wolves sometimes befriend, or more often kill, guard dogs (Bangs et al. 2005). Indeed, throughout the world, wolves also kill dogs wherever the two canids occur, even to the point of dogs' being an important food supply for some wolves (Fritts et al. 2003). Thus, guard dogs are a useful tool, but not a panacea. Volumes have been written about the use of guard dogs worldwide (Rigg 2001), and in that sense, there is little new in their use. In a theoretical context, however, dogs and other guard animals (Green 1989, Meadows and Knowlton 2000) can be thought of as behavior-contingent, multisensory disruptive stimulus producers, and continued understanding of their training and use may result in what amounts to the ultimate disruptive stimulus device.

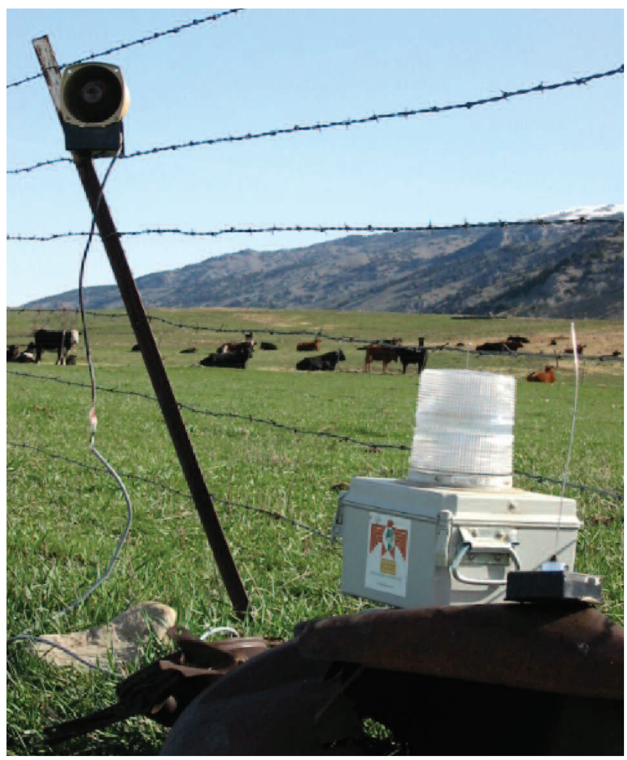

Figure 4. The radio-activated guard (Avian Systems Model 9000 frightening device). When a radio-collared predator approaches the area, the strobe light activates, along with a series of 30 sound effects. Photograph: John Shivik, US Department of Agriculture.

Aversive stimuli and behavior modification. Aversive conditioning using electrical stimulation is common in the psychological literature and has also been applied commonly as a pet training tool (e.g., electronic dog training collars). Linhart and colleagues (1976) and Andelt and colleagues (1999) used electric shock to teach captive coyotes not to attack specific prey. However, available technology was ineffective for conditioning wild wolves against attacking livestock, largely because of logistical concerns and variability in response to the negative stimulus (Shivik et al. 2003b). One approach, using electrified wires paired with novel signals, may promote an aversion to a barrier; "turbo fladry" that incorporates electrically charged wires, for example, is currently available (Carol's Creations, Arco, Idaho). Establishing conditioned avoidance to fladry could result in a simple but efficient barrier for many predators. Other devices, such as the electrified Nuisance Bear Controller (R. E. Arnold, Superior, Wisconsin) may disrupt bear damage to apiaries and then condition the bears to avoid these localized resources.

Physical harassment may be used to form an aversion to a behavior. For aversion, newly developed devices include paintball-type weapons using rounds filled with capsicum powder (PepperBall Technologies Incorporated, San Diego). Shotguns can be used to fire rubber bullets (Milstor Corporation, Indio, California) or beanbag rounds (Defense Technology Corporation of America, Jacksonville, Florida). Projectiles can be coupled with harassing dogs (Beckmann et al. 2004). However, sales of less-than-lethal ammunition may be limited to those authorized and trained by law enforcement personnel. Furthermore, their use may pose some risk both to the predator being shot and to the person who employs the projectiles. Capsaicin pepper rounds, for example, may require being within 20–30 meters (m) of a predator, and rubber bullets have limited accuracy at 60–100 m. Many predators are likely to develop a conditioned aversion to the person or vehicle applying the conditioning stimuli, rather than generalizing to an area or behavior. Furthermore, the duration of these methods' effectiveness is likely to be limited to less than 1 month for black bears (Beckmann et al. 2004).

Because a high degree of vigilance is necessary to effectively repel predators from a site, a radio warning system (i.e., remote alarm) for nuisance bears has been developed in Yosemite National Park; when a bear is detected at a campground, an automated system warns park rangers. The system has quadrupled the sightings of problem bears in campgrounds, and reduced the number of bear visits per night by one-third (Breck et al. 2005).

Conditioned taste aversion (CTA) is a powerful training technique that was initially heralded as a broadly applicable solution to the problem of animal damage, but was then mired in controversy and equivocal results and is now not used even where it is legal (Conover and Kessler 1994). CTA may, however, be useful in many situations and should continue to be examined, especially for limiting consumptive behaviors (e.g., bear damage to apiaries or crops), if not predation behaviors (i.e., hunting and killing) (Ternent and Garshelis 1999).

The use of contraception for predation management has recently been investigated, because predators that need to feed their offspring require more food than those that do not have young, and thus predators that have been sterilized are not as likely to damage livestock as are reproductive predators (Till and Knowlton 1983). Bromley and Gese (2001) showed that sheep predation was reduced and predator territories were maintained when coyotes were sterilized. The technique may be counterproductive as a conservation tool if reproductive output is essential, but there is room for more investigation, because sterilization may help to stabilize localized populations of predators and have longer-lasting effectiveness than lethal methods, at least for territorial predators. Appropriate chemical contraceptives and delivery systems have not yet been developed, however, and additional research is required.

Evaluating effectiveness and choosing a tool. There are three primary means to gauge the effectiveness and use of management tools: biological efficiency, economic efficiency, and psychological assuagement. Table 1 provides an overview of the biological and economical efficiency of various methods. Relative to conservation goals, identifying the most useful management technique is a process of optimizing the degree of intensive management relative to the biological importance of individual predators in the population (Shivik 2004). Economically, the effectiveness of a tool tends to be directly related to its cost and complexity; therefore, choosing a tool to use is also an optimization process, balancing cost and complexity against maximum sustainable effectiveness. Furthermore, because each method works for only a limited time, each method should be used only during the period of greatest potential for predator–human conflict. A RAG box, for instance, should be used only during the few months when calves are smallest and most vulnerable; the box should otherwise be removed from the field. It will lose all effectiveness if deployed throughout the year. Lastly, no one device is sufficient: Long-term conflicts will best be managed with a variety of tools.

In general, nonlethal methods are usually considered expensive (e.g., a RAG may cost \$2000–\$3000, in contrast with the < \$1 price of a bullet), but ancillary costs, longevity of effectiveness, and goals of conservation using each method should also be considered. Enjoying the coexistence of predators and livestock is a luxury that may be unaffordable in some countries (Fritts et al. 2003), but the usefulness of newly developed techniques may not be most appropriately evaluated by their ratio of cost to damage prevented; the expense is subsumed within the incalculable cost of the social decision to support predator populations.

It is important to note that the success of a livestock protection strategy is not wholly dependent on its biological or economic efficiency. From a biological perspective, the solution is simple: If humans prefer one species over another, they could choose to manage wholly for the preferred species

Table 1. Comparison of tools for managing human–carnivore conflicts.

Tool	Cost estimate (US dollars)	Duration of effectiveness (species deterred)	References
Electronic Guard	Not commercially available	40–50 days (coyote)	Linhart et al. 1992
Fertility control	600 per animal	2–3 years (coyote)	Bromley and Gese 2001
Fladry	781 per km fladry, 1328 per km turbo fladry	60 days (wolf), > 2 days (coyote), ineffective (black bear)	Musiani and Visalberghi 2001, Musiani et al. 2003, Shivik et al. 2003a, Mettler 2005
Guard dog	200–450 initial cost, 250 per year	Life of guard animal; typically years (nearly all predatory species worldwide)	Rigg 2001, Andelt 2004
Hazing/translocation	> 400 per bear	40 days (black bear)	Beckmann et al. 2004
Lights, noise, simple stimuli	50–200	Several days (wolf, coyote)	Koehler et al. 1990
Radio- or movement-activated guard	3000	3 months (wolf), weeks (black bear, bald eagle, turkey vulture)	Breck et al. 2003, Shivik et al. 2003a
Training collar	200–300	1–9 months (coyote), ineffective (wolf)	Linhart et al. 1976, Andelt et al. 1999, Shivik et al 2003a, 2003b

km, kilometer.

(e.g., livestock) and continue campaigns to remove all wolves (Coleman 2004). The human–carnivore relationship is a complex one, however (Kruuk 2002), with a variety of values and perspectives impinging. Therefore, when evaluating new devices and methods, the socioeconomic milieu of predator management should also be considered. That is, the success of a management technique often needs to be measured by the tolerance of humans for a predator, which is a social and psychological construct—not a predator ecology issue—that is directly related to the ultimate conservation of a species. For example, using $1 million per year (Ed Bangs, US Fish and Wildlife Service, Helena, Montana, personal communication, 13 April 2005) to protect domestic livestock from wolves in the Rocky Mountain West appears extreme given the low level of actual damage, an estimated loss of 128 cows in 2004 (Boyd 2005). However, if herculean efforts to protect livestock were not made, local social carrying capacity could be lower, and wolf recovery in the lower 48 United States could be jeopardized.

The subject of lethal control is also interesting and important both biologically and psychologically. Lethal removal may be an important long-term practice for selecting against depredation behaviors in predator populations (Woodroffe and Frank 2005) and is ultimately useful for conserving predators. Relative to human attitudes and actions, in numerous conversations with wolf managers I have been told that an element required for successful reintroduction of wolves in the western United States is having the ability to "bring wolf populations into recovery by shooting them." In fact, one of the most important tools for ensuring the successful reintroduction of some predators may be the ability to lethally remove them; excessive concern for an individual predator or distaste for a particular management technique could be indulged at the cost of a species. In terms of conservation in areas where predators and people interact, the required goal is not to convince the antipathetic to like carnivores, but to protect and assuage people enough that they trust biologists and managers and refrain from killing the predators themselves.

It is important for biologists to build a trusting relationship with local human populations in order to manage carnivores and conflicts effectively. For example, the persecution of carnivores depends more on the traditional view of a species than on the actual damage the species causes (Frank and Woodroffe 2001), and for a management program to be successful (both for humans and for wildlife), it will need to operate accordingly. The methods described in this article can provide both biological and psychological benefit.

Future needs

Many of the techniques and concepts described in this article have been subjected to minimal testing, and much more applied research is required. Of greater concern is the potential for methods to be misapplied and the resulting failures generalized, with subsequent loss of useful methods due to misunderstanding rather than reliable knowledge. Therefore, new tools should be applied in an adaptive management system during the limited periods of use indicated (table 1), and with a focus on understanding why they worked or failed to be effective.

Clever application of biological theory in concert with innovative, inexpensive technology could go a long way toward promoting human–carnivore coexistence. It is true that high-tech approaches such as some of those described in this article may be affordable only to affluent stakeholders, at least until more ingenious and inexpensive designs are invented (Sillero-Zubiri et al. 2004), but human coexistence with predators may be a luxury worth the effort.

Future solutions need to emerge from a mix of biology, sociology, and technology. Attracting students from fields outside the biological sciences, such as sociology and engineering, may be a useful approach. The study of human dimensions of wildlife management also appears to be growing in strength, and carnivore biologists should add understanding of human–ecosystem relationships to their arsenal of tools. While technological advances may well lead to further improvement in predator management, ultimately some of the tools that are most desperately needed are social ones.

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