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Non-lethal techniques for reducing depredation

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INTRODUCTION

Ever since humans domesticated the first animals several thousand years ago, there have been conflicts with large carnivores attacking livestock (Kruuk 2002). Every year, thousands of cattle, sheep, goats, poultry or farmed fish are killed by wild carnivores worldwide (Thirgood *et al.*, Chapter 2) (Table 4.1). The farmers, in turn, kill the predators. Lethal control of stock-raiders is common in all cultures and has a devastating impact on many populations of large carnivores (Woodroffe *et al.*, Chapter 1). Retaliatory killing was the most important reason for the historic eradication of large carnivores in large areas (Breitenmoser 1998). In addition to killing the predators, herdsmen have tried to protect their livestock, mainly because lethal control alone rarely reduced depredation to an acceptable level. For a traditional society, the investment in terms of labour and resources for the protection of livestock was high (Kruuk 2002). Rural cultures have consequently adopted a combination of non-lethal measures, lethal control and – strongly varying between cultures – an acceptance of losses. The application of non-lethal techniques was mainly a matter of technology and of cost–benefit considerations. From the perspective of modern society, there are two more reasons to propagate preventive measures conservation (lethal control threatens many carnivore populations), and ethical arguments (moral reservation against the killing of predators and against livestock being exposed to pain and suffering). In this chapter, we review both traditional and modern methods that have been applied to prevent depredation on livestock, and focus less on the welfare of individuals than on the conservation of populations. To make a difference at the population level, non-lethal techniques must be not only effective, but also applicable and acceptable and cost-effective for herdsmen on a large scale.

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Table 4.1. *Main diet and conservation status of mammalian carnivore species preying occasionally or regularly upon livestock*

Family, species and common name	Region	Status[a]	Wild prey (WP) and livestock (L)	Significance of livestock[b]	References
Canidae					
Canis aureus Golden jackal	Asia, Europe	Not listed	WP: rodents, lagomorphs, carrion; L: cattle (calves), small stock	Low	Yom-Tov *et al.* 1995
C. latrans Coyote	N.America	Not listed	WP: lagomorphs, rodents; L: small stock, cattle	Low	Sacks and Neale 2002 Windberg *et al.* 1997
C. lupus Grey wolf	Asia, Europe, N.America	Lower risk–vulnerable	WP: ungulates; L: small stock, cattle,	Low–high	Boitani 2000
C. l. dingo Dingo	Australasia	Not listed	WP: wallabies, rabbits; L: small stock, cattle	Low–medium	Corbett 1995
C. mesomelas Black-backed jackal	Africa	Not listed	WP: rodents, carrion; L: small stock	Low	Bothma 1971
C. rufus Red wolf	N.America	Critically endangered	WP: deer, rodents, lagomorphs; L: small stock, cattle	Low	Macdonald and Sillero–Zubiri 2004
Lycaon pictus African wild dog	Africa	Endangered	WP: ungulates; L: cattle, small stock	Low	Woodroffe *et al.* 1997

Ursidae					
Tremarctos ornatus Spectacled bear	S.America	Vulnerable	WP: fruits; L: cattle (calves)	Low	Goldstein 1992
Ursus americanus American black bear	N.America	Not listed	WP: fruits, berries; L: livestock, honey	Low	Jonker *et al.* 1998
U. arctos Brown bear	Asia, Europe, N.America	Not listed	WP: berries, fish, rodents; L: livestock, honey	Low–medium	Swenson *et al.* 2000
U. thibetanus Asiatic black bear	Asia	Vulnerable–critically endangered	WP: fruits, berries; L: small stock, cattle	Low	Servheen *et al.* 1999
Mustelidae					
Gulo gulo Wolverine	Asia, Europe, N.America	Vulnerable	WP: lagomorphs, rodents, carrion; L: sheep, reindeer	Low–medium	Landa *et al.* 2000c
Lutra lutra European otter	Europe	Vulnerable	WP: fish; L: fish (fish farms)	Low	Bodner 1998
Mellivora capensis Honey badger	Africa	Not listed	WP: small vertebrates, honey; L: honey	Low	Mills and Hes 1997
Hyaenidae					
Crocuta crocuta Spotted hyaena	Africa	Lower risk	WP: ungulates, carrion; L: small stock, cattle	Low	Kruuk 1972, Mills 1990

Table 4.1. (*cont.*)

Family, species and common name	Region	Status[a]	Wild prey (WP) and livestock (L)	Significance of livestock[b]	References
Hyaena brunnea Brown hyaena	Africa	Lower risk	WP: carrion, insects; L: small stock, cattle (calves)	Low	Mills 1990
H. hyaena Striped hyaena	Africa, Asia	Lower risk	WP: carrion; L: small stock	Low	Kruuk 1980
Felidae					
Acinonyx jubatus Cheetah	Africa, Asia	Africa: vulnerable–endangered; Asia: critically endangered	WP: ungulates; L: small stock, cattle (calves)	Low–high	Nowell and Jackson 1996, Marker 2000a
Caracal caracal Caracal	Africa, Asia	Not listed	WP: rodents, ungulates, lagomorphs; L: small stock	Low	Nowell and Jackson 1996
Puma concolor Puma	N. and S. America	Near threatened–critically endangered	WP: ungulates; L: cattle (calves), small stock	Low	Hansen 1992, Nowell and Jackson 1996
F. temmincki Asiatic golden cat	Asia	Vulnerable	WP: rodents, ungulates; L: small stock	Low	Nowell and Jackson 1996
Lynx lynx Eurasian lynx	Europe	Near threatened	WP: ungulates; L: small stock	Low	Breitenmoser *et al.* 2000

L. rufus Bobcat	N.America	Not listed	WP: lagomorphs; L: small stock	Low	Nowell and Jackson 1996
Panthera leo African/ Asiatic lion	Africa, Asia	Africa: vulnerable; Asia: critically endangered	WP: ungulates; L: cattle	Low–medium	Kruuk 1980, Saberwal *et al.* 1994
P. onca Jaguar	S. America	Near threatened	WP: ungulates; L: cattle	Low	Nowell and Jackson 1996
P. pardus Leopard	Africa, Asia	Africa: not listed–critically endangered; Asia: endangered–critically endangered	WP: ungulates; L: small stock	Low	Nowell and Jackson 1996
P. tigris Tiger	Asia	Endangered–critically endangered	WP: ungulates; L: cattle	Low–medium	Miquelle *et al.* 1999b
Uncia uncia Snow leopard	Asia	Endangered	WP: ungulates; L: small stock	Low–high	Oli 1991

[a] Conservation assessment according to the IUCN Red List 2002 (Red List: Table 4.3).
[b] Importance of domestic prey for the survival of the predator.

This may not be the same for all regions, as it depends on the technical and economic standard of a country, along with topographical and habitat factors and on the relative importance of carnivore conservation to the local society. We must consider such socio-cultural and economic differences when assessing the usefulness of individual techniques. Finally, we will discuss the implementation of non-lethal techniques in the wider context of carnivore conservation.

REVIEW AND ASSESSMENT OF PREVENTIVE MEASURES

The number of traditional and modern non-lethal techniques to reduce depredation is almost immeasurable. Variations on a common theme (shepherds, dogs and fences) have evolved into locally adapted solutions. Ideas based on new technology and biological understanding have been proposed and tested over and over again. Most of the experience has never been published in readily available journals. Table 4.2 summarises the non-lethal techniques and the technical and descriptive literature, and Table 4.3 lists relevant URLs.

Zootechnical methods and livestock husbandry

Guarding livestock has been the natural response to depredation losses since the beginning of domestication. Where shepherds are present, losses are generally lower than in free-ranging herds (Kaczensky 1996; Linnell *et al.* 1996). Guided grazing allows the avoidance of depredation hospots, penning stock at night, and quick and flexible responses to predator attacks. Shepherds are most effective in concert with herding and guarding dogs (Rigg 2001). In addition, this method allows the rapid detection of sickness and the disposal of carcasses that might attract scavengers. In developed countries, where large carnivores have been eradicated, farmers have developed husbandry systems where livestock range freely on mountain pastures and in forests, which expose the livestock to very high rates of depredation when the predators return (Linnell *et al.*, 1996; Breitenmoser 1998). Zootechnical options in a free-grazing system are limited. In regions with seasonal transhumance (seasonal movement of livestock between different regions), controlled reproduction is essential, so that no calving and lambing occurs on the exposed summer pastures, or during movement. Nevertheless, wherever large carnivores recover, shepherding must be reestablished. This is, however, often limited in practice through high labour costs and lack of experienced shepherds. Consequently, the solution to depredation is sought in new techniques (Table 4.2). In the USA, 39% of the cattle, 88% of the sheep and 63% of the goat operations applied

Table 4.2. *References to non-lethal techniques used for carnivore damage prevention*

Method	References	Remarks on efficiency (E), manpower requirement (M) and cost
Technical measures		
Fences		
Natural fences	Charudutt 1997; Fitzwater 1972; Jhala 2000; Kruuk 1980[a]; Mizutani 1993	[a]2–10% losses due to depredation, of which only 10% in bomas.
Electric fences	Andelt 1996; Angst *et al.* 2002[a]; Bangs and Shivik 2001[b]; Bourne 2002; Dorrance and Bourne 1980[c]; Fitzwater 1972; Gates *et al.* 1978[c]; Gutleb 2001[d]; Huygens and Hayashi 1999[d]; Knowlton *et al.* 1999[e]; LeFranc 1987; Levin 2002[f]; Linhart *et al.* 1982[g]; Linnell *et al.* 1996[f, h]; Mertens *et al.* 2002[c]; Nass and Theade 1988; Thompson 1979; Timm and Connolly 2001	[a]E high for game in enclosures. [b]Electric fences economic for night corrals. [c]Costs $713–1125/km. [d]E high against bears at beehives. [e]Coyotes dig under fence; maintenance labour-intensive. [f]Cats difficult to exclude, good results with captive lynx. [g]E high against coyotes, costs $0.7–2.8/m. [h]High costs for construction and maintenance (keep vegetation low), obstruction of wildlife.
Conventional netting fences	DeCalesta and Cropsey 1978[a,b]; Linnell *et al.* 1996[c]; Thompson 1978[b], 1979[b], 1984[d]	[a]Cost $1543/km. [b]Properly built and maintained netwire fences E high against coyotes. [c]Inefficient for bears, cats difficult to exclude. [d]Dingoes significantly excluded from main sheep area.
Fladry	Maughan (Table 4.3)[a]; Musiani and Visalbergh 2001[b]; Okarma and Jedrzejewski 1997[c]; Rilling *et al.* 2002[d] Volpi *et al.* 2002[b]; WGF report (Table 4.3)[e]	[a]M: four persons mount 4 miles in 4 days. Fladry is short-term deterrent, but not permanent solution. [b]Wolves excluded from food source in captivity. [c]Wild wolves captured with fladries and nets. [d]Only short time effect on captive wolves. They crossed the fladries after a few hours. [e]Jureano Mts wolf pack crossed fladry after several months and killed a calf.

Table 4.2. (*cont.*)

Method	References	Remarks on efficiency (E), manpower requirement (M) and cost
Repellents		
Visual repellents	Boggess *et al.* 1980[a]; Bomford and O'Brien 1990; Green 1994 *et al.* 1994; Koehler *et al.* 1990; Linhart *et al.* 1984[b]; Robel *et al.* 1981[c]	[a]Placing lights over corrals. [b]Strobe lights with sirens prevented depredation for 53–91 nights. [c]Electronic guard frightening device ($250): NWRC, Table 4.3). Lights over corrals reduced depredation.
Acoustic repellents	Andelt 1996[a]; Bomford and O'Brien 1990; Koehler *et al.* 1990; LeFranc *et al.* 1987; Linhart *et al.* 1992[a] and Pfeifer and Goos 1982[b]; Robel *et al.* 1981[c]; Shivik and Martin 2001[d]	[a]Electronic frightening device (strobe light and siren) reduced sheep losses on high summer range by 60%. [b]Propane gas exploders easy to use and cheap; reduced coyote depredation for 1 to 180 days. [c]Bells over night corrals reduced depredation. [4]Radio-activated guard prolongs time-span for habituation.
Projectiles	Linnell *et al.* 1996; Smith *et al.* 2000b[a]	[a]Rubber bullet shotguns and 12-gauge plastic slugs immediate positive results with bears. Use only by trained persons on short distance; risk to injure or kill the predator.
Electric collar	Andelt *et al.* 1999b; Asher *et al.* 2001; Linhart *et al.* 1976[a]; Shivik and Martin 2001[b]; Shivik *et al.* 2002[b]	[a]Successfully tested in captive coyotes attacking sheep. [b]High costs; not tested under field conditions.
Conditioned taste aversion (CTA)	Burns 1980[a], 1983[a]; Connolly 1995[b]; Conover and Kessler 1994[a,c]; Conover *et al.* 1979[a]; Dorrance and Roy 1978[a]; Ellins and Catalano 1980[d]; Ellins *et al.* 1977[d]; Forthman 2000[d]; Gustavson *et al.* 1974; 1982[d]; Linnell 2000[a,e]; Linnell *et al.* 1996[f]	[a]No positive effect under field conditions. [b]Denver Wildlife Research Center stopped CTA tests with LiCl because no reduction of depredation. [c]After 10 years testing CTA (54% of farmers considered it successful), only one used CTA. [d]Positive results. [e]Logistic problems in application. CTA prevents consumption, but not attacking or killing. [f]Ambiguous results regarding E.

Chemical repellents	Burns *et al.* 1984[a]; Hatfield and Walker 1994[a]; Landa and Tømmerås 1996; 1997[b]; Landa *et al.* 1998b[b]; Lehner 1987[a]; Linnell *et al.* 1996[c]	[a]Chemical repellents appear to be ineffective against coyotes but effective to some extent against [b]wolverine and [3]bears. [b]Certain E on wolverine and bears. [c]Capasaicin (bearspray) showed best results with bears.
Protection collars with non-toxic repellents	Burns *et al.* 1984[a]; Burns 1996[b]	[a]No significant effect with different chemicals in sheep neck collars. [b]Vichos collars did not deter coyotes.
Protection collars	Angst *et al.* 2002[a]; Hill and Simper 2002[b]; Linnell *et al.* 1996[a]; Steinset *et al.* 1996 [a]; King Collar (Table 4.3)[c]	[a]No significant effect against lynx and wolverine. Costs €20–30 per collar. [b]Studies with King Collars against coyotes in the USA. [c]Efficient against jackal, but not against caracals. 170 000 King Collars (polyethylene collar) in use against jackals in South Africa. Costs $1 per collar.
Zootechnical measures		
Flock/herd management		
Shepherding	Andelt 1996[a]; Angst *et al.* 2002[a]; Coppinger and Schneider 1995[b]; Jackson *et al.* 1994[a]; Jorgensen 1979[a]; Kaczensky 1996[a]; Kruuk 1980[a]; Landry 1998[a,b]; Linnell *et al.* 1996[a,b]; Nass *et al.* 1984[a]; Odden *et al.* 2002; Poulle *et al.* 2000; Tigner and Larson 1977[a]; Wick 1995[a]	[1]Fewer losses with shepherds present. [b]Combination with LGD and night-time corrals recommended.
Hotspots avoidance	Angst *et al.* 2000; 2002[a]; Ciucci and Boitani 1998[a]; Fritts 1982[a]; Jackson *et al.* 1994[a]; Kaczensky 1996[a]; Muzitani 1993; Pearson and Caroline 1981; Rabinowitz 1986[a]; Robel *et al.* 1981[a]; Stahl *et al.* 2002[a]	[a]Carnivores kill livestock mostly in specific areas (steep, rocky areas, forest land, areas with tall grass and shrubs). Avoiding such areas reduced depredation.
Control of calving and lambing	Angst *et al.* 2002[a]; Dorrance 1982[a]; Stahl *et al.* 2001a[a]; Robel *et al.* 1981[a]	[a]Newborn livestock is highly vulnerable to most medium-size and large carnivores.

Table 4.2. (*cont.*)

Method	References	Remarks on efficiency (E), manpower requirement (M) and cost
Confining livestock at night (night pens)	Andelt 1996[a]; Angst *et al.* 2002; Dorrance and Roy 1976; Jackson *et al.* 1994[b]; Knowlton *et al.* 1999[a]; Kruuk 1980; Linnell *et al.* 1996[b]; Nass *et al.* 1984; Robel *et al.* 1981	[a]Crowding at night requires enhanced health care.[b]Night pens must be predator-proof, otherwise risk of excessive killing.
Disposal of livestock carcasses	Andelt 1996[a]; Fritts 1982; Jones and Woolf 1983[a]; Linnell *et al.* 1996[a,b]; Robel *et al.* 1981[a]; Todd and Keith 1976	[a]Disposing of carcasses (disease) reduced losses to predators.[b]Removing kills (predation) provokes additional kills.
Guarding animals		
Livestock guarding dogs (LGDs)	Andelt 1999a, b[a]; Andelt and Hopper 2000[a]; Bergman *et al.* 1998; Black and Green 1985; Clemence 1992; R. Coppinger, 1992; Coppinger and Coppinger 1982, 1994, 1995, 1998, 2001; Coppinger *et al.* 1983[c,f], 1985, 1987, 1988[a], Coppinger and Schneider 1995; Green and Woodruff 1988, 1990[b]; Hansen and Bakken 1999; Hansen and Smith 2001; Landry 1998[b]; 2001[e]; Lorenz 1985[b]; Lorenz and Coppinger 1986[b]; Lorenz *et al.* 1986[g]; Olsen 1985; Pitt 1988[f]; Rigg 2001; Rousselot and Pitt 1999[c]; Scott and Fuller 1965[c]; Serpell and Jagoe 1995; Vandel *et al.* 2001; Warbington 2000; [d]Wick 1998	[a]Efficient against all predators, work best in combination with shepherds. [b]Training (socialization) and taking care of the pups very time-consuming. [c]Socialization not easy; many LGDs do not correctly bond to flock. Best E in age of 2–3 years. [d]LGDs often disturb (play) flock when young; may even injure or kill lambs. [e]LGDs may frighten hikers. [f]LGDs may roam and hunt wildlife. [g]Premature death of LGDs.
Donkey	Andelt 1995[a]; Braithwait 1996[b]; Bourne 1994[c]; Landry 2000[d]; Linnell *et al.* 1996; Marker 2000a[g]; Tapscot 1997[h]; Donkey (Table 4.3)	[a]Good E against small predators, but not against packs or large carnivores. [b]Unneutered jacks can be aggressive towards sheep. [c]May disturb ewes when lambing or trample lambs. [d]Not all individuals are protective; test

		donkey with a dog before use. [g]Using donkeys younger than 1 year is not recommended. [h]Some plants are toxic for donkeys.
Llama	Andelt 1995; Angst *et al.* 2002; Bangs and Shivik 2001[b]; Braithwait 1996[a]; Franklin and Powell 1993[c] Markham 1995; Meadows and Knowlton 2000; Warbington 2000	[a]Some E against small and medium predators, [b]but not against packs or large carnivores. [c]Using llamas younger than 1 year is not recommended.
Other species	Braithwait 1996; Marker-Kraus *et al.* 1996[a]; Pitt 1988	[a]Some anecdotal trials with zebras, cattle, baboons, stallions, horned oxen, mules, cows with calves and multi-species grazing.
Physiological measures and translocation		
Sterilization	Bromley and Gese 2001a, b; Conner 1995; Knowlton *et al.* 1999; Sacks 1996; Saunders *et al.* 2002[a]; Till and Knowlton 1983[b]	[a]Sterilization feasible with red fox.[b]Removing pups reduced coyote depredation.
Immuno-contraception	Balser 1964[1]; DeLiberto *et al.* 1998[b]	[a]Reproduction inhibited with diethylstilbesterol. [b]Immunocontraception using porcine zona pellucida (PZP) promising method to control coyote fertility.
Translocation	Funston 2001[a]; Linnell *et al.* 1997[a,b]	[a]Low to no effect. [b]Homing behaviour; most individuals continued depredation; reduced survival or reproduction after translocation; expensive.

Table 4.3. *Uniform resource locators (URL) to websites with additional information on non-lethal techniques*

Keyword	URL
Donkey	http://www.gov.on.ca/OMAFRA/english/livestock/sheep/facts/donkey2.htm
	http://www.agr.state.tx.us/pesticide/brochures/pes_donkeys.htm
Fladry	http://www.defenders.org/wildlife/wolf/idaho/fieldreports/idahoreports.html
Honey badger	http://www.badgers.org.uk/badgerpages/honey-badger-11.html
King Collar	http://brigham.sphosting.com/kingcollar/index.htm
LGD	http://www.awionline.org/farm/alt-farming2.html
Maughan	http://www.forwolves.org/ralph/fladry-jureano2.htm
NWRC (National Wildlife Research Centre)	http://www.aphis.usda.gov/ws/nwrc/index.html
Red List	http://www.redlist.org
Red wolf	http://www.epa.gov/docs/fedrgstr/EPA-SPECIES/1995/April/Day-13/pr-220.html
	http://southeast.fws.gov/pubs/alwolf.pdf
WGF report	www.defenders.org/wildlife/wolf/wolfupdate/fieldreports/fieldreport11.html

non-lethal prevention methods in 1999, summing up to almost $8 million in investment by the livestock owners. The National Wildlife Research Centre spent an additional $7.5 million on non-lethal management techniques (Shivik 2001).

Fencing

An anti-predator fence must keep out animals that not only can jump but also climb or dig. Different forms of protective fences have been developed worldwide, using natural materials or artefacts as thorn bushes, logs, bricks, wire and synthetics. Depending on the situation fencing can be used to (1) protect livestock in small night-time pens, (2) provide predator-proof grazing areas, or (3) exclude carnivores from entire regions. The type of fence varies according to the goals and materials available.

Fences made of natural material (wood, thornbush, earth, rocks, ditches filled with water) are mainly used for night-time pens (Linnell *et al.* 1996; Charudutt 1997). A famous example is the African boma (thornbush corral: Kruuk 1980; Ogada *et al.*, in press). Conventional wire-netting fences are used worldwide in different forms, depending on the terrain and the target predator (Linnell *et al.* 1996). Tests in Canada and the USA have tried to exclude dogs, coyotes (*Canis latrans*), black bears (*Ursus americanus*), grizzly bears (*U. arctos*) and polar bears (*U. maritimus*), but conclusive assessments have been limited (Linnell *et al.* 1996). Properly built and maintained net-wire fences were effective in tests with captive coyotes (Thompson 1979). DeCalesta and Cropsey (1978) successfully implemented Thompson's (1979) recommendations in the field. Grizzly bears and black bears made holes in chainlink or woven fences, dug underneath, or climbed over (Clarkson and Marley 1995). The world's longest wire-netting fence is in Australia, a 5300-km fence meant to exclude dingoes (*Canis lupus dingo*) from the main sheep areas of southeastern Australia. The fence is not completely dingo-proof, but limits immigration and hence assists lethal control (Thompson 1984, 1986). Considering the jumping and climbing ability of felids, netting fences without additional impediments have limited effect against them. Experiences from the Lakipia case study have shown that wire fences are less effective than brush fences at excluding lions and hyenas (Ogada *et al.* 2003; Frank *et al.*, Chapter 18).

Electric fences, causing a shock of several thousand volts, can improve existing wire-netting fences. One to three electric wires are added above or outside the fence. Such constructions prevented coyotes from entering pastures (Andelt 1996), and Eurasian lynx (*Lynx lynx*) from climbing into game farms (Angst *et al.* 2002). Plain electric wire fences with alternating live and earth wires must be adjusted in height, the number of and spacing between wires and voltage according to the carnivore that is to be excluded (details in Linnell *et al.* 1996). Multi-strand electric fences provide a cost-effective method for preventing coyote depredation (DeCalesta and Cropsey 1978; Dorrance and Bourne 1980; Linhart *et al.* 1982; Nass and Theade 1988). Electric fences are being widely and successfully used to protect beehives, livestock, garbage dumps and campsites from bears (Wade 1982; LeFranc *et al.* 1987; Clarkson and Marley 1995; Kaczensky 1996; Huygens and Hayashi 1999; Gutleb 2001; Levin 2002). Few studies address the efficiency of electric fences against felids, which seem to be difficult to exclude (Linnell *et al.* 1996). In South Africa, additional strands of electric wire atop jackal (*Canis mesomelas*) fences worked against caracals (*Caracal caracal*), and even leopards (*Panthera pardus*) (Bowland *et al.* 1993). Levin (2002) excluded Eurasian lynx in captivity from food resources using multi-strand wire fences. Solar-powered electric-fences are advantageous for remote areas, but like all electric fence systems, they need regular maintenance, which sometimes is a considerable problem limiting their efficacy especially if large ungulates like moose (*Alces alces*) or elephants (*Loxodonta africana*) occasionally destroy them (Knickerbocker and Waithaka, Chapter 14).

Fladries, brightly coloured flags sewn on ropes (Fladry: Table 4.3), have been used for hunting wolves (*Canis lupus*) in Europe for centuries. Most wolves fear fladries and rarely cross such barriers. Okarma and Jedrzejewski (1997) captured wild wolves, and Musiani and Visalberghi (2001) kept captive wolves away from food resource by means of fladries, although captive wolves crossed the fladries after a short time (Rilling *et al.* 2002). The practical value of this technique in preventing attacks is not yet known, but a fladry is cheap, highly mobile, and easy to use even in difficult terrain (Musiani *et al.* 2003).

In summary, fences can successfully protect livestock. They are most useful and cost-effective on small pastures and as night-time corrals. Fencing off larger areas is not only less efficient and more expensive, but also problematic, as long fences fragment the habitat, and wire-nettings sometimes become deadly traps for terrestrial wildlife.

Livestock-guarding animals

Livestock-guarding animals (LGAs) are able to detect an approaching predator and to interrupt the attack sequence (Smith *et al.* 2000a) (see also LGA: Table 4.3). LGAs live constantly within the flocks (Coppinger *et al.* 1983). They are either potential prey (herbivores) acting in self-defence or potential competitors (carnivores) to the attacking predators. The attention given to the herd is the key to the success of all LGAs (Coppinger and Coppinger 1998).

Livestock-guarding dog breeds (LGDs) appeared 5000 years ago in Asia (Olsen 1985). Transhumance and human migration have led to some 50 breeds across the Palaearctic (overview in Landry 1998). LGDs can protect any domestic species (R. Coppinger 1992), also in combination with other preventive systems in different habitats (Landry 2001). Their weight averages 35–65 kg (Landry 1998). Smaller dogs are sometimes used (e.g. in Navajo country: Black and Green, 1985; or in Africa: Coppinger and Coppinger 1998) but they might not be able to fight off a large predator and they act more as an alarm dog. In Africa (e.g. Kenya: Ogada *et al.* 2003), some dogs do not really defend the herd, but they bark at approaching predators and alarm the herders.

Juvenile LGDs must be socialized with the domestic species they will protect during a limited time-window of their development (Scott and Fuller 1965). The methodology of socialization was described by Lorenz (1985), Lorenz and Coppinger (1986) and Green and Woodruff (1990). Play behaviour – often simulating stalking and attack – occurs from 3 to 14 months and occasionally later (Landry 2001), but it should disappear from the adult dogs' behavioural repertoire (Coppinger and Schneider 1995) if a dog is properly trained to not disturb the flock. Subsequently, the LGD behaves as a member of the flock, in contrast to the herding dog, which shows a predatory behaviour towards livestock (Clemence 1992). LGDs chasing domestic or wild animals may be the result of bad selection or bad training and these individuals should be removed (Landry 2001).

LGDs are selected for their ability to respond (e.g. by barking) to any strange event and hence to disturb the predator. Although the dog may fight with predators such as wolves, it is not necessary to select it for aggressiveness (Black and Green 1985). LGDs are most effective in concert with shepherds. Several LGDs are essential against cooperatively hunting predators, such as wolves, and in rugged or wooded terrain (Landry 1998). Typically, three to seven dogs can protect a herd of 1000 head of livestock. LGDs should judge the severity of a situation and show an appropriate reaction, especially in areas where there are tourists and their pet dogs (Landry 2001). The correct use of LGDs may provide effective livestock protection, although never at 100% (review in Rigg 2001).

Dogs need special food, compared to the stock they protect. The advantage of other LGAs is that they are herbivores, live longer and usually do not frighten hikers (Andelt 1995; Landry 2000). Experiences with zebras (*Equus* sp.), horse stallions, horned oxen, mules, baboons (*Papio* sp.), cows with calves, and multi-species grazing (e.g. mixed sheep and cattle herds) remain anecdotal (Pitt 1988; Braithwait 1996; Marker *et al.* 1996), but donkeys and llamas (*Lama glama*) have certain significance as LGAs. Both are social animals and integrate best into a sheep herd when kept without conspecifics (Andelt 1995). Socialization is simple (Franklin and Powell 1993; Andelt 1995; Marker 2000a) and donkeys and llamas can be introduced into a herd at any age. They react to disturbance within the flock and chase away any intruder (Andelt 1995). Sheep tend to gather around their protector instead of fleeing (Andelt 1995; Landry 2000). Donkeys and llamas work best in small, penned herds where it is easy to maintain an overview (Bourne 1994; Andelt 1995). They have proved effective against small predators like red foxes (*Vulpes vulpes*) or coyotes (Franklin and Powell 1993; Raveneau and Daveze 1994; Andelt 1995). Donkeys worked against jackals, caracals, and cheetahs (*Acinonyx jubatus*) in Namibia (Marker 2000a). Donkeys and llamas are however potential prey of larger carnivores themselves. They feared pumas (*Puma concolor*: Andelt, 1995), and llamas were killed by wolves (Bangs and Shivik 2001). The llama's practical efficiency therefore remains controversial (Linnell *et al.* 1996; Meadows and Knowlton 2000).

Deterrents and repellents

Numerous deterrents and repellents have been tested against many different carnivores, but only a few have produced practical results (Table 4.2). We distinguish two conceptual groups (Smith *et al.* 2000b): frightening devices and aversive devices.

Frightening devices are those that immediately disrupt a predator's action, such as flashes, sirens, projectiles, explosives, and aggressive chemicals (Mason *et al.* 2001). It is difficult to assess their efficiency because of the general lack of experimental controls (Bomfort and O'Brien 1990), but they can be useful tools for a limited period in small areas (e.g. Angst *et al.* 2002). The effect can be strengthened through varying position, appearance, duration or frequency of the frightening stimuli, but they should be used in emergency situations only, to avoid habituation of the predator. The latest technology is a radio-activated guard (RAG), where the radio-tagged predator triggers the device on approach (Shivik and Martin 2001). Effectiveness of frightening devices probably depends on the availability of alternative prey. This must be considered, especially if the alternative is not game but the neighbours' sheep. Regardless of their actual effectiveness, initial results indicate that they are popular with livestock producers, and therefore may help reduce some of the social aspects of the carnivore–livestock conflicts (Bangs, in press).

The second group consists of aversive devices, that activate a learned negative association after a link between an unwanted behaviour (e.g. attacking sheep) and a negative stimulation, through repeated negative experience. Gustavson *et al.* (1974) suggested that conditioned taste aversion (CTA) might be an effective prevention tool, but many pen and field tests with chemicals (mostly LiCl) produced conflicting and inconclusive results (Burns 1983; Conover and Kessler 1994; Linnell 2000). Linhart *et al.* (1976) and Andelt *et al.* (1999) demonstrated that commercial dog-training collars worked for conditioning coyotes in captivity, and Shivik *et al.* (2002) expanded this concept to wild wolves. However, this technique still faces many practical problems regarding its application in the wild, and it is only applicable on an individual level.

Physiological measures and translocations

Anti-fertility agents have been proposed as a mean to limit coyote populations (Balser 1964) and to reduce livestock losses, because non-reproductive coyotes would kill fewer livestock. However, anti-fertility agents have failed to control reproduction of coyote (Balser 1964; Stellflug *et al.* 1984) or red fox (Allen 1982) in the field, mainly because of limited bait consumption. Recently, the interest in reproductive inhibition using immunocontraception has been revived (DeLiberto *et al.* 1998), mainly to control red foxes (Saunders *et al.* 2002). A similar concept is the sterilization of territorial, breeding coyotes in areas of chronic depredation. The principle is based on research by Till and Knowlton (1983) which indicated that depredations can be reduced by removing coyote pups, assuming (1) that breeders are the principal killers of livestock, and (2) that they will continue to maintain territories (and keep conspecifics away) while sterile (Zemlicka 1995; Sacks 1996). However, Scrivner *et al.* (1985), Conner (1995) and Sacks (1996) argued that the presence of lambs, rather than pups, determined coyote predation patterns. Even if the measures work, it is hard to see how they can be applied over large scales (practicality and economics), or for carnivore species of conservation concern. A sterilized individual is in effect dead from the point of view of population viability, and also occupies space that a reproductive individual could occupy. Translocation of individual carnivores has been a standard management tool for decades to mitigate depredation (and other conflicts with large carnivores) mostly in North America and southern Africa (Treves and Naughton-Treves, Chapter 6). This method suggests that only a few specialists are stock-raiders, and that these individuals, when displaced into areas with reduced conflict potential, will not return. The success rate of translocations is relatively low. The removed problem animals have often (1) showed homing behaviour, (2) reduced survival, or (3) resumed their conflict behaviour at the release site (review in Linnell *et al.* 1997). Moreover, the concept of specialists is controversial. Linnell *et al.* (1999) hypothesized that most large carnivores at least occasionally kill livestock. Stahl *et al.* (2001a) and Angst *et al.* (2002) found that in certain 'hotspots', any lynx would kill sheep, and that the removal of the problem animal did not resolve the problem.

Indirect measures

The application of non-lethal techniques alone will never solve the conflict between livestock breeders and carnivores. Indirect measures are intended (1) to increase wild prey availability, and (2) to mitigate the economic consequences of depredation through compensation. Both approaches must be combined with carnivore damage prevention into a holistic, integrated concept (see below).

APPLICATION OF NON-LETHAL TECHNIQUES

In Europe, most livestock problems are supposedly caused by wolves, Eurasian lynx, brown bears (*Ursus arctos*) and wolverines (*Gulo gulo*). For instance, approximately €2 million is paid annually for livestock losses to predators in Italy (Ciucci and Boitani, 2000). In Norway, lynx killed about 19 000 sheep between 1990 and 1995 (Breitenmoser *et al.* 2000) and wolves in the French Alps have been responsible for the death of about

8650 sheep (at ~€1.65 million compensation) since their return to France in 1992 (Poulle *et al.* 2000; Dahier 2000, 2002). Compensation programmes have been launched to cover predator damages in about half of the European countries (Boitani 2000; Breitenmoser *et al.* 2000; Landa *et al.* 2000c; Swenson *et al.* 2000; Swenson and Andrén, Chapter 20), but livestock protection remains a more effective solution to alleviate conflicts between predators and humans. Shepherding, guarding dogs and fencing have been constantly used in European countries where large predators have never disappeared. In areas where they were exterminated, the knowledge of these techniques has been lost, and, as a consequence, people need to (re)learn how to coexist with the large carnivores. Farmers are encouraged through financial incentives to implement traditional and new livestock protection techniques, for example in countries such as France or Switzerland (Poulle *et al.* 2000; Weber 2000). Even smaller carnivores that are potentially harmful to livestock, like red foxes (Hewson 1984) or river otters (*Lutra lutra*: Bodner 1998), may be deterred from killing sheep or farmed fish, respectively, by non-lethal techniques (pers. obs.; Bodner 1998). However, despite financial support as well as demonstrated effectiveness (review in Rigg 2001; Angst *et al.* 2002), implementation of non-lethal preventive measures is not always popular. In Norway and Sweden, livestock owners still prefer to control the numbers of wolverines through hunting them instead of herding sheep and semi-domestic reindeer (*Rangifer tarandus*) or translocating wolverines as is done in Finland (Landa *et al.* 2000c; Swenson and Andrén, Chapter 20).

Coyote depredation on livestock is an important economic problem for farmers in North America (Green *et al.*, 1984). Although depredation on sheep varies spatially and temporally, it is assumed that coyotes kill between 1% and 2.5% of adult sheep and between 4% and 9% of lambs in the Western USA (Andelt 1992). Whether reintroduced in the Rocky Mountains or recovering naturally in the Great Lakes region, wolves have also an impact on livestock production in the USA. In total, 148 cattle and 356 sheep were killed by wolves in the Rocky Mountains from 1987 to January 2001 (Bangs and Shivik 2001), and the injury or death of 377 domestic animals caused by wolves was documented in Wisconsin between 1976 and 2000 (Treves *et al.* 2002). A wide spectrum of non-lethal techniques has been developed throughout the continent to reduce coyote and wolf damage. Guarding dogs have generally been successful in protecting herds (Rigg 2001). Besides increasing efforts to relocate depredating wolves, more non-conventional prevention measures such as conditional taste aversion, shock collars, sterilization (only for coyotes: Bromley and Gese 2001a, b) or frightening devices are currently being tested. Preliminary results seem relatively encouraging (Bangs and Shivik 2001; Rigg 2001). In North America, bear depredation may be locally important, but the use of LGDs and/or electric fences to protect livestock, and on some occasions beehives, as well as displacement of cattle closer to human residences, were rated effective by most producers (Jonker *et al.* 1998; Andelt 1999a). In contrast, removal or harassment of nuisance bears and use of repellents such as human urine or kerosene did not solve the problems (Jonker *et al.* 1998). Guarding dogs also proved effective to protect cattle and sheep against puma (Andelt 1999a), a species known to take its toll of domestic animals locally (Nowell and Jackson 1996).

Large predators are problematic for livestock throughout Africa, not only along the border of protected areas (Nowell and Jackson 1996) but also well outside reserves (Marker 2000a). In the late 1970s, East African pastoral tribes lost between 2% and 10% of their livestock per year, mostly to lions (*Panthera leo*), spotted hyaenas (*Crocuta crocuta*) and black-backed jackals (Kruuk 1980, 2002). Cheetahs, wild dogs (*Lycaon pictus*) and striped hyaenas (*Hyaena hyaena*) were also involved to a lesser extent (Kruuk 1980). Livestock was herded in daytime and fenced in traditional enclosures (bomas) during the night. On open-range cattle farms in Namibia, leopards and cheetahs each killed annually an average of 320 cattle and 375 sheep between 1986 and 1991 (Nowell and Jackson 1996). However, the use of donkeys to protect livestock, especially calving herds, reduced losses considerably as long as guidelines for successful implementation were properly followed (Marker, 2000a). An LGD programme was also launched and it apparently has brought some promising results so far (Marker 2000b).

Livestock predation is also a serious issue in Asia. Acute depletion of wild prey in most of their range forces large predators to feed extensively on domestic animals, and indeed depredation on livestock caused by Asiatic lions, leopards, snow leopards (*Uncia uncia*) or tigers (*Panthera tigris*) has increased inexorably (Seidensticker *et al.* 1990; Miller and Jackson 1994; Saberwal *et al.* 1994; Miquelle *et al.* 1999b). In some areas, wolves are also highly dependent on domestic animals (Kumar 2001). To protect livestock, the pastoral communities usually use night-time vigils and guarding dogs, and build thorn corrals (Jhala 2000). The effectiveness of guarding dogs remains, however, a controversial question (Jhala 2000; Kumar 2001). In India, compensation for livestock losses is paid under specific conditions (Nowell and Jackson 1996). However, Oli (1991) considered that damage compensation has the best potential to reduce conflicts between local people and snow leopards.

INCORPORATION OF NON-LETHAL TECHNIQUES INTO A WIDER CONSERVATION CONCEPT

Non-lethal techniques to prevent livestock depredation are studied, propagated and eventually implemented worldwide today to promote carnivore conservation. This happens in Europe and the USA, where large carnivore populations are recovering as a consequence of protective laws, wild prey increase and a consolidation in agriculture, leaving more space for wild animals, and also in developing countries, where the growing human population and domestic stock increases the pressure on natural habitat and carnivore populations. Although the need for non-lethal techniques is obvious in both (and all intermediary) situations, the socio-cultural and economic conditions for their implementations differ considerably. What may be operational in one place may not work somewhere else. Here, we want to explore the integration of non-lethal techniques into a more general conservation concept.

The strongholds of many carnivore populations are protected areas, which may even act as a source for neighbouring areas. The surroundings are multiple-use landscapes where carnivores and wild prey coexist with humans and their livestock herds. Such landscapes are used for a variety of agricultural activities, hunting and recreation. These are the conflict areas where human-caused mortality of the predators is high. Nevertheless, the extended multiple-use landscape is important for the survival of the population, as few protected areas are large enough to host viable populations of large carnivore species (Woodroffe and Ginsberg 1998).

The abundance of a carnivore in the multiple-use landscape depends on: (1) the availability of wild prey, (2) the accessibility of livestock, which together define the ecological carrying capacity, and (3) the tolerance of humans towards the predator ('social carrying capacity'). Compared to the protected area as a reference, the carrying capacity regarding wild prey is lower in the multiple-use landscape, but the carrying capacity of wild and domestic prey combined – and hence the potential abundance of the predator – is higher, because livestock normally reaches very high densities compared to wildlife. The social carrying capacity however is limiting, as people usually do not tolerate predator densities as high, or higher, than those within the protected area.

If we want to adjust the use of non-lethal techniques to basic conservation goals, the crucial questions are: (1) how important is domestic prey, and (2) how significant is retaliatory killing for the survival of the carnivore population? We can imagine three different scenarios. First, in the case where availability of wild prey is high and livestock are rarely killed,

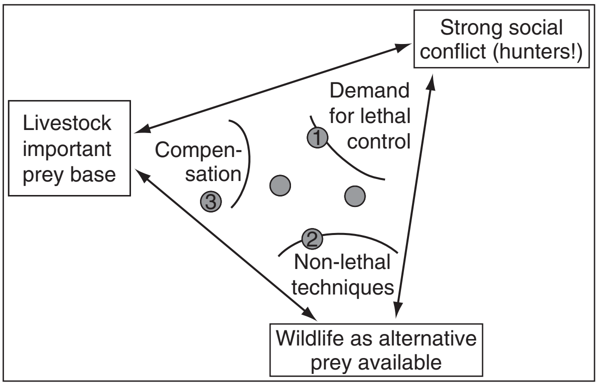

Figure 4.1. The 'depredation triangle' illustrates the cornerstones of the coexistence of large carnivores in a landscape used for livestock husbandry and other human activities such as hunting. The application of non-lethal techniques to prevent depredation will only be beneficial for the conservation of the population if wildlife as an alternative prey is available and if depredation is the main cause of the conflict. In practice, a balance between prevention, compensation and lethal control will be the likely solution for projects (grey dots). The numbers 1–3 refer to the approximate positions of the three examples given in the text.

depredation may not be frequent enough to encourage the habitual use of preventive measures (postition 1 in Fig. 4.1). This is, for instance, the situation in the Swiss Alps, where lynx occasionally kill free-ranging sheep, but mainly prey upon roe deer (*Capreolus capreolus*) and chamois (*Rupicapra rupicapra*) (Angst *et al.* 2000). Due to the rareness of these attacks and the fact that government compensates for losses, the incentive for sheep-breeders to apply preventive measures is weak. Habitual stock-raiders are shot, a measure more useful for managing the controversy than for substantially reducing depredation (Angst *et al.* 2002). But as most lynx prey entirely on wildlife, the occasional removal of problem animals does not harm the population.

Second, where wildlife and livestock are both readily available, but domestic stock is preferentially killed, the introduction of preventive measures, forcing the predator to switch to wild prey, would support the conservation of the carnivore population (position 2 in Fig. 4.1). An example is the return of the wolf into the Alps of France, Italy and Switzerland. Although wild ungulates are abundant, the wolves preferably kill the widespread, free-ranging sheep, which are an easy prey. The attacks on sheep herds provoked a major conflict and wolves were illegally killed. The implementation of preventive measures such as shepherds, LGDs, electric fences, etc. reduces the attacks considerably in the French Alps (Poulle *et al.* 2000), but does not hinder the further expansion of the wolf population, as an unexploited supply of wild prey is available.

Third, if wildlife is sparse and livestock readily available, predators inevitably prey on livestock. This was the case in parts of nineteenth-century Europe, when the wild ungulates had been almost eradicated, but the large carnivores still persisted (Breitenmoser 1998), and it seems today to be the situation for many carnivores, especially in northern Africa, the Middle East and Central Asia (see above), where wild prey have declined severely as a consequence of over-hunting, poaching and over-grazing by livestock (Karami 1992). It is also the case in northern Fennoscandia where semi-domestic reindeer are the only available ungulate prey for lynx and wolverine populations (Pedersen *et al.* 1999). The carnivore populations may suffer considerable losses from retaliatory killing, but the implementation of preventive measures would cut off the predators from their crucial food resource, still resulting in a decrease of the population. In such a situation, non-lethal techniques are not a real alternative to lethal control. The only solution would be to provide compensation that would motivate herdsmen to accept losses without retaliation, and to start a wild prey recovery programme where appropriate (position 3 in Fig. 4.1). In Turkmenistan's Kopetdag range, where a strong decrease of wild prey over the past 10 years has forced leopards to switch to domestic prey, the World Wide Fund for Nature (WWF) has established a compensation sheep herd, from which the local herdsmen can choose an equivalent in sheep for each cow, horse, sheep or goat lost to leopards (Lukarevsky 2002). The advantage of the compensation flock is not only that sheep remain a potential food resource for leopards, but also that the assessment procedure provides an additional monitoring of leopard presence.

In practice, compensation, non-lethal techniques and lethal control will not be exclusive alternatives, but rather concurrently applied management tools, and we must find the optimum balance for their application (Fig. 4.1), considering a wide scope of parameters defining the coexistence of predators and people (see also Treves and Naughton-Treves, Chapter 6). Depredation is often not the only cause of the human–carnivore conflict, and even successful implementation of prevention may not totally solve the conflict. In the example of the lynx in the Swiss Alps, attacks on sheep herds were prominently covered by the media (and hence taken seriously by the state authorities), but the conflict with hunters, who accused lynx of destroying local roe deer populations, was more threatening to the lynx population (Breitenmoser and Breitenmoser-Würsten 2001). Wherever we face a strong social conflict, the request for lethal control is strong (Fig. 4.1), and even the successful implementation of preventive measures may not result in a considerable decrease of illegal killing of predators. The combination of, and the balance between, non-lethal techniques (prevention), compensation of losses and lethal control must be adjusted according to an assessment of any given situation, considering not only depredation, but also wild prey availability and underlying socio-cultural conflicts.

CONCLUSIONS

Traditionally, herdsmen across the world have applied preventive measures because lethal control of the predators alone was not sufficient to limit the losses of livestock. Today, the (re-)introduction of old and new non-lethal techniques aims to mitigate the eternal conflict between predators and herders in order to minimize the killing of carnivores. The motivation is often, especially in Europe and North America, ethical scruples about killing animals. Sophisticated technical or physiological methods have been developed and tested, sometimes intended to change the individual predator's behaviour. Such techniques will have very limited significance for the conservation of threatened taxa or populations, especially in developing countries. In order to be conservation-effective, non-lethal methods must be acceptable (in accordance with local traditions) and applicable on a large scale (cheap and easy to use). Furthermore, the implementation and application of non-lethal techniques must be considered in the context of the conservation goals and all other management actions. Preventive measures may not always be the cheapest, and sometimes not even the most effective way of conserving a carnivore population. Non-lethal techniques, however, offer the opportunity to involve herders actively into carnivore management, and they can – in combination with other conservation measures such as compensation of losses and removal of habitual stock raiders – help to mitigate the conflict and hence to promote the coexistence of carnivores and people.

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