An evaluation report on the best damage mitigation practices used in wolf conservation

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Abstract

One of the challenges in wolf conservation relates to large carnivore depredation of sheep and cattle. Livestock damage is partly behind the low tolerance of wolves and their illegal killing in many countries. Actions have been targeted in many previous and current LIFE projects to mitigate the conflict. The recently started LIFE BOREALWOLF project aims to tackle the challenge in Finland.

This review report is prepared to primarily inform the project of the variety of damage prevention measures taken in North America and Europe, and to describe the scientific evidence of the associated effectiveness. Best practice measures are defined here as a collection of measures applied separately or in parallel in ordinary livestock husbandry.

Measures that have undergone experimental testing can be distinguished as ex ante measures that mitigate problems by: 1) removing wolves (killing or translocation) or livestock from sites with a high risk of encounter; 2) preventing wolves from coming into contact with livestock (with fences, livestock guardian dogs (LGDs), shepherds); or 3) scaring wolves further away from the site (with LGDs, shepherds, deterrents producing lights, noise, electric shock). No corresponding experiment has been conducted to test the efficiency of risk-modelling tools, chemical deterrents, or ex post measures such as specific compensation schemes.

There is increasing evidence that many measures will help to decrease wolf damage. The effectiveness of measures has been either compared experimentally (trials) to the level prior to the intervention in the same sites or to the level of nearby locations. Although helpful measures exist, recent reviews reveal that little experimental experience has been gained from many specific measures or their integration, particularly in the European (or Finnish) context.

Many recent scientific reviews conclude that livestock depredation by grey wolves can be effectively reduced by electric fences and deterrents. The construction of fixed large carnivore fences is now a recommended and increasingly popular mitigating measure in Finland. The review indicates that additional protection can be gained in Finland from more mobile temporary measures such as electrified (power) fladry.

The emphasis on livestock protection and fencing as concrete actions links the ongoing LIFE BOREALWOLF project to many previous and current LIFE projects. The future will show the extent to which livestock producers will welcome the aid the project has to offer, and to which the project will realise the potential of collaboration and livestock protection.

Tiivistelmä

Yksi keskeisistä susikannan hoidon ja suojelun haasteita liittyy tuotantoeläinvahinkoihin. Monissa maissa etenkin lammas- ja karjatilojen kokemat vahingot selittävät osaltaan matalaa suden läsnäolon sietämistä ja laitonta pyyntiä. Monet Euroopan Unionin LIFE-projektit ovat pyrkineet toimenpiteissään lieventämään vahinkoja, ja tähän pyrkii myös Suomessa vuoden 2019 lopulla alkanut SusiLIFE-projekti (engl. LIFE BOREALWOLF).

Osana projektin aloittamista tehtiin kartoitus Euroopassa ja Pohjois-Amerikassa käytössä olevista susien tuotantoeläinvahinkojen lieventämiseen tähtäävistä menetelmistä, LIFE-projektien soveltamista menetelmistä sekä niiden tutkimuksissa osoitetusta tehokkuudesta. Kartoituksella pohjustetaan menetelmien yhteiskäytön ympärille rakentuvien parhaiden käytäntöjen laatimista.

Kansainvälisissä tutkimuksissa on huomio keskittynyt ns. ex-ante menetelmiin, joilla pyritään estämään vahinkoja tai lisävahinkoja tapahtumasta. Kokeellista tutkimusta esimerkiksi susivahinkojen korvausjärjestelmien tehokkuudesta ei ole juurikaan tehty. Vahinkojen tai lisävahinkojen syntyä estävissä menetelmissä 1) susi tai sudet tapetaan tai otetaan kiinni ja siirretään pois, 2) susia estetään pääsemästä kontaktiin suojeltavien eläinten kanssa (petoaidat, vahvistetut yö-aitaukset, laumanvartijakoirat, paimenet, tuotantoeläinten siirrot), tai 3) susia karkotetaan erilaisin ääniin, valoihin tai sähköiskuin kauemmas eli yritetään saada aikaan suden tai susien käyttäytymismuutos. Kokeellista tutkimusta ei ole susilla tehty esimerkiksi kemiallisten houkuttimien tai karkottimien tehosta, tai epäsuorista ennaltaehkäisyn apuvälineistä, kuten riskimallinnuksista.

Kokeelliseen tutkimukseen pohjaavaa näyttöä on enenevästi kertynyt siitä, että monin keinoin voidaan vähentää vahinkoja. Käyttöön otetun suojausmenetelmän tai -menetelmien tehoa on niissä verrattu samojen kohteiden vahinkotasoon ennen menetelmän käyttöönottoa, tai siten että verrokkina on ollut läheinen kohde ilman testattavaa suojausmenetelmää. Hyvin harvassa tutkimuksessa koe- ja kontrollikohteet ovat olleet satunnaistettuja. Vaikka monesta menetelmästä on apua, kokeellista tutkimusnäyttöä puuttuu edelleen osasta tunnettuja suojausmenetelmistä ja etenkin niiden soveltamisen yhdistelmistä.

Monet viime vuosien tutkimuskatsauksista päätyvät havaintoon, että suurpetojen tuotantoeläinvahinkoja voidaan tehokkaasti ehkäistä etenkin sähköistetyillä aidoilla, ja tilapäisesti karkottimilla. Pitkäaikaisen suojan antava suurpetoaita on enenevästi Suomessa suosittu menetelmä. Tilapäiseen tai nopeasti syntyväät suojaustarpeeseen tehokasta lisäapua voi saada sähköistetystä lippusiimasta.

Tuotantoeläinten suojaamiseen tähtäävät SusiLIFE-projektin toimenpiteet yhdistävät sen moniin aiempiin ja käynnissä oleviin LIFE-projekteihin. Tulevaisuus näyttää sen, missä määrin tuotantoeläinten pitäjät tämän projektin ja muiden eurooppalaisten projektien tukeen tarttuvat, ja miten yhteistyö onnistuu tuottamaan parempia edellytyksiä suurpetojen ja ihmisten rinnakkaisololle.

Sammanfattning

En av utmaningarna vad gäller skyddet av vargar anknyter till rovdjursattacker på får och nötboskap. Skador på boskapsbesättningar är en av orsakerna till att vargen bemöts med intolerans och utsätts för illegalt dödande i många länder. Flera tidigare och pågående Life-projekt har sökt avhjälpa denna konflikt. Det nyligen lanserade projektet VargLIFE tar itu med problematiken i Finland.

Denna översikt av avsedd främst för att informera projektet om de skadeförebyggande åtgärder som har vidtagits i Nordamerika och Europa samt att redogöra för vetenskapliga belägg för åtgärdernas effektivitet. Med bästa åtgärder avses här en samling åtgärder som genomförs enskilt eller parallellt inom vanlig djurhållning.

De åtgärder som bekräftats genom experimentella försök kan betraktas som förhandsåtgärder som avhjälper problemen genom att 1) eliminera vargar (genom att döda eller flytta dem) eller boskap från platser med hög risk för möten, 2) förhindra vargar att komma i kontakt med boskapen i området (med stängsel, boskapsvaktande hundar, herdar), eller 3) fördriva vargarna (med boskapsvaktande hundar, herdar, ljud- och ljusskrämmor, elstötar). Motsvarande försök har inte genomförts för att testa effekten av riskmodelleringsverktyg, avskräckande medel eller åtgärder i efterskott, till exempel specifika ersättningssystem.

Det finns allt mer bevis för att många åtgärder bidrar till att minska vargskador. Åtgärdernas effektivitet har antingen jämförts genom försök med skadenivån före interventionen i samma områden eller jämförts med andra närliggande områden. Trots att det finns användbara åtgärder visar nya undersökningar att det saknas försöksbaserad information om specifika åtgärder eller genomförandet av dem, speciellt i en europeisk (eller finländsk) kontext.

På senare tid har man i många vetenskapliga undersökningar dragit slutsatsen att det går att effektivt minska vargpredationen på boskap med hjälp av elstängsel och avskräckande metoder. Permanenta rovdjursstängsel är numera den skadeförebyggande metod som rekommenderas i Finland och som blivit allt mer populär. Enligt översikten kan man i Finland eventuellt erhålla ytterligare skydd med hjälp av flyttbara tillfälliga lösningar så som elektriska lapptyg.

Betoningen på skyddet av tamboskap och användning av stängsel som konkreta åtgärder länkar det aktuella VargLIFE projektet till flera tidigare och pågående Life-projekt. Framtiden kommer att utvisa i hur stor omfattning boskapsuppfödarna välkomnar den hjälp som projektet kan erbjuda och i vilken omfattning projektet kan förverkliga potentialen för samarbete och skydd av tamboskap.

Introduction

One of the key challenges in wolf conservation in many countries relates to large carnivore depredation of livestock. While wolves usually consume large wild animals (e.g. Newsome et al. 2016), they occasionally encounter and attack livestock such as cattle and sheep, and may wound or kill animals, damaging the livelihoods of livestock producers. Many LIFE projects have regarded livestock damage as a partial reason for the low tolerance of wolves and their illegal killing, and targeted actions to mitigate the conflict (Silva et al. 2013).

The return of wolves to Western Europe and increasingly to human-dominated European landscapes (Chapron et al. 2014) and North America has invited researchers to seek and test the efficiency of livestock protection measures in an attempt to mitigate the conflict related to livestock husbandry and wolf conservation.

This short report is prepared primarily to inform the LIFE BOREALWOLF project, which started in November 2019. The report briefly reviews the variety of damage prevention measures taken mainly in North America and Europe, and describes the available scientific evidence concerning their effectiveness. The review maps the measures used and developed on two continents, discussing best practice in preventing damage to livestock, i.e. cattle and sheep. Best practice measures are defined here as a collection of measures, applied separately or in parallel, in ordinary livestock husbandry. Based on well-designed empirical tests (and best science), the measures are most effective in preventing damage. Naturally, the best practice measures meet legal requirements and a variety of other societal needs, such as high public acceptability of their ethicality and the desired ecological consequences (for an emphasis on criteria, see Treves et al. 2016). It is essential for users that best practice methods are cost-effective to install and maintain (Lance et al. 2010). It is noteworthy that the contexts of the application of measures vary, and the effectiveness of the measures depends, for example, on many known and unknown factors that may differ case-specifically (e.g. Dalerum et al. 2020).

The data of the report, i.e. the available research literature, was collected primarily from the available English scientific literature (original articles, reviews, meta-analysis). In the case of previous LIFE project materials, the data sources include grey literature, mainly project reports. The gathered information will be used as background information in the LIFE BOREALWOLF project actions A1.4 to lay out a plan for building a damage prevention toolbox guide (plan executed in C3.1), and to identify links from this project to other European large carnivore LIFE projects.

Material and methods

The relevant research literature was sourced from several journal databases, including the Agricultural Science Collection, Biological Science Collection, DOAJ Directory of Open Access Journals, EBSCOhost Academic Search Complete, EBSCOhost SocINDEX, JSTOR Biological Sciences Collection, Natural Science Collection, SpringerLink Journals Complete, Wiley Online Library, Taylor & Francis Soc Sci & Hum with Sci & Tech, and Google Scholar. The search words were "wolf", "livestock", and "damage". When relevant peer-reviewed research articles were found, their relevant references were also examined when available. It was soon found that the recent four research reviews on the same theme (Miller et al. 2016, Treves et al. 2016, Eklund et al. 2017, Bruns et al. 2020) and the metal-analysis of Van Eeden et al. (2018) were the most important indirect source for listing the most relevant articles to the task at hand.

The specific criteria for the relevant peer-reviewed article was that 1) the study design included a wolf-related damage mitigation experiment or quasi-experiment (treatment/trials with control) with quantitative measurements, 2) the animals protected from encountering wolves were cattle or sheep, and 3) the article was written in English or included an English summary.

Each relevant research article was read, the study design was categorized, and the key result and management advice or practical guidance (if they existed) were extracted. No statistical analysis was made for the findings, because very recent reviews and meta-analyses existed that provided calculations of the efficiency of the variety of measures in terms of the percentage change in wolf visits/livestock loss (before/after; Miller et al. 2016), risk ratio (RR) (e.g. Eklund et al. 2017, Khorozyan & Waltert 2019a, Bruns et al. 2020), or mean effect size, (Hedges' d) (Van Eeden et al. 2018). Although they are potentially helpful metrics, the calculations can be criticised for combining data from sources that lack a standard for the consistent application of treatments, and having too much variation in specific methods used, to enable reliable method-level estimation (Treves et al. 2016).

The grey literature, mainly the project reports of the previous LIFE projects, was screened to simply list the wolf-related livestock mitigating measures applied, and the associated experiences gained from the projects. The LIFE Project search (https://ec.europa.eu/environment/life/project/Projects/index.cfm) was used with the following search criteria: Strand = "Nature"; Species = "Mammals (Canis Lupus)", Free text = "livestock". Among the projects listed in the search results, the year of funding covered the years 1992 –2017. The resulting list was complemented with some wolf-related projects listed by Silva et al. (2013).

Results

The variety of the tested mitigating measures

Recent reviews clearly focus on the "ex ante" methods in which efforts are made to prevent the damage from occurring in the first place. While one may define mitigation as "*the process or result of making something less severe, dangerous, painful, harsh, or damaging*" (Merriam-Webster), the aforementioned reviews do not include "ex post" methods in their scope. This may partly be explained by the fact that very few systematic efforts have been made to empirically test the effects of specific large carnivore damage compensation arrangements on social acceptance or tolerance, for example (but see Naughton-Treves et al. 2003), or to test with a control the role coupling the compensation with prevention would play in motivating livestock producers to implement ex ante methods (Nyhus et al. 2005, Reinhardt et al. 2012). In addition, the reviews do not include risk modelling as a damage mitigation measure, perhaps because modelling may not be regarded as an operational field method, and the value of the predictive models has not been compared experimentally to control situations lacking the predictive risk model information, for example. Similarly, ex ante activities such as monitoring the wolf's presence (as "warning systems") are missing, perhaps because no systematic experiments specific to the measure exist (but see Stone et al. 2017, who mention "radio telemetry" and "human presence" as methods applied in the combination to other methods in the treatment area). Only Bruns et al. (2020) include methods that help to detect large carnivore mortality as an ex post mitigating measure, but they refer to no systematic experiments.

Recent reviews categorise ex ante mitigating measures for large carnivore damage in partly different ways. Treves et al. (2016) focus on the measures being tested by rigorous experiments in the two main categories, i.e. lethal and non-lethal methods. Miller et al. (2016) evaluate four categories under lethal and non-lethal mitigation techniques: 1) deterrents; 2) indirect management of land or wild prey; 3) predator removal and preventive husbandry. They include a list of 32 subcategories. Eklund et al. (2017) list seven categories of method being examined in research interventions: 1) changing livestock type; 2) keeping livestock in enclosures; 3) guarding or livestock guard dogs; 4) predator removal; 5) using shock collars on carnivores; 6) sterilising carnivores; and 7) using visual or auditory deterrents to frighten carnivores (of which changing livestock type in the case of wolverines and sterilisation in the case of coyotes). Van Eeden et al. (2018) include five methods in their meta-analysis: 1) livestock guardian animals; 2) deterrents; 3) fencing; 4) lethal control; and 5) shepherding. Khorozyan & Waltert (2019a) have three main categories: aversion; husbandry; and management. These categories have five, four, and three subcategories respectively.

Finally, the most recent review by Bruns et al. (2020) analyses the effectiveness of several measures in mitigating wolf-related livestock damage, namely: 1) deterrents (radio-activate guard RAG box, shock collar, fladry); 2) fencing (night shelter, electric fence, electrified fladry); 3) guard dogs; 4) herding; 5) lethal control; 6) mixed measures (herding, dogs, and deterrents; dogs and fencing); and 7) translocation of wolves.

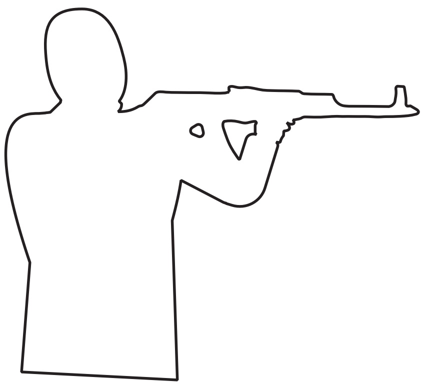
To summarise the categories of method that have undergone experimental testing, it may be meaningful to distinguish methods that mitigate problems by either removing wolves (killing or translocating them) or livestock from the sites with a high risk of encounter, methods that primarily prevent wolves from coming into contact with livestock (fences, LGDs, shepherds) or methods (partly overlapping with the previous category) in which wolves are scared away from the site (LGDs, shepherds, deterrents; visual, auditory, electric shock).

The tested efficiency of the mitigating measures

Removing wolves

There is a long history of attempting to mitigate large carnivore problems by killing the carnivores, either unselectively or selectively. The latter targets problematic individuals or packs. There have been long periods in which killing wolves was not only made easy by setting very little restrictions on hunting them, but in which there were also financial incentives to further motivate local people to remove them (for Finnish cases, see e.g. Mykrä et al. 2005, Pohja-Mykrä et al. 2005). The lethal control of wolves has been and still is one of the methods used in many countries suffering livestock damage, and experimental research has been largely conducted in North America to reveal its effectiveness as a measure to decrease the occurrence of subsequent depredation.

Bjorge & Gunson's (1985) report was one of the first to compare and report the livestock damage level before and after the lethal control (mainly poisoning). During the six-year study period, the number of wolves decreased drastically, and the damage levels decreased to some two-thirds of the level prior to the control. The survivors of packs depleted by wolf control demonstrated variable behaviour, including emigration, death from starvation, and increased dependence on livestock (ibid., for impact of wolf removal on the remaining pack, see also Gehring et al. 2003).

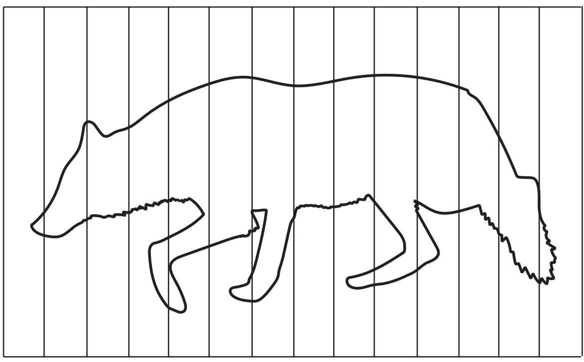


Many researchers in the USA have since examined the effect of lethal control (mainly trapping), but only three articles draw conclusions based on before-after-design quasi-experiments. The first, the study published by Harper et al. (2008), analysed the effect of removing wolves after depredation by trained trappers, who limited the trapping to within 0.8 km of the property boundary and usually to 15 days (Paul 2001). Compared with two control groups (with no trapping or with only unsuccessful trapping attempts), the trapping of wolves did not substantially reduce the following year's depredations at state or local levels. However, more specific analyses made by Harper et al. (2008) indicated that in certain situations, killing wolves was more effective than no action.

Further experimental research was conducted by Bradley et al. (2015), who compared the effects of no wolf removal, partial pack removal, and full pack removal to additional livestock depredation by wolf packs in three states after the initial depredation. They discovered that compared to no removal, rapid and full pack removal reduced the occurrence of subsequent depredations by 79% over a span of five years, whereas in the case of partial pack removal, it was reduced by 29% over the same period. Partial pack removal was most effective if conducted within the first seven days following depredation, after which there was only a marginal value (ibid.).

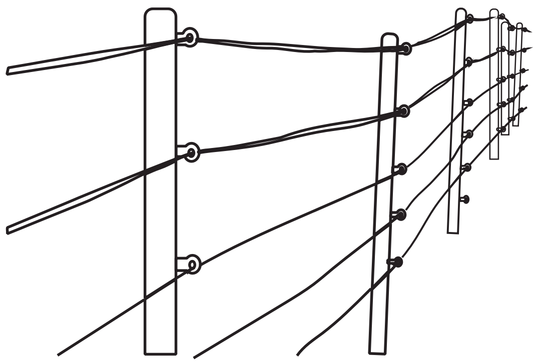
A recent experiment was conducted by Santiago-Avila et al. (2018a, 2018b), who tested the effect of selective trapping and killing of wolves near sites of verified depredation, compared to a any non-lethal intervention as control. No statistically significant difference in effect was detected within the same year, although some indication was found that there were side-effects of the lethal intervention such as displaced depredations on neighbouring farms (ibid.).

To summarize the findings concerning lethal control, one can conclude that little evidence is available from controlled experiments to provide guidance to European countries using different lethal control methods than those tested. For example, the Bern Convention prohibits the tested methods, and poisoning or trapping with foot-hold traps or neck snares are illegal wolf-hunting methods in most countries, including Finland. It seems that efficiency greatly depends on the specific implementation – it should take place very rapidly after the occurrence of the first depredation and target the problem individual (if not the whole pack). Since the attacks typically occur in the summer, the specific targeting of a "problem individual" is challenging. One should also note the potential consequences when considering the option, i.e. how the pack survivors behave. There is little evidence in the research literature to inform wildlife agencies about the probable impacts.



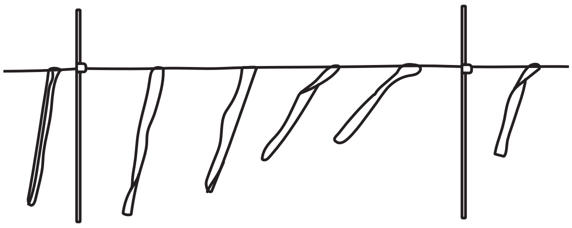
Translocating wolves is another method that removes specific animals from depredation sites. In their recent experiment, Bradley et al. (2015, see also Bradley et al. 2005) analysed what happened after 88 wolves were trapped, equipped with radio collars, and translocated after confirmed livestock predation had occurred, or in some cases, pre-emptively (when there was an imminent risk). Interestingly, the researchers observed that a minority (≥¼) of the translocated wolves preyed on livestock after release. Based on the experiment, it seemed that livestock depredations largely stopped for at least the remaining grazing season. It was also discovered that translocated wolves had a lower annual survival rate (0.60) than other radio-collared wolves (=control), and sixteen (20%) homed back to their capture site. The tendency to return (very soon) naturally decreased the effectiveness of the method. Swedish experiences from 2013 (a female wolf returned four times to her old territory) show the tendency can be strong (Swedish Environmental Protection Agency 2014). According to Bradley et al. (2015), selectively translocating alpha individuals (reproducing males or females) was no better a strategy than removing non-alphas. Benefits of wolf translocations (external to damage mitigation) included the establishment of new packs and the augmentation of existing packs, which both served to help further wolf recovery. One can conclude that wolf translocating can be used as a livestock damage mitigating measure in some cases where other methods are not applicable. In Finland, for example, this method is not generally regarded as acceptable (e.g. it is not among the applicable methods listed by national wolf management plans), regardless of its efficiency. Given the notable costs of captioning and translocating wolves, and the tendency of animals returning, it is not cost-efficient method in preventing damages.

Building physical barriers that prevent encounters



The effect of building fences (incl. non-electric and electric fences, night shelters) around or on pastures with registered wolf attacks on cattle or sheep has been tested mainly in European countries as part of the LIFE COEX project. The specific type of mobile fence varied from case to case, but most often wire fences with three to six electric wires and mesh net fences were used. The maximum height ranged from 100–135 cm from the ground (Salvatori & Mertens 2012). After electric fences were installed, the damage suffered by holdings from wolf attacks decreased by 100% in Portugal and Croatia, 99% in Spain, and 58% in Italy.

Fladry is a line (or electrified wire) with strips of fabric set around a livestock enclosure (or a bait site when the idea is to test the method). The efficiency has been tested mainly in North America in the last two decades (e.g. Musiani et al. 2003, Gehring et al. 2006, Lance et al. 2010, Davidson-Nelson et al. 2010), but the most recent experiments have been conducted in Europe (Iliopoulos et al. 2019).



Musiani et al. (2003) have conducted experimental research among both captive and wild wolves to test whether a fladry line will keep wolves from accessing the nylon twine, suspended 50 cm above the ground and with plastic flags (50 x 10 cm) at 50-cm intervals. Fladry prevented captive wolves from crossing the line for up to 28 hours in 18 experiments. When fladry was set around bait sites (with carcasses of wild ungulates killed in vehicle collisions), wild wolves did not access the two 100-m^2 baited sites (100 km apart from each other) during two 60-day tests. Prior to the setting of fladry, the bait sites were approached by the wild wolves, and the carcasses were usually consumed. The same result was observed when fladry was set around cattle pastures: the wild wolves visited the two 25-ha test pastures and attacked the cattle prior to the setting of fladry, but they did not cross them in any of the 23 detected approaches. Wolves killed cattle during the experiment on neighbouring farms (control) and after the 60-day treatment period (later trials) on the tested ranches.

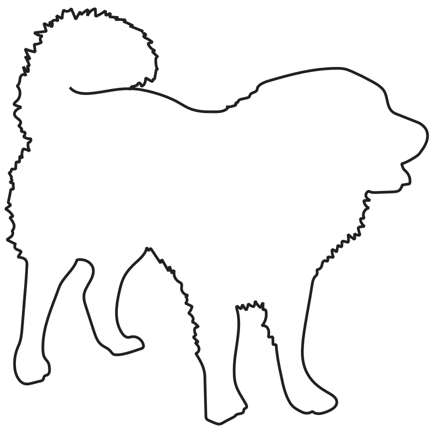
Lance et al. (2010) continued the same line of research by testing the effectiveness of an electrified fladry (i.e. "turbo fladry") and ordinary fladry with captive and wild wolves during two-week trials. Electric fladry contained two wires with a pulsed energy output >2000 V, one located 50 cm above the ground, the other 13 cm above the ground. The trial results indicated that electrified fladry was 2–10 times more effective than other fladry at protecting food items over an 18 m^2 area from captive animals. In the field trials (pasture size 16–122 ha), electrified fladry lines were set 1 m outside the existing barbed wire fence. Wild wolves visited the control pastures twice, but never the treatment pastures that had electrified fladry. Interestingly, 83% of farmers who used fladry reported being willing to continue to use it under certain conditions. In applying the method, one should note that several factors may cause systems to fail, including branches falling on the fence, other animals crossing it, and heavy snowfalls (ibid.).

Davidson-Nelson & Gehring (2010) tested the effect of fladry combined with the effect of an ordinary electric fence (see also Gehring et al. 2006). Sheep farms had 5-strand, high-tensile fencing with two electrified wires located 30 cm and 65 cm above ground-level; cattle farms had 3-strand high-tensile fencing with two electrified strands (located 40 cm and 65 cm above ground-level). The researchers observed wolf visits to the pastures of the control farms (located within 3 km of the farms with fladry, and having only an ordinary electric fence), but no visits to the farms with fladry. However, no depredations due to wolves occurred on the control farms during the trial. The researchers concluded that annual depredation losses would have to exceed 37 lambs or 11 calves to equal the approximate costs of using fladry on a 150-ha farm (ibid.).

The most recent published fladry experiment was conducted by Iliopoulos et al. (2019), who focused on fladry's effect "*under realistic field conditions before advocating fladry use by local pastoralists, who are typically skeptical of novel methods they perceive to be 'foreign' and* *'naïve' of local realities".* The researchers built experimental baiting stations within known wolf-pack territories, offering dead sheep and goats first without and then with fladry installed. The orange flags were of the same size and interval as in the experiments introduced above. The material was polyester. The flags were hung from one 4-mm nylon rope and were attached to the rope to allow their free oscillation and rotation. The rope was attached to the posts with tie wraps (cable ties) 75–80 cm above the ground. The researchers observed that the feeding rate of all wolf packs reduced to zero immediately after fladry was set in place. The effective repelling lasted from 23 to 157 days and ended with the removal of fladry. Wolf approaches near the fladry line also reduced by 75% (ibid.). The experiment supported the observation made in the previous experiments that the method's effectiveness (and probably many others based on the neophobia of the wolves) depended partly on the attractiveness of the livestock, wolf habituation, and how desperate the wolf was (i.e. hungry).

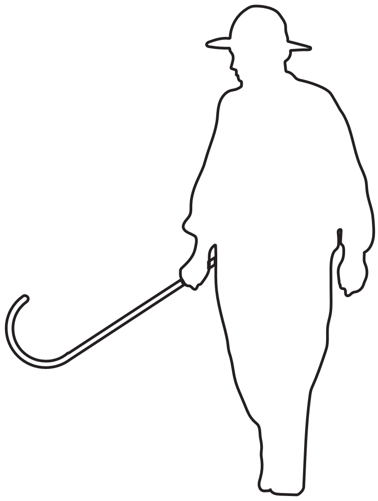
Guardian animals and shepherds

Livestock guardian animals (most often dogs (LGDs)) and people (e.g. shepherds) are primarily measures that prevent wolves from coming into contact with livestock and not deterrents. For example, there are French video recordings of the interactions between wolves, LGDs, and sheep in which wolves are not frightened by LGDs (e.g. Landry et al. 2014) but react to them more as barriers to repeatedly overcome. One may therefore regard LGDs primarily as disruptive stimulus tools (Gehring et al. 2010). Some controlled experiments have been conducted during the last two decades in the USA to protect cattle, and some controlled experiments have been conducted in Southern Europe to protect cattle and sheep with the aid of LGDs.



Gehring et al. (2010) studied how LGDs that socialised and bonded to cattle could reduce the use of 10–40-ha fenced cattle pastures by wildlife, including wolves, coyotes, white-tailed deer and mesopredators (see also Gehring et al. 2006). Both treatment and control farms' pastures had strengthened fences with four to five electric wires (7,000 V, lowest strand 25 cm, highest 110 cm from the ground). When LGDs and strengthened fences were present in treatment farms, wolf visits declined to zero on them but increased on the control farms. In addition, and white-tailed deer spent less time in the pastures protected by the LGDs (ibid.).

European tests have been conducted in Portugal, Spain, and Italy, exploring the effectiveness of one to two dogs per holding. Salvatori & Mertens (2012) do not explicate what other methods (if any) were used to protect livestock in combination with the LGDs in the quasi-experiments. Compared to the period prior to the trial, the damage level dropped by 27% in Portugal and 65% in Spain. In Portugal, it was estimated that to be cost-effective a year after a dog(s) reaches adulthood (i.e. 16 months after integration), the LGD must associate to a reduction in damage of at least €520. This calculation does not include the potential costs related to the high mortality of young LGDs during the first two years.



Some research articles report the role human guards or shepherds may play in preventing wolf damage to livestock (Iliopoulus et al. 2009, Stone et al. 2017). The former indicates that the shepherds may prevent the most severe damage.

Scaring devices – other deterrents

In addition to the above-mentioned deterrents, some experiments have been conducted, particularly in the USA, to investigate the conditions that make wolves avoid certain sites, using different devices. Some simply disrupted the stalk or attack of a wolf (or wolves) by producing a stimulus like a strobe-light-siren, noise (e.g. Fritts 1982, Fritts 1992), or taste (e.g. Gustavson 1982). Shivik et al. (2003) have reported experiences gained from an experiment in which a movement-activated guard device (MAG), based on a strobe light, various sounds, and a passive infrared movement detector, were used to prevent wild wolves within their territory approaching a bait station (deer carcass) and consuming the baited meat. The researchers discovered that consumption was reduced on MAG plots compared to the pre-treatment level and the control plot (the latter by 68%). The stimulus did not produce an aversion to the food source (ibid.).

Another line of the research tested an electronic shock collar on wolves designed to make them avoid bait stations. The idea was to condition wolves with a painful experience associated with hearing an auditory signal. After the primary learning phase, the wolf should avoid sites (pastures etc.) where the same auditory signal was produced when the wolf approached.

Summary of the reviews – what do the authors recommend?

There is increasing evidence that all the methods that have undergone empirical testing decrease wolf visits and the damage level on farms, either compared to the level prior to the intervention or on neighbouring farms. Although this is a general rule, the recent reviews reveal that little experience has been gained from many specific methods or their integration to evaluate their effectiveness, particularly in the European (or Finnish) context.

Gehring et al. (2010) compared the non-lethal tools in terms of the initial and annual costs, relative maintenance, longevity of control, relative effectiveness, potential of wolf habituation, flexibility, greenness, biological efficacy, ease of deployment, and generality. They gave the highest relative ranks to LGDs and the second-highest to fences, fladry, or visual and auditory deterrents. However, they acknowledged that neither randomised and controlled ("gold standard" LGD experiments, nor before-after-control-impact (BACI) ("silver standard") design experiments, had been conducted to provide relatively strong evidence of efficiency. (For standard terms, see Treves et al. 2016, 2019). Many specific factors contributing to effectiveness were not well known, such as the role of specific landscape types, livestock, and dog breeds, livestock herd size and distribution, or the ideal behaviour of LGDs in encounters. The researchers also noted that there are many other positive or negative impacts to consider other than preventing the killing of livestock. These included e.g. economic factors, the impact of LGDs on other wildlife, the impact of aggressive LGDs on livestock, other dogs, and humans, and the fact that wolves might on some occasions kill the LGDs (ibid.).

Treves et al. (2016) recommended LGDs and fladry as methods outperforming lethal methods in terms of functional effectiveness. This is confirmed in the convincing experiments. They also noted that lethal control had legal limitations, and negative ecological (wolf-related) or ecosystem-level (side-)effects.

Eklund et al. (2017) compared only the tested effectiveness of the methods with no additional criteria (Fig. 1). They concluded that there were few scientific publications containing evidence of the effectiveness for any intervention intended to prevent livestock depradation, and that some popular methods in many countries, such as carnivore deterring fences (for recommended methods in many countries, see Reinhardt et al. 2012) had not been experimentally tested. Nevertheless, they regarded fencing as having great potential to protect livestock against multiple carnivores if their biology and behaviour was considered during construction (i.e. tendency of predators to dig under or jump/climb over the fence). In the case of LGDs, they concluded that intervention could work well in areas where the likelihood of a carnivore attack was high, and where livestock were confined in a way that allowed a dog to supervise the flock without straying, particularly at night. Lethal control was socially controversial but might reduce damage. They added that the level of effectiveness might depend on timing (season, delay after the damage), the ability to remove "the problem individual", and whether the removal was targeted at (an) individual(s) of the sink or source population. Eklund et al. (2017) found that visual and auditory deterrents were have repelling properties (particularly electrical fladry) but noted their relatively short longevity of effectiveness due to habituation.

Khorozyan & Waltert (2019a) concluded that livestock depredation by grey wolves could be effectively reduced by electric fences, physical deterrents, LGDs, guardian animals, and calving control. Bruns et al. (2020) regarded fencing and deterrents as the most effective measures against wolves (Fig. 1). While acknowledging their high potential, they emphasised the temporary role the methods played (see also review of Khorozyan & Waltert 2019b) and the role that the structure, proper maintenance, and the lack of flaws played in the success. Other methods such as shock collars were not regarded as practical measures due to limited battery life, the extensive effort to identify and collar livestock-killing wolves, and the high cost of capturing and collaring wolves. The researchers did not recommend herding (shepherds) as suitable in Germany, because it was neither well known nor already applied, and was (too) impractical, poorly paid, and time-consuming. Instead, the researchers emphasized that a combinations of measures might magnify the overall effectiveness of livestock protection in comparison with the application of single measures, such as the use of electric fladry and fences, or LGD and fences.

Summary of the LIFE projects – what methods have they promoted?

Of the at least 36 LIFE projects targeted at wolves, at least 20 featured activities focusing on livestock protection. The number was higher if mitigation was defined broadly, i.e. as including information sharing with livestock producers, the devising of a wolf management plan, providing wolves with compensatory food by managing prey animal populations, or activity aimed at preventing illegal lethal control of wolves. Most projects focused strongly on ex ante methods, supporting the building of either fixed or mobile traditional and electric fences (at least 14 projects). Many projects aimed to provide protection for calving cows, new-born/young livestock during the day/night, or the entire flock/herd during the night (e.g. LIFEMedWolf). Another commonly applied method in the LIFE projects was the use of LGDs (at least 10 projects). At least two projects included the activation of shepherding.

In addition, at least 14 LIFE projects started compensation schemes or developed the performance of the existing scheme to be faster and more reliable (see also Silva et al. 2013). Some LIFE projects also developed innovative ex post methods, related to the compensation of the animal loss to the producer by providing them with animals (sheep) instead of money.

Fig. 1. A summary of the calculations made in the published reviews to describe the method effectiveness on wolf visitation and/or damage. RR < 1 indicates that there was a lower risk of carnivore attack when a method was applied (value 0 = no attacks occurred during the test).

Type of intervention	*Eklund et al. 2017 (RR)*	*Bruns et al. 2020 (RR)*
Fences, fladry	Sheep; 0.25	0.00-0.42
Shepherd/herding	Sheep, goats; 0.21	0.03
LGDs	-	0.00–1.23
Shock collar	0.15	0.00
Visual and auditory deterrents	Sheep, cattle; 0.23	0.00
Predator removal	Individual wolf: sheep, cattle; 0.71–0.93 Pack: sheep, cattle; 0.21	Individual wolf: sheep, cattle; 0.71–0.98 Pack: sheep, cattle; 0.21 Translocating; 0.62

Best practices

A recent study by Fernández-Gil et al. (2018) concluded that sheep damage was the main concern in many EU countries. They estimated that wolf management was mainly based on lethal control in seven out of ten European wolf populations and was applied in twelve member states, of which there was no compensation scheme in five. It was also very common for member states to have compensation schemes (twelve had one, six of which also applied lethal control) and apply different preventive measures. The latter applied to Finland, which had a compensation scheme, restricted lethal control (i.e. derogations from strict protection), and other preventive measures. The Finnish compensation scheme covered damage caused to arable and horticultural land, nursery plantations, and harvested crops, damage caused to a domestic animal (including semi-domestic reindeer), farm animals, a honey crop, and fences, buildings, and other structures used for the keeping of animals. A precondition for receiving compensation was that the party suffering the damage had, using available reasonable means, attempted to prevent the damage or its spread (Finnish Game Animal Damages Act 105/2009). Some novel ideas were also presented for how to complement the current compensation mechanism with a new financial scheme (Hiedanpää et al. 2016).

Fernández-Gil et al. (2018) evaluated the best coexistence methods obtained from research and EU-funded projects such as those that optimised livestock protection by mixing traditional preventive measures and modern technology. They listed the LGDs, fences, deterrents, and rearing of autochthonous breeds as belonging to the best practice toolkit.

Based on the recent scientific reviews of effectiveness, it can be confirmed that many non-lethal methods are increasingly promising measures within the current legal frame that emphasize both wolf conservation and damage mitigation. The common challenge in many countries seems to be the lack of knowledge and/or negative attitudes to non-lethal methods or preference for lethal control (for negative attitudes, see e.g. Rigg et al. 2011). The LIFE projects have participated in fostering the cultural change. This is also the case in the recently initiated LIFE BOREALWOLF project. The challenge of negative attitudes and an emphasis on livestock protection and fencing as concrete actions link the ongoing LIFE BOREALWOLF project to many other previous and current LIFE projects.

In Finland, some 500–600 annually registered dogs belong to breeds that are commonly used as LGDs (Kuoppala 2015). Several dozen Finnish farms use LGDs (the exact number is unknown), often with other preventive measures such as fencing (Otstavel et al. 2009). There is no historical tradition of the method in Finland. Livestock damage occurring outside the reindeer herding area in Finland are rare compared to many European countries: there have been some 30–50 occasions of sheep depredation by wolves every year, and fewer than 20 occasions of other livestock damage by wolves every year between 2010 and 2017 (MMM 2018). The expected cost of preventing wolf depredations with the aid of LGDs therefore probably exceeds the prevented damage. A fixed large carnivore electrified fence has for several decades been the recommended method in livestock damage prevention in Finland. It is targeted at wolf, brown bear, and lynx, and it typically consists of five wires, the highest 140 cm above the ground, and the lowest 20 cm above the ground (Finnish Wildlife Agency 2018). Its efficiency has not been tested in a controlled experiment in Finland (with verified approaches of wolves to treatment pastures, with matching control), but very few occasions of wolf depredation have been recorded within the enclosures.

Recommendations to the project:

In addition to supporting livestock producers in building fences, there may be an additional need of (more) mobile and rapid solutions such as electrified fladry. There is a delay today between a livestock owner enquiring about the material and the delivery and building of the fence. The review may suggest that power fladry is an effective temporary measure. Similarly, other deterrents should probably be tested and applied when necessary. The reviews also suggest that in the case of many measures, little information is available to evaluate their anticipated cost efficiency (i.e. net utility).

The LIFE BOREALWOLF project features many activities that aim to prevent livestock damage, and other issues that aim at increasing the tolerance and acceptance of coexistence with wolves. The coming years will show the extent to which livestock producers have welcomed the aid the project has to offer, as well as the extent to which the project will realise the potential of collaboration and livestock protection.

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