Effectiveness of behaviour-based interventions in reducing livestock depredation by wolves (*Canis lupus*)

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Supplementary materials

Limiting factors to the meta-analysis: studies excluded from the quantitative review

A large number of studies included in the systematic review could not be included in the statistical analysis due to data limitations (see Table 1). The exclusion of studies from the quantitative synthesis (meta-analysis) was done at the full data extraction phase, where the major determining factor was the data requirements for the effect size calculations (RR and SMD). SMD calculations required means and their corresponding measure of variance, in many studies there were no measures of variance reported (*n*=7). We attempted to retrieve variance measures by requesting the raw data from authors (Rigg et al. 2011, Salvatori & Mertens 2012 and Samelius et al. 2021) and were able to incorporate one additional dataset (Samelius et al. 2021) in the analysis. Furthermore, we excluded studies that did not have usable control data to calculate an effect size (*n*=4) or studies that combined multiple interventions in one treatment (n=1, Stone et al. 2017). Finally, we excluded a report from the U.S. Fish and Wildlife Service that reported the reduction in depredation after intervention, with no quantitative measures for depredations before the use of nonlethal tools (*n*=1).

Table S1. List of studies not included in quantitative synthesis with corresponding reasons for exclusion as well as a summary of the results used in the qualitative synthesis.

Reference	Intervention	Title	Study name	Reason for exclusion from quantitative synthesis	Results
Stone et al. 2017	Combination of nonlethal tools	*Adaptive use of nonlethal strategies for minimising wolf-sheep conflict in Idaho*	Wood River Wolf Project adaptive use of nonlethal tools to protect sheep bands	Excluded from quantitative review because the study combines multiple non-lethal tools and the results cannot be attributed to one single tool thereby rendering it unusable in the meta-analysis.	Over the 7-year period, sheep depredations were 3.5 lower in the protected area versus the non-protected area.
Rossler et al. 2012	Shock Collar	*Shock Collars as a Site-Aversive Conditioning Tool for Wolves*	Site-Aversive Conditioning to livestock farms	Excluded from quantitative review due to the absence of control farms, and the before/after controls could not be used due to a lack of quantitative data for the measures of interest (depredation, wolf visits) to the farms before the start of the treatment.	2 farms with livestock pastures surrounded by shock zones. Farm A = 2 visits in the shock zone, Farm B = 0 visits in the shock zone. No more livestock depredations.
Rigg et al. 2011	Livestock Guarding Dog	*Mitigating carnivore-livestock conflict in Europe: lessons from Slovakia*	On-farm livestock-guarding dog trials	Excluded from quantitative review due to lack of variance (SE, var…) data or raw data to calculate the variance.	Mean losses on treatment farms (LGDs) x=1.1 sheep (n=13) and mean losses on control farm x=3.3 sheep (n=45 farms).
Schultz et al. 2005	Shock Collar	*Experimental use of dog-*	Dog training collars to deter	Excluded from quantitative review due to lack of control for the measure of	After initial shocking, shock

		training shock collars to deter depredation by gray wolves	wolves from livestock in Wisconsin	interest (*depredation*). The only usable data (mean distance moved before/after shocking) was not a variable of interest for our research question.	collar beeper and command center seem to be able to keep wolves (*n*=2) from cattle farm that had previously suffered depredations. It however did not keep non-collared wolves from predating on calves.
Salvatori & Mertens 2012	Electric Fence	*Damage prevention methods in Europe: experiences from LIFE nature projects*	Electric fences: PORTUGAL	Excluded from quantitative review due to lack of variance (SE, var...) data or raw data to calculate the variance.	*N*=10 holdings 100% reduction in depredation
			Electric fences: SPAIN		*N*=30 99% reduction in depredation
			Electric Fences: ITALY		*N*=239 57.80% reduction in depredation NOTE: some holdings did not keep their sheep in the fenced areas. Losses were self-reported.
			Electric Fences: CROATIA		*N*=11 100% reduction in depredation
	Livestock Guarding Dog		Livestock guarding dogs: PORTUGAL		*N*=64 holdings Mean annual number of animals killed per holding: Before = 11.1 After = 6.4
			Livestock guarding dogs: SPAIN		*N*=42 holdings Mean annual number of animals killed per holding: Before = 15.1 After = 5.3
Breck et al. 2002	RAG-box (radio-activated guard)	*Non-lethal radio activated guard for deterring wolf depredation in Idaho: summary and*	Case history 1: Salmon River	Excluded from the quantitative review because the results were descriptive and the quantitative data was not sufficiently detailed (nor was there a true before/after setup) to extract a non-biased effect size.	RAG box firing and snow tracking showed that wolf tried to enter the pasture but was repelled by the RAG box. No calves were

		call for research			killed during the 30-day trial period.
			Case History 2: East Fork of the Salmon River		No calves were killed when the RAG box was functional, even though wolves approached the pastures (the RAG box was activated). A calf was killed the night the RAG box misfunctioned, but no other calves were killed after fixing of the box.
U.S. Fish and Wildlife Service 2009	Fladry ; Range Riders	*Mexican Wolf Recovery Program: Progress Report# 12 Reporting Period: January 1–December 31, 2009*	Proactive management to reduce livestock depredation by wolves	Excluded from quantitative review due to lack of quantitative data.	Fladry (*n*=4): in all four management activities across Arizona and New Mexico fladry reduced depredation by 100%, as no livestock were killed after instatement of fladry barriers.
					Range riders (*n*=4): in two out of four studies, range riders reduced depredation by 100, whereas two other studies, had one and ten depredation incidents, respectively.

R-scripts

1. *Script standardised Mean Difference meta-analysis*

```
################################################
# Installing the metafor package (one time operation)
install.packages("metafor")

# Installing the remote packages before installing the "development' versions of the metadat
# and metafor packages
install.packages("remotes")
remotes::install_github("wviechtb/metadat")
remotes::install_github("wviechtb/metafor")

# Installing the numDeriv and clubSandwich packages
install.packages("numDeriv")
install.packages("clubSandwich")

#(Based on materials from the Meta-Analysis Workshop for ESMARConf202 by Wolfgang Viechtbauer)
################################################
```

```r
# Loading the metafor package
library(metafor)

# Reading in data from SMD nonlethal excel file and naming it "dat'
library(readxl)
dat <- read_excel("data_SMDnonlethal.xlsx")

# Examining the data
dat

# Spreadsheet-like view
View(dat)

# # CALCULATING STANDARDISED MEAN DIFFERENCE (Hedges g) for each individual study # #

###Shivik et al.,2003: Case study 1: Primary repellents in wolf territories in Wisconsin (bait sites): FLADRY

# Transforming Standard Error from data to usable standard deviation
#SE1 = 0.515 to standard deviation
sd1i <- 0.515*sqrt(6)
sd1i

# SE2 = 0.458 to standard deviation
sd2i <- 0.458*sqrt(6)
sd2i

# Calculate SMD
escalc(measure="SMD", m1i=2.49, sd1i=sd1i, n1i=6,
      m2i=2.00, sd2i=sd2i, n2i=6)

###Shivik et al.,2003:Case study 1: Primary repellents in wolf territories in Wisconsin (bait sites): MAG

# Transforming Standard Error from data to usable standard deviation
#SE1 = 0.183 to standard deviation
sd1i <- 0.183*sqrt(6)
sd1i

# SE2 = 0.402 to standard deviation
sd2i <- 0.402*sqrt(6)
sd2i

escalc(measure="SMD", m1i=1.06, sd1i=sd1i, n1i=6,
      m2i=1.78, sd2i=sd2i, n2i=6)

###Rossler et al., 2012: Site-Aversive Conditioning to Bait Sites

# Transforming Standard Error from data to usable standard deviation
#SE1 = 0.06 to standard deviation
sd1i <- 0.06*sqrt(10)
sd1i

# SE2 = 0.15 to standard deviation
sd2i <- 0.15*sqrt(4)
sd2i
```

```
escalc(measure="SMD", m1i=0.2, sd1i=sd1i, n1i=10,
       m2i=0.9, sd2i=sd2i, n2i=4)

###Hawley et al., 2009: Shock collar trials for bait stations

# Transforming Standard Error from data to usable standard deviation
#SE1 = 3.043 to standard deviation
sd1i <- 3.043*sqrt(5)
sd1i

# SE2 = 20.435 to standard deviation
sd2i <- 20.435*sqrt(5)
sd2i

escalc(measure="SMD", m1i=9.420, sd1i=sd1i, n1i=5,
       m2i=55.531, sd2i=sd2i, n2i=5)

###Gehring et al., 2010a: Utility of livestock protection dogs for deterring wolves from cattle farms

# Transforming Standard Error from data to usable standard deviation
#SE1 = 0 to standard deviation
sd1i <- 0*sqrt(6)
sd1i

# SE2 = 0.008 to standard deviation
sd2i <- 0.008*sqrt(5)
sd2i

escalc(measure="SMD", m1i=0, sd1i=sd1i, n1i=6,
       m2i=0.021, sd2i=sd2i, n2i=6)

###Samelius et al., 2021: Keeping predators out: testing fences to reduce livestock depredation at night-time corr
als
escalc(measure="SMD", m1i=0, sd1i=0, n1i=7,
       m2i=1.429, sd2i=1.397, n2i=7)

### Now manually export SMD data to Excel file under yi (SMD measure) and vi (variance measure) for further
steps

# # FITTING A RANDOM EFFECTS MODEL AND MAKING A FOREST PLOT # #

# Fiting a random-effects model
res <- rma(yi, vi, data=dat)
res

# Rounding results to 2 digits
print(res, digits=2)

# Making a forest plot with model results and legends
mlabfun <- function(text, res) {
  list(bquote(paste(.(text),
                    " (Q = ", .(formatC(res$QE, digits=2, format="f")),
                    ", df = ", .(res$k - res$p),
                    ", p ", .(metafor:::.pval(res$QEp, digits=2, showeq=TRUE, sep=" ")), "; ",
                    I^2, " = ", .(formatC(res$I2, digits=1, format="f")), "%, ",
                    tau^2, " = ", .(formatC(res$tau2, digits=2, format="f")), ")")))}
```

```
forest(res, slab=paste(reference, sep=" - "), cex=0.9, mlab=mlabfun("RE Model", res),
      psize=1, header = "Intervention and Author(s)", xlim = c(-9,4), ylim=c(-2, 18), order=dat$Type, rows=c(1:2,5,8
,11,14),
      alim = c(-6,2), refline = 0, xlab = "Standardized Mean Difference (Hedges g)")

### Switch to bold italic font for the next step
par(cex=0.8, font=4)

### Adding text to the subgroups
text(-9, c(3,6,9,12,15), pos=4, c("Shock Collar",
                                "Livestock Guarding Dog",
                                "Tall fence + top electrified",

                                                  "Fladry",
                                "Movement Activated Guard"))
### Adding a legend on the reffline
op <- par(cex=0.8, font=1)
text(c(-1,0,1),     17, c("Effective", "<  1  > ", "Ineffective"))
```

2. *Script relative risk ratio meta-analysis*

```
################# CALCULATING RELATIVE RISK RATIOS (RR) ###################

# load the metafor package
library(metafor)

# Reading in data from SMD nonlethal excel file and naming it '‘dat'
library(readxl)
dat <- read_excel("data_RRnonlethal.xlsx")

# Examining data
dat

# Spreadsheet-like view of the data
View(dat)

# Calculate RR based on 2x2 tables
# The variables corresponding to the 2x2 tables are: n_deaths_treatment, n_survival_treatment, n_deaths_control, n
_survival_control
#
#          |     deaths              survival

# treated  | n_deaths_treatment  n_survival_treatment
# control  | n_deaths_control    n_survival_control

# Computing log risk ratios and corresponding sampling variances
dat <- escalc(measure="RR", ai=n_deaths_treatment, bi=n_survival_treatment,
             ci=n_deaths_control, di=n_survival_control, data=dat)

# Examining RR data
dat

# Or in spreadsheet version
View(dat)
```

```r
# yi = the log risk ratios
# vi = the corresponding sampling variances

############## FITTING A RANDOM EFFECTS MODEL AND MAKING FOREST PLOT #########

# fitting random-effects model (the default is to use REML estimation)
res <-rma(yi, vi, data=dat)
res

# Rounding results to 2 digits
print(res, digits=2)

# Estimating the average risk ratio (and 95% CI/PI) or summary effect size
predict(res, transf=exp, digits=2)

# Making a forest with model results and legends with log risk ratio backtransformed to RR
mlabfun <- function(text, res) {
  list(bquote(paste(.(text),
                  " (Q = ", .(formatC(res$QE, digits=2, format="f")),
                  ", df = ", .(res$k - res$p),
                  ", p ", .(metafor:::.pval(res$QEp, digits=2, showeq=TRUE, sep=" ")), "; ",
                  I^2, " = ", .(formatC(res$I2, digits=1, format="f")), "%, ",
                  tau^2, " = ", .(formatC(res$tau2, digits=2, format="f")), ")")))}

forest(res, slab=paste(reference), xlim=c(-32, 12), at=log(c(0.0001,0.05, 0.25, 1, 4, 16)), atransf=exp,
       ilab=cbind(dat$Outcome_Type, dat$Intervention_object, dat$Sample_size__n_),
       ilab.xpos=c(-19,-14,-10), cex=0.7, ylim=c(-3, 20),
       order=dat$Intervention, rows=c(1:3,6,9:16),
       mlab=mlabfun("RE Model for All Studies", res),
       psize=1, header="Intervention and Author(s)", xlab = "Relative risk ratio (RR) of behaviour-based intervention"
)

### Setting font expansion factor and use a bold font
op <- par(cex=0.7, font=2)

### Adding additional column headings to the plot
text(c(-19,-14,-10),     19, c("Outcome type", "Unit", "n="))
text(c(-2.5,0,2.5), font = 1,    19, c("Effective", "<  1  > ", "Ineffective"))

### Switching to bold italic font for the subgroups
par(cex=0.75, font=4)

### Adding text for the subgroups
text(-32, c(17,7,4), pos=4, c("Fladry",
                              "Turbo fladry",
                              "Biofence"))

# Same forest plot with subgroup analyses (forest plot represented in the thesis report)
mlabfun <- function(text, res) {
  list(bquote(paste(.(text),
                  " (Q = ", .(formatC(res$QE, digits=2, format="f")),
                  ", df = ", .(res$k - res$p),
                  ", p ", .(metafor:::.pval(res$QEp, digits=2, showeq=TRUE, sep=" ")), "; ",
                  I^2, " = ", .(formatC(res$I2, digits=1, format="f")), "%, ",
                  tau^2, " = ", .(formatC(res$tau2, digits=2, format="f")), ")")))}
```

```
forest(res, slab=paste(reference), xlim=c(-32, 12), at=log(c(0.0001,0.05, 0.25, 1, 4, 16)), atransf=exp,
       ilab=cbind(dat$Outcome_Type, dat$Intervention_object, dat$Sample_size__n_),
       ilab.xpos=c(-19,-14,-10), cex=0.7, ylim=c(-1, 23),
       order=dat$Intervention, rows=c(3:5,8,12:19),
       mlab=mlabfun("RE Model for All Studies", res),
       psize=1, header="Intervention and Author(s)", xlab = "Relative risk ratio (RR) of behaviour-based intervention"
)

### set font expansion factor (as in forest() above) and use a bold font
op <- par(cex=0.7, font=2)

### add additional column headings to the plot
text(c(-19,-14,-10),     22, c("Outcome type", "Unit", "n="))
text(c(-2.5,0,2.5), font = 1,    22, c("Effective", "<  1  > ", "Ineffective"))

### switch to bold italic font
par(cex=0.75, font=4)

### add text for the subgroups
text(-32, c(20,9,6), pos=4, c("Fladry",
                             "Turbo fladry",
                             "Biofence"))
### set par back to the original settings
par(op)

### fit random-effects model in the three subgroups
res.f <- rma(yi, vi, subset=(Intervention=="Fladry"), data=dat)
res.tf <- rma(yi, vi, subset=(Intervention=="Electrified Fladry"),     data=dat)
res.b <- rma(yi, vi, subset=(Intervention=="Biofence"),  data=dat)
res.f
res.tf
res.b

### add summary polygons for the three subgroups
addpoly(res.f, row=10.5, mlab=mlabfun("RE Model for Subgroup", res.f))
addpoly(res.b, row= 1.5, mlab=mlabfun("RE Model for Subgroup", res.b))

################# DOING A META-REGRESSION EFFECT MODIFIERS #################

# fit mixed-effects meta-regression model on '‘Intervention'
res <- rma(yi, vi, mods = ~ Intervention, method="DL", data=dat)
res
```

Excel files

The supplementary digital Excel file "*Supplementary materials. Excel files"* with the review (meta-) data contains worksheets with 1) the full data extraction sheet with meta-data and quantitative data for each study 2) the sheet *data_RRnonlethal* with relative risk studies used for R analyses (also see Script relative risk ratio meta-analysis) and 3) the sheet *data_SMDnonlethal* with standardised mean difference used for R analyses (also see Script Mean Difference meta-analysis).