Inland Norway University of Applied Sciences

Faculty of Applied Ecology and Agricultural Sciences

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Master thesis

Grazing among carnivores

Managing cattle depredation across the Western-world.

Master in Applied Ecology

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Abstract

Extensive and free-ranging grazing practices of cattle are used throughout Europe and North America. Large carnivores such as wolves and bears may prey on cattle. With the recent recovery of large carnivore populations in the Western world, cattle depredation is expected to increase. To mitigate potential conflicts, it is therefore important to find best practice for cattle grazing in carnivore-exposed areas. In my thesis I examined depredation rates of cattle by carnivores in different regions of Europe and North America and performed a survey and an interview study on cattle farming practices, losses to carnivores and other causes of mortality, and mitigation techniques to reduce depredation.

My objectives were (1) to examine cattle depredation over time in carnivore-exposed areas across different countries; (2) to understand the possible geographical variation in cattle depredation in relation to carnivore species present, cattle and carnivore densities, grazing system and preventive measure(s) applied; and (3) subsequently, make recommendations. I hypothesised that predator density influences cattle depredation. Further, I hypothesised higher depredation rates for herds in extensive and free-ranging systems than in systems where cattle grazes in close vicinity to the farm. I expected to see differences between continents and areas both in depredation rates and commonness and effectiveness of measures applied, due to differences in habitat, farming practices, carnivore densities and carnivore management.

Depredation statistics, cattle- and carnivore densities were collected from 25 areas in Europe and North America. The survey was carried out in 18 areas and the interview with eight of the survey participants. I mapped depredation trends over time and modelled depredation of cattle as a function of carnivore presence and density, year, and forest cover. To analyse the social data, I performed a descriptive and inferential analysis, using non-parametric tests.

Cattle depredation increased over time in 70% of the areas in Europe and 60% of the study areas in North America. Cattle depredation was positively related to wolf density in Europe, but only weakly in North America. The social study results aligned with this finding and also showed that depredation occurred more often in extensive and free-grazing systems. Lastly, measures to prevent cattle depredation differed greatly between the continents. While electric fencing was most common in Europe, Americans used lethal control, avoidance and herding to a larger extent. In general, a higher number of preventive measures are commonly used in North America than in Europe.

There is urgent need of a standardised, uniform method to monitor livestock depredation. Especially throughout Europe, where cattle depredation has increased the most and, according to the interviewees, the problem of cattle depredation has become more urgent. I wrote recommendations about: I) the carnivore species, II) replacement of electric fencing and avoiding carnivores, III) carnivores avoiding cattle, IV) lethal control of carnivores.

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1 Introduction

For the last few decades, large carnivores have been recolonizing many areas in Canada, Europe and the United States (Mech 2017), mainly because of stronger legal protection and effective policies (Chapron *et al.* 2014). Managing the recovery of carnivores in a human-dominated landscape is a controversial challenge. Large carnivores both scare and fascinate people (Kruuk 2002) and perceived negative impacts on human livelihoods make conservation of carnivores complicated (Chapron *et al.* 2014). The sparsely populated landscape in which carnivores once thrived does not exist anymore, there are little areas left where carnivores can live without interacting with humans (Mech 2017). Precisely these interactions between carnivores and humans can sometimes result in negative impacts on human livelihood and lead to a negative perception of carnivores. This perceived image of carnivores was the main driver for the near-extinction of many species (Breitenmoser 1998).

In Europe and North America livestock has been grazing in outfields for over thousands of years (Austrheim *et al.* 2008). There are many forms, from the free-grazing of livestock in the boreal forest and Alps (Scotton & Crestani 2019), to the use of extensive rangelands on the great plains (Heady 2019). Throughout the years, practices changed as an adaption to the absence of large carnivores, and livestock was left largely unattended in forested- and mountainous areas (Zimmermann, Wabakken & Dötterer 2003). The production of livestock in outfields has been an important policy goal throughout the western world (Rønningen, Renwick & Burton 2012). However, with the return of carnivores, it is not possible to perform this practice the same way.

Carnivores prey on animals, and this feeding habit comes directly into conflict with livestock grazing (Kaczensky 1999). Annually, <1-5% of the livestock that is raised, is lost to carnivores. Although this is a relatively low number (Baker *et al.* 2008), the losses can be locally significant, both in terms of livestock biomass as economic impact (Knowlton, Gese & Jaeger 1999). In general, the predation of livestock by carnivores is the main source of conflict between humans and large carnivores (May *et al.* 2008; Macdonald & Loveridge 2010) and it influences their coexistence greatly (Reynolds & Tapper 1996). Livestock depredation has been described as a matter of conservation concern (Treves & Karanth 2003; Woodroffe, Thirgood & Rabinowitz 2005) and to be able to conserve large carnivores and perform livestock husbandry it is of utmost importance to prevent or mitigate the conflict. Therefore, measures to prevent negative impacts on depredation of livestock are essential (Miller *et al.* 2016; Eklund *et al.* 2017; van Eeden *et al.* 2018).

There is a wide variety of preventive measures to protect livestock from large carnivores (Shivik 2006; Treves, Wallace & White 2009). These range from lethal (e.g., culling) to non-lethal methods (e.g., fences, guarding dogs), overarching policy goals (e.g., carnivore population caps), interventions that are funded by authorities or initiated and performed by affected parties (e.g., compensation systems

and increased guarding), to the transfer of information (e.g., public meetings) (Eklund *et al.* 2017). During the last two decades, much has been published on measures to prevent livestock depredation. However, only a few articles actually evaluate effectiveness of these measures (Miller *et al.* 2016).

The evidence that exists, suggests that the effectivity of lethal control as preventive measure varies, while the use of guarding-dogs, fencing or herdsman can significantly reduce losses (van Eeden *et al.* 2018) . The combination of multiple non-lethal management actions has shown a higher effectiveness in preventing livestock attacks than single actions (Moreira-Arce *et al.* 2018). However, it is not only the preventive measure that determines the likelihood of predation in grazing areas, also ecological, e.g. prey biomass (Miller 2015) and social conditions e.g. compensation, can play a part (Ugarte *et al.* 2019). Most literature on livestock depredation covers several species together or only small livestock species (e.g., sheep and goats). There is little research focusing on depredation or preventive measures of larger species as cattle. This can be explained by the fact that cattle are depredated in lower numbers than smaller livestock (Zimmermann, Wabakken & Dötterer 2003).

Overall, cattle depredation is more often included in studies in North America than in Europe, but these studies primarily focus on a singular measure. e.g., the use of livestock-protection dogs (Gehring *et al.* 2011) or lethal control (Bradley *et al.* 2015). Pimenta *et al.* (2017) studied the effect of husbandry system applied and individual management practices to prevent depredation of cattle in Portugal. They found that cattle depredation mostly occurred in free-grazing systems, characterised by large herds on communal lands further away from shelter and seldom confined. They found that night confinement was the most important factor reducing wolf (*Canis lupus)* attacks. A study on wolf depredation on fenced cattle in Montana and Idaho, also found that larger pastures with more cattle located farther from residences were more likely to have cattle depredation (Bradley & Pletscher 2005). These findings identify that depredation of cattle is influenced by the grazing system and measures must be adjusted towards the system applied. Wolves were described as an important predator of cattle in many reports from North America (Muhly & Musiani 2009), as well as in some European countries, such as Greece and Portugal (Iliopoulos *et al.* 2009; Pimenta *et al.* 2017).

Despite that cattle are depredated in lower numbers than sheep, farmers and veterinarians have raised concern about carnivore-induced stress and behavioural changes of cattle in outfields (Zimmermann, Wabakken & Dötterer 2003). This concern in combination with an increase in local meat production (Tofastrud *et al.* 2019) and the call for national food security has led to the start of the project "CarniForeGraze". As part of this project the best practice for cattle farmers in a landscape shared with carnivores is examined. This is important to achieve coexistence, productivity and sustainability (Janeiro-Otero *et al.* 2020). The goal is to find factors of success, but also risk factors of depredation and stress that carnivores induce on cattle.

Although the project focusses primarily on cattle farming in Norway, in this thesis I incorporate international experiences to find factors of success and failure when it comes to cattle grazing in carnivore-exposed areas.

To my knowledge, there is no review of depredation of cattle and possible measures applied across the western world. Therefore, it is of great value to analyse depredation of cattle on an international scale and to further analyse the topic by surveying cattle farming representatives in grazing areas where large carnivores are present. This may uncover new findings on how free-grazing practices can be applied in this situation. For this thesis, I examined depredation rates of cattle by large carnivores in areas in Europe and North America and performed a survey with involved parties in these countries. My specific objectives are (1) to examine cattle depredation over time (2010-2020) in carnivore-exposed areas across different countries, with regards to cattle density, carnivore density and depredation rates. (2) To understand the possible geographical variation in cattle depredation with relation to carnivore species present, cattle-and carnivore densities, grazing systems and preventive measure(s) applied. (3) Study the measures and write recommendations for free-grazing and extensive grazing systems. I decided to combine evidence-based research (cattle depredation statistics) with social science (experience with depredation and measures).

Although it is difficult to make specific hypotheses on the topic due to the lack of literature available on cattle depredation, I hypothesised that carnivore depredation on cattle is influenced by different conditional variables in the areas, such as carnivore species present and their density, cattle density (Eklund *et al.* 2017), and grazing system applied. Also, I hypothesised that wolf density increases cattle loss to depredation. Besides the carnivore species, the applied grazing system can significantly influence cattle depredation. Therefore, I hypothesised higher depredation rates for herds in extensive grazing systems further away from farms and free-ranging systems, compared to intensive systems with fenced pastures close to the farm. The carnivore species present and grazing system influence the use and effectiveness of measures to protect cattle as well (Mkonyi *et al.* 2017). Because the study is conducted on an international scale and ecological and social factors that are specific for an area influence depredation and the measures applied differ per location, I expected to see differences between continents and areas both in depredation rates and measures applied.

2 Materials and methods

The approach of combining two or more different research methods is known as triangulation. In my thesis I combine a study of depredation numbers with a social study of cattle depredation experiences. Triangulation can increase credibility and validity of the research findings (Heale & Forbes 2013), but also brings complexity to the presentation of the study. Therefore, the depredation statistics and social study are treated separately in the methods and results chapter. The general approach is shown in Figure 1. For the statistical analyses of the depredation statistics and social study the confidence level was set to 5%.

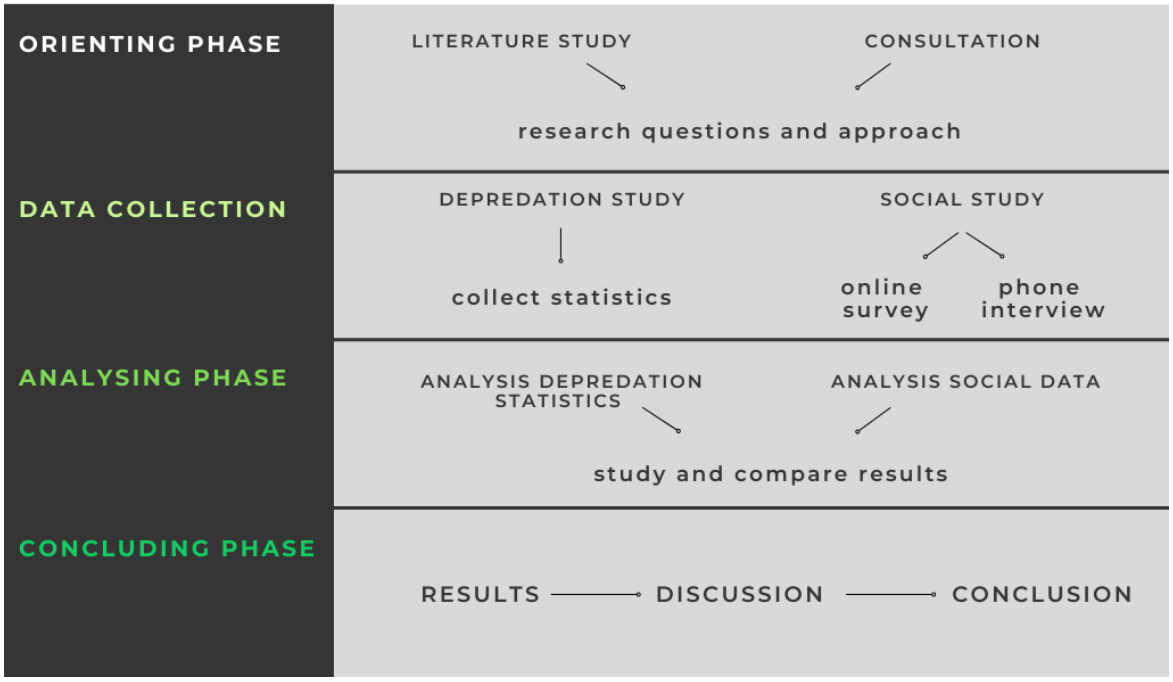

Figure 1. General research approach of my thesis on cattle depredation in western countries.

2.1 Study area

The study is limited to Europe and North America, because similar grazing systems are found there. Therefore, information on depredation and preventive measures applied can be a valuable addition to the "CarniForeGraze" project, that seeks a best practice approach for cattle farmers in carnivore-exposed areas. Different countries, states and provinces were selected. In certain countries, only regional data was available. To avoid misleading results, data from such regions replace the national data**.** Consequently, the term 'area' is used to describe both countries and regions. I selected areas where carnivores are present in cattle grazing areas as initial sample (Appendix I). I was provided with sufficient depredation statistics from 25 of the selected areas (Appendix II) and the survey was done for 18 of the selected areas, from which eight participants were interviewed (Table 1, Appendix III).

Area	Scale	Nation	Continent	Depredation	Survey	Interview
Croatia	Nation	Croatia	Europe	**X**		
Czech-Republic	Nation	Czech-Republic	Europe	**X**	**X**	
Finland	Nation	Finland	Europe	**X**	**X**	
France	Nation	France	Europe	**X**	**X**	**X**
Greece	Nation	Greece	Europe	**X**		
Innlandet county	County	Norway	Europe	**X**	**X**	
Lithuania	Nation	Lithuania	Europe	**X**		
Lower Saxony	County	Germany	Europe	**X**	**X**	
Portugal	Nation	Portugal	Europe	**X**	**X**	
Arges county	County	Romania	Europe	**X**		
Saxony	County	Germany	Europe	**X**	**X**	**X**
Slovenia	Nation	Slovenia	Europe	**X**	**X**	**X**
Sweden	Nation	Sweden	Europe	**X**		
Switzerland	Nation	Switzerland	Europe	**X**	**X**	
Veneto region	Region	Italy	Europe		**X**	**X**
Alberta	Province	Canada	North America	**X**	**X**	
British-Columbia	Province	Canada	North America	**X**	**X**	**X**
Kodiak island	Island	Canada	North America		**X**	**X**
Manitoba	Province	Canada	North America	**X**		
Ontario	Province	Canada	North America	**X**		
Quebec	Province	Canada	North America	**X**		
Saskatchewan	Province	Canada	North America	**X**	**X**	**X**
Minnesota	State	U.S.A.	North America	**X**		
Montana	State	U.S.A.	North America	**X**		
Oregon	State	U.S.A.	North America	**X**		
Washington	State	U.S.A.	North America	**X**		
Wyoming	State	U.S.A.	North America	**X**	**X**	**X**

Table 1. Areas included in the study, including the scale, nation and continent. In the last three columns, the X marks which study methods are applied in the areas.

2.2 Depredation statistics study

2.2.1 Data collection

Depredation statistics - response variable

Experts (members of the large carnivore initiative in Europe and statal governmental carnivore experts in North-America) were contacted and asked to provide statistics on cattle depredation by large carnivores over the last 10 years (2010-2020). Alternatively, they were asked for other sources for this information. For this step, a total of 92 people were contacted. If this did not yield a response, I left out the area. In addition, I received information about the availability of cattle depredation numbers, cattle and carnivore densities. These were not equally well registered in all areas. From the initial sample, 13 areas proved to yield insufficient data and I received data from 25 areas (Table 1). In Appendix I the limitations of all excluded areas are described.

Conditional variables - predictor variables

The same experts provided statistics on cattle- and carnivore densities. For carnivore densities, population estimates would ideally be divided by the size of the population's distribution range. However, in this thesis the carnivore population estimate was divided by the area's surface in m^2, because the exact carnivore-distribution was not available for each area. The same method was applied for cattle densities. When the proportion of cattle that grazes outside was not registered, experts were asked for an estimate. In addition to carnivore and cattle densities, forest coverage (2018) was compiled for each area. To achieve this, a raster-file with global forest cover was downloaded from Copernicus Land Monitoring Service (Copernicus 2021) and the approximate forest cover for each area was calculated in QGIS (QGIS Development Team 2021). Other predictor variables were the presence/absence of each carnivore species, year in which depredation occurred, the area and continent where it occurred and the total amount of carnivore species present.

2.2.2 Statistical analyses

Mapping data over time

I used QGIS to explore and visualise the depredation trend in different areas over time. First, I divided the total number of depredations of an area by the total number of cattle present, to get the percentage of total cattle taken by carnivores per area. Then, to calculate a trend, I applied this formula:

$$Depredation\ trend = \frac{\%\ \text{total cattle last year}}{\%\ \text{total cattle first year}}$$

The result was a number <1 if depredation increased and >1 if it decreased. Finally, to visualise the trend in different areas, I mapped this with different colours.

Data exploration

For the statistical analyses I worked in Rstudio (Rstudio Team 2020) with R version 4.0.4 (R Development Core Team 2019). Before performing the statistical analysis, I studied the data using the package "Tidyverse" (Wickham 2017) following the data exploration protocol described by Zuur, Ieno and Elphick (2010). The collinearity between the predictor variables was checked by calculating the Pearson correlation coefficient (Kassambara 2016). If the correlation between two predictor variables was > 0.7, only one of the predictors was used during modelling. I also studied if predictor variables had a different effect on cattle depredation depending on conditional variables as continent to find possible interactions. Lastly, I plotted the response variable over time and for the different areas and studied the patterns to check for spatial and temporal dependency.

Model building

The data consists of depredation numbers over time from the same areas. Because the data consists of repeated measurements of the same area, a random effect is included to account for spatial and temporal autocorrelation. Besides that, the response variable included a high number of zeroes. Therefore, I used a generalised linear mixed model (Brooks *et al.* 2017) and applied both negative binomial and zero-inflated negative binomial models (Blasco-Moreno *et al.* 2019). In addition, the total number of depredations of an area by itself is not comparable to the number of another area. Because this does not represent the percentage of total cattle that was killed. There is a so-called differential "exposure" in the data, in this case different sizes of the cattle population in an area (Dobson & Barnett 2018). Therefore, an offset of the total number of cattle was included in the model.

Model selection and validation

Model selection was performed by hypothesis testing (Johnson & Omland 2004). Total depredation was used as the response, to test the effect of conditional variables on depredation. Wolf density is an important predictor of cattle depredation according to literature (Muhly & Musiani 2009) and was included. Other variables that were included during model building were brown bear (*Ursus arctos)* density, year of depredation, number of carnivore species (nc), cattle density and forest cover. Furthermore, I included an interaction between wolf density and continent. I used the Akaike Information Criterion (AIC) (Mazerolle 2019) to find which model had the best model fit. To validate the model fit, I plotted the fit of the residuals versus fitted values of the model with the "DHARMa" package. I also ran the goodness-of-fit tests on the scaled residuals (Hartig 2019), dispersion, zero inflation and temporal- and spatial correlation were also tested. I predicted the effects on depredation with the final model, these predictions were plotted with "sjPlot" (Lüdecke 2019).

2.3 Social study

2.3.1 Data collection

To collect data about experience with depredation and preventive measures, I used a mixed-mode survey approach. This consisted of a *fixed-form internet surve*y combined with a *post-survey semi-structured* interview. This method has many advantages; e.g., improvement of the response rate and reduction of coverage errors (Gigliotti 2011; Dillman, Smyth & Christian 2014). It can also yield more detailed information through discussing the results with participants after the internet survey. To identify relevant informants for the survey, the same experts from §2.3.1 were asked for a contact involved with cattle farmers and had experience with depredation by large carnivores, e.g., a cattlemen's association. The survey yielded 18 respondents (Table 1, Appendix III).

The *formal survey* and *semi-structured interview* are components of the social study approach. There is one additional component, namely the *initial request* to participate in the survey. Each of these components can influence the results of the survey. In the initial request, someone is asked to participate in the survey. Two main points needs to be covered, 1) the legitimate reasons for collecting the data and 2) the respondents' benefits or reasons to help. How the request is framed can affect the response rate (Tourangeau & Ye 2009). Often, the initial request tends to emphasise benefits of participation. However, literature suggests that emphasising the disadvantages of not participating yields in a higher response rate (Tourangeau & Ye 2009; Lynn 2019). Which is in line with the prospect theory that avoidance of negative outcomes is a stronger driver than the achievement of positive outcomes (Kahneman 1979). Therefore, in the initial request was emphasised that not participating leads to the loss of helpful information shared during the interview and afterwards (see Appendix IV).

2.3.2 Study design

Formal survey

Barbara Zimmerman, project leader of the "CarniForeGraze" project conducted a postal survey about depredation of cattle across the western world (1999). This survey formed the base of my study design, as the results might be compared later in the project. The 1999 survey contained questions about the geographical location, cattle grazing methods, carnivore species, cattle depredation, measures to prevent depredation and tolerance towards carnivores. These topics were used as sections of my survey. The questions were mainly close-ended, either multiple-choice regarding the topic or a rating question, using the Likert-scale (Likert 1932). In Table 2 the sections of the survey and the specific questions used in the analysis are shown. The survey also included another section about the acceptance of large carnivores, and there were more detailed questions about e.g., the cattle breeds used, time and season of depredation (Appendix V).

Nettskjema was used to design and conduct the survey. This tool makes it possible to keep complete anonymity of respondents. It is illegal to collect personal data without permission from the Norwegian data protection services (NSD). I consulted an NSD adviser at Inland Norway University of Applied Sciences, she confirmed that the survey could be conducted without notifying it. The survey was piloted and tested by three people outside of the project, two from North America and one from Norway. The final design of the survey is included in Appendix V.

Table 2. Topics and corresponding question topics of the survey used in the analysis of the survey data

Section	Topic of the question	Type
Geography	Country or state where the survey is answered	Open-ended
	Area to which the survey applies	Open-ended
Cattle grazing methods	Which husbandry method(s) are applied? - Intensive/ extensive/ free grazing/ other	Multiple-choice
	Rate the mortality factors of cattle in your areas (diseases, parasites, accidents, lightening and storms, wild carnivore depredation, dog depredation, theft by humans, traffic collisions, poisoning, consumption of metal waste, other) - Not important – little important – neutral – important – very important (0-4)	Likert-/ordinal-scale
Carnivores	Carnivore species present - Bear / Cougar / Coyote / Wolf / Lynx	Multiple-choice
Cattle and carnivores	Carnivore species that kill cattle - Bear / Cougar / Coyote / Wolf / Lynx	Multiple-choice
	Importance of a carnivore species for cattle depredation (for each species) - Not important – little important – neutral – important – very important (0-4)	Likert-scale-/ordinal scale
	Occurrence of a carnivore species depredating cattle - Never – rarely – yearly –monthly – weekly	Likert-scale
Preventive measures	Rate the commonness of each measure to prevent cattle depredation (zoning, wild prey management, translocation, lethal control, indoor night confinement, herding, guarding night only, guard animal other, electric fencing, deterrents disruptive stimuli, deterrents aversive stimuli, avoiding areas) - Not common – little common – neutral – common – very common (0-4)	Likert-/ordinal scale
	Rate the effectiveness of each measure to prevent cattle depredation (same measures as above) - Not effective – little effective – neutral – effective – very effective (0-4)	Likert-/ordinal scale
	Do farmers receive compensation for cattle depredation? - Yes/no	Multiple-choice

Semi-structured interview

As final part of the social study I conducted a semi-structured interview. This method consists of a set of pre-decided questions, and the possibility to add questions during the interview (DiCicco-Bloom & Crabtree 2006). I interviewed after the survey for several reasons. First, English is not always the participants native language. By conducting the survey first, they were able to translate and prepare themselves for the interview. Furthermore, it is useful to collect data before the interview and discuss answers with the participant. The questions asked or discussed with the participant depended on the results of the survey and the statistics about the country.

In general, the most important topics to discuss were cattle grazing systems, depredation of cattle and measures to prevent depredation. Appendix VI shows an example of the interview design.

The interview was conducted by phone or an online calling appliance. Because I gathered qualitative data with the survey, I decided to interview 4 respondents from Europe and 4 from North America. All interviews were recorded on an analogue recorder (Sony ICD-BX140) with the participants consent. This was in line with the NSD regulations and ensured that none of the recordings can be published online. After the interviews, I listened back to the recording and wrote down a detailed transcript.

2.3.3 Statistical analysis survey

During the survey, I gathered information about depredation of cattle, preventive measures and conditional variables of the area. The general aim is to analyse the relationships between depredation of cattle, measures applied and conditional variables of an area (e.g., carnivore species) (see Fig. 2).

Data exploration

Before the analysis, I selected a dataset with the variables I considered important to answer the hypotheses. These variables are related to cattle depredation, preventive measures and conditional variables. The multiple-choice questions in the survey can be interpreted as presence/absence questions (binomial variables). For example, in the question about which grazing systems are present, selected systems categorized as 'present' and not selected systems as 'absent'. The questions about the mortality factors and measures are a rating, can be interpreted as an ordinal scale (0-4). No continuous variables were collected with the survey. I plotted all variables separately and used the "Likert" package in R (Bryer, Speerschneider & Bryer 2016) to visualise the Likert-questions. The mortality factors and preventive measures were transformed to an ordinal scale (0-4). For these variables, the collinearity was checked.

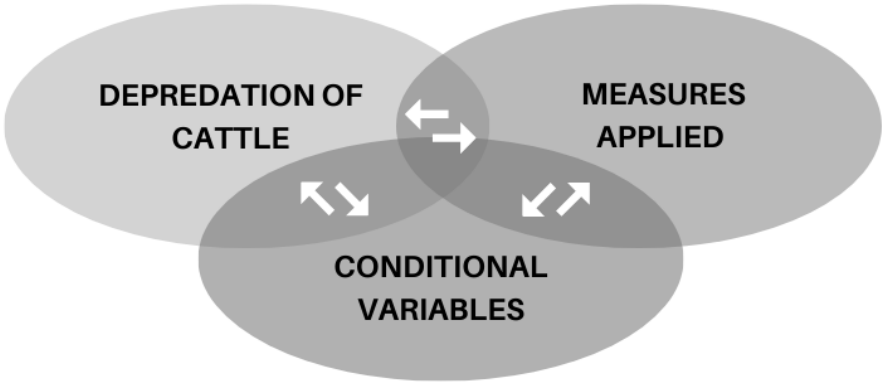

Figure 2. Key relationships explored: depredation of cattle, preventive measures applied and conditional variables

Reliability of the questions

When handling ordinal survey data, it is common to measure the reliability of questions when they share the same topic. If questions are related, the answers should be internally consistent, thus there should be a strong positive correlation between the response (Barry 2017). The Cronbach's alpha (Cronbach 1951) is a measure to estimate how strongly selected questions correlate, it gives a coefficient between 0 and 1, the closer to 1 the greater the internal consistency and thus reliability of the questions (Gliem & Gliem 2003). The Cronbach's alpha test was run on questions that shared related topics. These are depredation occurrence, depredation importance, mortality factors and measures (Table 3). The test was run with the "Psysch" package (Revelle 2018), if the value was between 0.7 and 0.9 (Bland & Altman 1997), the questions were considered internally consistent.

Table 3. Variables that were used to test the reliability of the questions, including the topics they are associated with.

Topic	**Variables tested**
Depredation occurrence	Depredation occurrence of: - Bear / Cougar / Coyote / Wolf / Lynx
Depredation importance	Depredation importance of: - Bear / Cougar / Coyote / Wolf / Lynx
Mortality factors	The importance of each mortality factor*
Measures	The commonness of each measure* The effectiveness of each measure*

***see table 2 for all the mortality factors and measures tested in the survey.**

Descriptive analysis

I did not collect continuous variables and it was important to acknowledge the "noncontinuous" character of the data (Heeringa, West & Berglund 2017) when analysing. During the data exploration, variables were studied separately and together. These explorations functioned as a descriptive analysis of the data. The descriptive analysis was used to determine which relationships between variables were interesting to study in a subsequent inferential analysis, by looking at patterns and possible effects of different variables on depredation and preventive measures applied.

Inferential analysis

Because the general aim was to study the relationships between depredation on cattle, measures applied and conditional variables (Fig. 2), it would be interesting to use these components together in a model. But keeping in mind the "noncontinuous" character of the data, applying a linear regression with multiple variables was not possible.

Therefore, the first step was to perform bivariate analysis on interesting relationships between two variables. I performed bivariate tests (The Mann-Whitney U test and Kruskal & Wallis) between *depredation* and a conditional variable and *measures* and a conditional variable. Conditional variables considered were grazing system, carnivore species present and continent.

Response variables that can be used for depredation are depredation occurrence and depredation as a mortality factor. The response used for measures to prevent cattle depredation was either commonness- or effectiveness of measures. The same method was applied to the conditional variables.

The selected response variables were on an ordinal scale (Likert-question) and were transformed to (0-4) to perform the analysis. The predictor variables were either binomial (free grazing - yes/no) or numerical (number of carnivores present). Neither the depredation- or the preventive measures response variables were normally distributed. Therefore, the Mann–Whitney U test (or Wilcoxon rank sum test) was used to test for differences between two groups on the response variable (Mann & Whitney 1947; Fay & Proschan 2010). If the predictor variable had more than two groups, the extended version of the former test, the Kruskal-Wallis test was used (Kruskal & Wallis 1952). Both of these tests are nonparametric and can be used on a response variable with no specific parametric distribution (Fay & Proschan 2010). Nonparametric tests focus on the ranking of data instead of the numerical value itself (Henderson, Comiskey & Alonso 2007), which makes them appropriate for this analysis.

2.3.4 Textual analysis interview

Data exploration and descriptive analysis

The aim of the interview was to gather more detailed information about key topics. To explore the interview data, I carried out a textual analysis through generating a series of word clouds. The topics I focussed on were; depredation on cattle, depredation in grazing systems, depredation by brown bear and wolf and preventive measures that are applied. Because the survey results showed clear differences between Europe and North America for these topics, in this analysis I also compared the continents to each other.

I used the "Wordcloud2" package (Lang *et al.* 2016) to generate the word clouds. Word clouds of words said during the interview were created, interpunction and common words of speech were removed beforehand. In addition, I read the transcripts repeatedly and found interesting quotes to use in the results and discussion as support, when the interview data was in alignment or contrast with the survey data or existing knowledge from literature.

3 Results

3.1 Depredation statistics

3.1.1 General results

Depredation statistics, carnivore-densities and cattle densities were collected from 25 areas - 14 from Europe and 11 from North America. Although it was the goal to collect statistics from 2010-2020, these were not available in all areas. In fact, only 2 areas had this time-span available (Finland and Slovenia). In 15 areas the depredation data was available for the period from 2011-2019. All others had shorter periods, or a 10 years period further back in time (see Appendix VII for all available time-spans).

Depredation statistics over time

There was an increasing trend of cattle depredation in 10 out of 14 areas in Europe and in 7 out of 11 areas in North America (Fig. 3). In Europe depredation was on average 4.46 times higher in the last year than in the first year, in North America this ratio between the last and first year was 2.70. The number of depredated cattle were in general higher in the northern areas in North America.

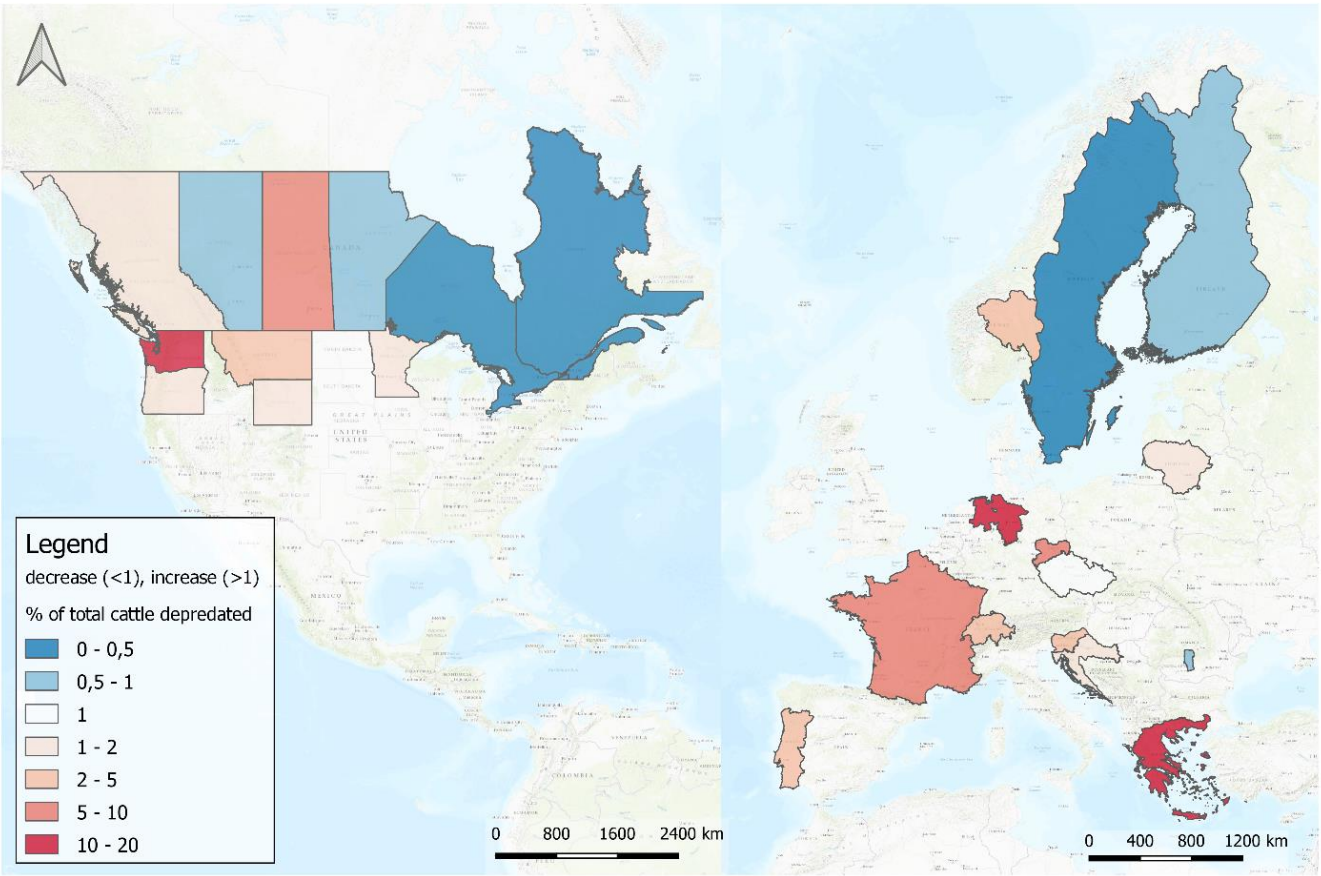

Figure 3. Cattle depredation trends (ca 2010-2020) for the European and North American areas used in the depredation statistics analysis. Depredation trend = change in percentage of total cattle predated by large carnivores between the first and last year. Blue areas show a decreasing trend, while red areas show an increasing trend (Esri Topo World, 2021).

Cattle- and carnivore densities

The average cattle density per km^2 was higher in Europe (10.93) than in North America (4.01). In most areas, the total cattle inventory is published annually, but in France it is only published once in ten years. The same applies for the carnivore densities; in British-Columbia, Manitoba and Romania, therefore there is little variation for these areas. Wolf densities were not available for the areas "Saskatchewan" and "Ontario" so they were excluded for the final analysis. Bear densities are collected for all 12 areas where present (see Appendix VIII). Wolf densities (km ^{2}) were on average higher in North America (0.006) than in Europe (0.004), with the highest densities in Canada (0.01) (Fig. 4). Bear densities were the highest in British-Columbia (0.016), Greece (0.004), Scandinavia (0.006), Slovenia (0.021) and Romania (0.025).

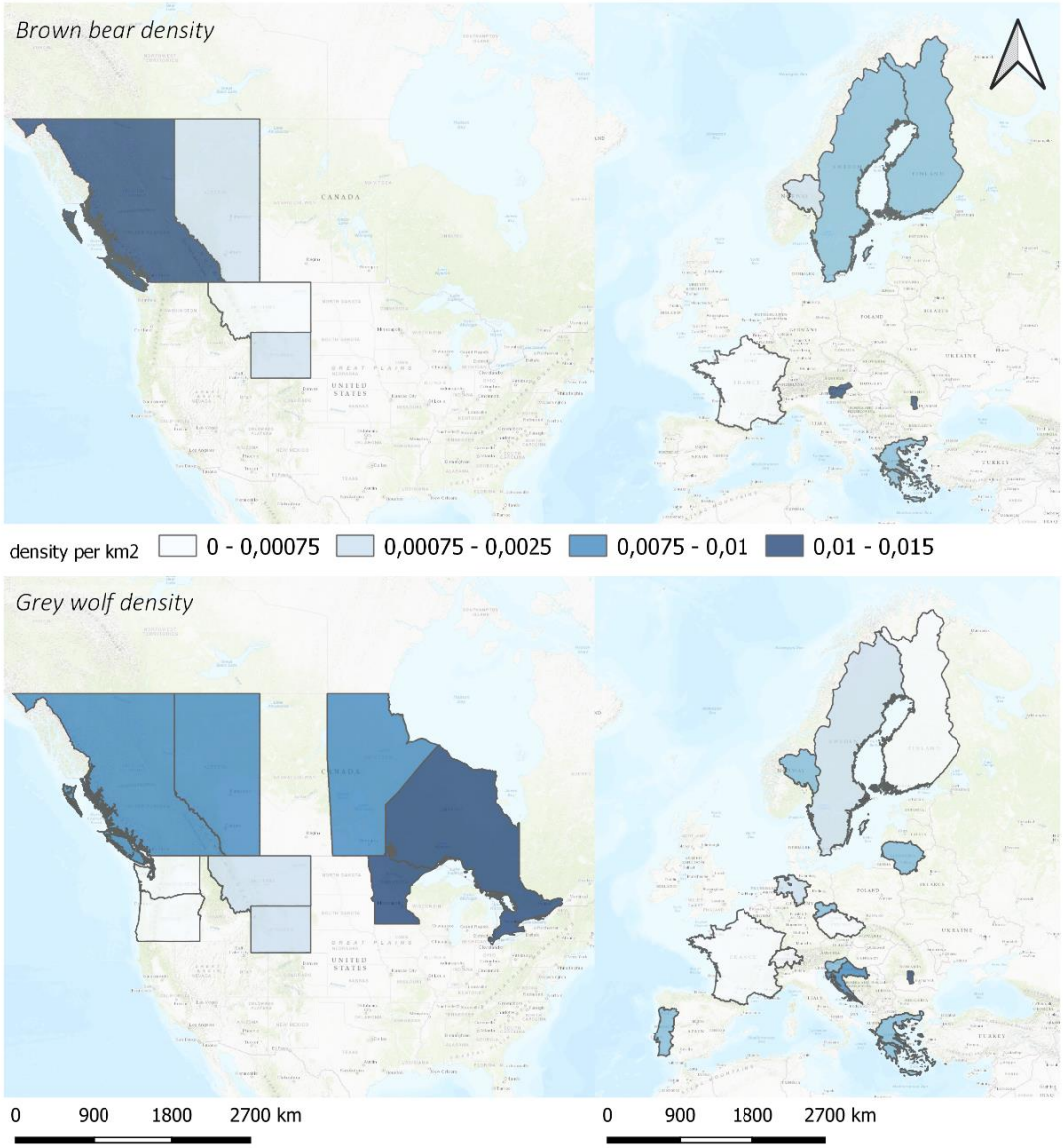

Figure 4. Collected bear- and wolf densities (ca 2010-2020) of the European and North American areas used in the depredation statistics analysis. The average density for each area is shown on this map (Esri Topo World, 2021).

There are in total six large carnivore species present in the complete study area (n = 25). Densities were not collected for other large carnivore species present, such as Black bear (*Ursus americanus*), Cougar (C*ougar concolor*), Coyote (*Canis latrans*), Lynx (*Lynx spec.)*. Black bear, Cougar and Coyote were only present in North America, thus areas with more than three carnivore species were solely present in North America (Appendix VIII).

3.1.2 Relationships between depredation and predictor variables

Significantly higher depredation was found in areas with either two or five carnivore species present, as compared to one, three or four species present (Fig. 5; Kruskall-Wallis chi squared = 0.49, df = 5, p-value < 0.001). Most observations had 2 carnivore species present (67), followed by 3 species (48) and then 5 (46).

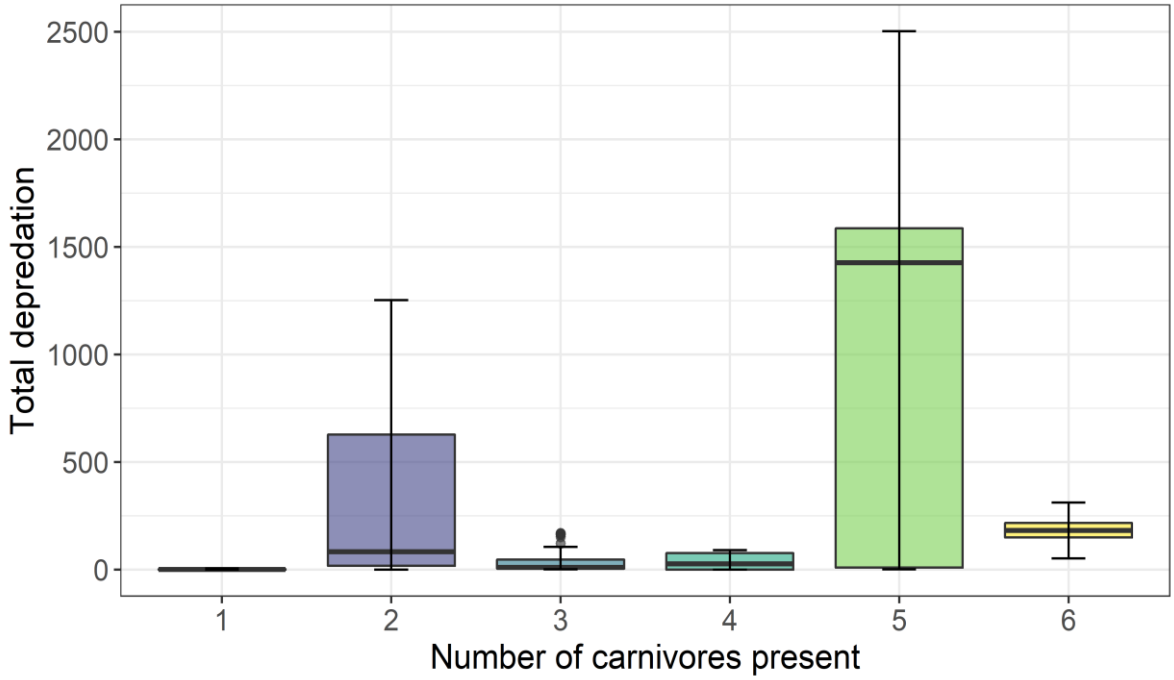

Figure 5. Total number of killed cattle varying over the number of carnivores present. The carnivore species that are present are black bear, brown bear, cougar, coyote, grey wolf and lynx.

On average, depredation numbers were lower in Europe and the highest depredation numbers are measured in North America. However, the difference in depredation between the continents was not significant (Wilcoxon rank sum test, W = 4382, p-value = 0.4177). Wolf, brown bear and coyote showed most variance in depredation numbers (see plots Appendix IX), but wolf depredation had the clearest increasing pattern over time. Depredation numbers increased with wolf density (Fig. 6). However, this pattern was more apparent in Europe than in North America. There was a significant correlation between total depredation and wolf density (Pearson's product-moment correlation = 0.25, t = 3.61, df =204, p-value = <0.001).

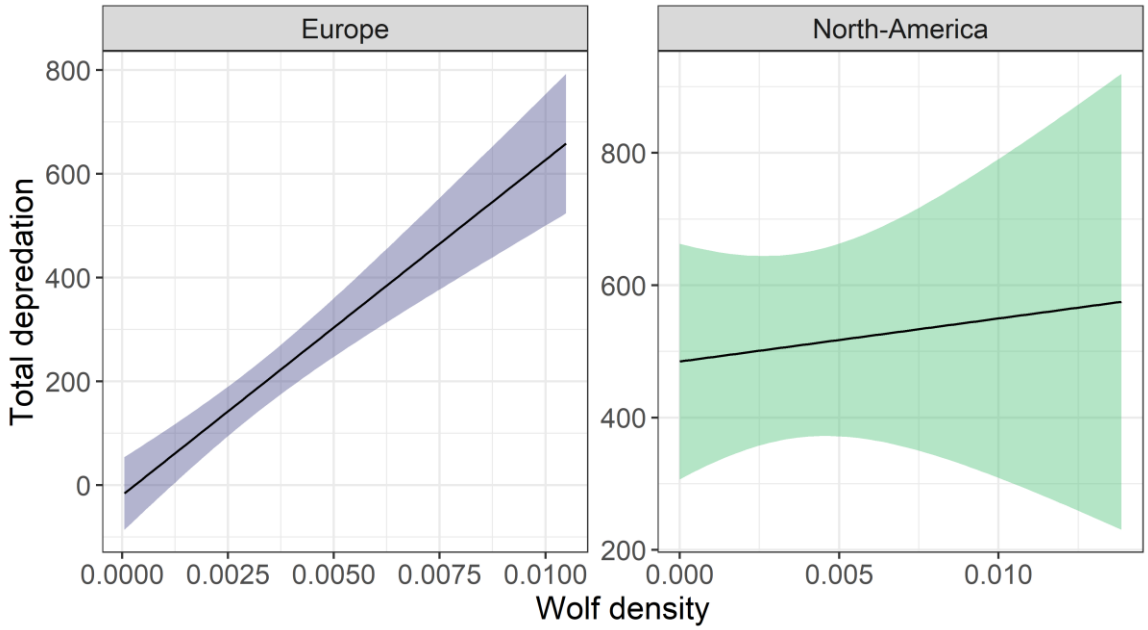

Figure 6. Total cattle depredation in an area as a function of wolf density per km^2.

3.1.3 Model results

For model selection, six top models were used (Table 4), none of the predictor variables were strongly correlated. The model with the best fit was a GLMM negative binomial model, in which total depredation is modelled as the function of wolf density in an interaction with continent, with a random effect of the area id, and cattle total as an offset. This model scored best when it comes to the AIC (Table 4).

Table 4. Top six models in model selection, with used predictors, degrees of freedom, AICc score and Akaike weight

Model	***Variables included***	***df***	***AICc***	***weight***
NB7	dep_total ~ wolf density * continent + (1|area id) + offset(log(cattle_total))	6	2006.1	0.9695
NB	dep_total ~ wolf density + (1|area id) + offset(log(cattle_total))	4	2014.1	0.0171
NB4	dep_total~ wolf density + bear density + (1|area id) + offset(log(cattle_total))	5	2016.1	0.0063
NB5	dep_total ~ wolf density + (1|continent/area id) + offset(log(cattle_total))	5	2016.1	0.0063
NB8	dep_total ~ wolf density + number of carnivores + (1|continent/area id) + offset(log(cattle_total))	9	2020.3	<0.001
NBF	dep_total ~ 1 + (1|area id) + offset(log(cattle_total))	3	2031-4	<0.001

In the final model estimates (NB7), there was a significant positive effect of wolf density on cattle depredation (Estimate= 1.0477, p-value = <0.0001). The effect of continent (p-value >0.05) by itself did not have a significant score, but the interaction of wolf density with continent North America had a significant negative effect (Estimate= -0.9448, p-value = 0.0004).

In general, the model fit was not validated. Wrong dispersion was confirmed when plotting residuals vs. predicted values and plotting histograms of the estimated values to test for dispersion. For some areas, there was very little variance in wolf density over time, which caused deviations in the QQ-plot and clustering and significant quantile deviations in the residual vs. predicted plots (Appendix X). Attempts to improve the model fit by incorporating different variables into the model, run the model with and without random effect and using surface area as offset, did not yield a better fit.

The predictor variable wolf density differed across the areas – with no variance over time in some areas. It was not possible to exclude these areas, because the sample size would be too small. Therefore, the model had to be interpreted very carefully. The model showed an increasing effect of wolf density on cattle depredation, with a stronger effect in Europe than in North America, as visible in the plot of depredation over wolf density in Figure 6.

3.2 Social study

3.2.1 General results

The survey had a total of 21 respondents, 12 from Europe and 9 from North America. 8 out of 21 respondents were also interviewed; 4 from Europe and 4 from North America (Fig. 7).

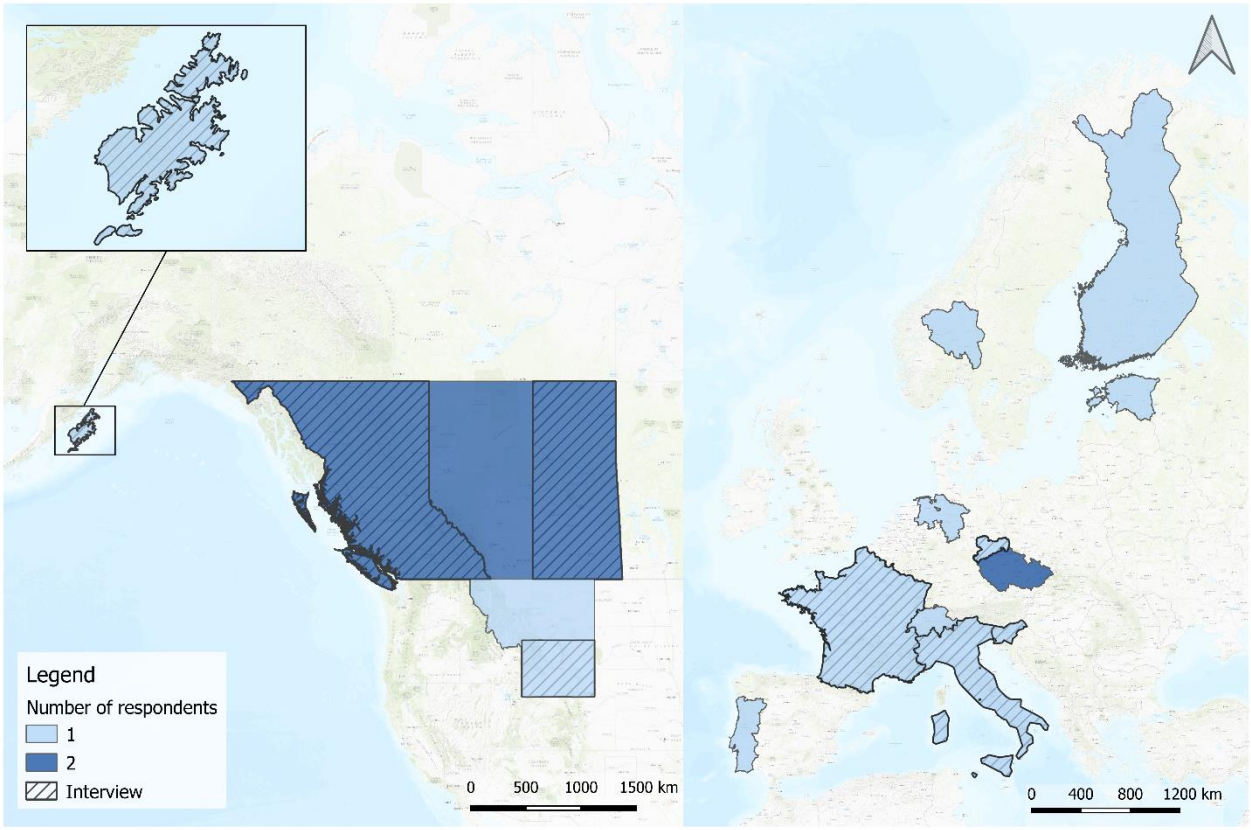

Figure 7. Geographical distribution of 21 respondents of the survey and the 8 interviews in Europe and North America. The light-blue areas had one survey respondent, the dark blue areas two, in the areas marked with a dashed pattern the respondent was also interviewed (Esri Topo World, 2021).

The Cronbach alpha test was run to estimate to what extent questions share the same topic (Cf. table 3 for the explicit variables). For all topics except depredation importance the alpha value was > 0.7. This indicates that the measurements of (the topics of) depredation occurrence, mortality factors and preventive measures were internally consistent. Consequently, they were used for further analysis.

3.2.2 *Descriptive analysis*

Grazing systems and mortality factors

All grazing systems (intensive grazing, extensive grazing and seasonal free-grazing) are applied in both Europe and North- America (Fig. 8). However, intensive grazing on pastures close to the farm is applied more often in Europe than North America, extensive grazing on large fenced areas and free grazing are applied more often in North America. Although extensive grazing is applied often on both continents, free grazing is applied in only 3 areas in Europe, while it is applied in more than half of the areas in North America.

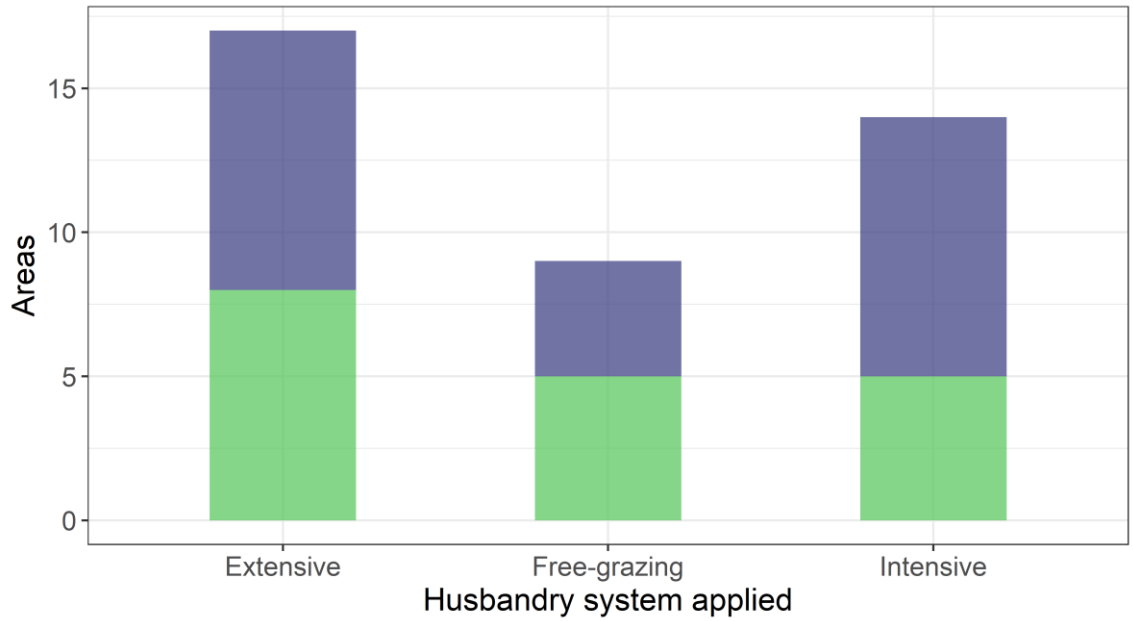

Figure 9. Number of areas with presence of extensive, free ranging and intensive grazing systems. The purple bars represent Europe and the green bars North America.

In general, mortality factors received higher importance scores in North America than in Europe (Fig. 9). Particularly, wild carnivore depredation was scored higher in North America than in Europe, with an average score between "important" and "very important", while the average score in Europe was "neutral". Accidents, diseases and other mortality factors were scored similarly on both continents, which is "neutral".

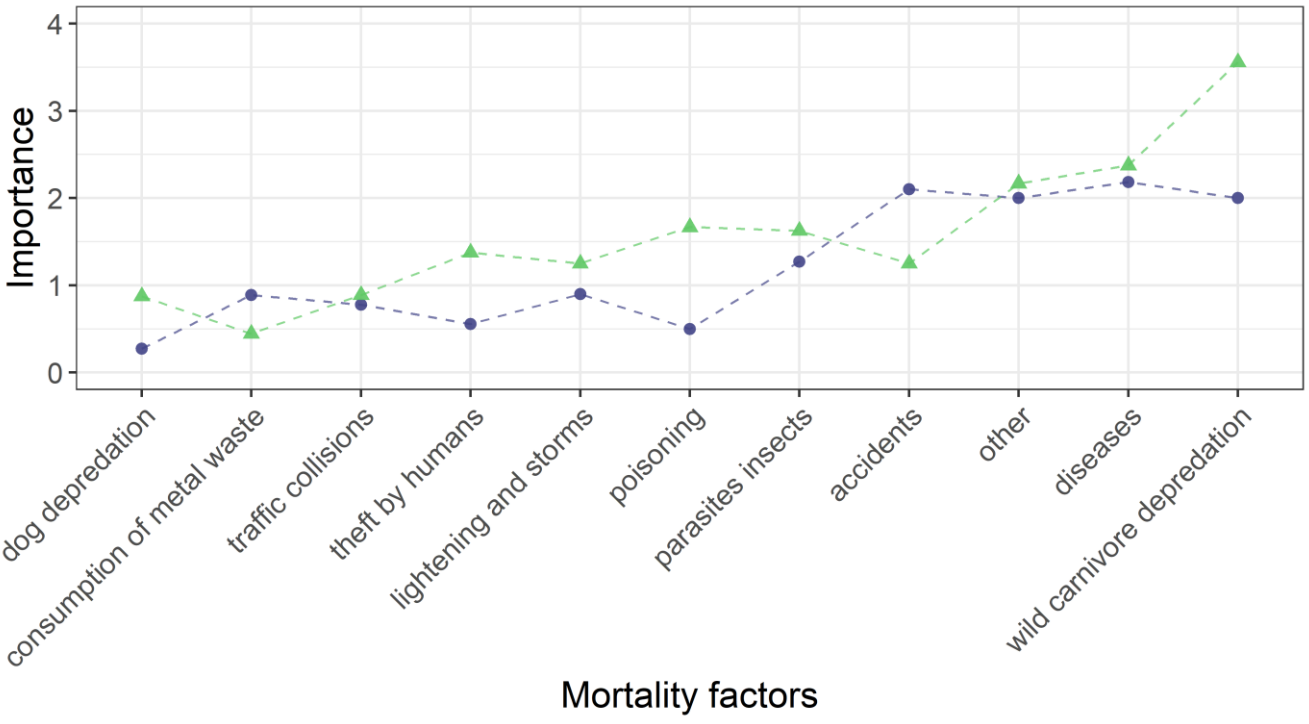

Figure 8. The mortality factors of cattle rated on importance from 0-4, where 0 = "not important", 1= "little important", 2 = "neutral important", 3 = "important", 4 = "very important". The purple points indicate the importance in Europe and the green points in North America.

Carnivore species

Wolves are present in 17 out of 18 areas, the only area where wolves are absent is Kodiak Island, Alaska. Bears are present in most areas (4) in North America and half of the areas in Europe (6). Lynxes are present in about half of the areas in both continents (11). In all areas where wolves and bears are present, depredation by these species is reported to happen, whilst this is rarely the case in areas where lynxes are present (3).

Depredation

Respondents also indicated how often they experience cattle depredation by different carnivore species (Fig. 10). Cougar and Coyote are only present in North America and therefore not shown. Wolf depredation is rated as occurring "weekly", "monthly" or "yearly" in most areas in Europe and North America (>50%). Bear depredation is on the contrary rated as "never" or "rarely" occurring in the majority of areas in Europe (73%), whilst it is mostly rated as occurring "weekly" and "monthly" (44%) and "yearly" (44%) in North America. Most respondents rated lynx depredation as "never" or "rarely" in both North America (100%) and Europe (89%), only in Europe few respondents experienced it "yearly" (11%).

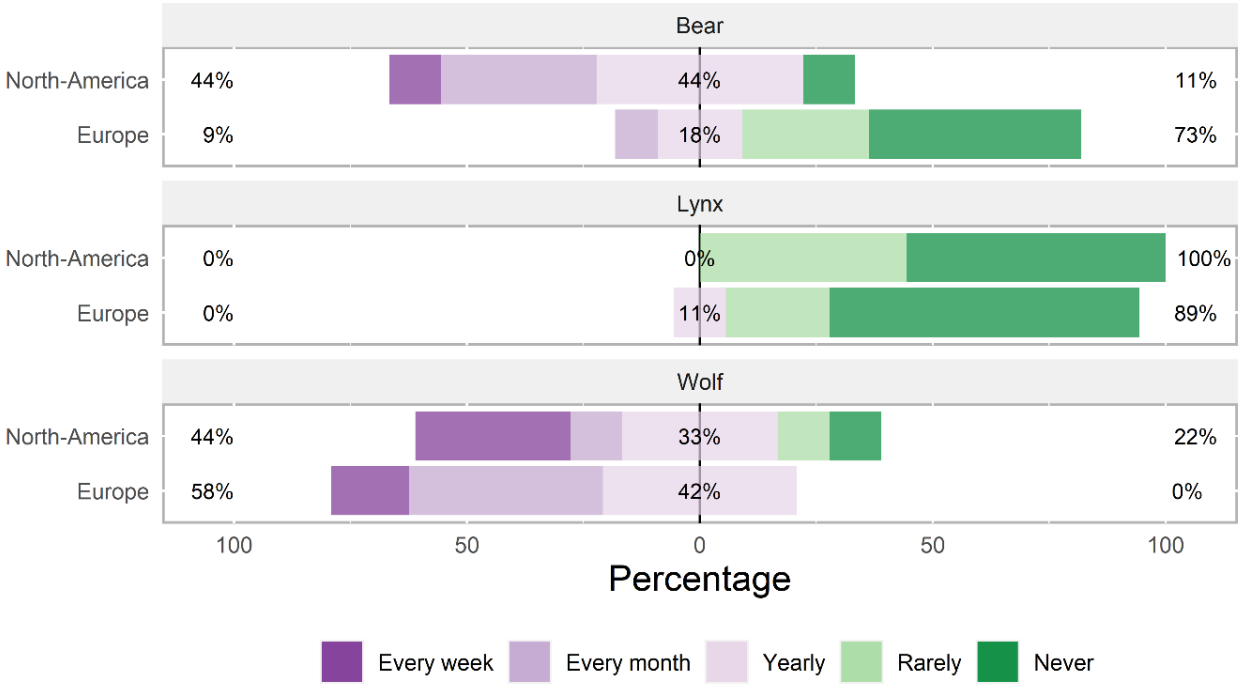

Figure 10. Depredation occurrence for the carnivore species bear, lynx and wolf. The percentages specify how many respondents answered "positive" (every week or month), - "neutral" (yearly) or "negative" (rarely or never).

Measures to prevent depredation

Measures more commonly used in North America are lethal control, translocation, night guarding, avoiding areas and wild prey management. While in Europe electric fencing, indoor night confinement and informative gatherings scored most common. The effectivity of most measures is rated similarly on both continents (Fig. 11). But there are some notable differences. As the use of deterrents, rated "neutral" in North America but "not/little effective" in Europe. Also, electric fencing that scored between "effective" and "very effective" in Europe, but between "little effective" and "neutral" in North America. For lethal control an opposite score is given, where it is rated as "effective" to "very effective" in North America but around "neutral" in Europe.

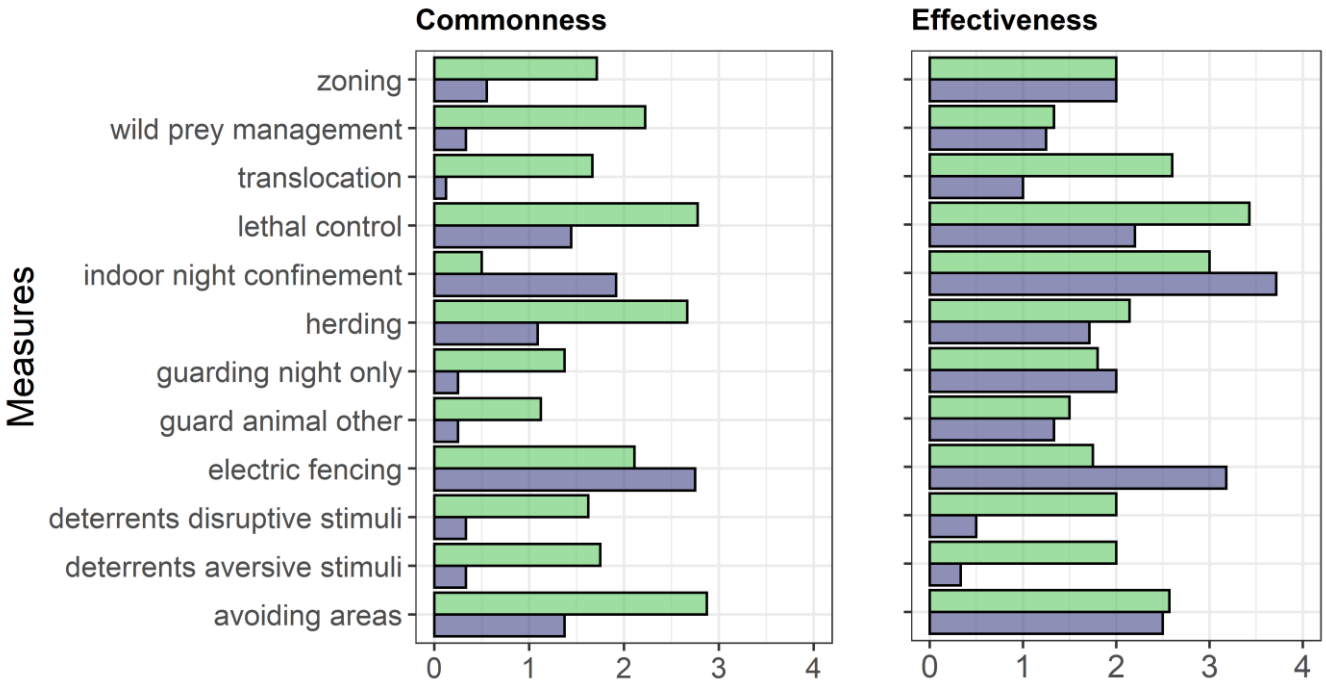

Figure 11. Commonness and effectiveness of measures both rated on an ordinal scale from 0 = "not used/effective", 1 = "rarely used/effective", 2 = "neutral", 3 = "common/effective", 4 = "very common/effective. The purple bars represent Europe and the green bars North America.

3.2.3 Inferential analysis

Number of carnivores

The importance of depredation as mortality factor significantly differed with the number of carnivore species present (Fig. 13A; Kruskal-Wallis chi-squared = 9.5792, df = 4, p-value = 0.04815). The highest scores were given in areas with 4 or 5 species present (North America) followed by areas with 1 species, 2 species and finally 3 species. This shows that the number of carnivore species present does not per se increase the importance of depredation as a mortality factor. In all except one of the areas where one species was present, this concerned the wolf.

Grazing system

The importance of depredation as mortality factor was significantly higher in extensive and free grazing systems (Figure 12B, Wilcoxon rank sum test, W =21, p-value = 0.03608). However, when the occurrence of depredation was analysed separately for bears and wolves, it was not related to grazing close or far from the farm (p-value = >0.05).

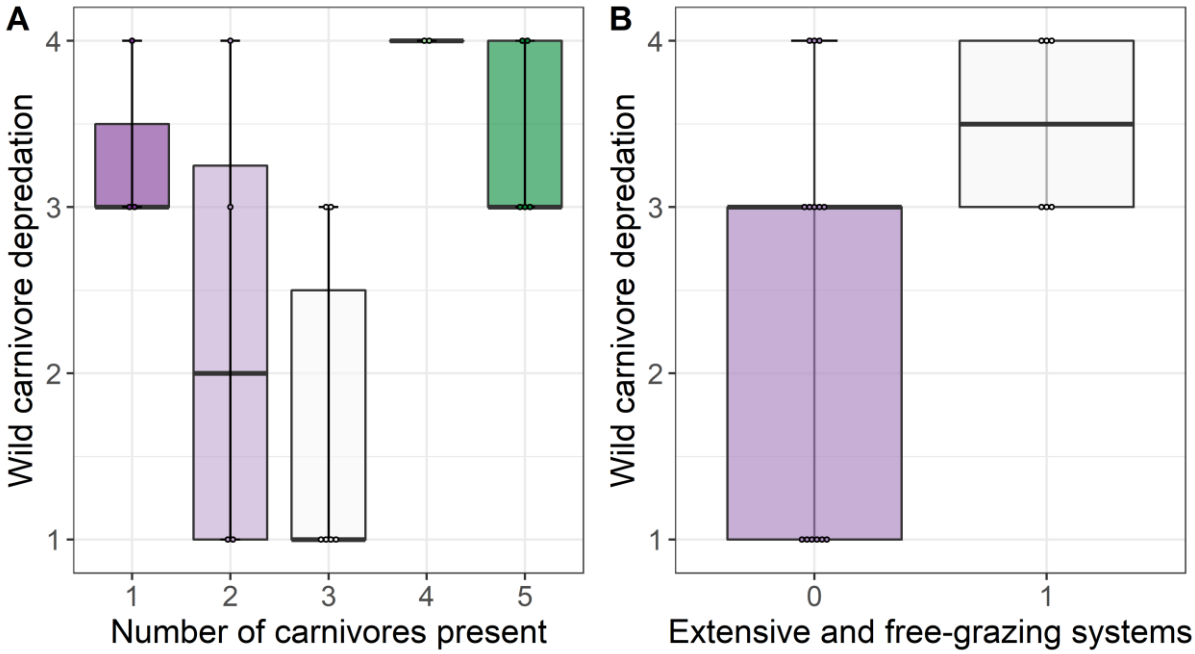

Figure 12. Boxplot of the importance of carnivore depredation in relation to the number of carnivores present (A) and the grazing system applied, where 0 stands for intensive grazing systems and 1 for systems further away from the farm (B).

Interview results on depredation and cattle grazing systems

Participants explained in what grazing system depredation is more likely to happen. In Europe, the word “outside” was said most often, other words said more than once were “beef-cattle”, “confined”, “unattended” and “wolves” (Fig. 13A). Participants from North America said “unattended” and “systems” the most, followed by “calves”, “every-system” and “free-grazing” (Fig. 13B). Both continents share similar themes as outside grazing, supervision and confinement and calving.

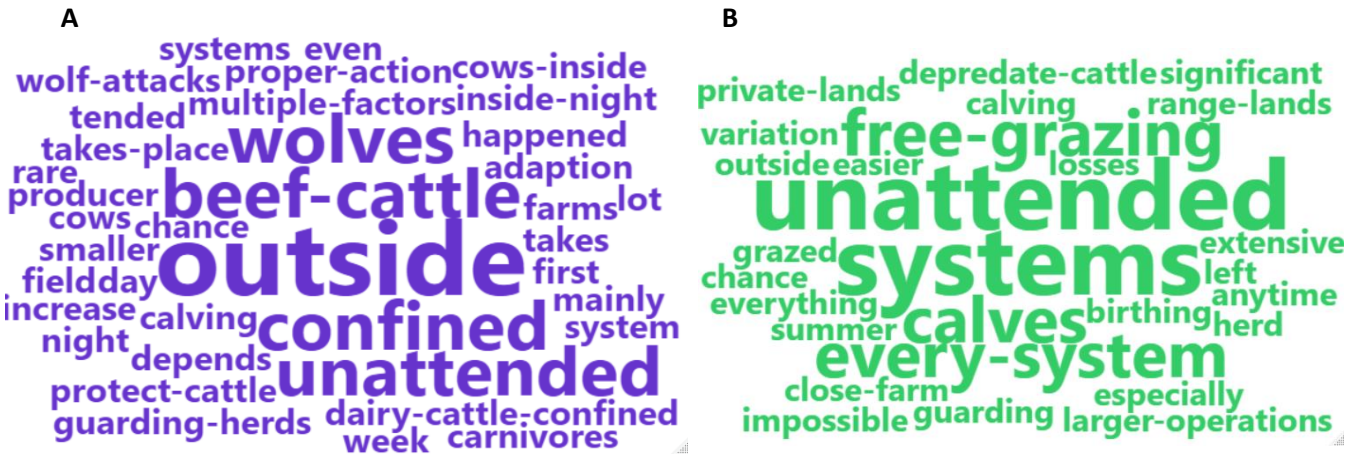

Figure 13. Word clouds with what people said about depredation connected to the grazing system applied in (A) Europe and (B) North America. The size of the word indicates how often it is said.

In Europe participants said cattle depredation happens in "[…] fenced pastures without carnivore proof fences, also in free-grazing systems, with little supervision". This was confirmed by another European participant: "[…] mostly where cows are free-grazing, without supervision or protection […]". A North American participant mentioned distance to the farm: "[…] close to the farm, you can guard cattle. On range lands, […] and unattended this is impossible, […] easier to depredate cattle in extensive, free grazing systems."

Interview results on carnivores

The difference how participants perceived bears and wolves as predators of cattle was evident in how people spoke about bear (Fig. 14) and wolf (Fig.15). In general, bear was not seen as an important predator of cattle in Europe as the words "not-present", "little-damage" and "individuals" indicate (Fig. 14A.). In North America often used words were "grizzly", "black-bears", "areas", "local", "forest", "mountainous" and "feeding-on-cattle", which indicates it is more common (Fig. 14B).

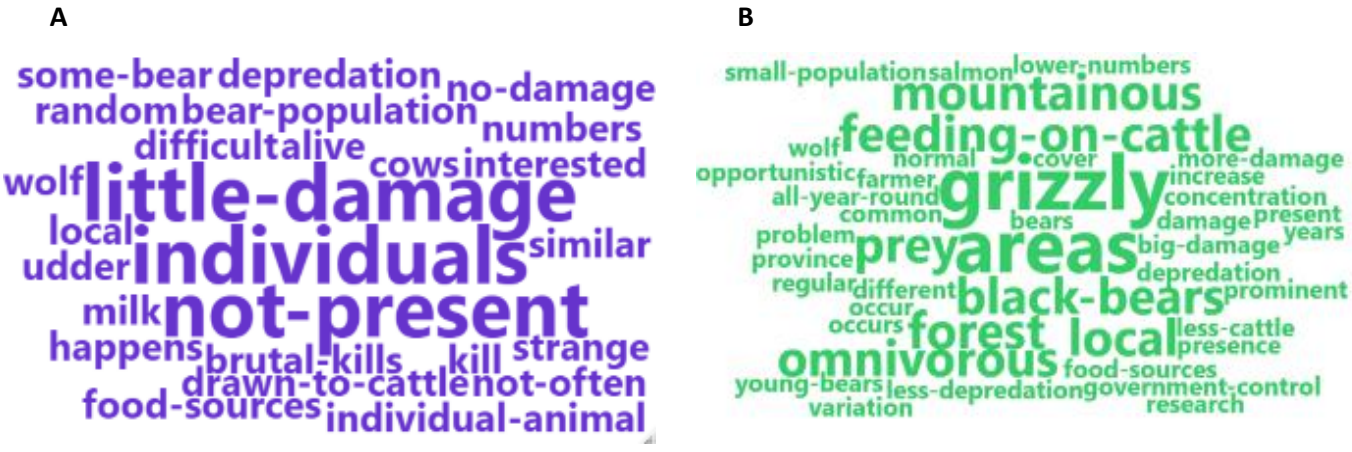

Figure 14. Word clouds with what people said about depredation by bears in (A) Europe and (B) North America. The size of the word indicates how often it is said.

More specific, European participants described it as "[…] happens, but not often. Some bears are not interested in cattle, some are more drawn to them". The randomness and low occurrence were also mentioned by the participants from North America: "Bears are omnivorous and opportunistic when killing cattle […] in mountainous areas, less cattle are present". Another participant from North America said "[…] locally grizzly bears cause more damage than wolves".

The wolf was described as common predator on both continents, see e.g., "increase", "depredation" and "important-predators" (Fig. 15). In Europe the words are very diverse, from "confinement" to "wolf-pack", there is many words that were mentioned once (Fig. 15A.). This is the same for North American participants, that only said "wolves" and "widespread" multiple times (Fig. 15B.).

A **B**

Figure 15. Word clouds with what people said about depredation by wolves in A) Europe and B) North America. The size of the word indicates how often it is said.

Explicitly, European participants described wolf depredation as: "[…] protected by law and have depredated on cattle, some farmers have quit grazing cattle […]" and "[…] was a rare occasion, […] has increased and raised concern under farmers. Mainly during calving". Both of these quotes suggested that cattle depredation has increased. North American participants described it as "[…] the first predator of cattle. […] a function of their strictly carnivorous diet" and "[…] wolves probably do more damage, because they are more widespread'.

Measures to prevent cattle depredation

The relationship between commonness/effectiveness of measures and the presence of bear and wolf was studied. Effectiveness of measures showed a similar pattern (Fig.16B), with a higher average score in areas with only wolf present, this difference tested significant (Wilcoxon rank sum test, W = 960.5, p-value = 0.0318).

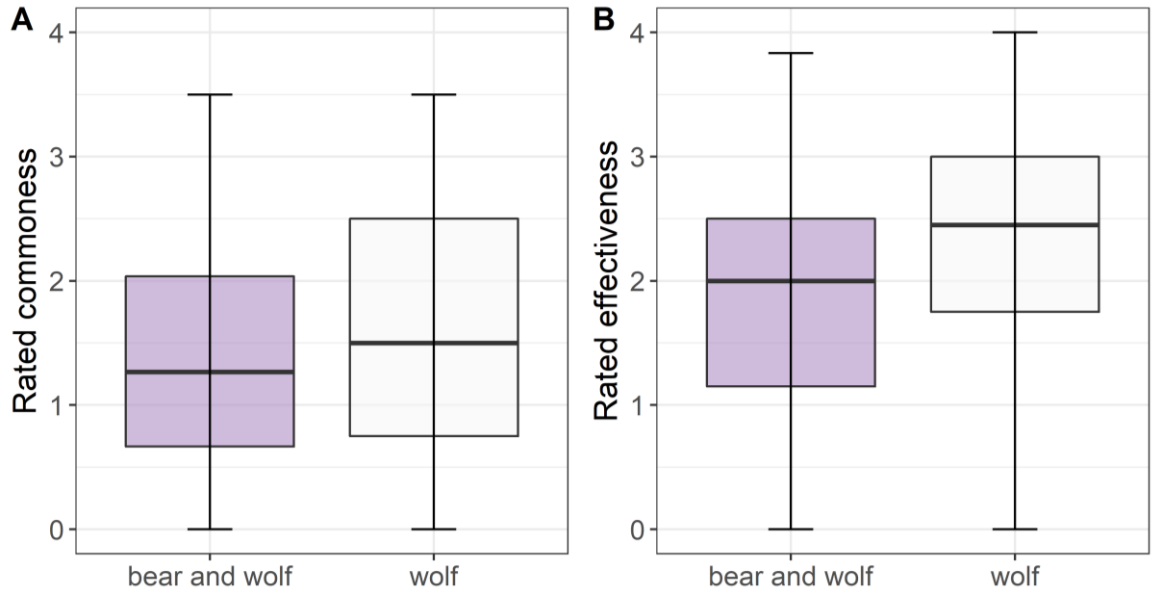

Figure 16. Average rated commonness (A) and effectiveness (B) of measures in areas with and without bear and wolf present. Shown on an ordinal scale from 0 = "not used/effective", 1 = "rarely used/effective", 2 = "neutral", 3 = "common/effective", 4 = "Very common/effective".

Electric fencing and lethal control

Electric fencing and lethal control scored differently between the continents on both commonness and effectiveness (Fig. 17). The use of lethal control is scored "common" in North America, but "rarely used" in Europe (Fig. 17A.), this difference tested significant (Wilcoxon rank sum test, W = 18.5, p-value = 0.0226). The effectiveness is not shown in the plot, because the differences did not test significant. Lethal control scored higher in North America, and electric fencing scored higher in Europe.

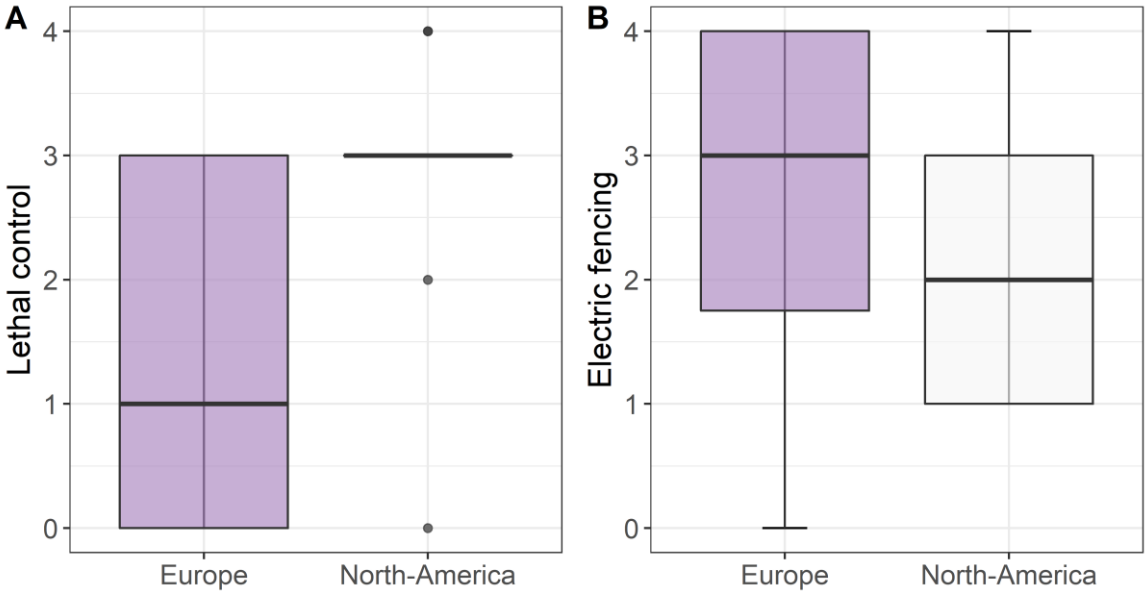

Figure 17. The commonness of lethal control (A) and electric fencing (B) as measures to prevent cattle depredation. Shown on an ordinal scale from 0 = "not used", 1 = "rarely used", 2 = "neutral", 3 = "common", 4 = "very common.".

Interview results

Lethal control

Lethal control was explained thoroughly in both continents. In Europe the words “national-law”, “European-union”, “possible” describe the legal situation of lethal control (Fig. 18A.). In North America “population-management”, “focus-on-cattle”, “permit” and “specific situations” are rather connected to the execution of lethal control (Fig. 18B.). In particular, European participants said: “[…] specific conditions, e.g., to defend cattle […]” and “[…] very specific situations, otherwise forbidden by law”. Participants from North America mainly spoke about the execution of lethal control, such as: “Wolves that focus on cattle are taken out, bears are often not taken out for killing cattle, only in specific situations. […] complicated because of social concern”.

A **B**

Figure 18. Word clouds what people said about lethal control in (A) Europe and (B) North America

Electric fencing

Participants from Europe described electric fencing as “effective” whilst one of the most used phrases in North America was “not-effective” (Fig. 19). Furthermore, in Europe the words “maintenance”, “costly”, “height” and “requirements” showed that the measure was perceived costly with certain requirements (Fig. 19A). In North America “pasture-size” and “not-possible” showed that using electric fencing is perceived as difficult to apply (Fig. 19B). More specific, European participants said: “Most common measure, but not always possible […] fencing is in conflict with traditions […]”. The requirements were also mentioned: “[…] high voltage and a height of 1.25-1.30”. It was also said that “[…] there are no subsidies for cattle protection, very costly and often financially impossible. […] growing demand”.

A

B

Figure 19. Word clouds what people said about electric fencing as a measure in (A) Europe and (B) North America.

One participant from North America said: "[…] depend on electric fencing in intensive grazing systems. Yet, in some areas it is not possible to use – e.g., for biodiversity protection". However, other participants from North America said: "[…] used to keep cattle at a place, […] no protection against depredation" and "areas too large to fence" was a common verdict.

Interview results other measures

In Europe indoor night confinement was scored high in effectivity, but not as commonly applied. Therefore, it was only discussed with participants that indicated the use of night confinement. These participants said: "[…] cattle are mostly left unattended in the field", but also "one farmer who lost cattle to carnivores started to confine cattle at night". Although the measure is rated uncommon in North America, one participant said "fenced areas where you bring the cattle to sleep can be efficient. […] depredation happens at dusk and dawn, secluding them during this time helps".

In North America, other common measures were avoiding areas and herding. Participants said "[…] use carnivore numbers to decide where to graze […]" and also "areas with a higher "bear-chance" are being avoided". None of the participants in Europe confirmed that they used this measure.

Herding is commonly applied in North America, but not in Europe. One European participant said: "Cattle are fenced out or free-grazing, usually not herded […]". Participants from North America mentioned that herding cattle is not the same practice as herding sheep but rather: "[…] observing and checking up on the herd regularly. […] cattle are herded when they are moved to another place". Another North American participant said: "Range patrol is the best management practice. […], range-riders supervise and keep track of the large herds, that split up in sub herds".

4 Limitations and challenges

It is important to consider the limitations of the study before concluding anything about the results. The design of this thesis consists of different study methods, although these methods and the type of data collected are different, limitations in data collection and the analysis were similar. Here, I present these limitations, provide information on an improved approach and explain how the results are still interesting

4.1 Limited availability of data

I aimed to collect cattle depredation statistics for 47 areas, on a large scale (e.g., country, state), these were available for 25 areas. The limited availability of depredation data was addressed in former research in Europe (Linnell & Cretois 2018). Collecting cattle- and carnivore densities proved a complicated task, which does not yield representative densities on a large scale. There are different methods to monitor densities for regions in the area or they are not monitored at all. Respondents from the survey indicated that it was difficult to answer the questions for the large areas (e.g., states)– because of big variation within the area. This limited their capacity to provide me with representative data. Other variables that might influence depredation of cattle as vegetation cover and -types (Treves *et al.* 2011), wild prey density present (Ugarte *et al.* 2019) and grazing system applied were not available for the analysis of depredation statistics. This information is (often) not available on a larger scale, but would be interesting to include when modelling depredation.

This method could be improved by focussing on smaller areas, where representative cattle- and carnivore densities are available. It might be possible to collect carnivore- and grazing cattle numbers within the cattle grazing area. In smaller areas, there is more specific information available on vegetation cover- and types, wild prey populations and grazing systems applied. This gives a unique overview of cattle depredation across the western world.

4.2 Lack of variation in predictor variable

In five areas wolf densities were only available every five years, because of different monitoring methods. This was problematic when modelling, because the predictor variable did not change over time for these areas.

The analysis could be improved by collecting more precise wolf estimates, as mentioned this could be possible on a smaller scale. Besides this, collecting other variables that possibly influence depredation can improve modelling depredation. There is unmeasured variance within the areas, it is important to find what causes this variance. Despite that I cannot make strong inferences about the model estimates, the model indicates an interesting trend and the low model fit means that there are ways to improve the analysis of international depredation data.

4.3 Limited response

I corresponded in German, French, English and Norwegian to achieve respondence to the survey. From 35 potential participants, 21 responded. From 21 respondents I interviewed eight.

The sample size could be increased by surveying farmers in the areas, instead of organisations. But it might be necessary to translate the survey for some European countries where it is not custom to speak English. Although the social study results do not represent the whole area or continent, I was able to capture key differences between participants from Europe and North America.

4.4 Triangulation

In this thesis I applied methodological triangulation, which can increase the credibility and validity of research findings but it also adds complexity (Heale & Forbes 2013; Noble & Heale 2019). Furthermore, using three different study methods and analyses was time-consuming.

Application of triangulation could be improved by planning out the research path/process to ensure there is enough time for each method. Because of limited time, I did not compare the survey results to the results from 1999-survey. This would increase the sample size and give more possibilities for advanced analysis such as ordinal regression, complicated statistical techniques in general require a bigger sample size (Kraemer & Blasey 2015). It would be particularly interesting to see if the rating of mortality factors and use / effectiveness of measures has changed over time.

5 Discussion

In this study I found that; **I)** cattle depredation by large carnivores occurred in Europe and North America. Actually, **II)** in most areas in Europe and half of the areas in North America cattle depredation has increased over time. Notably, **III)** wolf-related variables were important predictors of cattle depredation. In the analysis of depredation statistics, the final model showed an increasing effect of wolf density on total depredation of cattle. Additionally, the interaction term in the model indicated a stronger effect in Europe than in North America. This was an interesting finding, that pinpoints a difference between the continents. The social study results aligned with this finding. Lastly, **IV)** measures to prevent cattle depredation differed greatly between the continents, where in general, preventive measures were more commonly used in North America than in Europe.

5.1 Cattle depredation in Europe and North America

I & II) I found that in 6 out of 11 areas in North America cattle depredation increased over time. In North America, policies towards large carnivores started changing early in the 20th century and grizzly bears and wolves received protection in most states in the 1970s, subsequently most populations expanded (Linnell, Swenson & Anderson 2001). Although protection of wolves was removed in some regions and there were local declines, in general the trend was an increase (Gompper, Belant & Kays 2015). Notably, in 3 of the 4 study areas where depredation decreased, wolf densities decreased as well (MFFP 2016). Based on the social study, cattle depredation seemed an important part of cattle husbandry in the areas in North America, with depredation occurring in all grazing systems, common use of different preventive measures and depredation seen as most important mortality factor. In North-American literature, cattle depredation is described frequently, e.g., in Idaho, Montana and Wyoming most of the reported wolf depredations were on cattle (Bradley & Pletscher 2005)

In Europe, cattle depredation has increased in 11 out of 14 areas. This is in line with the recovery and recolonisation of carnivore populations the last few decades (Trouwborst 2010; Chapron *et al.* 2014). In the social study, depredation seemed less common in Europe, with most depredation in extensive grazing systems, few commonly used preventive measures and lower importance of depredation as a mortality factor. This gave the impression of a relatively new experience in Europe, where cattle depredation in literature is described as infrequent (Linnell & Cretois 2018), except in particular areas as Portugal and Greece (Iliopoulos *et al.* 2009; Pimenta *et al.* 2017).

The wolf is described as a common predator of cattle in both Europe and North America. However, brown bear is only considered a common predator of cattle in North America, especially where subspecies of brown bear occur that are bigger than European brown bears (Zedrosser *et al.* 2011), e.g., the Kodiak brown bear. Important to note is presence of wolf in all study areas except one, and

presence of brown bear in half of the areas. Also, there were up to six predator species in the North American dataset, whilst the maximum was three in Europe (Appendix VIII). Even though there are more predator species in North America, bear- and wolf depredation were rated as most prevalent. This was in line with studies on depredation in the western world, which mainly focussed on *canid*- (dog family incl. wolves) and *ursid* (bear family) species (van Eeden *et al.* 2018). The importance of depredation as mortality factor differed significantly with the number of carnivore species present in an area, what could indicate that the carnivore species present influence the depredation of cattle.

(III) Wolf density was an important predictor in the final model of the depredation statistics, and different conditional variables in the social study seemed to influence depredation, e.g., the grazing system, more depredation in areas with extensive and free-grazing systems. However, the unmeasured ecological and social characteristics differ greatly between the individual study areas. For example, distance to vegetation cover is found to be associated with the number of livestock losses with more wolf depredation occurring farther away from cover (Treves *et al.* 2011). Bear depredation, however, is more likely to occur in areas with more vegetative cover (Wilson *et al.* 2005; Hipólito *et al.* 2020). These characteristics are not tested in the analyses but could influence depredation greatly (Mkonyi *et al.* 2017; Ugarte *et al.* 2019).

5.2 Measures to prevent cattle depredation

(IV) In general, the number of commonly used measures was higher in North America than in Europe. The measure rated most common in Europe is electric fencing. Multiple interview participants described electric fencing as the measure they promote in their area. Although electric fencing is a widely recommended measure (Eklund *et al.* 2017), it is scored less common in North America. According to interview participants the measure is less common because “grazing areas are too large to fence”. Other reasons why electric fencing is impossible to apply is biodiversity protection and landscape design (SGC 2021). Landscape design was also named as limiting factor by participants from Europe, but more limiting were the costs and lack of subsidies to protect cattle (DREAL 2021).

Measures that were more commonly used in North America are lethal control, avoiding carnivore-exposed areas and herding. Contrarily, respondents from Europe rated lethal control as an uncommon measure, which is not surprising considering that the European Habitats Directive 92/43/EEC strictly protects large carnivores (European communities 1992). However, lethal control of individuals is allowed under very specific circumstances and only if there is no satisfactory alternative e.g., to prevent serious damage to livestock (Habitat’s directive, article 16.1). In the interview one participant said: “Killing is allowed according to the Directive, but has not been changed in our national law, therefore we cannot apply lethal control”. This might be the case for multiple EU-countries.

The effectiveness of measures was rated similarly in Europe and North America. For example, the measure to avoid carnivore-exposed areas is scored between neutral and effective on both continents. However, some measures were rated very differently, such as electric fencing and lethal control. Electric fencing is rated effective in Europe, but little effective in North America. Lethal control is rated neutral in Europe, yet very effective in North America. Effectiveness of measures to prevent livestock depredation has been studied for over 40 years, and in recent years efforts were made to evaluate the research on these measures by independent reviews (Miller *et al.* 2016; Treves, Krofel & McManus 2016; Eklund *et al.* 2017; van Eeden *et al.* 2018). These works all concluded the lack of scientific evidence that hinders any inference about the effectiveness of measures (van Eeden *et al.* 2018).

In the European union, electric fencing was applied in LIFE projects, and based on these experiences high effectiveness was reported in different countries (Salvatori & Mertens 2012). However, other work reported no significant difference in depredation between fenced and unfenced areas (Rigg *et al.* 2011). In North America, electric fencing is described as an effective method to protect sheep from predators (Dorrance & Bourne 1980), but not for cattle (Scasta, Stam & Windh 2017). This was in line with the interview results, where electric fencing was described as ineffective in extensive cattle grazing systems.

In my study, lethal control was rated very effective in North America, but according to literature effectiveness of lethal control varies greatly and can either be effective, ineffective or counter-productive (van Eeden *et al.* 2018). Although it is impossible to make inferences about the effectiveness of lethal control, in practice people seemed to be convinced that lethal control works (Scasta, Stam & Windh 2017). Most interviewees from North America described lethal control as effective, but emphasised the importance of pack removal instead of killing individual carnivores.

There are many measures that have not been tested adequately in extensive and free grazing systems. These include disruptive and aversive deterrents (e.g., fladry, sound- and light devices) and night confinement. These measures can be effective to prevent depredation, especially when combined. However, the application in free grazing systems is difficult, cattle often split up in sub herds (KSWCD 2021) and it is unclear where to apply deterrents.

5.3 Conclusion

In this thesis I relied on three sets of data (depredation statistics, survey and interview) to analyse depredation of cattle and analyse experience with cattle depredation across the western world. Interestingly, I found similarities between the results of the depredation statistics analysis, survey and the interview. The depredation statistics showed a trend of increasing cattle depredation in Europe and half of the areas in North America. The most abundant carnivore species across Europe and North America, the wolf, was an important predictor of cattle depredation, especially in Europe.

While the wolf was considered an important predator of cattle on both continents, the brown bear is only considered an important predator of cattle in North America. In the social study it appeared that depredation occurred more often in extensive- and free-grazing systems. These systems are applied in remote mountainous and/or forested areas in Europe and there, carnivore populations are recovering (Breitenmoser 1998; Scotton & Crestani 2019). Although a very small proportion of cattle is depredated, locally cattle depredation can be a problem for farmers. Especially, when no financial support is received to protect cattle.

Eventually, cattle depredation by large carnivores in Europe might increase. There is need for financial support of cattle farmers in carnivore-exposed areas, to prevent conflicts and damages. Besides, the nation-wide databases of cattle depredation, cattle and carnivore inventories need to be improved. There is urgent need of a standardised, uniform method to monitor livestock depredation throughout Europe. Based on the results, it was not possible to conclude which measure is most effective. But I have gathered interesting information about application of measures across the Western world. Accordingly, I have written recommendations for cattle farming in extensive and free grazing systems.

5.4 Recommendations for cattle farming in extensive and free grazing systems

In this study I gathered information on extensive- and free grazing systems. These systems have little supervision, no to little fencing and tend to be further away from the farm. Based on the social study and literature on preventive measures, I wrote recommendations on the following topics **I**) the carnivore species, **II**) replacement of electric fencing and avoiding carnivores, **IV**) carnivores avoiding cattle, **V**) lethal control of carnivores.

If brown bear populations in Europe keep increasing (Chapron *et al.* 2014), depredation by bears might increase too. It is important to consider the increasing trend of carnivore species.

I) Both bear and wolf should be considered as potential predator when protecting cattle from depredation.

Although electric fencing was rated as a common and effective measure in Europe, mountainous and/or forested areas are difficult or impossible to fence. Considering the maintenance necessary to keep the fences functional, this can become very costly. Instead of physical fencing, some farmers used virtual fencing to keep cattle confined (e.g., Nofence©). The Nofence collar consists of a GPS-collar system with a sound- and electric warning system activated when the animal leaves the defined grazing area and effectively changes cattle movement (Umstatter, Morgan-Davies & Waterhouse 2015). This method can replace electric fences but does not protect against depredation. However, it can be combined with another measure, namely avoidance of certain predation hot spots.

II) Using the virtual fencing technique, it is possible to avoid areas where carnivores are present (Nofence 2021). This can be done very accurately **if** carnivores are GPS/collared in the same area.

Nevertheless, information about the exact location of large carnivores is confidential and researchers are careful not to share this information with the public, due to possible disturbance or illegal killing of carnivores. Besides that, carnivores move fast and far, it can be challenging to avoid them if they are present within a certain range.

In Norway, carnivores might be equipped with a GPS-collar for research purposes. In theory (and this is a wild card), it would be possible to equip a shock-collar on carnivores and learn them to avoid areas where cattle are grazing. This measure was not included in the study because it was not carried out by farmers and only scientifically evaluated in *one study* on wolves in Wisconsin (Hawley *et al.* 2009; Eklund *et al.* 2017). This study showed that wolves started to avoid areas where the shock collars were activated. Altogether, there is little evidence, therefore:

III) Research or test the measure of shock collars on carnivores.

Collaring all carnivores is financially and logistically impossible. However, collaring the wolf pack in an area where depredation is a problem, can be tested. Annually, millions of Norwegian kroner are spent on livestock loss compensation (Miljødirektoratet 2021) and it is preferred not to kill carnivores within the carnivore zone. Nonetheless, collaring wild carnivores with shock-collars will come with ethical considerations and possibly public opposition.

Lethal control of predators is applied commonly within the boreal zone. However, the effectiveness of lethal control varies a lot (van Eeden *et al.* 2018). Concerning cattle depredation, partial pack removal might be ineffective (Bradley *et al.* 2015) when reducing local damage of wolves.

IV) Considerations should be made when culling wolves to reduce damage to livestock. In different studies random culling of wolves has shown to be counter-effective for this purpose (Treves, Krofel & McManus 2016), it would be interesting to study the effect in Norway, so that better decisions can be made.

Acknowledgements

During my studies, I came to the realization that working with humans is an essential part of nature management and -conservation. We (read: ecological scientists) need to communicate and work together with other involved parties to make our scientific work is worth the effort. In the Netherlands, I grew up in an agricultural environment. The killing of livestock by large carnivores is the most prominent conflict between large carnivores and humans. Without public support it is very difficult for carnivores to exist. I think working together with farmers is key to conservation. The project "CarniForeGraze" focusses on livestock grazing practises in carnivore-exposed areas and I was fortunate to join this project for my master thesis. The project is funded by the Norwegian Research Council (project number 302674), Hedmark Landbruksselskap, Statsforvalteren I Innlandet and Inland Norway University of Applied Sciences.

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Reference list

Austrheim, G., Solberg, E.J., Mysterud, A., Daverdin, M. & Andersen, R. (2008) Hjortedyr og husdyr på beite i norsk utmark i perioden 1949–1999. *Rapport zoologisk serie,* **2,** 2008.

Baker, P.J., Boitani, L., Harris, S., Saunders, G. & White, P.C. (2008) Terrestrial carnivores and human food production: impact and management. *Mammal Review,* **38,** 123-166.

Barry, D. (2017) Do not use averages with Likert scale data. *Enterp. Anal***,** 24.

Bland, J.M. & Altman, D.G. (1997) Statistics notes: Cronbach's alpha. *Bmj,* **314,** 572.

Blasco-Moreno, A., Pérez-Casany, M., Puig, P., Morante, M. & Castells, E. (2019) What does a zero mean? Understanding false, random and structural zeros in ecology. *Methods in Ecology and Evolution,* **10,** 949-959.

Bradley, E.H. & Pletscher, D.H. (2005) Assessing factors related to wolf depredation of cattle in fenced pastures in Montana and Idaho. *Wildlife Society Bulletin,* **33,** 1256-1265.

Bradley, E.H., Robinson, H.S., Bangs, E.E., Kunkel, K., Jimenez, M.D., Gude, J.A. & Grimm, T. (2015) Effects of wolf removal on livestock depredation recurrence and wolf recovery in Montana, Idaho, and Wyoming. *The Journal of Wildlife Management,* **79,** 1337-1346.

Breitenmoser, U. (1998) Large predators in the Alps: the fall and rise of man's competitors. *Biological Conservation,* **83,** 279-289.

Brooks, M.E., Kristensen, K., Van Benthem, K.J., Magnusson, A., Berg, C.W., Nielsen, A., Skaug, H.J., Machler, M. & Bolker, B.M. (2017) glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. *The R journal,* **9,** 378-400.

Bryer, J., Speerschneider, K. & Bryer, M.J. (2016) Package 'likert'. *Analysis and Visualization Likert Items. CRAN*.

Chapron, G., Kaczensky, P., Linnell, J.D., von Arx, M., Huber, D., Andrén, H., López-Bao, J.V., Adamec, M., Álvares, F. & Anders, O. (2014) Recovery of large carnivores in Europe's modern human-dominated landscapes. *Science,* **346,** 1517-1519.

Copernicus (2021) Copernicus Services Land

Cronbach, L.J. (1951) Coefficient alpha and the internal structure of tests. *psychometrika,* **16,** 297-334.

DiCicco-Bloom, B. & Crabtree, B.F. (2006) The qualitative research interview. *Medical education,* **40,** 314-321.

Dillman, D.A., Smyth, J.D. & Christian, L.M. (2014) *Internet, phone, mail, and mixed-mode surveys: the tailored design method*. John Wiley & Sons.

Dobson, A.J. & Barnett, A.G. (2018) *An introduction to generalized linear models*. CRC press.

Dorrance, M.J. & Bourne, J. (1980) An evaluation of anti-coyote electric fencing.

DREAL (2021) 'CarniForeGraze' - interview cattle depredation (ed. E. Den Hartog). not published.

Eklund, A., López-Bao, J.V., Tourani, M., Chapron, G. & Frank, J. (2017) Limited evidence on the effectiveness of interventions to reduce livestock predation by large carnivores. *Scientific reports,* **7,** 1-9.

European communities (1992) Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. pp. 7-50. EUR-lex.

Fay, M.P. & Proschan, M.A. (2010) Wilcoxon-Mann-Whitney or t-test? On assumptions for hypothesis tests and multiple interpretations of decision rules. *Statistics surveys,* **4,** 1.

Gehring, T.M., VerCauteren, K.C., Provost, M.L. & Cellar, A.C. (2011) Utility of livestock-protection dogs for deterring wildlife from cattle farms. *Wildlife Research,* **37,** 715-721.

Gigliotti, L.M. (2011) Comparison of an internet versus mail survey: A case study. *Human Dimensions of Wildlife,* **16,** 55-62.

Gliem, J.A. & Gliem, R.R. (2003) Calculating, interpreting, and reporting Cronbach's alpha reliability coefficient for Likert-type scales. Midwest Research-to-Practice Conference in Adult, Continuing, and Community ….

Gompper, M.E., Belant, J.L. & Kays, R. (2015) Carnivore coexistence: America's recovery. *Science,* **347,** 382-383.

Hartig, F. (2019) DHARMa: residual diagnostics for hierarchical (multi-level/mixed) regression models. *R package version 0.2,* **4**.

Hawley, J.E., Gehring, T.M., Schultz, R.N., Rossler, S.T. & Wydeven, A.P. (2009) Assessment of shock collars as nonlethal management for wolves in Wisconsin. *The Journal of Wildlife Management,* **73,** 518-525.

Heady, H. (2019) *Rangeland ecology and management*. Routledge.

Heale, R. & Forbes, D. (2013) Understanding triangulation in research. *Evidence-based nursing,* **16,** 98-98.

Heeringa, S.G., West, B.T. & Berglund, P.A. (2017) *Applied survey data analysis*. CRC press.

Henderson, A., Comiskey, J. & Alonso, A. (2007) Framework for Assessment and Monitoring of Biodiversity.

Hipólito, D., Reljić, S., Rosalino, L.M., Wilson, S.M., Fonseca, C. & Huber, Đ. (2020) Brown bear damage: Patterns and hotspots in Croatia. *Oryx,* **54,** 511-519.

Iliopoulos, Y., Sgardelis, S., Koutis, V. & Savaris, D. (2009) Wolf depredation on livestock in central Greece. *Mammal Research,* **54,** 11-22.

Janeiro-Otero, A., Newsome, T.M., Van Eeden, L.M., Ripple, W.J. & Dormann, C.F. (2020) Grey wolf (Canis lupus) predation on livestock in relation to prey availability. *Biological Conservation,* **243,** 108433.

Johnson, J.B. & Omland, K.S. (2004) Model selection in ecology and evolution. *Trends in ecology & evolution,* **19,** 101-108.

Kaczensky, P. (1999) Large carnivore depredation on livestock in Europe. *Ursus***,** 59-71.

Kahneman, D. (1979) Prospect theory: An analysis of decisions under risk. *Econometrica,* **47,** 278.

Kassambara, A. (2016) ggcorrplot: Visualization of a Correlation Matrix using'ggplot2'. *R package version 0.1,* **1**.

Knowlton, F.F., Gese, E.M. & Jaeger, M.M. (1999) Coyote depredation control: an interface between biology and management. *Journal of Range Management***,** 398-412.

Kraemer, H.C. & Blasey, C. (2015) *How many subjects?: Statistical power analysis in research*. Sage Publications.

Kruskal, W.H. & Wallis, W.A. (1952) Use of ranks in one-criterion variance analysis. *Journal of the American statistical Association,* **47,** 583-621.

Kruuk, H. (2002) Hunter and Hunted: Relationships Between Carnivores and People. *Oryx,* **37**.

KSWCD (2021) 'CarniForeGraze' - interview cattle depredation (ed. E. Den Hartog). not published.

Lang, D., Chien, G.-t., LazyData, T. & Lang, M.D. (2016) Package 'wordcloud2'. Recuperado el.

Likert, R. (1932) A technique for the measurement of attitudes. *Archives of psychology*.

Linnell, J.D. & Cretois, B. (2018) *Research for AGRI Committee-The revival of wolves and other large predators and its impact on farmers and their livelihood in rural regions of Europe*. European Parliament.

Linnell, J.D., Swenson, J.E. & Anderson, R. (2001) Predators and people: conservation of large carnivores is possible at high human densities if management policy is favourable. *Animal Conservation,* **4,** 345-349.

Lüdecke, D. (2019) _sjPlot: Data Visualization for Statistics in Social Science_.

Lynn, P. (2019) Applying prospect theory to participation in a CAPI/web panel survey. *Public Opinion Quarterly,* **83,** 559-567.

Macdonald, D. & Loveridge, A. (2010) *The biology and conservation of wild felids*. Oxford University Press.

Mann, H.B. & Whitney, D.R. (1947) On a test of whether one of two random variables is stochastically larger than the other. *The annals of mathematical statistics***,** 50-60.

May, R., Van Dijk, J., Wabakken, P., Swenson, J.E., Linnell, J.D., Zimmermann, B., Odden, J., Pedersen, H.C., Andersen, R. & Landa, A. (2008) Habitat differentiation within the large-carnivore community of Norway's multiple-use landscapes. *Journal of Applied Ecology,* **45,** 1382-1391.

Mazerolle, M.J. (2019) AICcmodavg: Model selection and multimodel inference based on (Q)AIC(c).

Mech, L.D. (2017) Where can wolves live and how can we live with them? *Biological Conservation,* **210,** 310-317.

MFFP (2016) Harvest Status Report on Grey Wolf (ed. Ministère des Forêts de la Faune et des Parcs). Quebec.

Miljødirektoratet (2021) Tap av husdyr og tamrein.

Miller, J.R. (2015) Mapping attack hotspots to mitigate human–carnivore conflict: approaches and applications of spatial predation risk modeling. *Biodiversity and Conservation,* **24,** 2887-2911.

Miller, J.R., Stoner, K.J., Cejtin, M.R., Meyer, T.K., Middleton, A.D. & Schmitz, O.J. (2016) Effectiveness of contemporary techniques for reducing livestock depredations by large carnivores. *Wildlife Society Bulletin,* **40,** 806-815.

Mkonyi, F.J., Estes, A.B., Msuha, M.J., Lichtenfeld, L.L. & Durant, S.M. (2017) Socio-economic correlates and management implications of livestock depredation by large carnivores

in the Tarangire ecosystem, northern Tanzania. *International Journal of Biodiversity Science, Ecosystem Services & Management,* **13,** 248-263.

Moreira-Arce, D., Ugarte, C.S., Zorondo-Rodríguez, F. & Simonetti, J.A. (2018) Management tools to reduce carnivore-livestock conflicts: current gap and future challenges. *Rangeland ecology & management,* **71,** 389-394.

Muhly, T.B. & Musiani, M. (2009) Livestock depredation by wolves and the ranching economy in the Northwestern US. *Ecological Economics,* **68,** 2439-2450.

Noble, H. & Heale, R. (2019) Triangulation in research, with examples. Royal College of Nursing.

Nofence (2021) Nofence Grazing Technology.

Pimenta, V., Barroso, I., Boitani, L. & Beja, P. (2017) Wolf predation on cattle in Portugal: assessing the effects of husbandry systems. *Biological Conservation,* **207,** 17-26.

QGIS Development Team (2021) QGIS Geographic Information System. Open Source Geospatial Foundation Project. .

R Development Core Team (2019) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Revelle, W. (2018) Package 'psych'. *The comprehensive R archive network*, pp. 338.

Reynolds, J. & Tapper, S. (1996) Control of mammalian predators in game management and conservation. *Mammal Review,* **26,** 127-155.

Rigg, R., Finďo, S., Wechselberger, M., Gorman, M.L., Sillero-Zubiri, C. & Macdonald, D.W. (2011) Mitigating carnivore–livestock conflict in Europe: lessons from Slovakia. *Oryx,* **45,** 272-280.

Rønningen, K., Renwick, A. & Burton, R. (2012) Western European approaches to and interpretations of multifunctional agriculture–and some implications of a possible neo-productivist turn. *Rethinking Agricultural Policy Regimes: Food Security, Climate Change and the Future Resilience of Global Agriculture. Emerald Group Publishing Limited***,** 73-97.

Rstudio Team (2020) RStudio: Integrated Development for R. . Rstudio, Inc, Boston, MA.

Salvatori, V. & Mertens, A.D. (2012) Damage prevention methods in Europe: experiences from LIFE nature projects. *Hystrix, the Italian Journal of Mammalogy,* **23,** 73-79.

Scasta, J., Stam, B. & Windh, J. (2017) Rancher-reported efficacy of lethal and non-lethal livestock predation mitigation strategies for a suite of carnivores. *Scientific reports,* **7,** 1-11.

Scotton, M. & Crestani, D. (2019) Traditional grazing systems in the Venetian Alps: Effects of grazing methods and environmental factors on cattle behaviour. *Journal of Environmental Management,* **250,** 109480.

SGC (2021) 'CarniForeGraze' - interview cattle depredation (ed. d.E. Hartog). not published

Shivik, J.A. (2006) Tools for the edge: what's new for conserving carnivores. *BioScience,* **56,** 253-259.

Tofastrud, M., Zimmermann, B., Devineau, O., Hessle, A., Aletengqimuke, S., Dickel, L., Hegnes, H., Møllevold, O.H., Skoglund, B.H. & Spedener, M. (2019) Beiteatferd, habitatseleksjon og produktivitet hos storfe på utmarksbeite.

Tourangeau, R. & Ye, C. (2009) The framing of the survey request and panel attrition. *Public Opinion Quarterly,* **73,** 338-348.

Treves, A. & Karanth, K.U. (2003) Human-carnivore conflict and perspectives on carnivore management worldwide. *Conservation Biology,* **17,** 1491-1499.

Treves, A., Krofel, M. & McManus, J. (2016) Predator control should not be a shot in the dark. *Frontiers in Ecology and the Environment,* **14,** 380-388.

Treves, A., Martin, K.A., Wydeven, A.P. & Wiedenhoeft, J.E. (2011) Forecasting environmental hazards and the application of risk maps to predator attacks on livestock. *BioScience,* **61,** 451-458.

Treves, A., Wallace, R. & White, S. (2009) Participatory planning of interventions to mitigate human–wildlife conflicts. *Conservation Biology,* **23,** 1577-1587.

Trouwborst, A. (2010) Managing the carnivore comeback: international and EU species protection law and the return of lynx, wolf and bear to Western Europe. *Journal of Environmental Law,* **22,** 347-372.

Ugarte, C.S., Moreira-Arce, D., Simonetti, J.A., Valenzuela, C.M., Acuña, E., Ortega, A., Cancino, J.C., Rodríguez-Echeverry, J., Echeverria, C. & Oyarzún, C. (2019) Ecological attributes of carnivore-livestock conflict. *Journal of Wood Chemistry and Technology,* **29,** 43-58.

Umstatter, C., Morgan-Davies, J. & Waterhouse, T. (2015) Cattle responses to a type of virtual fence. *Rangeland ecology & management,* **68,** 100-107.

van Eeden, L.M., Eklund, A., Miller, J.R.B., López-Bao, J.V., Chapron, G., Cejtin, M.R., Crowther, M.S., Dickman, C.R., Frank, J., Krofel, M., Macdonald, D.W., McManus, J., Meyer, T.K., Middleton, A.D., Newsome, T.M., Ripple, W.J., Ritchie, E.G., Schmitz, O.J., Stoner, K.J., Tourani, M. & Treves, A. (2018) Carnivore conservation needs evidence-based livestock protection. *PLOS Biology,* **16,** e2005577.

Wickham, H. (2017) tidyverse: Easily Install and Load the 'Tidyverse'.

Wilson, S.M., Madel, M.J., Mattson, D.J., Graham, J.M., Burchfield, J.A. & Belsky, J.M. (2005) Natural landscape features, human-related attractants, and conflict hotspots: a spatial analysis of human–grizzly bear conflicts. *Ursus,* **16,** 117-129.

Woodroffe, R., Thirgood, S. & Rabinowitz, A. (2005) *People and wildlife, conflict or co-existence?* Cambridge University Press.

Zedrosser, A., Steyaert, S.M., Gossow, H. & Swenson, J.E. (2011) Brown bear conservation and the ghost of persecution past. *Biological Conservation,* **144,** 2163-2170.

Zimmermann, B., Wabakken, P. & Dötterer, M. (2003) Brown bear-livestock conflicts in a bear conservation zone in Norway: are cattle a good alternative to sheep? *Ursus***,** 72-83.

Zuur, A.F., Ieno, E.N. & Elphick, C.S. (2010) A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution,* **1,** 3-14.

Appendix

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Appendix I - Selected areas and limitations for inclusion

Table_Apx 1. Table of the initial sample with the area specified, the data availability indicated with red (not available) and green (available) and the reason why there was no data available.

Country	Region	Statistics	Survey	Reason for no data
Albania	-			No data available
Austria	-			No (second) response
Belarus	-			No response
Bosnia & Herzegovina	-			No response
Bulgaria	-			Too late response
Canada	Alberta			
	British Columbia			
	Labrador			No data available
	Manitoba			
	Ontario			
	Saskatchewan			
	Quebec			No survey respondent
Croatia	-			
Czech Republic	-			
Estonia	-			
Finland	-			
France	-			
Germany	Brandenburg			No response
	Saxony			
	Lower Saxony			
Greece	-			No survey respondent
Latvia	-			No data available
Lithuania	-			No survey respondent
Hungary	-			
Italy	Veneto			No (second) response
Macedonia	-			No data and respondent
Norway	Innlandet fylke			
Poland	-			No data a
Portugal	-			
Romania	-			No survey respondent
Serbia	-			
Slovakia	-			Too late response
Slovenia	-			
Spain	Castille			No response
	Galicia			No response
	Leon			No response
Sweden	-			
Switzerland	-			
Ukrain	-			
U.S.A	Alaska			No data available
	Idaho			No (second) response
	Michigan			
	Minnesota			
	Montana			
	Oregon			
	Washington			
	Wyoming			

Appendix II – Reference list depredation data

Aarnes, S., Tobiassen, C., Brøseth, H., Bakke, B.B., Eiken, H.G. & Hagen, S. (2016) Populasjonsovervåking av brunbjørn. DNA-analyse av prøver innsamlet i Norge i 2015. NIBIO Rapport.

Aarnes, S.G., Tobiassen, C., Brøseth, H., Spachmo, B., Bakke, B., Hagen, S. & Eiken, H.G. (2013) Populasjonsovervåking av brunbjørn 2009-2012: DNA analyse av prøver innsamla i Norge i 2012. Bioforsk Rapport, 8, 1-61.

Aarnes, S.G.B., Henrik; Bakke, Beate Banken; Fløystad, Ida; Eiken, Hans Geir; Hagen, Snorre B. (2017) Populasjonsovervåking av brunbjørn. DNA-analyse av prøver innsamlet i Norge i 2016.

Adamec, M., Jerina, K., Kos, I., Krofel, M., Potočnik, H., Skrbinšek, T. & Majić Skrbinšek, A. (2013) Status, management and distribution of large carnivores-bear, lynx, wolf & wolverine-in Europe. Univerza v Ljubljani, Biotehniška fakulteta.

Aldea, A. (2020) Cattle depredation Arges county romania Carphathia European Wilderness Reserve Brașov – România.

APHIS (2011-2019) Wildlife Damage / Reports and Publications / Program Data Reports. Animal and Plant Health Inspection Service (APHIS), U.S: Department of Agriculture (USDA).

Balys, V. (2020) Cattle depredation Lithuania 2010-2019. State livestock registry.

Bartol, M., Boljte, B., Černe, R., Jelenčič, M., Jonozovič, M., Konec, M., Kos, I., Kraševec, R., Krofel, M. & Kuralt, Ž. (2017) Spremljanje varstvenega stanja volkov v Sloveniji v letih 2017/2020. Drugo delno porocilo—porocilo za sezono, 2018.

Becker, S., Roussin, T., Krausz, E., Martorello, D., Simek, S. & Kieffer, B. (2010-2019) Washington gray wolf conservation and management annual reports 2011-2019. US Fish and Wildlife Service Rocky Mountain Wolf Program Annual Report. –US Fish and Wildlife Service, pp. WA-1–WA-24. Washington Department of Fish and Wildlife

Bédard, K. (2020) Cattle depredation by large carnivores in Quebec 2011-2019. Quebec minstry of forests, fauna and parcs.

Berce, T. (2020) Cattle depredation by wolves and brown bear in Slovenia 2010-2020. Zavod za gozdove Slovenije (Slovenian Forest Service).

Bourquin, N. (2021) Analysis of depredation data Switserland 2005-2020. Federal Office of the Environment FOEN Biodiversity and Landscape Division, Bern

Branch, M.W.F. (2020) Carnivore populations in Manitoba. (ed. E. Den Hartog).

Bray, F. & Torre, A. (2020) BD communale/outil d'extraction. SIDDT, système d'Information Dédié aux Territoires.

Bundesamt, S. (2019) Land- und Forstwirtschaft. Statistisches Jahrbuch 2019. Statistisches Bundesamt.

Statistics Canada. (2020a) Table 32-10-0130-01 Number of cattle, by class and farm type (x 1,000).

Statistics Canada. (2020b) Table 32-10-0406-01 Land Use.

Chapron, G., Kaczensky, P., Linnell, J.D., von Arx, M., Huber, D., Andrén, H., López-Bao, J.V., Adamec, M., Álvares, F. & Anders, O. (2014) Recovery of large carnivores in Europe's modern human-dominated landscapes. Science, 346, 1517-1519.

Das Niedersächsische Ministerium für Umwelt, E., Bauen und Klimaschutz (2020) Umweltkarten Niedersachsen, nutztierschaden, rinder; alle jahren. Das Niedersächsische Ministerium für Umwelt, Energie, Bauen und Klimaschutz.

Dokumentations- und Beratungsstelle des Bundes zum Thema Wolf, D. (2010-2020) Wolfsterritorien in Deutschland; zusammenfassung nach bundesländern.

Erb, J. & Humpal, C. MINNESOTA WOLF POPULATION UPDATE 2020.

Eurostat (2009-2020) Number of bovine animals European Commission.

Fløystad, I., Brøseth, H., Bakke, B.B., Eiken, H.G. & Hagen, S.B. (2019) Populasjonsovervåking av brunbjørn. dna-analyse av prøver innsamlet i norge i 2018.
FWP (2013) Grizzly Bear Management Plan for Southwestern Montana 2013. Montana Fish, Wildlife and Parks (FWP).
GPSAS (2020) Ūkinių gyvūnų registro (Annual livestock register). VALSTYBĖS ĮMONĖ ŽEMĖS ŪKIO INFORMACIJOS IR KAIMO VERSLO CENTRAS, Vilnius.
Hart, J. & Shar, D. (2019) USDA-Wildlife Services wolf damage management in Minnesota 2019. USDAAPHIS-Wildlife Services, Grand Rapids, Minnesota.
Hauke, T., Lena, S., Tomke, L., Raphaela, E. & Heiko, H. (2019) Steckbriefe zur Tierhaltung in Deutschland: Milchkühe. Thünen-Institut für Betriebswirtschaft, Braunschweig.
Heckbert, M. (2020) Cattle depredations by large carnivores in Alberta. Alberta environment & Parks.
Iliopoulos, Y., Sgardelis, S., Koutis, V. & Savaris, D. (2009) Wolf depredation on livestock in central Greece. Mammal Research, 54, 11-22.
Inman, B., K. Podruzny, A. Nelson, D. Boyd, T. Parks, T. Smucker, M. Ross, N. & Lance, W.C., M. Parks, and S. Wells (2020) Montana Gray Wolf Conservation and Management
2019 Annual Report. Montana Fish, Wildlife & Parks, Helena, Montana.
Jeremić, J., Štrbenac, A., Kusak, J., Huber, Đ. & Korsa, A. (2016) Izvješće o stanju populacije vuka u Hrvatskoj u 2016. godini. Hrvatska agencija za okoliš i prirodu, Zagreb.
Kaczensky, P., Chapron, G., von Arx, M., Huber, D., Andrén, H. & Linnell, J. (2013) Status, Management and Distribution of Large Carnivores – Bear, Lynx, Wolf and Wolverine in Europe. Part 1. IUCN/SSC Large Carnivore Initiative for Europe.
Kindberg, J.a.S., J.E. (2011-2017) Björnstammens storlek i Sverige.
Kutal, M. (2021) Cattle depredation czech republic 2005-2018. Faculty of Forestry and Wood Technology Mendel University Brno, Czech Republic.
Landbruksdirektoratet (2011-2019) Statistikk fra søknader om produksjonstilskudd i jordbruket.
Linnell, J.D. & Cretois, B. (2018) Research for AGRI Committee-The revival of wolves and other large predators and its impact on farmers and their livelihood in rural regions of Europe. European Parliament.
Maartmann, E. (2020) Storfetap av rovdyr 2010-2019. Miljødirektoratet, Rovbase 3.0.
Mertzanis, Y. (2020) Cattle depredation by large carnivores in Greece 2006-2019. Hellenic Farmers Insurance Organization.
Montana, L.L.B. (2020) Livestock Loss Statistics 2013-2019. Departement of Livestock Montana Government
Niedersächsisches Ministerium für Ernährung, L.u.V. (2019) Tierproduktion in Niedersachsen 2019. Institutionen Tierbestände Leistungen Erzeugung.
Norberg, H. (2020) Data of Finland "CarniForeGraze" project Finnish Wildlife Agency
ODFW (2011-2019) Oregon Wolf Conservation and Management Plan. (ed. O.D.O.F.A.Q. (ODFW)).
OMAFRA (2011-2019) Cattle depredation by large carnivores in Ontario (2011-2019). (ed. O.W.D.C.P. (OMAFRA)). Ontario Ministry of Agriculture, Food and Rural Affairs.
ONCFS (2018) Bilan du suivi hivernal de la population de loups / Hiver 2017-2018. Office National de la Chasse et de la Fauna Savage (OFB), Office National de la Chasse et de la Fauna Savage, ONCFS
ONCFS (2019) Bilan hivernal de la population de loup: le seuil des 500 loups est attaint (ed. O. Office National de la Chasse et de la Faune Sauvage). Office francais de la biodiversité (OFB).
Pimenta, V. & Barroso, I. (2020) wolf_damage_cattle_Portgugal_05_17. Inistitute for Nature Conservation and Forests, Portugal (ICNF).

Potočnik, H., Krofel, M., Skrbinšek, T., Ražen, N., Jelenčič, M., Kljun, F., Žele, D., Vengušt, G. & Kos, I. (2014) Spremljanje stanja populacije volka v Sloveniji (3): 1., 2. in 3. sezona-2010/11, 2011/12 in 2012/13: projektno poročilo za akcijo C1:(LIFE08 NAT/SLO/000244 SloWolf).

Sächsisches Staatsministerium für Energie, K., Umwelt und Landwirtschaft (2020) Agrarbericht in Zahlen 2020. (ed. K. Sächsisches Staatsministerium für Energie, Umwelt und Landwirtschaft). Freistaat Sachsen

Schurmann, K. (2020) Cattle depredation by large carnivores 2016-2020. Ministry of Forests, Lands, Natural Resource Operations and Rural Development British-Columbia.

Service, N.A.S. (2010-2020) Cattle inventory incl. calves and on feed. United States Department of Agriculture (USDA).

Simčič, G., Fležar, U., Bartol, M., Černe, R., Berce, T., Krofel, M., Potočnik, H., Jelenčič, M., Kuralt, Ž. & Stergar, M. (2020) Spremljanje varstvenega stanja volkov v Sloveniji v letih 2018 in 2019. Lovec, 103, 328-331.

Sin, T., Gazzola, A., Chiriac, S. & Rîșnoveanu, G. (2019) Wolf diet and prey selection in the South-Eastern Carpathian Mountains, Romania. PLoS ONE, 14, e0225424.

Siv Grethe Aarnes, Ida Fløystad, Henrik Brøseth, Camilla Tobiassen, Hans Geir Eiken & Hagen, S.B. (2015) Populasjonsovervåking av brunbjørn

DNA-analyse av prøver innsamlet i Norge i 2014 Bioforsk.

Siv Grethe Aarnes, C.T., Henrik Brøseth, Beate Banken Bakke, Berit & Kleppe Hansen, B.S., Snorre B. Hagen og Hans Geir Eiken (2014) Populasjonsovervåking av brunbjørn: DNA-analyse av prøver innsamlet i Norge i 2013. Bioforsk.

Svensson, L., Wabakken, P., Maartmann, E., Åkesson, M., Flagstad, Ö. & Hedmark, E. (2010-2019) Inventering av varg vintern 2018–2019.

Viltskadesenteret Sverige. (2010-2019) Viltskadestatistik 2010-2019.

Szewczyk, M., Nowak, S., Niedźwiecka, N., Hulva, P., Špinkytė-Bačkaitienė, R., Demjanovičová, K., Bolfíková, B.Č., Antal, V., Fenchuk, V. & Figura, M. (2019) Dynamic range expansion leads to establis hment of a new, genetically distinct wolf population in Central Europe. Scientific reports, 9, 1-16.

Tobiassen, C., Brøseth, H., Bakke, B.B., Aarnes, S., Hagen, S.B. & Eiken, H.G. (2012) Populasjonsovervåking av brunbjørn 2009-2012: DNA-analyse av prøver samlet i Norge i 2011. Bioforsk Rapport.

USDA, N.A.S.S. (2010-2020) Cattle inventory (ed. U.s.d.o. agriculture).

van Manen, F.T., Haroldson, M.A. & Karabensh, B. (2011-2019) Yellowstone Grizzly Bear investigations: Annual reports of the Interagency Grizzly Bear Study Team US Geological Survey.

Wabakken, P., Svensson, L., Maartmann, E., Åkesson, M. & Flagstad, Ø. (2010-2019) Bestandsovervåking av ulv vinteren 2015-2016.

WDFW (2011-2019) Washington gray wolf conservation and management annual reports. US Fish and Wildlife Service Rocky Mountain Wolf Program Annual Report.–US Fish and Wildlife Service, pp. WA-1–WA-24 (ed. W.d.o.f.a.w. (WDFW)).

WYSGA (2021) 'CarniForeGraze' - interview cattle depredation (ed. E. Den Hartog). not published.

Zhou, L. (2020) Cattle depredation by large carnivores in Manitoba 2010-2020. Manitoba Agricultural Services Corporation (MASC).

Zimmermann, F., Weber, J., Molinari, P., Angst, C., Breitenmoser-Wuersten, C., Capt, S. & Breitenmoser, U. (2006) Monitoring der Raubtiere in der Schweiz 2005. KORA Muri bei Bern.

Appendix III – Participants of survey and interview

Table_Apx 2. Table with the organisations that participated in the survey. The X marks which organisations participated in the interview.

Area	Participant	Interview
Alberta	Alberta beef producers	
Alberta	Winisk Research and Consulting	
Alpes de Provence France	Unité Territoriale de la Direction Régionale de l'Environnement, de l'Aménagement et du Logement	**X**
British-Columbia	British Columbia Cattlemen's' association	
British-Columbia	Livestock protection programme	**X**
Czech-Republic	Association of Private Farming of the Czech Republic	
Czech-Republic	Czech Beef Cattle Association	
Estonia	Republic of Estonia environmental board	
Finland	The Central Union of Agricultural Producers and Forest Owners (MTK)	
Inland Fylke Norway	Norges bondelag	
Kodiak Island Alaska	Kodiak soil and water conservation district	**X**
Lower saxony	Wolfsbüro	
Montana	Blackfoot challenge	
Portugal	Pecuária	
Saskatchewan	Saskatchewan crop insurance	
Saskatchewan	Saskatchewan Cattlemen's association	**X**
Saxony	The Saxon State Office for Environment, Agriculture and Geology	**X**
Slovenia	Slovenian forest service	**X**
Switzerland	Agridea	
Veneto region Italy	Direzione Agroambiente, Programmazione e Gestione ittica e faunistico-venatoria	**X**
Wyoming	Wyoming Stock Growers Association	**X**

Appendix IV– Initial request

Dear name,

Farming of unattended livestock in areas with large carnivores may be a challenge. It is addressed by the 'CarniForeGraze' project, which was recently started in Norway. In this context, I seek information on the farming of cattle in different landscapes with carnivores.

To this end, I have developed an online survey. It contains questions about

a) cattle husbandry practices,

b) carnivores,

c) cattle depredation by carnivores, and

d) measures to prevent depredation.

Since your organization works with cattle farmers, we expect you to have some of this information. Therefore, it would be very helpful if you participate in the survey.

To allow comparisons between Western countries, the survey will be used in areas and countries across Europe and North America. Eventually, it will thus yield an overview on cattle depredation and applied management actions across multiple countries and states. Based on this, I hope to arrive at some recommendations for cattle farming in carnivore areas.

This should be interesting to everyone that tries to prevent depredation of cattle. The final results of the study are shared with participants. In the final report statistical data about cattle depredation is combined with experience. This combination is valuable for every participant, but especially when carnivore populations are recovering in your area.

I perform this survey for my master thesis and will process all data myself. My only interest is cattle depredation and husbandry practices that may prevent this. Thus, I will not be collecting any personal data, also not from your computer. Your responses will not be identifiable, and you will remain anonymous.

After the survey, I would also like to have a short (telephone/on-line) interview with you, to further discuss some of the questions.

Please feel free to ask me any questions, either through mail, phone or during the interview.

Thank you so much for participating,

Emma den Hartog
+31641197466
Emma.denhartog@outlook.com

Appendix V – Survey design

Page 1

Introduction

Dear participant,

With this survey I mean to gather knowledge on cattle farming in a landscape with carnivores. Gathering this information is an important goal of the Norwegian project 'CarniForeGraze'.
Free range cattle farming is an important practice in Norway, both culturally as economically. In this practice, cattle are left unattended in outfields. In Norway these outfields are also used by carnivores. To be able to keep performing traditional practices and ensure local meat production, it is vital to know how to best prevent cattle depredation.

Your organisation has hands-on experience with cattle farmers/ranchers in your area; therefore, it is very useful if you fill in this survey. Eventually I will have gathered an overview on cattle depredation and applied management actions across multiple countries and states. This is an interesting end product for everyone that tries to prevent or manage depredation of livestock.

I perform this survey for my master thesis and will process all data myself. It is important to inform you that I am not collecting any personal data, also not from your computer. My only interest is to study cattle depredation and husbandry practices to prevent this. You, as a person will stay in anonymity.

Besides the written part of the survey,

I would like to have a short interview on some of the questions from the survey. Mainly to discuss depredation by carnivores and preventive measures used more in detail.

Please feel free to ask me any questions, either through mail, phone or during the interview.

Thank you so much for participating, it means a lot for my research and I cannot wait to see the results.

Emma den Hartog

Inland Norway University of Applied Sciences

emma.denhartog@outlook.com

Page 2

Geography

This survey is answered for the following country/state/province: *

The given answers are conforming: *

- ○ The entire country/state/province
- ○ A specific area

State the specfic area the answers are conforming to:

ⓘ This element is only shown when the option "A specific area" is selected in the question "The given answers are conforming:"

Cattle farming methods

Which of these husbandry methods are applied for cattle?

It is possible to pick multiple answers

- [ ] Intensive cattle farming within a fenced pasture system
- [ ] Cattle farming on extensive fenced areas (cattle ranches)
- [ ] Free-ranging cattle
- [ ] Other

Which other husbandry methods?

This element is only shown when the option "Other" is selected in the question "Which of these husbandry methods are applied for cattle?"

Which calving methods are applied?

- ○ Unguarded calving
- ○ Calving under controlled conditions indoors
- ○ Calving under controlled conditions outdoors

I want to clarify that all following questions focus on grazing cattle (free grazing, extensive areas fenced areas). Because our project focusses on management of free grazing cattle in outfields.

Are cattle in the area used for dairy, beef or both?

- ○ Dairy
- ○ Beef
- ○ Both

Which cattle breeds are used for dairy in the area?

This element is only shown when the option "Dairy" or "Both" is selected in the question "Are cattle in the area used for dairy, beef or both?"

Which cattle breeds used for beef in the area?

This element is only shown when the option "Both" or "Beef" is selected in the question "Are cattle in the area used for dairy, beef or both?"

Are cattle breeds used for both dairy and beef?

- ○ Yes
- ○ No
- ○ I don't know

Which breeds are used for both?

ⓘ This element is only shown when the option "Yes" is selected in the question "Are cattle breeds used for both dairy and beef?"

Rate the importance of various mortality factors for free-ranging cattle and cattle on extensive fenced areas

	Very important	Important	Neutral	Little important	Not important	I don't know
Diseases	○	○	○	○	○	○
Parasites, insects	○	○	○	○	○	○
Accidents	○	○	○	○	○	○
Lightening and storms	○	○	○	○	○	○
Wild carnivore depredation	○	○	○	○	○	○
Dog depredation	○	○	○	○	○	○
Theft by humans	○	○	○	○	○	○
Traffic collisions	○	○	○	○	○	○
Poisoning	○	○	○	○	○	○
Consumption of metal waste	○	○	○	○	○	○
Other	○	○	○	○	○	○

If other factors are important, which factors are these?

Leave empty if there are no other factors

Carnivores/predators

The following questions are about carnivore species. Please answer these questions for the carnivore species that are present and you know about. So, feel free to not answer for species that are not present.

What carnivore species are present?

- [ ] Bear
- [ ] Wolf
- [ ] Lynx
- [ ] Feral dog
- [ ] Coyote
- [ ] Puma/Mountain lion

What are the hunting regulations for brown bear?

This element is only shown when the option "Bear" is selected in the question "What carnivore species are present?"

What are the hunting regulations for wolf?

This element is only shown when the option "Wolf" is selected in the question "What carnivore species are present?"

What are the hunting regulations for lynx?

This element is only shown when the option "Lynx" is selected in the question "What carnivore species are present?"

What are the hunting regulations for feral dog?

This element is only shown when the option "Feral dog" is selected in the question "What carnivore species are present?"

What are the hunting regulations for coyote?

This element is only shown when the option "Coyote" is selected in the question "What carnivore species are present?"

What are the hunting regulations for puma/mountain lion?

This element is only shown when the option "Puma/Mountain lion" is selected in the question "What carnivore species are present?"

Cattle and carnivores/predators

Are cattle predated by carnivores in the concerned area?

- ○ Yes
- ○ No, but it happened in the past
- ○ No

What carnivores kill or killed cattle?

ⓘ This element is only shown when the option "No, but it happened in the past" or "Yes" is selected in the question "Are cattle predated by carnivores in the concerned area?"

it is possible to select multiple species

- ☐ Bear
- ☐ Wolf
- ☐ Lynx
- ☐ Feral dog
- ☐ Coyote
- ☐ Puma/Mountain lion

ⓘ This element is only shown when the option "Yes" is selected in the question "Are cattle predated by carnivores in the concerned area?"

How important is the carnivore species for cattle depredation?

Rate how important a carnivore species is for cattle depredation in general. For example, if bears kill most cattle, they are very important.

	Very important	Important	Neutral	Little important	Not important	I don't know
Bear	○	○	○	○	○	○
Wolf	○	○	○	○	○	○
Lynx	○	○	○	○	○	○
Feral dog	○	○	○	○	○	○
Coyote	○	○	○	○	○	○
Puma/Mountain lion	○	○	○	○	○	○

Choose for each carnivore species how often depredation on cattle occurs

	Never	Rarely	Most years	Every year	Every month	Every week
Bear	○	○	○	○	○	○
Wolf	○	○	○	○	○	○
Lynx	○	○	○	○	○	○
Feral dog	○	○	○	○	○	○
Coyote	○	○	○	○	○	○
Puma/Mountain lion	○	○	○	○	○	○

ⓘ This element is only shown when the option "Yes" is selected in the question "Are cattle predated by carnivores in the concerned area?"

Do carnivore species kill adults, calves or both?

For the carnivore species present in the area, choose which option fits best.

	Only calves	Mostly calves	Even amount of calves and adults	Mostly adults	Only adults	I don't know
Bear	○	○	○	○	○	○
Wolf	○	○	○	○	○	○
Lynx	○	○	○	○	○	○
Feral dog	○	○	○	○	○	○
Coyote	○	○	○	○	○	○
Puma/Mountain lion	○	○	○	○	○	○

What is the distribution of cattle depredation occurrences?

ⓘ This element is only shown when the option "Yes" is selected in the question "Are cattle predated by carnivores in the concerned area?"

- ○ Local/ranch scale
- ○ Distributed all over the carnivore exposed areas

This element is only shown when the option "Yes" is selected in the question "Are cattle predated by carnivores in the concerned area?"

Cattle depredation is higher in areas where:

This element is only shown when the option "Yes" is selected in the question "Are cattle predated by carnivores in the concerned area?"

- ○ Wild prey density is high
- ○ Wild prey densityy is low
- ○ No difference because of wild prey density
- ○ I don't know

Besides depredation, are you aware of any other effects of carnivores on cattle in your region/country?

Effects may be behavioral in nature or pertain to non-lethal production losses.

- ○ Yes
- ○ No
- ○ I don't know

What are these effects?

This element is only shown when the option "Yes" is selected in the question "Besides depredation, are you aware of any other effects of carnivores on cattle in your region/country?"

Cattle depredation is higher in areas where:

This element is only shown when the option "Yes" is selected in the question "Are cattle predated by carnivores in the concerned area?"

- ○ Sheep/goat density is high
- ○ Sheep/goat density is low
- ○ No difference because of sheep/goat density
- ○ I don't know

Management

The next questions are regarding measures to reduce and precent cattle depredation. For different measures, I first ask you how common it is (question 1), and then how effective these measures are (question 2).

This element is only shown when at least one of the options "Coyote", "Feral dog", "Puma/Mountain lion", "Bear", "Lynx" or "Wolf" are selected in the question "What carnivore species are present?"

How common are the following measures used to prevent cattle depredation in your area/country?

	Not used	Rarely used	Neutral	Common	Very common	I don't know
Electric fencing	○	○	○	○	○	○
Non-electric fencing	○	○	○	○	○	○
Herding	○	○	○	○	○	○
Feral dog	○	○	○	○	○	○
Guard animal: dogs	○	○	○	○	○	○
Guard animal: dogs	○	○	○	○	○	○
Guard animal: other livestock: castrate	○	○	○	○	○	○
Guarding; day and night	○	○	○	○	○	○
Guarding; night only	○	○	○	○	○	○
Indoor night confinement	○	○	○	○	○	○
Outdoor night confinement	○	○	○	○	○	○
Electric devices; monitoring	○	○	○	○	○	○
Avoiding areas; f.e. forest	○	○	○	○	○	○
Zoning	○	○	○	○	○	○
Wild prey management	○	○	○	○	○	○
Sterilization	○	○	○	○	○	○
Lethal control	○	○	○	○	○	○
Translocation	○	○	○	○	○	○
Deterrents: aversive stimuli	○	○	○	○	○	○
Deterrents: disruptive stimuli	○	○	○	○	○	○
One-sided information	○	○	○	○	○	○
Informative gatherings	○	○	○	○	○	○
Workshops	○	○	○	○	○	○
Other?	○	○	○	○	○	○

This element is only shown when at least one of the options "Coyote", "Feral dog", "Puma/Mountain lion", "Bear", "Lynx" or "Wolf" are selected in the question "What carnivore species are present?"

How effective are the following measures in your area/country?

	Not effective	Little effective	Neutral	Effective	Very effective	I don't know
Electric fencing	○	○	○	○	○	○
Non-electric fencing	○	○	○	○	○	○
Herding	○	○	○	○	○	○
Feral dog	○	○	○	○	○	○
Guard animal: dogs	○	○	○	○	○	○
Guard animal: dogs	○	○	○	○	○	○
Guard animal: other livestock, castrate	○	○	○	○	○	○
Guarding: day and night	○	○	○	○	○	○
Guarding: night only	○	○	○	○	○	○
Indoor night confinement	○	○	○	○	○	○
Outdoor night confinement	○	○	○	○	○	○
Electric devices; monitoring	○	○	○	○	○	○
Avoiding areas; f.e. forest	○	○	○	○	○	○
Zoning	○	○	○	○	○	○
Wild prey management	○	○	○	○	○	○
Sterilization	○	○	○	○	○	○
Lethal control	○	○	○	○	○	○
Translocation	○	○	○	○	○	○
Deterrents: aversive stimuli	○	○	○	○	○	○
Deterrents: disruptive stimuli	○	○	○	○	○	○
One-sided information	○	○	○	○	○	○
Informative gatherings	○	○	○	○	○	○
Workshops	○	○	○	○	○	○
Other?	○	○	○	○	○	○

Do cattle farmers/ranchers select cattle groups based on age / reproductive status as a preventive measure against carnivores?

- ○ Yes
- ○ No
- ○ I don't know

Which groups are turned out to grazing areas?

ⓘ This element is only shown when the option "Yes" is selected in the question "Do cattle farmers/ranchers select cattle groups based on age / reproductive status as a preventive measure against carnivores?"

- ○ (lactating) Cows with calves
- ○ Dry cows without calves
- ○ Heifers and steers younger than 24 months
- ○ All of the above

Do farmers/ranchers get compensation for cattle lost to carnivores?

- ○ Yes
- ○ No
- ○ I don't know

Are measures to prevent depredation required to receive compensation?

ⓘ This element is only shown when the option "Yes" is selected in the question "Do farmers/ranchers get compensation for cattle lost to carnivores?"

- ○ Yes
- ○ No
- ○ I don't know

Is proof of a carnivore kill required to receive compensation?

ⓘ This element is only shown when the option "Yes" is selected in the question "Do farmers/ranchers get compensation for cattle lost to carnivores?"

- ○ Yes
- ○ No
- ○ I don't know

Is there a fixed amount of compensation for lost cattle?

This element is only shown when the option "Yes" is selected in the question "Do farmers/ranchers get compensation for cattle lost to carnivores?"

- ○ Yes
- ○ No
- ○ I don't know

What is the fixed amount per cow?

This element is only shown when the option "Yes" is selected in the question "Is there a fixed amount of compensation for lost cattle?"

Are sheep/goat farmers in the area/country financially supported by the government or NGO's to shift to cattle because of depredation?

- ○ Yes
- ○ No
- ○ I don't know

Select the option that describes the number of small livestock (sheep and goats) farmers in your area the best:

- ○ Decreasing
- ○ Stable
- ○ Increasing

Are you aware of any cattle farmers/ranchers that have changed to a cattle breed exerting greater anti-predator behaviour during the last 20 years?

- ○ Yes
- ○ No
- ○ I don't know

To which breed did they shift?

This element is only shown when the option "Yes" is selected in the question "Are you aware of any cattle farmers/ranchers that have changed to a cattle breed exerting greater anti-predator behaviour during the last 20 years?"

Acceptance

The next question is about acceptance of large carnivores, which is a very subjective topic. I do not ask for an exact answer. For the following two questions, please indicate how acceptable depredation of large carnivores is in your region.

How is the acceptence of the human population in your area towards large carnivores?

	Entirely unaccept-able	Unaccept-able	Neutral	Acceptable	Entirely acceptable	I don't know
Bear	○	○	○	○	○	○
Wolf	○	○	○	○	○	○
Lynx	○	○	○	○	○	○
Feral dog	○	○	○	○	○	○
Coyote	○	○	○	○	○	○
Puma/Mountain lion	○	○	○	○	○	○

How is the acceptence of the human population in your area towards depredation of cattle by large carnivores?

	Entirely unaccept-able	Unaccept-able	Neutral	Acceptable	Entirely acceptable	I don't know
Bear	○	○	○	○	○	○
Wolf	○	○	○	○	○	○
Lynx	○	○	○	○	○	○
Feral dog	○	○	○	○	○	○
Coyote	○	○	○	○	○	○
Puma/Mountain lion	○	○	○	○	○	○

How is the acceptance of cattle farmers/ranchers in your area towards depredation of cattle by large carnivores?

	Entirely unaccept-able	Unaccept-able	Neutral	Acceptable	Entirely acceptable	I don't know
Bear	○	○	○	○	○	○
Wolf	○	○	○	○	○	○
Lynx	○	○	○	○	○	○
Feral dog	○	○	○	○	○	○
Coyote	○	○	○	○	○	○
Puma/Mountain lion	○	○	○	○	○	○

How is your personal acceptance towards large carnivores?

	Entirely unaccept-able	Unaccept-able	Neutral	Acceptable	Entirely acceptable	I don't know
Bear	○	○	○	○	○	○
Wolf	○	○	○	○	○	○
Lynx	○	○	○	○	○	○
Feral dog	○	○	○	○	○	○
Coyote	○	○	○	○	○	○
Puma/Mountain lion	○	○	○	○	○	○

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Concluding

Is there any other information about grazing cattle in a carnivore exposed area you want to share?

Feel free to fill in any information I forgot to ask about that seems important to you

Thank you so much for participating in this survey.

I hope to have an interview with every participant within two weeks of the survey. For this I will contact your organisation directly.

Appendix VI – Example interview design

CarniForeGraze international interview

Area: British-Columbia
Participant: Livestock protection programme, BC's cattlemen's association
Date and time: 21-01-2021, 19:00 CET

1. Ask about recording

Survey in general

2. Feedback – survey not very specific – hard to answer for a large area.

2.1. Is there anything you would like to be more specific about?

Cattle grazing systems

3. Systems applied

3.1. Can you describe these different systems in British Columbia?
3.2. Does depredation occur in all systems?
3.3. What is the calving system?
3.2. Are there any differences in depredation between the systems?

4. Mortality factors
    - Wild carnivore depredation

4.1. Carnivore depredation most important mortality factor?

5. Farm size

In the survey there is no question about farm size.
5.1. Can you tell me about cattle farm size in British-Columbia?

Cattle depredations

6. Carnivores (from survey)
    - Depredation by: grizzly bears, wolves, mountain lion and coyote; black bear?
    - Wolf most depredation; other species varies

6.1. What about black bears? – do they kill cattle?
6.2. Depredation by wolves is high, are wolves the most abundant carnivore species? Habitat overlaps?
6.3. What about bears?
6.3. Depredation by mountain lion and coyote is less, are these less abundant? Easier to control?

7. Environment

Another element that was not in the survey.
7.1. Do you think the proximity to forested areas has an effect on cattle depredation?
7.2. Are other aspects of the environment influencing depredation?

8. Farm size

IF answer for given for farm size
8.1. Does farm size or herd size influence depredation?

Measures

9. Measures (from survey)
    - Fencing
    - Herding
    - Electric devices for monitoring
    - Avoiding areas and zoning
    - Wild prey management
    - Lethal control
    - Deterrents - range patrol, bells, scare devices
    - Informative gatherings/workshops

9.1. Electric fencing is scored as rarely used, why is it used less than other measures?

9.2. Herding is a common measure, how is this used?

9.3. How are electric devices for monitoring used: what is it exactly? – GPS-collars?

9.4. Is carnivore habitat avoided? Does zoning apply to carnivore habitat?

9.5. In what way is wild prey managed to decrease depredation of cattle?

9.6. When is lethal control of carnivores applied? (when a predator takes livestock/population regulation/set number of predators killed each year)

9.7. Can you explain how deterrents are used?

9.8. Informative gatherings; workshops – what are they about?

10. Compensation; acquirements

10.1. Are you aware of any cases where farmers have to apply measures to receive compensation?

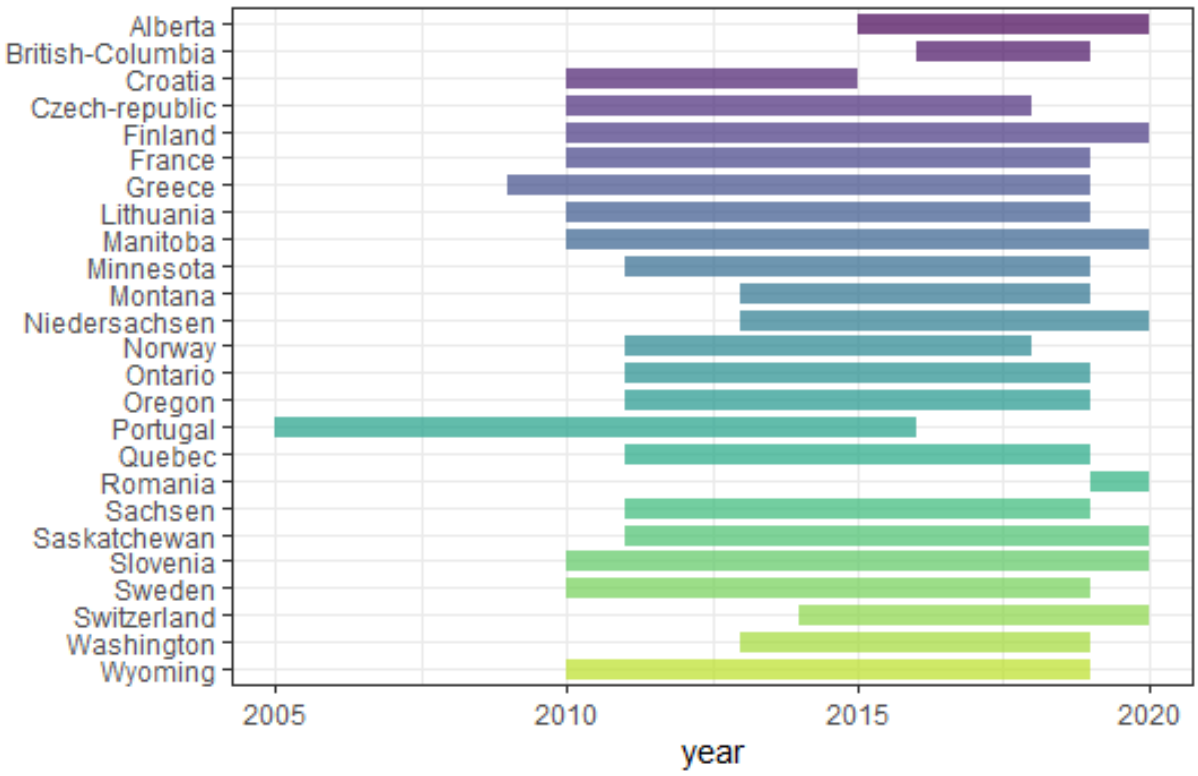
10.2. Do farmers/ranchers often manage to meet the acquirements to receive compensation?

11. Carnivore species and measures

Not literally asked in survey

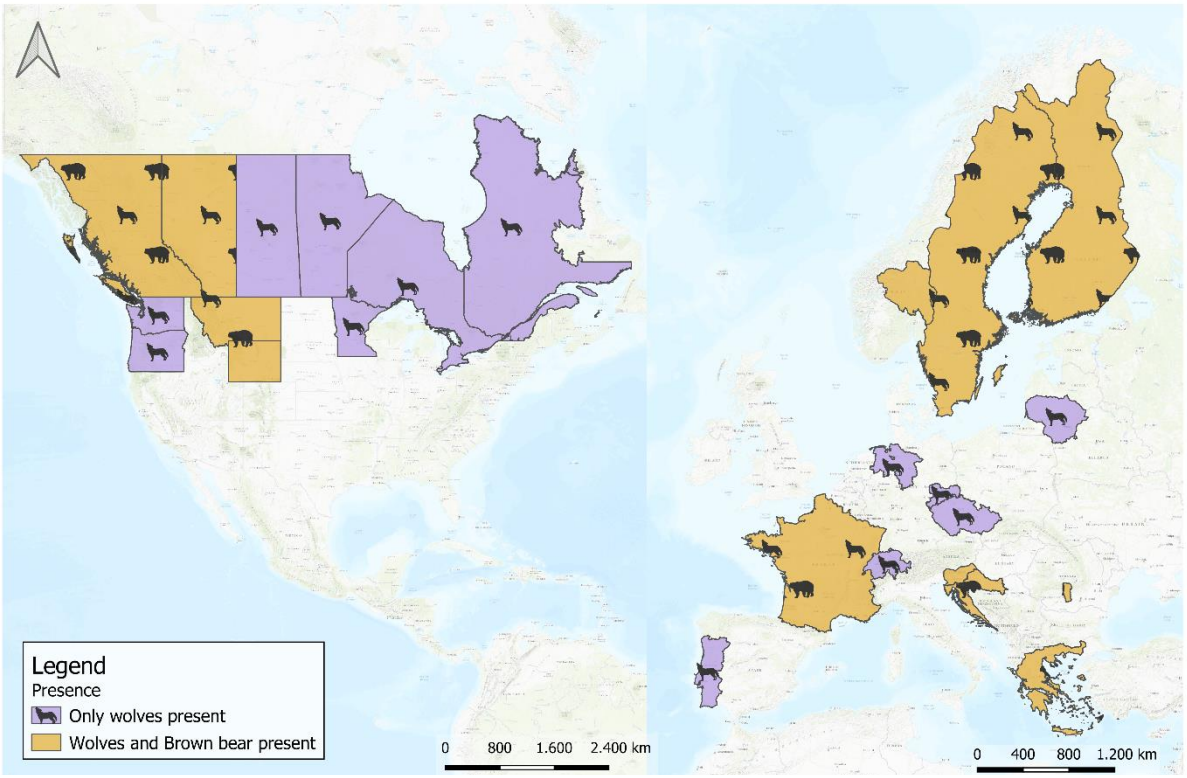
11. 1. Are different measures to prevent depredation applied/acquired for different carnivore species? Is it necessary?

Appendix VII- Availability of depredation data over time

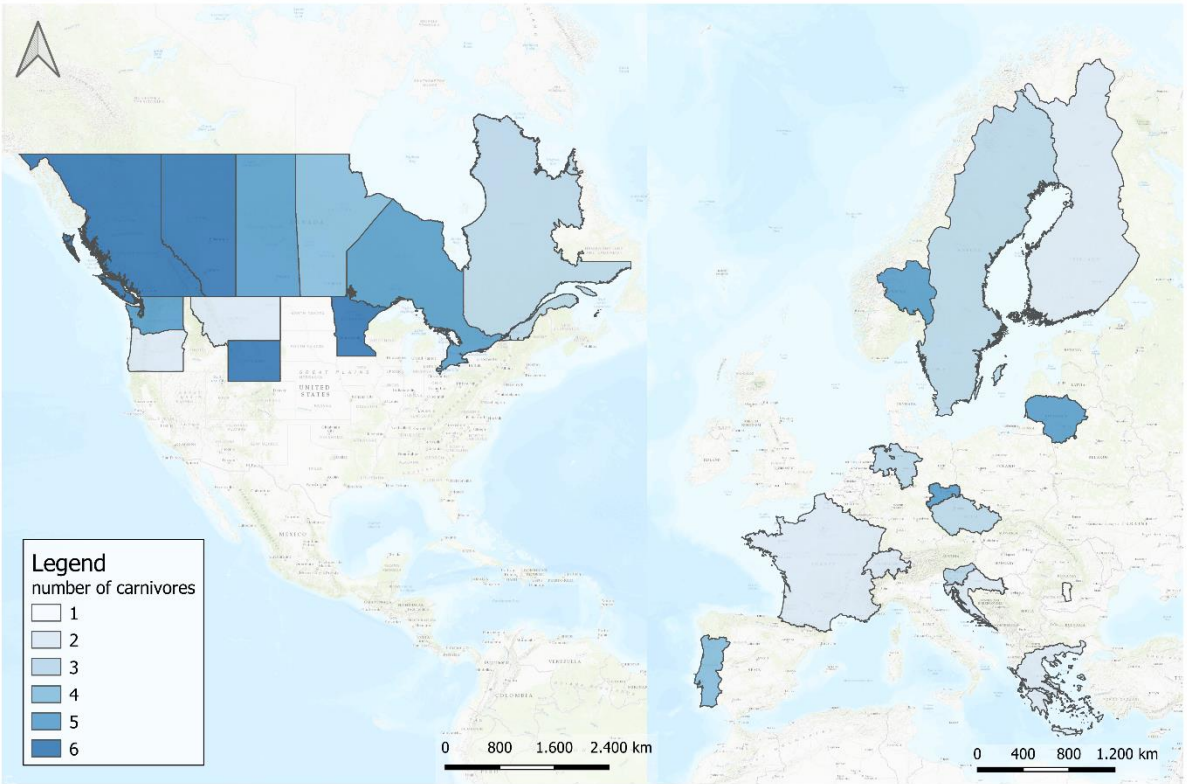


Figure_Apx 1. The availability of cattle depredation statistics over time for all study areas. The study areas on the Y-axis with the availability in years on the X-axis.

Appendix VIII - Carnivore presence bear and wolf and number of species present

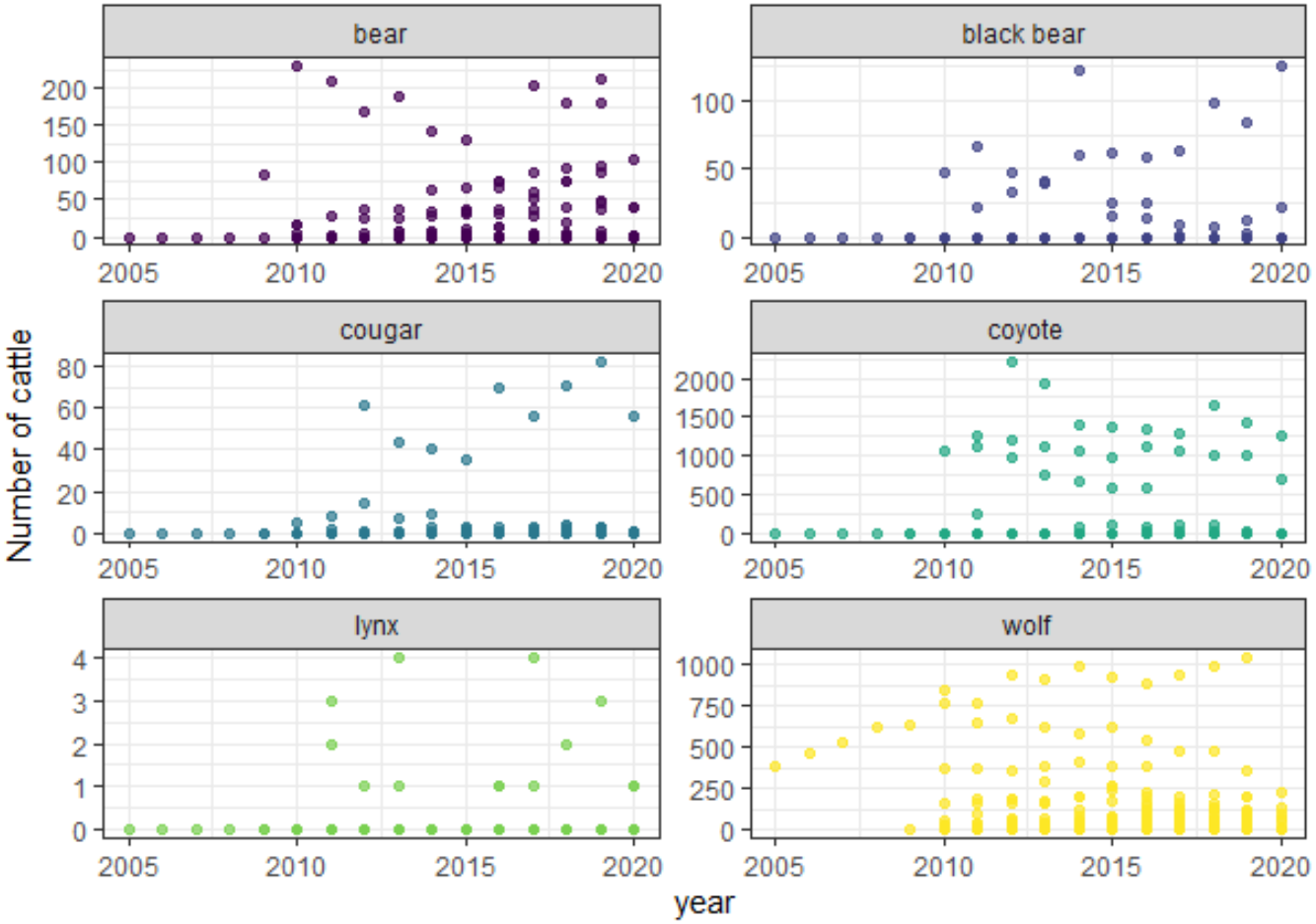


Figure_Apx 2. Map showing the presence of Wolf and Brown bear throughout the study areas. In the pink areas only wolves are present, and in the orange areas both wolf and bear (Esri Topo World, 2021).



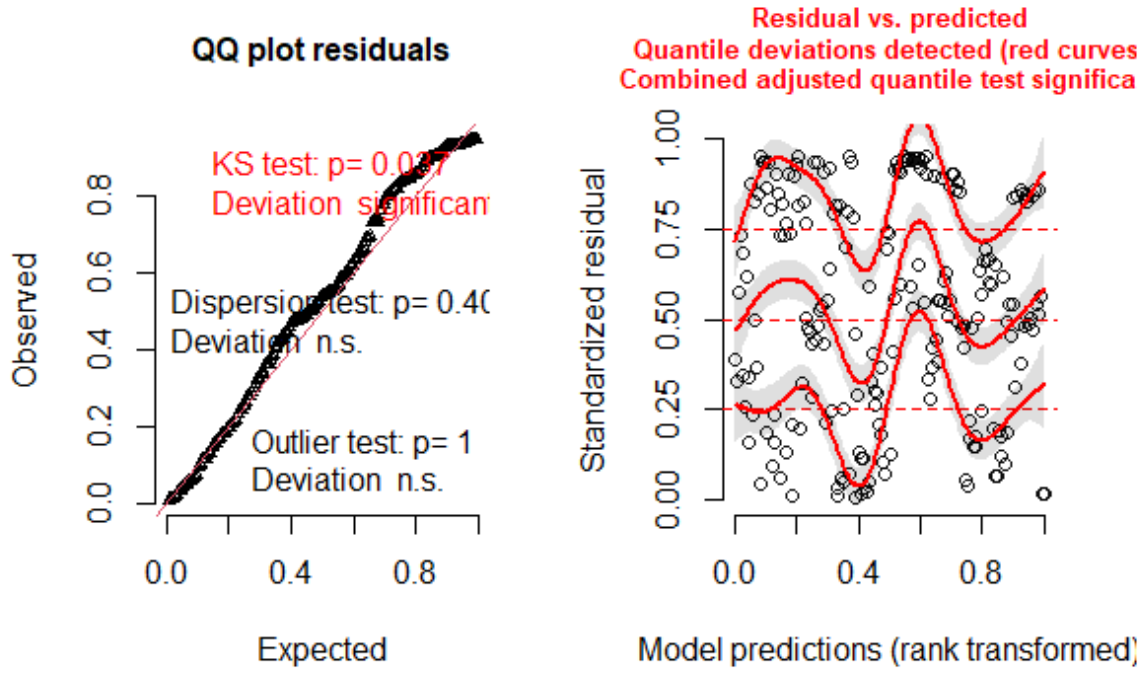
Figure_Apx 3. Maps showing the number of carnivores present throughout the study areas. With increasing darkness of the colour blue, the number of carnivores present increases (Esri Topo World, 2021).

Appendix IX – Depredation trends carnivore species

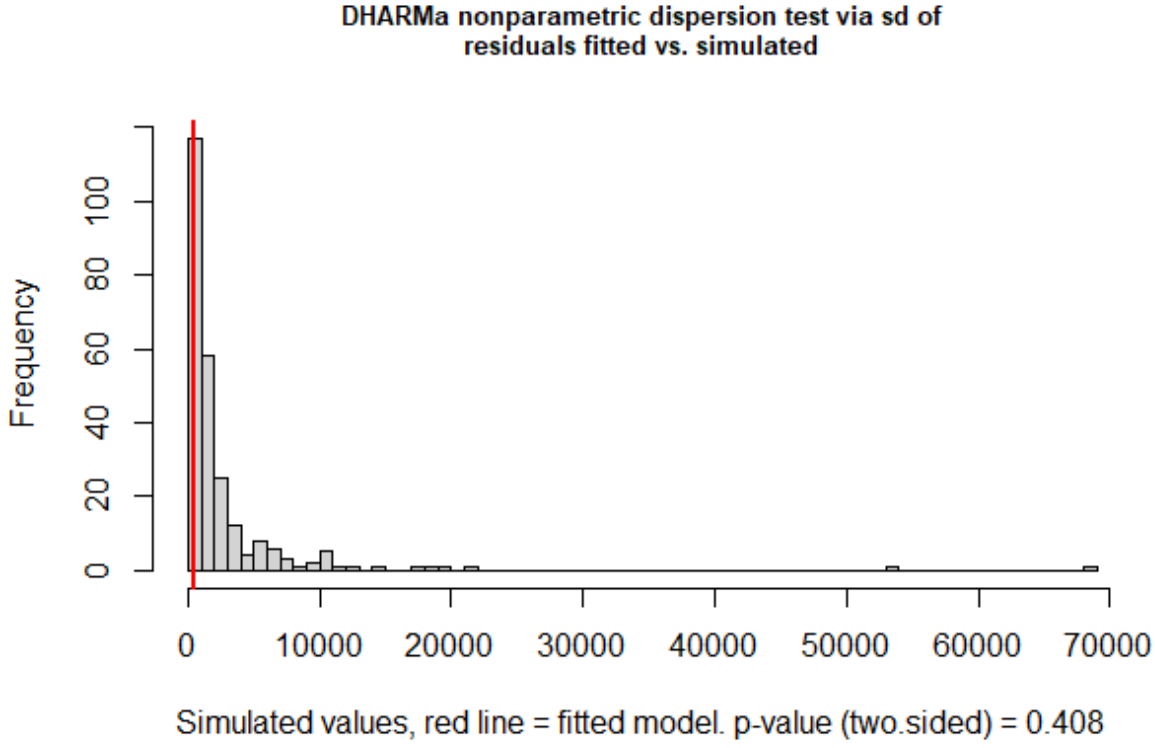


Figure_Apx 3. Scatterplots with total depredation plotted over time for the six carnivore species present in the total study area.

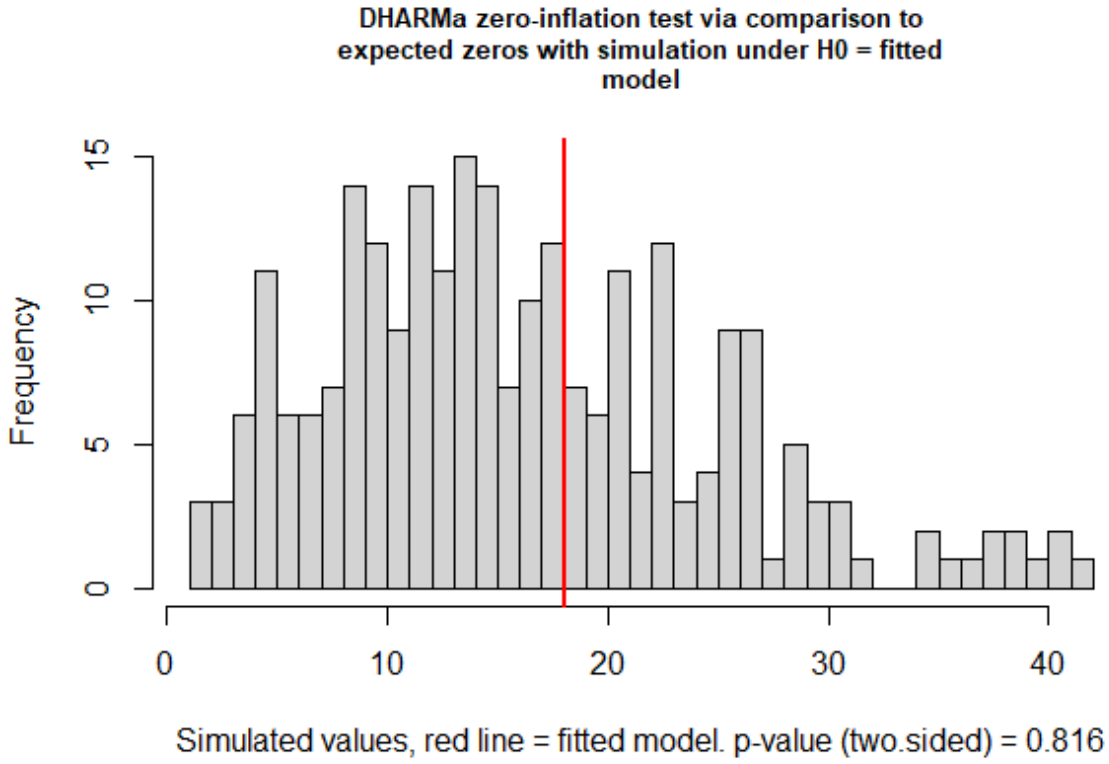
Appendix X – DHARMa residual- and goodness-of-fits tests



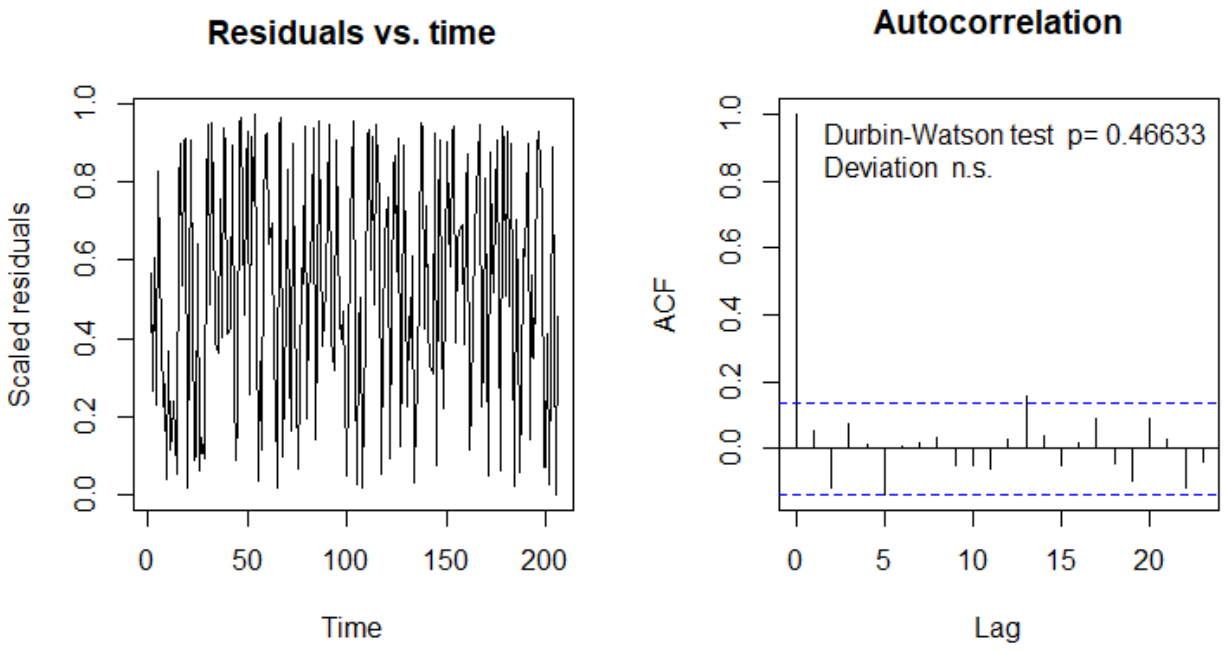
Figure_Apx 4. Dharma residual diagnostics plot of model NB7.



Figure_Apx 5. DHARMa dispersion test result of model NB7.



Figure_Apx 6. Dharma zero-inflation test result of model NB7.



Figure_Apx 7. DHARMa test for temporal autocorrelation result of model NB7.