Master Thesis in Geographical Information Science nr 144

Geographical expansion rate of a brown bear population in Fennoscandia and the factors explaining the directional variations

Lisbet Hougaard Baklid

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Department of
Physical Geography and Ecosystem Science
Centre for Geographical Information Systems
Lund University
Sölvegatan 12
S-223 62 Lund
Sweden

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GEOGRAPHICAL EXPANSION RATE OF A BROWN BEAR POPULATION IN FENNOSCANDIA AND THE FACTORS EXPLAINING THE DIRECTIONAL VARIATIONS

Master degree thesis, 30 credits, in Geographical Information Science (GIS).
Department of Physical Geography and Ecosystem Science, Lund University.

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Supervisor: 1: Ulrik Mårtensson, University of Lund

Scientific summary

Author: Lisbet Hougaard Baklid

Geographical expansion rate of a brown bear population in Fennoscandia and the factors explaining the directional variations

The brown bears, *Ursus arctos* L., in the Scandinavian peninsula were distributed in almost all counties before aimed reduction during the 1700-1900s (Swenson et al. 1995). From 1981-2013 the population increased more than five times (Chapron et al. 2014) to about 3000 individuals (Kindberg et al. 2014). The aim of the master thesis was to find the geographical expansion rate in this bear population in the period 1981-2019 and identify the factors influencing the expansion in this period. The study area is within latitude 58-70 degrees North and longitude 11-27 degrees East.

By two methods in ArcGIS, I found the expansion rates in eight directions in four subpopulations. The source data of bears is shot female bears in Sweden, and adjacent areas in Norway and Finland.

When using linear regression, the expansion varied from 1.19 km/year (0.23-2.15 km/year 95% confidence interval) in direction 270-315 in the second Northern subpopulation to 5.16 km/year (4.05-6.27 km/year 95% confidence interval) in direction 90-135 degrees in the second-Southern subpopulation. The expansion rate was significant in 18 of 32 directions. It was significant positive in all directions in the Southern subpopulation and in direction 90-135 degrees in all subpopulations.

By using Minimum Convex Polygon, MCP, the estimated average expansion from 1981-2019 in the different directions varied in the three Southern subpopulations from 1.02-5.08 km/year but in the Northern subpopulation the expansion was negative in direction 135-315 degrees and about 0 in direction 315-45 degrees. The average expansion for each subpopulation from South to North was estimated to 3.20, 2.63, 2.55 and 0.67 km/year. Linear estimation by MCP give in general higher expansion rate than linear regression due to methodical reasons. The expansion is generally highest towards East and South-East and lowest to the West and partly to the North and South-West.

The fit of seven models was estimated and validated in R by using Akaike's Information Criterion defined by ΔAIC_c and AIC_{cWt}. Forest has the highest positive impact on all four targets. Higher density of roads has some positive impact. Percent of calving areas and mountain are the most negative single factors to expansion. The model with highest coefficient of determination, R^2=0.3556, include the factors forest, mountain, percent calving areas, spring pastures in mountain and density of roads and railways for the target expansion rate by MCP. The results suggest that barriers in West and partly North and Southwest of the subpopulations are highly related to the less suitable bear habitat mountain and calving and spring pastures in reindeer husbandry

Key words: Geography, GIS, brown bear, expansion rate, Ursus arctos, Fennoscandia, Sweden, barrier

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Scientific summary in Norwegian – Vitenskapelig sammendrag

Forfatter: Lisbet Hougaard Baklid

Geografisk ekspansjonsrate i en brunbjørnbestand i Fennoskandia og faktorene som forklarer variasjonene

Brunbjørner, *Ursus arctos* L., levde i nesten alle fylker i Norge og Sverige inntil en målrettet reduksjon på 1700-1900-tallet (Swenson et al. 1995). Fra 1981-2013 økte den over fem ganger (Chapron et al. 2014) til omtrent 2500-3300 individer (Kindberg et al. 2014). Mål i denne masteroppgaven var å finne geografisk ekspansjonsrate i bestanden i perioden 1981-2019 og identifisere faktorene som påvirker ekspansjonen i samme tidsperiode. Studieområdet er innenfor breddegrad 58-70 Nord og lengdegrad 11-27 Øst.

Med to metoder i ArcGIS fant jeg ekspansjonsraten i åtte retninger i fire delbestander. Kildedata er skutte hunnbjørner i Sverige og tilgrensende områder i Norge og Finland.

Ved bruk av lineær regresjon varierte ekspansjonen fra 1.19 km/år (0.23-2.15 km/år 95% konfidensintervall) i retning 270-315 i den nest-nordligste delbestanden, til 5.16 km/år (4.05-6.27 km/år 95% konfidensintervall) i retning 90-135 grader i den nest-sørligste delbestanden. Det var signifikant resultat i 18 av de 32 retningsområdene. Det var signifikant i alle retninger i den sørligste delbestanden og i retning 90-135 grader i alle delbestandene.

Ved bruk av Minimum Convex Polygon, MCP, varierte den estimerte ekspansjonen i de ulike retningene og delbestandene fra 1.02-5.08 km/år i de tre sørligste delbestandene, men i den nordligste delbestanden var raten negativ i retning 135-180, 180-225, 225-270 og 270-315 grader og omtrent 0 i retning 315-360 og 0-45 grader. Gjennomsnittlig ekspansjon i de ulike delbestandene fra sør til nord, ble beregnet til henholdsvis 3.20, 2.63, 2.55 og 0.67 km/år. Lineær beregning ved MCP gir generelt en høyere ekspansjonsrate enn ved lineær regresjon som følge av metodikk. Ekspansjonen er generelt høyest mot øst og sørøst og lavest mot vest og delvis nordvest og sørvest.

Ulike faktorer som kan påvirke ekspansjonen, ble testet i ulike modeller i R ved Akaike's informasjonskriterie. Skog har størst positiv betydning. Høyere veitetthet har noe positiv betydning. Fjell og prosent andel kalvingsområder er de mest negative enkeltfaktorene. Modellen med høyest forklaringsgrad, R^2=0.3556, var for lineær ekspansjon ved MCP for faktorene skog, fjell, vårbeite i fjell, tetthet av vei og jernbane og prosentandel kalvingsområder. Resultatene indikerer klart at barrierer i vest og delvis nord og sørvest i delbestandene skyldes mindre egnede habitater som fjell, samt høy andel kalvingsområder og vårbeite. Bjørnenes predasjon og forstyrrelse på reinkalver og simler vår og tidlig sommer i disse fjerntliggende områdene gir høy score på en konfliktskala.

Nøkkelord: Geografi, GIS, brunbjørn, ekspansjonsrate, Ursus arctos, Fennoskandia, Sverige, barriere

Veileder: Ulrik Mårtensson
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Institutt for naturgeografi og økosystemvitenskap, Universitetet i Lund
Thesis nr 144

Summary - popular version

Lisbet Hougaard Baklid

Geographical expansion rate of a bear population and the factors that impact

Many large carnivore populations have due to conflicts been reduced. The bear population on the Scandinavian peninsula has been widely distributed and connected to the populations in Finland and Russia. During the 1700-1900's the bear population was decimated because of bounties and hunting. During the 1900's the bears was included in conservation aims. In this study, I describe the geographical distribution and expansion in the Fennoscandian bear population and factors influencing in the period 1981-2019.

The expansion rate varied in the different directions and subpopulations. The Southern subpopulation increased by 2.03 km/year in range from 1981-2019 using linear regression. The average expansion for each subpopulation is also estimated by simplified linear estimation to 3.20, 2.63, 2.55 and 0.67 km/year for the Southern, second-Southern, second-Northern and Northern subpopulation, respectively. The highest expansion rate was in direction 90-135 degrees in the second Southern subpopulation, respectively 5.16 km/year by method 1 and 5.08 by using method 2. Generally, the highest expansion was to the East and South-East and lowest to the West and partly North and South-West. In the Northern subpopulation the density of bears was more sparsely.

I also identified the factors influencing the expansion of female brown bears. I chose combinations of factors to be tested by Akaike's Information Criterion. The best fit models had compliance or correlation, r, of 36.5-59.6%. The analyses show that forest is the most positive factor and gains bears. Lower road density hamper expansion in some degree. Human density, settlements and cities and spring pastures in forest have low or no impact. Several factors synonym to remote areas in and near alpine areas have a high negative score, like reindeer pastures in spring and early summer in mountain, and number of reindeer there, though the most negative factors are percent calving area and mountain. The areas in West and partially North and Southwest of the subpopulations represent very tough barriers to bear expansion and are highly related to alpine areas and reindeer pastures used in spring and early summer when the reindeer does and calves and are most vulnerable, and the bears may predate and stress the calves and does.

Key words: Geography, GIS, brown bear, expansion, range, Fennoscandia, Sweden, barrier

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List of acronyms

Geographical Information Science - GIS
Akaike's Information Criterion - AIC
Minimum Convex Polygon – MCP
The International Union for Conservation of Nature – IUCN
Sexually selected infanticide - SSI
Brottsförebyggande rådet / Swedish National Council for Crime Prevention – BRÅ
The Scandinavian Brown Bear Research Project - SBBRP
Swedish Veterinary Institute - SVA
Corine Land Cover - CLC
Southern subpopulation – S
Second-Southern subpopulation – SS
Second-Northern subpopulation – SN
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1. INTRODUCTION

Variation in the distribution of species is a central theme in evolutionary ecology due to the theory of fitness, including survival and competition (Soulé, 1986). Lakes, rivers and mountains often create natural barriers for further expansion for many terrestrial species. Until the Industrial Revolution there was fewer human constructions or human dominated landscapes except for agriculture. The human development since World War II, created new barriers to wildlife species, and decreased landscape connectivity in many parts of the Northern Hemisphere, i.e. railways, highways, cities, hydropower energy production, cabin areas, and mine activities (Proctor et al, 2012; Garcia et al, 2007; Martin et al, 2012, Schwartz et al, 2012). Conservation biology is a science aiming at protection of species, their habitats and ecosystems (Soulé, 1986). The science of conservation biology concerns the factors that affect the loss of biodiversity, i.e. changed land use causing changed landscape and habitat fragmentation for many wildlife species. It also focuses how endangered and scarce species can be reintroduced or increase in numbers by management and restoration. Corridors and landscape connectivity and permeability of suitable habitats are parts of this science to evaluate and secure genetic and demographic viable populations and even recolonize into areas of suitable ecosystems.

The International Union for Conservation of Nature (IUCN) has developed standards for the status of species on the 'Red List for Threatened Species'. The Red List for Threatened Species is published at a global and a national scale, giving the status for species with populations that have shown a decline in distribution and density or numbers due to overexploitation, nature phenomenon, barriers or habitat loss. Due to reduced and small populations, reduced genetic diversity and inbreeding may be factors that escalate the risk of extinction (Soulé, 1986).

In the perspective of conservation biology, there are many examples illustrating the need for suitable habitats without negative human influence. Reindeer (*Rangifer tarandus*) in Norway have been split into several small and isolated subpopulations by alpine resorts, traffic, technical infrastructure, ski trails and cabins (Nellemann et al., 2010). Tigers (*Panthera tigris*) in Central India prefer forested areas, rugged terrain and low human activity, and they avoid non-forested areas with high human activity (Reddy et al., 2017). Their range has been reduced due to increased human activity and settlements. Mountain foxes (*Vulpes lagopus*) show avoidance behavior towards red foxes (*Vulpes vulpes*) in their natural habitats and, due to climate change, the red foxes are distributed at higher elevation in natural mountain fox habitats (Shirley et al., 2009). The interspecific competition between the two species is human-induced. An example of direct human actions is the illegal killing of wild animals, which can sabotage the management and bring species to critical population levels. Turkalo et al. (2016) found that primary illegal killing and secondly habitat loss are the factors that bring a population of African forest elephants (*Loxodanta cyclotis*) in a persistent negative decline. To recover this elephant population, they estimated that the population needed about 60 years to double their size, three times more than for the savannah elephants. The importance of targeted management to achieve viable populations within the frame of the biology of each species is therefore increasing, just as the importance of landscape and population connectivity that secures core areas and corridors to achieve species' genetic flow and viable population size. Not only for conservation, but also for harvesting species through adaptive hunting, there is a need for knowing the effective population size and its dynamics with the natural and human-induced environment within a frame of genetic and demographic minimum viable population.

For several species in Europe and North America like the large predators, the legal overexploitation by using bounties and no hunting quotas, was very comprehensive in the 1700s and 1800s. In several cases populations were brought to local, regional or national extinction. During the 1900's killing of the terrestrial large carnivores was prohibited at local, regional and national scales. In the decades after protection several populations increased in numbers and expanded into previous geographical ranges. As for other large carnivore populations, several bear populations have increased geographically and still are recolonizing and expanding into new areas (Pyare et al, 2004; Jerina et al, 2008; Schwartz et al, 2002; Schwartz et al, 2006; Frary et al, 2011; Wiegand et al, 2004; Rice et al, 2009; Murphy, 2016). As these populations expand geographically, many of them encounter natural barriers and barriers built by humans.

The common Swedish and Norwegian brown bear, *Ursus arctos*, population showed a similar pattern of decline in population size and distribution. The Scandinavian brown bear population in Norway and Sweden was drastically reduced during the 1700s-1900s, due to bounties and free hunting, and the political goal was extinction (Swenson 1994, Swenson 1995). The national bounties were eliminated in Sweden and Norway in 1893 and 1931, respectively. Functional extinction in the sense of no possibility of viable population, because of no or very few females, occurred in all Norwegian counties by 1931. The last female bear in the Norwegian part of the original Scandinavian bear population, was shot in 1956. The bears in Sweden survived in four geographical subpopulations, as determined by four female concentration areas, mainly in the more remote forest and alpine areas in the Northern counties Norrbotten, Västerbotten and Jämtland (Swenson 1994b). The Swedish population grew from about 131 individuals at the lowest level in the beginning of the 1900s to about 500 in 1981 and further to 300-900 bears in 1994 due to prohibition of hunting (Swenson 1994a, Swenson et al 1994b). In 2008 the number of bears in Sweden was estimated to about 3 300 bears or 2968-3667 bears, the highest number of Swedish bears in modern times (Kindberg et al., 2011). The population estimation for 2013 and 2017 were about 2 782 bears and 2877 bears, respectively (Kindberg et al, 2014; Kindberg & Swenson 2018). The total increase from 1981-2013 in the Swedish bear population was anyway more than five times (Chapron et al, 2014). The Swedish bear population has been the fastest growing bear population in the world for the last decades and it is the second largest bear population in Europe after Romania.

As a population increases in numbers, there should be a geographical expansion as well. Several studies have focused on the expansion in recolonizing bear populations (Schwartz et al, 2002; Kojola et al, 2006; Jerina et al, 2008). The distribution of grizzly bears in the Greater Yellowstone Ecosystem showed an increase in area of 48% and 34% for the 1990s compared to the 1970s and 1980s, respectively (Schwartz et al, 2002). Jerina et al (2008) estimated the Slovenian brown bear population's spatial expansion rate to be 1.6-1.9 km/year and a net annual population growth of 1,7% for the period 1945-1995 using signs of bear presence. Both studies and studies of grizzly bears by Schwartz (2006) documented different expansion rate in different directions caused by landscape features and human activities.

Large carnivores may kill livestock, hunting dogs and/or economically valuable game species, causing conflict with humans, based on both economic and non-economic interests (Linnell et al, 2005). The acceptance of illegal hunting and the acceptance of large carnivores including brown bears, therefore vary geographically at local, regional and national scales both in Fennoscandia and other parts of the world (Gunther et al, 2004; Kaczensky et al, 2011; Gangaas et al, 2013; Andrén et al, 2006; Liberg et al, 2012; Swenson et al, 2011). Even in areas where hunting quotas are controlled and within viable terms, there still might be illegal hunting due to conflicts with humans. Suutarinen (2017) found that despite legal hunting in the period 1998-2016, illegal killing of grey wolves, *Canis lupus*, regulated both the numbers and the distribution of wolves in Finland. Liberg (2012) found that poaching slows the expansion of wolves in Europe and causes about half of the mortality in the Scandinavian wolf *Canis lupus* population. Illegal killing of protected animal species without respect for legal hunting quotas or regional and local conservation aims, may therefore *reduce* the positive effects of connectivity on expansion and *increase* the negative effects of natural barriers and barriers of human constructions and activities. Illegal hunting may therefore create or reinforce barriers for recolonizing.

2. AIMS OF THE STUDY

Chapter 1 and 3 provide the background knowledge and basis for the rest of the study, including the hypothesis. To understand and analyze the expansion in the connected Swedish-Norwegian-Finnish bear population, it is important to know the factors that either improve or reduce the chances for bears to disperse into new areas and thereby expand the range of the population. The aims of my study were

1. *to calculate the geographical expansion rate of female brown bears in Fennoscandia in the years 1981-2019* and
2. *identify natural and human-induced landscape features and activities that either reduce or increase the rate of female population geographical expansion*.

I have chosen to study the female bears by the shot female bears of two important reasons:
1)The female bears in contrary to the male bears, are philopatric which means that most of them establish their home area close to or overlapping their mother's home area (Støen et al. 2005; Zedrosser et al. 2007), ref. Chapter 3.5.
2) Swenson et al. (1998) found that the last position of all the shot females due to license hunting, in total give a very good representative reflection of the female bear population distribution.

Due to population estimates and bears shot due to hunting and damage control, I expected the expansion rate to be positive during the study period of 1981-2019 for female bears *(hypothesis 1a)*, although the expansion rate may have varied in time. Because female bears are philopatric (Swenson et al., 1998; Kindberg et al., 2011; Jerina et al., 2008) and due to the philopatric dispersal pattern, I expected the female expansion to be linear *(hypothesis 1b)*. Due to different distribution of suitable bear habitat, landscape permeability / corridors and factors influencing negatively, the expansion rate totally and over time may have been different in the four subpopulations *(hypothesis 1c)* and the expansion rate might have varied in different directions *(hypothesis 1d)*.

I expected that natural barriers, such as large bogs and lakes, wide rivers, and bare mountain, would hamper or stop the female geographical expansion *(hypothesis 2a)*. I expected human-induced landscape features, such as railways, roads with a certain amount of traffic and standard, road density and towns and settlements, to hamper the expansion *(hypothesis 2b)*. Illegal killing is expected to hamper the expansion in vulnerable reindeer areas used in spring and in areas of higher reindeer density *(hypothesis 2c)*. The potentially high losses of reindeer calves (Karlsson et al. 2012), is higher than that of any of the other predators during spring except for casual presence of wolves, and bear presence thereby cause a high score on the Potential Conflict Index (Gangaas et al. 2013).

I expected that some land cover types promote the female population geographical expansion, such as forested areas of pine and spruce and other habitats preferred by bears *(hypothesis 2d)*.

3. STUDY AREA

3.1 Location

The study area is 385 505 km^2 within about latitude 58 - 70 North and longitude 11 - 27 East. It represents the location of shot female bears 1981-2019 and a zone of 50 km around them, ref. Chapter 4.4.1 and Figure 10, though the marine areas and most of the islands in the Gulf of Bothnia and the Baltic Sea are excluded. The study area shown in Figure 1 includes:

- the counties of Dalarna, Gävleborg, Västernorrland, Jämtland*, Västerbotten*, Västmanland and Norrbotten*, and the Northern parts of Värmland, Örebro, Uppsala, Södermanland and Stockholm. Some areas* close to the Norwegian border are outside the defined study area.
- Eastern parts of the Norwegian counties Trøndelag, Nordland and Innlandet and some Southern parts of Troms og Finnmark.
- Western parts of Lapland County in Finland.

Norrbotten county is the largest county; 98 000 km^2 and almost all of it is a part of the study area.

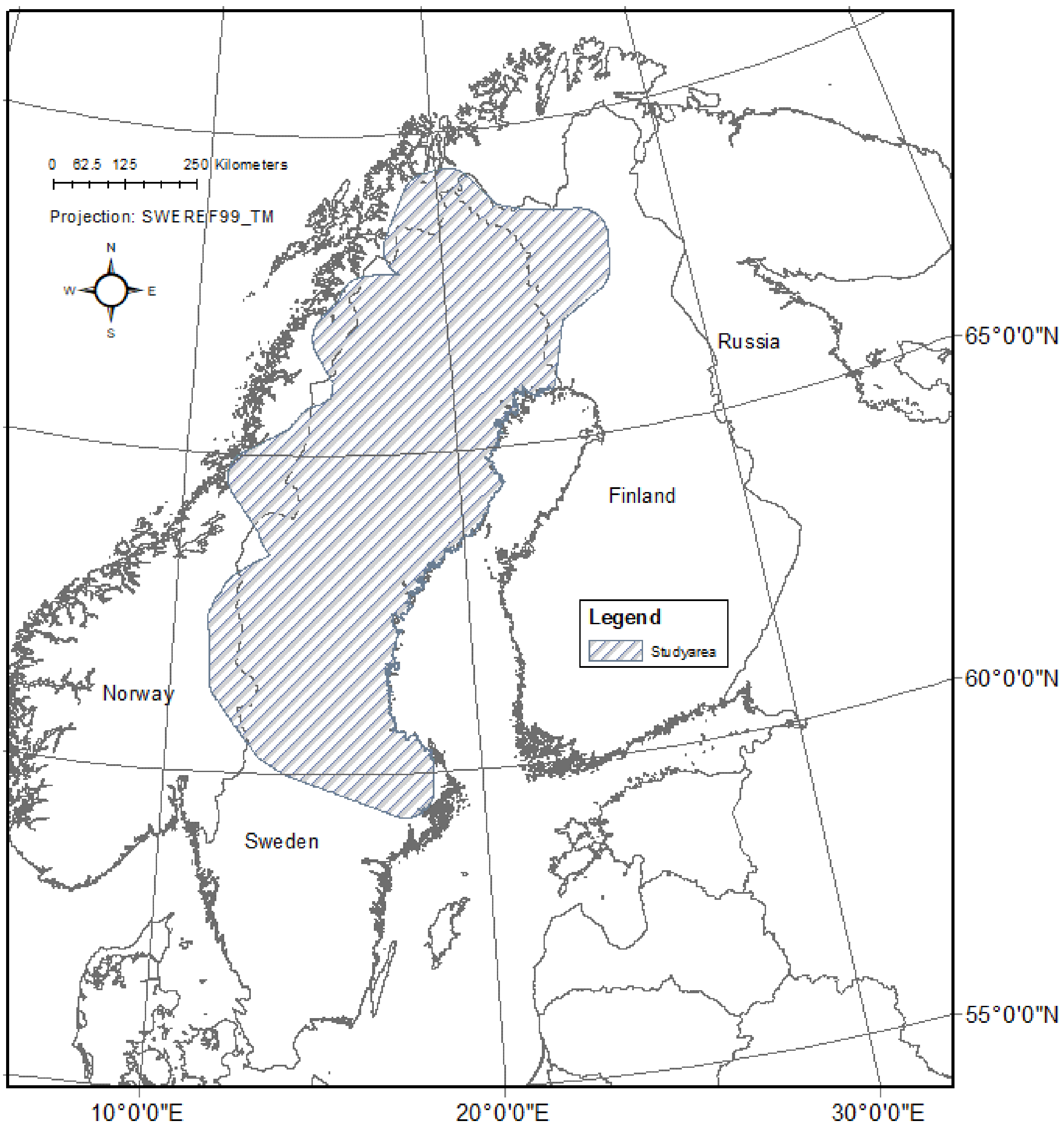

Figure 1. The study area is marked with cross hatching. Area of the analyses is North of latitude 58. Areas within Norway, Sweden and Finland between approximately 11- 27 degrees East is included. Projected coordinate system: SWEREF99_TM. Map source: DIVA-GIS.

3.2 Topography and vegetation

The terrain within the study area varies from sea level at the Gulf of Bothnia and the coast of Norway and up to 2100 meters a.s.l. The higher terrain levels, like lower and higher mountain areas, dominate the areas along the border between Norway and Sweden, see Appendix 10.

The biogeographical zone is boreal, including South, Middle and North boreal zone. The forests are dominated by Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) and secondary birch *(Betula spp.)*. The lower high Alpine areas are shrub-dominated semi-open areas with *Salix spp.* and the higher mountain areas are bare areas above tree line.

In the subalpine areas the downy birch (*Betula pubescens spp. czerepanovii)* is often the dominant tree species growing up to 8 meters in height. The forests in the Northern counties are more influenced by Polar climate. The tree line is therefore lower in the Northern areas, and the proportion of birch is higher than in the South. Though forests dominate about 75-80% of the land area within the study area, about half the area of Norrbotten is bare mountain and mountain forest.

Lakes, rivers and bogs are quite common and evenly distributed in the landscape. Most of the lakes and bogs are less than 5x5 km. Few rivers are wider than 15 meters.

3.3 Human population density, roads and railways

The human population density in the study area is varying from 0 to about 24 750 persons per km^2, and the mean is 1004-1005 per km^2 (Statistics Sweden, Norwegian Mapping Authorities and Ministry of Education and Culture Finland – Paituli), see Appendix 11. Especially Norrbotten, Västerbotten and Jämtland have large areas with no permanent settlements, like the mountains in the West of Sweden and East of Norway. In the adjacent area and in Finnish parts of the study area, the population density is mostly 0-1 persons per km^2. In urban areas the human density is highest. In general, the human density decreases in the gradient South – North and coastal-mountains.

Road density varies with human population density. The number of vehicles and road standards are often related so the roads with highest traffic have the highest standard. The highest number of motor vehicles traffic is on national and some regionally important roads, and the traffic is denser close to and in populated areas, especially the cities, see Appendix 13. The amount of traffic may also vary seasonally. Highways are generally larger barriers to humans and wild land-living animals, than gravel roads due to width, physical construction, and number of vehicles passing. Along some of the highways and regional roads there are game fences.

Railways are not as widespread as roads. A railway net almost only exists in the Southern and Southeastern parts of the study area.

3.4 Brown bear population growth

Swenson et al. (1994) estimated the population growth in the Swedish brown bear population to 1.5 % annually during the period 1943-1993. Kindberg et al. (2005) found an increase rate in the population of 5.5% in the period 1997-2005 while Kindberg et al. (2011) found a slightly lower increase 4.5% in the period 1998-2007. Though there was an increase as described in the 1900's on a national level, the growth varied between 0 and 10.2 % in different counties for the years 1998-2007.

During 2008-2013 the population decreased by -3.2% annually, most likely due to higher hunting quotas (Kindberg et al., 2014), see figure 3. The decline was only in Norrbotten and Jämtland, respectively -8.3 % and -7.1 %, whereas it was stable in the other counties.

The population estimation in each county in 2013 varied; 906 bears in Jämtland, 593 in Norrbotten, 412 in Dalarna, 381 in Gävleborg, 300 in Västerbotten, 173 in Västernorrland and 17 in Värmland (Kindberg et al. 2014). Though the estimation for 2008 was about 3 300 bears (Kindberg et al. 2011), the later estimations for Sweden was lower, 2771-2980 bears totally (Kindberg & Swenson 2018). The change is shown in Figure 3.

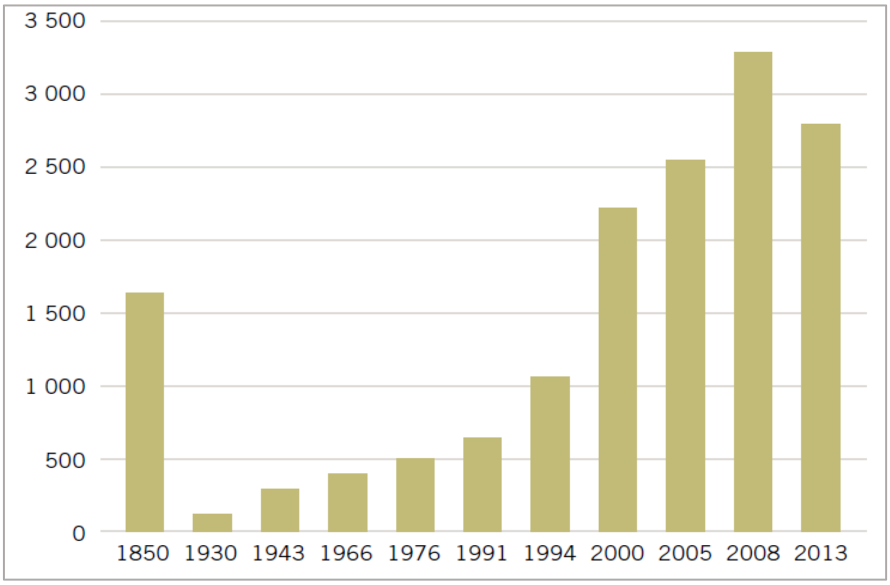

Figure 2. Estimated size of the brown bear population from 1850-2013 (Kindberg et al. 2014).

In the years 2012-2017 Kindberg & Swenson (2018) found no statistical changes in number of bears in the Swedish population. Though based on DNA-analyses in collected scats from both bear sexes, there seem to be a reduction of bear density and bear distribution in population the from 2013 to 2017 (Kindberg et al., 2014, and Kindberg et al., 2018), see Figure 3 and 4. Areas in Norway and Finland within the population have principally very low density.

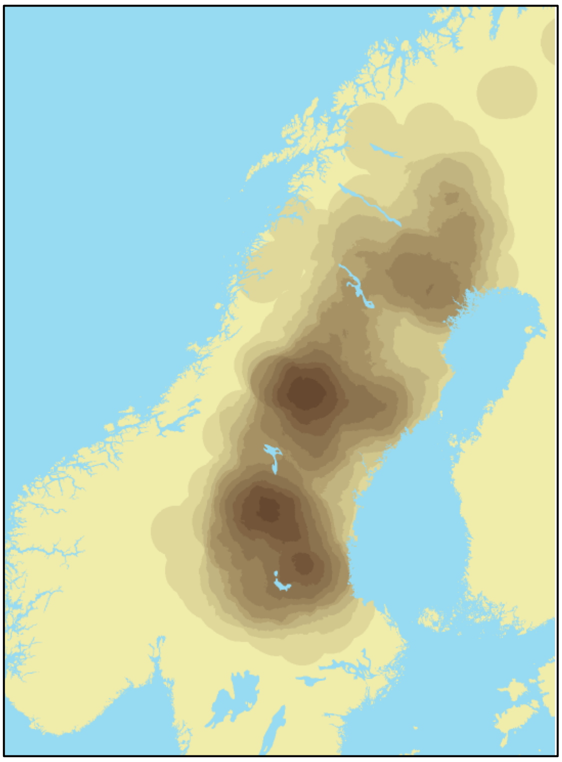

Figure 3. Bear density within the population in 2013 (Kindberg et al., 2014).

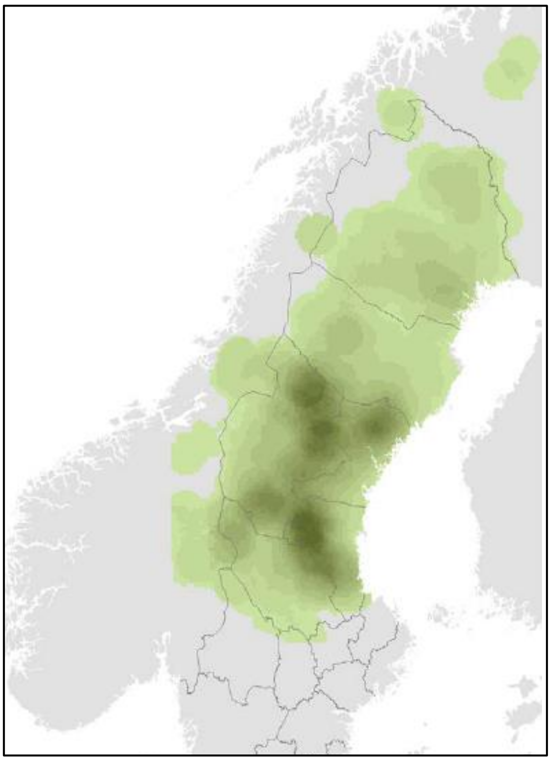

Figure 4. Bear density within the population in 2017 (Kindberg et al., 2018).

The darker value of color the more bears/ km^2 though the scale is not the same in the two figures.

3.5 Brown bear population structure

The area that each adult bear uses is called its home area (Swenson et al, 2010). The size of each home area depends on bear density, mating season, food resources, age of both males and females, and whether females are with or without cubs. The home areas overlap, and the sizes are smaller in areas with high bear density than in those with low density.

The sizes of the home area vary from minimum 20 km^2 for a female with cubs to 8 300 km^2 for an adult male bear (Swenson et al, 2010). The average for females without cubs are respectively 217 km^2 in the South and 280 km^2 in the North of Sweden. Females with cubs have an average home area size of 124 km^2 in the South and 137 km^2 in the North. For adult males, the average home area size is 833 - 1088 km^2. The male home areas may be larger outside areas with higher female density than inside (Krofel 2010).

The female reproduction period starts at the age of 4-6 and 5-7 resp. South and North of Sweden (Swenson et al., 2010). After the age of 20 the reproduction rate decreases but due to hunting and damage control few female bears reach the age of more than 20 years anyway.

Female bears are philopatric (Støen et al 2005; Zedrosser et al. 2007). The average dispersal distance of females from natal area is 27 km and never documented farther away than 80-90 km in Sweden (Støen et al. 2006; Swenson et al. 1998). The female dispersal pattern keeps the female areas quite concentrated. When the number of females increases in a subpopulation, the female concentration area is typically increasing geographically as well (Swenson et al 1998). Kindberg et al. (2011) and Kindberg et al. (2014) defined the female concentration areas as core areas where 90% of the female bears in the quotas were shot during harvest hunting period in the autumn.

Both Swenson (1998) and Jerina (2008) found that the density of female brown bears from the center of the core area towards the peripheral, decrease more rapidly than for males. The proportion of males versus females in the core area were about 51% versus 49% and outside the core areas in so called peripheral areas, about 75% versus 25% (Swenson, 1998; Jerina, 2008). Kindberg et al. (2011) even suggests that the density of adult females may be higher than that of adult males in the center of the core area.

Near the outer front of the female core area, also called expansion front in an increasing brown bear population, it is difficult to estimate the bear density because it varies within quite short distances (Swenson et al., 1998; Kindberg et al., 2011; Jerina et al., 2008). Due to philopatry the density and the proportion of female brown bears decline rapidly the further away from the core area. There is a decline of male bears as well but not as rapidly because males disperse further away from their natal area, sometimes several hundred kilometers. The female expansion is therefore probably linear.

3.6 Brown bear habitats and individual movements

3.6.1 Habitat selection in natural environment

In Sweden, the bears are significantly spending more time in forested rugged terrain far from settlements and resorts than any other terrain type (Nellemann et al. 2007). Female bears located > 10 km from towns and/or resorts significantly spend more time in rugged forested terrain than flatter forested terrain or in bogs. Far from human settlements, for *both* female and male bears the use of rugged forested areas was significantly higher than expected compared to availability. All areas dominated by bogs were used less than expected and flatter forested terrain was used according to availability. This is supported in a larger scale by Katajisto (2006) who found that brown bear home areas in Sweden are randomly distributed in forested areas with a low level of human influence. Though the bears in the South select forest and, in some degree, avoided semi-open land and other land covers, the bears in the Northern parts of Sweden often prefer semi-open land, secondly prefer forest and avoid in some degree the other land covers. Most of the areas in Norway, Finland and Sweden are therefore good or suitable habitat for brown bears because most of the land areas are covered by forest.

In the peak berry season in August and September bears select locations in forest with a higher occurrence of lingonberries (*Vaccinium vitis-idaea*) and blueberries (*Vaccinium myrtillus*), and even eat crowberries (*Empetrum nigrum*) (Hertel et al. 2016).

The Swedish bears spend the time from October-November to March-May denning (Friebe 2001, Manchi 2005). They prefer denning in habitats dominated by open canopy of Scots pine forest and habitats with moist soil and rich vegetation before mountain coniferous forest and bogs (Elfström 2008). They avoid den sites in alpine mountain birch forest, water, peat, exposed bedrock, gravel pits and deciduous forest.

3.6.2 Habitat selection versus influence of human activity and settlements

Nellemann et al. (2007) found in a study area in Sweden that there was no significant difference in bear use between zone 0-5 km and 5-10 km from roads. In the zone within 10 km from resorts and settlements 52% of the bears of both sexes were subadults. More than 74 % of the females were located more than 10 km from any town or resort. Martin et al. (2013) found that human activity had negative effects on individual movements on hourly and daily scales during the non-denning season and the effects were greater for females with cubs than for lone females. Proximity to human settlements doesn't influence circadian movements but human activity like traffic, and roads does (Ordiz et al. 2014).

Within their home range, females select habitats and activity patterns that minimize the human-caused disturbance indicated by distance to houses and low-traffic roads (Martin et al. 2010). During the main periods of the human activity the bears are located on steeper slopes and in less human disturbed area, still they select habitats that provide abundant food, like ants and berries anyway.

Females with cubs though show habitat selection patterns of avoiding adult males as cub predators (Steyaert et al. 2016). The anti-predator behavior has two main patterns; 1) avoiding habitat possibly used by elder male bears to avoid predation, so called sexual selected infanticide (SSI), see Chapter 3.9, and 2) choosing habitats with protective characteristics to gain shields to secure their cubs against predation risk from adult male bears. In a human-dominated landscape, mother bears selecting human associated habitats were significantly more successful in avoiding losing their cubs due to SSI than other mother bears. Steyaert et al. (2013) also found spatiotemporal segregation between sexes during the mating season for females with cubs-of-the-year, because in contrast to adult males, the mothers with the cubs selected less rugged landscape relatively close to certain human-related landscapes, and in more open habitat types. The theory is that the successful mothers use human associated habitats to gain a more effective shield against male bears than the unsuccessful mother bears, because adult male bears older than 4 years avoid human associated landscape (Steyaert et al., 2016; Nellemann et al. 2007).

In general, the Swedish brown bears seem to avoid areas close to human presence with high mortality risk caused by humans as a behavior towards ecological sink habitats (Steyaert et al. 2016). Selected habitats, in spite of high mortality risk due to humans so called potential ecological traps, were agricultural fields especially oat *Avena sativa* fields. Although Leclerc et al. (2016) found that there is consistent individual variation among bears in habitat selection in for example bogs and cut blocks, the likelihood of preference is very consistent.

3.7 National parks, nature reserves and other protected areas

Hunting is prohibited in most of the national parks and most of the other protected nature areas. These areas are described as remote with low public attention and law enforcement (Swedish Environmental Protection Agency, www.naturvardsverket.se). There is very low human activity. In the national parks, bears are legally mostly shot by damage control and the number has been low.

There are 29 national parks and almost 4000 nature conservation reserves in Sweden, in addition to the Natura 2000 areas established the last 15 years (Swedish Environmental Protection Agency, www.naturvardsverket.se), see Appendix 12. The nine first national parks in Sweden were established in 1909, the largest of them Sarek 1970 km^2 and Stora Sjöfallet 1278 km^2. The largest was protected in 1963, Padjelanta 1984 km^2. All three of them in Norrbotten. Not far from these are the national parks Pieljekaise, Muddus, Abisko and Vadvetjåkka. Except for Muddus, the mentioned national parks are in the Western part of the counties adjacent to the Norwegian border.

National parks and other protected nature areas cover 1.6 and 9 % respectively of Sweden's land area of 411 000 $km^2$and about 90 % of the Swedish national park area is in the county of Norrbotten. Half of the other protected nature areas are in the county Norrbotten and about 40 % of them cover areas in Västerbotten, Jämtland and Dalarna counties. In adjacent areas in Norway and in Finland within the study area, there are protected areas as well, but hunting and damage control is generally not prohibited.

3.8 Predation and conflicting interests

3.8.1 Predation on domesticated animals and wildlife species causing potential conflict

The main diet of brown bears in Sweden is berries (Stenset et al., 2016). During spring and summer ants and ungulates comprise most of the dietary energy content though bears also eat herbs, wasp and graminoids (Dahle et al., 1998; Stenset et al., 2016).

The most important dietary energy source during spring is ungulates (Dahle et al. 1998) and it gives valuable proteins to the bears after the denning period. Swenson et al. (2010) found that about 26% of the moose *Alces alces* calves in a study area in the Southern bear subpopulation in Sweden were killed by brown bears. Ninety-two percent of the predation was in the first four weeks after birth of the calves in mid-May – mid-June. The predation was mainly on moose adults in spring and moose calves in early summer. Every adult female bear in the Southern subpopulation in average kill 6.1-9.4 moose calves per year (Rauset et al. 2012) and about 0.08% of the adult moose cows may be killed by bears in the same area (Dahle et al. 2013).

Compared to wolves the bear's predation on moose is minimal because the total predation on moose by wolves in wolf territories is several times higher. The average number of days between every moose predation in the Scandinavian wolf territories during June-September has been estimated to 1.71, about 9.4-11.6 times higher than estimated during winter due to higher predation on calves during June-September (Sand et al., 2007). The wolves challenge the tolerance of the reduced hunting quotas of moose (Wikenros et al., 2015). The tolerance of bears is higher because of possibility of bear hunting and presence of bears have lower conflicts with other hunting tradition and competition of prey.

In Norway the number of claims for compensation due to losses of free-ranging sheep, *Ovies aries*, at summer pastures by bears and number of dead sheep are strongly related to the density of brown bears in the same area (Mabille et al. 2015). No other factors influenced strongly on predation rate. In some areas more than 50% of the predated sheep were killed or deadly injured by bears and the losses were highest in July and August. The bears also scare and stress the sheep herds when they are hunting causing quick movements of the herds back to the farm or dispersal out in a larger area. The local losses may be approximately 10-20% in some places, and up to 94.4% of the predated sheep ewes and 42.4 % lambs have been documented predated by bears (Knarrum et al. 2006), indicating locally high score on Potential Conflict Index, PCI, mentioned by Gangås et al. (2013). According to the Norwegian Environment Agency at www.rovbasen.no, the number of sheep documented killed and most probably killed by bears 01.01.2010-31.12.2019 in Norway was 3541 and 1404 though the number of bears in Norway registered in the same period has never been more than 166 bears and most of them are living at both sides of the national border, shows population reports from Rovdata, www.rovdata.no. Fløystad et al. (2019) describes 57 female and 91 male bears in 2019.

Dahle et al. (1998) found that the predation on free-ranging reindeer, *Rangifer tarandus,* in Sweden is of importance in the Northern parts of Sweden. During springtime the reindeer are grazing on the snow-free areas in a snow-covered landscape in the lower mountain areas mostly in the Western parts of Sweden and Eastern parts of Norway and forest areas within the study area in Finland. These areas are often directed to South and South-East/-West direction in the landscape (www.same.se). The same habitats where reindeer graze and calve in spring may be the same areas that bears select of grazing reasons. Sivertsen et al. (2016) also suggested that brown bears show a behavior of selecting those areas as a part of predation-prey interactions. High density in semi-domesticated reindeer herds during calving time make the reindeer even more vulnerable. At the same time the reindeer seem to have lost much of their anti-predation behavior due to breeding and domestication.

The losses of reindeer caused by bears are in general assumed to be higher in the forest Sami villages than in the mountain Sami villages due to higher density of bears in the more forested areas (Karlsson et al., 2012). A study in and close to calving ground in two forest Sami villages in Norrbotten where there was assumed high proportion of losses of reindeer due to bears, show that brown bears may kill adult reindeer and calves at a predation rate of 0.02 reindeer does and 0.4 calves per bear and day the bear has been in the calving area. The only factor that shows significant relationship to predation rate and risk of predation was the number of days a bear was present in the area. The losses were higher, the higher number of days that bears were close to and in areas with calves. Other factors like the bears' age, sex, reproductive status, and Sami village may influence predation, in example there was higher predation rate for female bears with elder cubs. The losses of reindeer calves varied from 30-50% between calving and marking of the calves and 63-100% of the disappeared calves may have been killed by bears. About 99.7% of the killed calves was killed in the period 1 May – 9 June with a peak from mid-May till 1 June. This shows that the reindeer does and their calves are especially vulnerable to predators in the calving season in May where the does also try to restitute after a long and tough winter. In forested areas the bears both predate semi-domestic reindeer in spring and moose in the early summer. Frank et al. (2017) describes adaptions in reindeer husbandry in this period that can reduce the losses of calves and protect the reindeer during the calving period. Though, the high potential predation loss by up to about 50% of the reindeer calves, indicate very high score on the Potential Conflict Index, PCI, mentioned by Gangås et al. (2013).

3.8.2 Situation and interests of reindeer husbandry

From the North of Dalarna and Gävleborg counties to the Finnish and Norwegian border and in the adjacent areas in Finland and Norway, there are free-ranging, semi-domestic reindeer grazing, see Appendix 14. The areas cover almost all the study area except for the Southern parts in Sweden. Most of the reindeer owners are of Sami origin and the reindeer husbandry is important to the Sami indigenous population of cultural and economic reasons and as a very important part of the Sami identity and history.

In both Finland, Sweden and Norway within the study area the number of reindeer has varied. During 1981-2015 the number of reindeer in the winter herd in Sweden has varied in 20-30 years cycles from about 219 - 296 000 reindeer and most of the variation has been in Norrbotten county (Statistics Sweden, 2003). The number of reindeer has been quite stable at about 50 000 reindeer in both Västerbotten and Jämtland. More than 55% of the reindeer in Sweden live in Norrbotten.

About 90% of the 4500 reindeer owners in Sweden live in Norrbotten (Swedish Board of Agriculture, 2003). The number of reindeer per owner was about 30-41 in Norrbotten, and 159 and 171 in Jämtland and Västerbotten, respectively. The reindeer owners in Sweden are organized in 51 Sami villages and concession areas and each of them has grazing rights in a mapped area (www.sametinget.se), 2015). Most of the Sami villages have seasonal grazing areas, like calving ground in the spring, winter grazing areas etc.

In Norway the number of reindeer is highest in Finnmark, about 75% of the total 240-280 000 reindeer in spring before calving in Norway (Statistics Norway 2020, ssb.no). Inside the study area the number of Norwegian reindeer owners are less than 100 and about 15-20% of the total number of reindeer.

In Finland the reindeer husbandry is mostly in the Northern County of Lapland. About 200 000 reindeer are totally allowed in winter herd. In the North-Western Finland the reindeer husbandry area appears moving within shorter distances and less area units. Some of the calving areas are very close to settlements (M. Anttonen, Reindeer Herder's Association Finland, pers.comm.)

Every new year in the reindeer husbandry starts with the calving season. The new calves will hopefully grow up to become adults or simply increase in weight until the slaughtering in the autumn, giving income to the owner. The spring is a very vulnerable period for does and calves where they easily might be stressed by distractions. The spring and calving areas are therefore vulnerable at this time of the year regarding chasing and predation by predators.

The toughest climatic period of the year is normally the winter because the animals lose weight due to poorer pasture and cold temperatures. During the summer they have to restitute and fatten by grazing and get into good condition before a new hard period of the year, the winter.

The climate has changed due to the global warming and increased greenhouse effect (Loe et al. 2016), and according to Riseth (2017) and Loe et al. (2016) the climate changes are influencing the conditions for the reindeer comprehensively. More precipitation in areas with frost leads to very high snow depths and very late spring like the winter of 2019-2020, and the reindeer husbandry was therefore funded by the national authorities in Norway to support refeeding of the reindeer in spring 2020, announced by the Norwegian Ministry of Agriculture and Food, www.lmd.dep.no . Rain-on-snow events and icing events lead to consequences for the conditions of the reindeer like changed snow packing (Loe et al. 2016). The pattern of shifting melting and icing during winter lead to challenges in several areas because the ice makes their food resources inaccessible (Riseth 2017). The higher temperatures in the growth season leads to overgrowing of shrubs and trees in previously open or semi-open areas in alpine areas leading to less suitable pastures. The climate changes will be even more powerful further on in this century.

3.9 Mortality, hunting and illegal killings

Legal hunting

The hunting period of bears in Sweden is from 21 August until 15 October (Swedish Environmental Protection Agency, www.naturvardsverket.se). In parts of Norrbotten the hunting ends on 30 September if the quota hasn't been filled before. The quotas are defined every year for each county. The bear hunting is conducted by bear hunters specifically and moose hunters incidentally (Bischof et al. 2007).

Bischof et al. (2009) found that legal hunting in Sweden is additive to other mortalities like intraspecific predation, accidents, damage control removals and illegal hunting/poaching. Legal hunting is the most important mortality factor influencing the growth of the Swedish bear population. About 80% of the total mortality rate was caused by humans within the period of 1984-2010 (Swenson et al., 2010). About 27% and 43% of all death causes in respectively the Southern and Northern study areas in 1990-2005 was caused by humans. The other mortality causes and combinations of them are of important magnitude and show more selectivity in terms of sex and age than legal hunting (Bischof et al.2009). Natural deaths are mostly caused by other bears (Swenson et al., 2010).

Gosselin et al. (2015) found that in the period 1990-2011 there were two periods of hunting pressure in the Southern bear subpopulation in Sweden; low hunting pressure in the years 1990-2005 and high hunting pressure in the years of 2006-2011. In the first period the population growth was positive and in the second it showed at decrease of about 2% annually. This supports the previous results that legal hunting strongly influences changes in the bear population.

Sexual selected infanticide

The adult male bears may kill cubs they think they are not the father of to get the female into new oestrus and inseminate the same female, known as sexually selected infanticide, SSI (Bellemain et al., 2006). About 40-50% of all cubs of the year die each year and about 80% of them have been killed during the mating season by a male adult bear due to SSI (Swenson 2010).

When an older dominating male has died, the younger less dominating males kill more cubs to mate with the mothers up to 1.5 years after the dominating male was killed (Swenson 2010). Gosselin (2014) concluded that increased hunting pressure increased the level of SSI. Increased hunting pressure thereby resulted in decreased cub survival. All demographic rates, except yearling survival, were lower under high hunting pressure. The potential reproductive capacity of adult females influenced population growth more during *high* than during *low* hunting pressure, but survival of adult females was more important for population growth during *high* hunting pressure. They suggest that SSI could explain 13.6% of the variation in population growth.

Poaching and illegal hunting

Brottsförebyggande rådet or the Swedish National Council for Crime Prevention, BRÅ, (2007) described organized forms of illegal hunting on large carnivores by snowmobiles in reindeer areas in Sweden. They claimed that there are differences in intensity in illegal hunting on large carnivores depending on season of the year. Some of the illegal hunting is organized with and without illegal donations to those persons killing large predators in the reindeer areas. They pointed out that the attitudes differ between the Sami villages considering accepting or not-accepting poaching. BRÅ emphasized that large predators kill reindeer and due to losses and stress the reindeer farmers are mostly or often negative to large predators and more tolerant to illegal hunting.

Swenson et al. (2010) found that the illegal bear hunting was much higher in the Northern bear population than in the Southern, 21% and 6% documented and suspected killed bears of total mortality for radio-marked bears, respectively. Swenson et al. (2011) also found that most of the bears that are killed illegally are killed in May-June in the Northern subpopulation. The second highest illegal hunting rate on bears in the North, is during the moose hunting in the autumn. In the Southern study area, there were no seasonal trends in documented or suspected illegal deaths. They estimated that the annual rates of illegal mortality among adult females to be 0.1-0.6% in the South and 2.3-3.1% in the North.

Persson et al. (2009) found that illegal killing of wolverines in the large national parks in the North of Sweden hampers an increase in the wolverine population. Rauset et al. (2013) found that poaching is an important cause of mortality and survival rate for bears, lynx and wolverines in the large national parks Sarek, Padjelanta and Stora Sjöfallet in Northern Sweden. The risk for lynx, wolverine and bears to be killed inside the three large national parks was 2.3-2.8 times higher than in surrounding, unprotected areas. Non-forested areas inside the national parks overall represented a higher risk for bears to be killed illegally. For bears, the peak for illegally killed radio-marked individuals was May in the late snow season and secondly September in the regular moose and bear hunting season. They also found that reindeer calving areas showed tendency of higher risk for bears and wolverines of being killed illegally.

The poachers often use snowmobiles in the spring to achieve their illegal purposes (BRÅ, 2007) and this is supported by Rauset et al. (2015) who found that snowmobiles are used during spring to illegally kill both wolverines and bears in Sweden. BRÅ (2007), Forsberg & Korsell (2005) and Rauset (2013) emphasized that the access for snowmobiles and the low enforcement and public attention in these relevant areas are important factors for not being caught when illegally killing large predators. Proximity to human infrastructure and/ or permanent human activity did not affect mortality on a local or a regional scale in the study by Rauset (2013).

Persson et al. (2009) found that up to 60% of adult mortality in wolverine population in Northern Scandinavia was caused by poaching and the risk of being killed illegally was higher during the snow-covered season of December - May. They found that poaching forms a substantial part of the wolverine population dynamics in Northern Scandinavia. The distribution of wolverines by Kleven et al. (2019) may support this in some remote mountain areas. Andrén et al. (2006) found that even the poaching rate for lynx was statistically higher in Sarek within the national park than in any other study areas in Sweden and Norway.

Liberg & Sand (2020) found that in Sweden poaching-related disappearance rate on territorial wolves in the period 2001-2017, especially 2011-2017, was larger than any known mortality factors for territorial wolves in Sweden. The disappearance rate was positively correlated to population size and negatively correlated to legal hunting.

Swenson et al (2011) found that illegal killing didn’t seem to affect bear population trends, but it may be important locally. Rauset et al. (2013) found that the bear mortality caused by poaching, is additive other death causes, which means it may hamper population growth and expansion.

4. METHODS

ArcGIS 10.5.1 were used for spatial processes and calculations. Excel was used for performing linear calculations for aim 1. R was used for correlation analyses and the statistical tests of Akaike's Information Criterion, AIC, for aim 2.

4.1 Source data

4.1.1 Data of shot bears

The projected coordinate system is SWEREF99_TM and projection is Tranverse Mercator. All registered shot female bears of all ages in Sweden and parts of Norway and Finland were included, see Appendix 1 and Table 1.

Sweden: As for previous studies of estimating core areas and population size in the Swedish brown bear population, killed bears due to license hunting in Sweden is used, which is a reliable data source (Swenson et al., 1994, Swenson et al., 1995, Bischof et al., 2009). The data of shot bears in the Swedish license hunting are used for the years 1981-2003 from The Scandinavian Brown Bear Research Project (SBBRP). For the years 2004-2019 the data of license hunted bears are from the Swedish Veterinary Institute (SVA) and the Norwegian Environment Agency. About 4500 bears were shot in license hunting in Sweden during the years 1981-2019, and of those there were 1944 female bears with documented sex and coordinates for location included in the analyses, see Figure 5. Data not included are five female bears without coordinate data in the period 1981-1995, seven bears in the period 2009-2016 without registered sex and about three females due to ongoing investigations.

Implemented in the study are also 229 female bears shot in Sweden due to damage control and self-defense, registered as "skyddsjakt". They are included to obtain a more realistic view of the distribution of female bears, especially in remote areas in Norrbotten. Registered illegally killed female bears are also included and some of these have been entered the quota for damage control.

Norway: Of 215 bears registered as shot in Norway during 1981-2019, 24 female bears were registered dead illegally and legally in the same period according to NEA. Nine of them are not included in the study because their last location was in Finnmark, more than 100 km from the Swedish border, and therefore considered a part of the Finnish-Norwegian-Russian bear population. Some of the bears are excluded from the analyses because of unknown sex. In total there are 14 female bears included from Norway in the analyses.

Finland: According to Schregel et al. (2015) the Swedish female bear expansion has not been genetically visible in Finland, and the female distribution has hardly been close to the Swedish border until recently. In dialogue with the Finnish Wildlife Agency shot female data from the municipalities Enontekiö, Muonio, Kittilä, Kolari, Pello, Rovaniemi, Ylitornio, Tervola, Simo and Ranua in the North-West of Finland are included in the analyses. The data are from 1993-2019 because location data only exist after the Hunting Law renewal in 1993. Within the Finnish area described there are 13 shot female bears included in the analyses and the first is registered in 1998.

The number of female bears included in the analyses, is in total 2200.

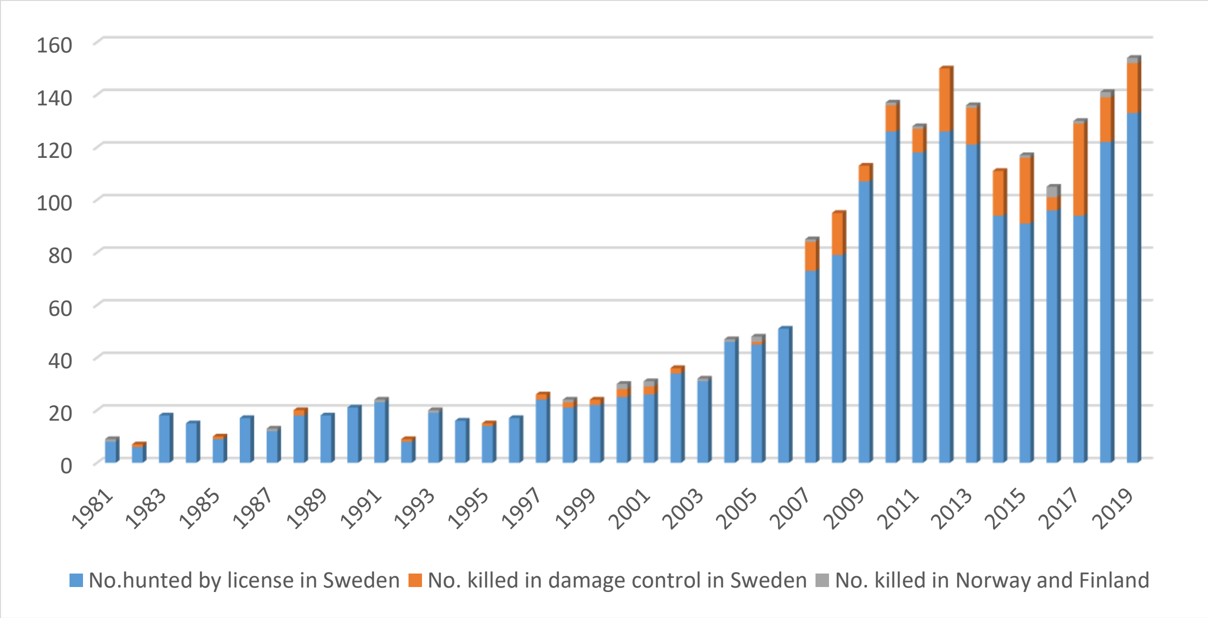

Figure 5. Number of killed female bears in the years 1981-2019 by license hunting in Sweden (blue), number of killed female bears in damage control in Sweden (orange) and number of female bears killed in Norway and Finland (grey) as a part of the Swedish population. Source: SVA, Norwegian Environment Agency, SBBRP and Finnish Wildlife Agency.

4.1.2 Natural and human factors that may impact the expansion

I have chosen the factors that are supposed to impact the most on the expansion rate and bear presence in a large scale in the study period and the choices are due to 1) known knowledge, ref. Chapter 3, and 2) my own exploration of the geographical data available in my study, see Appendices 1-22.

The source data for the analyses are listed in Table 1.

Table 1. Overview of the source data for the analyses.

No.	Name of data	Description	Source of data
1	Shot bears	Individual	Scandinavian Brown Bear Research Project (SBBRP), National Veterinary Institute (SVA), Norwegian Environment Agency , Finnish Wildlife Agency
2	Land cover	Corine Land Cover 2018. Vector layer.	National Land Survey Sweden, Norwegian Institute of Bioeconomy Research (NIBIO) and Finnish Environment Institute
3	Human population	No. of inhabitants per unit or polygon in the layers.	Statistics Sweden (www.scb.se), Norwegian Mapping Authorities (geonorge.no), Ministry of Education and Culture Finland - Paituli
4	Roads	All road lines. Meters.	National Land Survey Sweden, Norwegian Mapping Authorities, Finnish Transport Infrastructure Agency
5	Railways	All railway lines. Meters.	National Land Survey Sweden, Norwegian Mapping Authorities, Finnish Transport Infrastructure Agency
6	Protected areas	National parks and other protected areas. Both owned by private landowners and government.	National Land Survey Sweden, Norwegian Environment Agency, Finnish Environment Institute
7	Spring pastures, including calving areas	Including the pastures early summer and spring in Sweden and spring pastures in Norway and Finland	Sami Parliament in Sweden, NIBIO/ The Norwegian Agriculture Agency, Reindeer Herders' Association (@SYKE, LUKE)
8	Pastures in calving period	Including the areas used in calving period in Sweden and Norway and spring pastures in Finland.	Sami Parliament in Sweden, NIBIO/ The Norwegian Agriculture Agency, Reindeer Herders' Association (@SYKE, LUKE)
9	The reindeer districts	The reindeer districts and Sami villages in Finland, Sweden and Norway, both Sami and others	Sami Parliament in Sweden, The Norwegian Agriculture Agency, Reindeer Herders' Association (@SYKE, LUKE)
10	Number of reindeer in reindeer husbandry	Maximum allowed number of reindeer in winter herd within each reindeer district/village in Norway 2018/2019, Finland 2019/2020 and Sweden 1999.	Sami Parliament in Sweden, The Norwegian Agriculture Agency, Reindeer Herders' Association (@SYKE, LUKE)

Land cover

The layer of Corine Land Cover 2018 was merged for the three countries.

Road and railway density

The layers for roads and railways were merged and the density of roads and railways should also be a good parameter for describing the amount of traffic.

Human density

The layer for population was given by units in the three countries and the layers were merged.

Reindeer districts and number of reindeer

In the three countries the maximum allowed number of reindeer in winter herd was plotted into the layers for reindeer district or Sami village in the national layers within the study area. They express the geographical areas for the administrative units of reindeer husbandry. The layers were selected each and every one into separate layers. Then they by the function Union were merged. In some areas the districts or villages were overlapping so the numbers were summarized for every polygon.

Protected areas
The layers for protected areas were merged. The protected areas with an area < 5 km were excluded from the layer.

Pastures used in calving period
The areas used in reindeer calving period for oxen, does and calves was selected for Sweden. In Norway the data are equal to spring pastures. In Finland the data for calving areas was not accessible so I used the spring pastures. The layers were merged.

Spring pastures
The reindeer spring pastures in the three countries was merged. The areas include reindeer pastures in spring in Norway and Finland, including the calving areas and pastures of spring and early summer in Sweden, including pastures during calving period. The pastures of early summer were not accessible in Norway and Finland.

4.2 Method of calculating the expansion rate using linear regression, aim 1

When studying the data of shot bears in the years 1981-1983, the previous mentioned four subpopulations display as natural to follow. The shot data for 1981-1983 were divided into four geographical groups: Northern (N), second-Northern (SN), second-Southern (SS) and Southern (S). I made a polygon of the outer locations for every subpopulation the period 1981-1983 using convex hull in the tool Data Management – Minimum Bounding Geometry - Hull, hereafter called Minimum Convex Polygon (MCP), see Figure 6 and Appendix 2.

The center point in each of the subpopulations was found for each subpopulation MCP by using Spatial statistics – Measuring Geographic Distributions – Median Center. The shot bear data for each year were then divided into the closest subpopulation of 1981-1983 polygons by using the function Analysis – Generate Near Table, showing for each shot female both shortest distance and angle to the closest median center. Planar method was used.

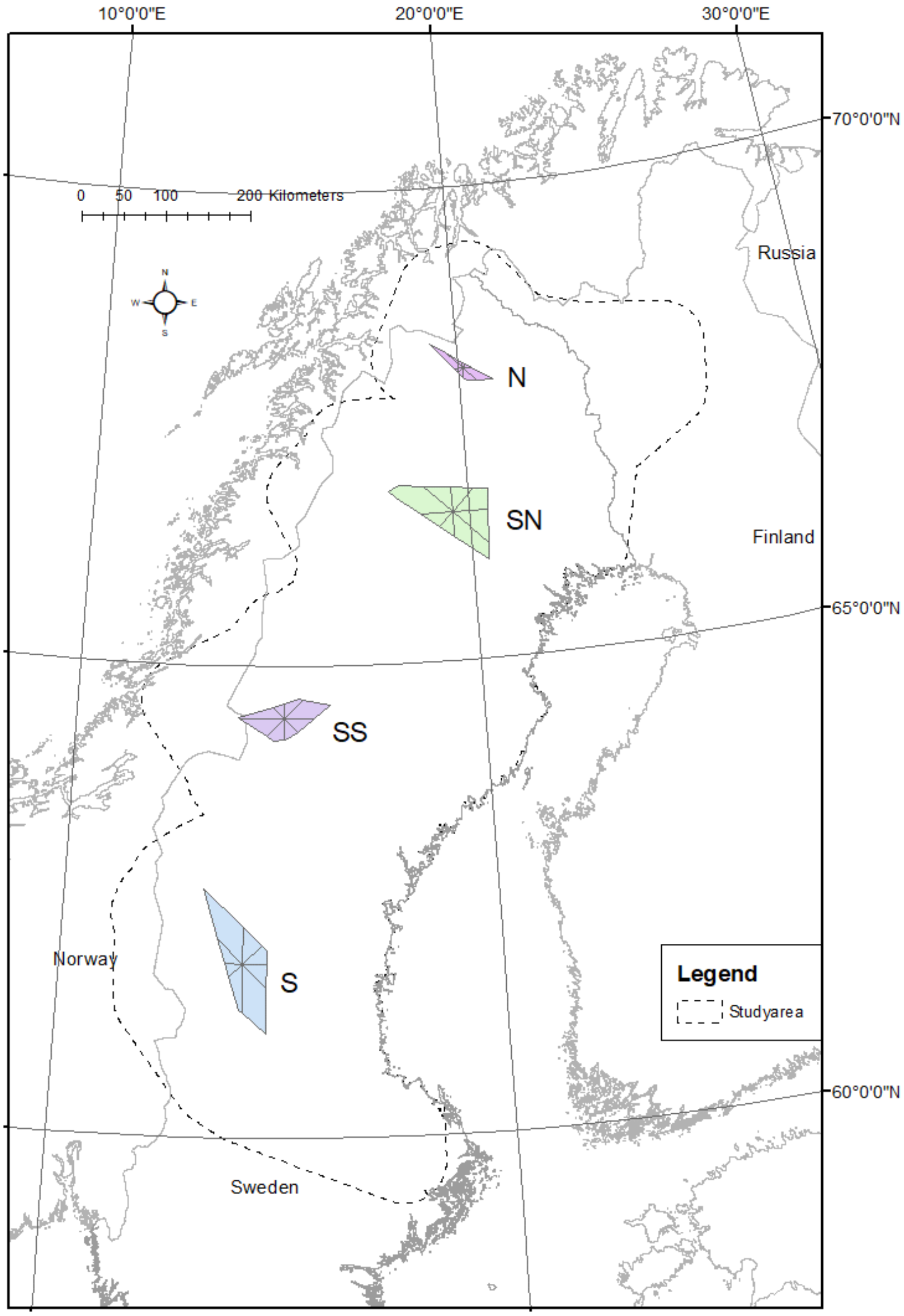

Figure 6. The four sub-populations in the period 1981-1983. Each Minimum Convex Polygon was divided in 8 angle directions. The populations are called S, SS, SN and N.

The data were then grouped into each year and subpopulation, and the angle was recoded to be from the closest median center to each shot female bear location. The codes for angle were grouped eight angle directions 1-8, see Table 2.

Table 2. Directions or angle areas used for every location and MCP.

Direction - name	**Direction, degrees**	**Code**
North	0,1-45	1
East	45,01-90	2
East	90,01-135	3
South	135,01-180	4
South	180,01-225	5
West	225,01-270	6
West	270,01-315	7
North	315,01-360	8

To find the outer front of the female areas the three outermost shot female bears in every direction and year were selected to be included in further analyses. If there were more locations than three, more locations were only included if the distance to the median center was at least 2/3, using 0,6667 in the calculations, of the outermost location in the same direction and year. In the first period, 1981-1983, all the locations were included, and they were never higher than 5.

To find the expansion rate in km/year in every direction and subpopulation I calculated by using linear regression using the parameters distance from median center and year.

I ran a simplified data estimation to avoid misleading conclusions caused by too few data to select each year and to reduce sensitivity for outliers the first 10-15 years. The control was run in each direction where no linear relationship was proven, or negative linear relationship was proven. To run the test, I selected the 10 outermost locations in each period using the periods mentioned in Chapter 4.3.

4.3 Method of calculating the expansion rate using Minimum Convex Polygon, aim 1

The median center of the subpopulations was found as described in Chapter 4.2. Each MCP was then divided into the 8 directions by creating a table for each subpopulation with the fields object ID, distance, bearing, latitude and longitude. The latitude and longitude in each table were for the coordinates of the median center of the subpopulation. The tables were then imported in ArcMap, and by using the tool Data Management Tools - Bearing Distance To Line and Cut Polygon Tool each MCP for subpopulations was divided into the eight directions.

The shape files for each year were merged into shape files of six periods each of them for six years: 1984-1989, 1990-1995, 1996-2001, 2002-2007, 2008-2013 and 2014-2019. The data for each period were then divided into each period by using the method Analysis - Generate Near Table by using the same method as mentioned for method 1 regarding angle and distance. Then the tables were imported into ArcMap and the function Data Management Tools – Minimum Bounding Geometry were used by convex hull to make a polygon for the outer locations for each period. This means a minimum convex polygon (MCP) 95% confidence interval. I used the same MCP-polygon for each of the subpopulations for the period 1981-1983, which were made in method 1. Then I divided all the polygons in all seven periods into the 8 directions, see Table 1, by using the tool Bearing Distance To Line and Cut Polygon Tool.

The area of each angle area in each MCP multiplied by 8 was used to find the average distance from the center of it. By using the formula for area of a circle, $A=\pi * r^2$, the average distance from the center point to outer line in every direction was estimated for each angle area in each MCP. The average distance is the radius in the formula. The number of years, x, and distance, y, $\Delta y/\Delta x$, is the expansion rate per year in the actual period, subpopulation and direction. The estimation was done for period to period and for the period 1981-1983 to the period 2014-2019.

For the Northern-Northern subpopulation the Minimum Convex Polygon for five periods doesn't include the median center for the same subpopulation of 1981-1983. In these cases, I have used a simple method to correct the calculated radius to include the distance from the median center to the MCP for the actual period, to achieve the correct distance in each angle. The distance from the median center measured by the two sides of each angle divided by 2, is then the distance from median center to the new front. If there are no MCP for the period in the angle direction, then I have used the angle sides for the MCP of 1981-1983. This means negative distances.

4.4 Factors that hamper and gain expansion, aim 2

4.4.1 Targets

The values tested towards different selected combinations of factors that may impact the expansion, were:

1. linear expansion rates by linear regression (Figure 7)
2. linear expansion rates by using Minimum Convex Polygon, MCP *(Figure 8)*
3. bear presence over study period by added Minimum Convex Polygon, MCP *(Figure 10)*
4. bear presence over the study period by tool Kernel Density *(Figure 11 and Appendix 3)*

All the targets are shortly defined and listed in Appendix 9.

I used the angle areas in each MCP to insert the value of the estimated expansion rate by both linear regression and linear expression for each MCP described in Chapter 4.2.1 and 4.2.2, in the period 1981-2019, see Figures 7 and 8. In both cases using linear regression and linear function for MCP, each cell in the raster layers express an expansion rate value in meter.

In the cases where no significant linear expansion was found by linear regression, I used the following criteria:

- If the number of shot females was ≤20, then the value 100 was given.
- If the number of shot females was >20, the expansion rate was too uncertain and not significant. This is the case in the directions 1, 2 and 7 in subpopulation SS and in direction 5 in subpopulation SN. To make the analyses possible I chose to type the value 500 as a kind of reasonable value, in those four directions.

The areas within the study area outside the MCP's were given the value -1.

To create the layer of bear presence by added MCP's, I

- gave every MCP for the seven periods and subpopulations the value 1 for bear presence.
- merged the MCP for each subpopulation and period.
- created a 50 km zone around the merged MCP's and inserted the value 0 in a field of bear presence in this 50 km zone.
- eliminated the marine areas and islands in Sweden from the study area, see Figure 1.
- added the fields of bear presence by using Field Calculator, in the layer of merged MCP's in a new field as a parameter of bear presence in the period 1981-2019. The layer of 50 km zone around them was merged with the layer of MCP's. This resulted in bear presence values 0 - 7 for the whole study area, as an expression of bear presence in the study period.

To create the layer of bear presence by the tool Kernel Density, I

- merged into one layer the layers of shot females for every year.
- used the tool Kernel Density to create a layer of density of shot females 1981-2019 to represent bear presence in the same period.
- Before the analyses in R, the resulting field was multiplied by 1 000 000 to avoid many decimals.

4.4.2 Conversions of featuring variables – factors that may impact

The source data was prepared for the analyses by several methods. All the factor layers are shortly defined and listed in Appendix 9.

Land cover

The layer of Corine Land Cover 2018 for the three countries was divided into five groups by SQL and separate layers for each of them were made. The five groups are called Open, Forest, Mountain, Artificial and Agricultural, see Appendix 10. Presence of the class was in each layer given the value 1 and not presence the value 0. The layers are named after the land cover group.

Road and railway density
A new layer for density of roads and railways was created by using the function Line Density. The layer is called Roadandrail in R.

Human density
The layer for population was converted into a layer of human population density by number of inhabitants per $km^2$by using the tool Kernel Density. The layer is called Human_density.

Number of reindeer
The number of reindeer in winter herd was used as described in Chapter 4.1.2. The layer is called Rein_no.

Protected areas
All the protected areas in the analyses were given the value 1 and outside the value 0. The layer is called Naturpro5.

Pastures used in calving period
The areas used in reindeer calving period for oxen, does and calves was selected for Norway and Sweden. In Norway the data are equal to spring pastures. In Finland the data for calving areas was not accessible so I used the spring pastures. The layer is called Calvspring.

Spring pastures
The reindeer spring pastures in the three countries was merged. The areas include reindeer pastures in spring in Norway and Finland, including the calving areas and pastures of spring and early summer in Sweden, including pastures during calving period. The pastures of early summer were not accessible in Norway and Finland. The layer is called Springrein.

Percent of calving areas in units
To find the layer of percent of area used in calving period, I used the merged layer of pastures used in calving period. The layer was given the value 1 and the area in study area outside this merged layer was given the value 0.

I then separated each angle area in the MCP's to a layer, totally 32 layers. The percent area of calving period areas was calculated by Field Calculator. I also made 50 km belts outside each MCP and divided them into the 8 selected angles in the study. The units used for estimation are the 32 angle areas in the added MCP's for the four subpopulations and I also created similar angle delineations in the 50 km belt outside the MCP's to use as new units. Some of the belts were overlapping so I used the following key:

- The whole belt around MCP of the Northern subpopulation, N, minus the MCP of the second Northern subpopulation SN.
- The belt outside the second Northern subpopulation, SN, minus the belt around the Northern subpopulation and minus the MCP's of the subpopulations SS and N.
- The belt outside the second-Southern subpopulation, SS, minus the MCP's of the Southern and second Northern subpopulation, and minus the belt of the second Northern subpopulation, SN.
- The belt outside the Southern subpopulation, S, minus the MCP of the SS subpopulation and the belt around the MCP of the M subpopulation.

I calculated percent calving area for each of the included area units. The layers of the included 50 km belts and MCP's was then merged into one layer of percent of pastures during calving period, see Appendix 15. In R the layer is named Percent_ca.

Spring pastures in respectively land cover forest, land cover mountain and open and land cover mountain– three layers
The layer of spring pastures in Finland and Norway and pastures of early summer and spring in Sweden, including calving areas, was given the value 1 and the area in the study area outside those areas was given the value 0.
I then by using tool Intersect with the respective layers created CLC2018, divided into 1) spring pastures in forest and 2) spring pastures in mountains and open areas, and 3) spring pastures in mountain, see Appendix 19. The layers are named respectively SpringF, SpringOM and SpringM in R.

Number of reindeer in spring pastures, spring pastures in land cover open and mountain and mountain
By using the function Times, I created layers of number of reindeer in 1) spring pastures and 2) spring pastures in land cover mountain and open, and 3) spring pastures in mountain, see Appendix 16. The resulting layer is named Spring_no, SpringOMno and SpringMno in R.

Added layers of Naturepro5, spring pastures in land cover open and mountain, and land cover mountain
I used the function Plus to make an overlay operation adding the values of the raster layers for protected areas, spring pastures in mountain and open areas, and mountain. Every layer had the value 1 so the values is from 0-3, see Appendix 17. The value 3 indicate highest potential negative impact. The resulting layer is named Class_unsuit in R.

I made a version of Naturepro5, spring pastures in land cover open and mountain, and mountain, see above, where the value was 1 if the factors were present and 0 if not. The resulting layer is named Unsuitable.

I created a layer using the scaled version of Naturepro5, spring pastures in land cover open and mountain , and mountain, see above, where the scale 0-3 was multiplied by the raster layer of number of reindeer by function Times, see Appendix 18. The resulting layer is named NatSprOMM in R.

The study area and all the other layers, both targets, see Chapter 4.4.1, and the features was converted into raster by cells of 1000x1000 meter and one of the layers was used as a base to get compliance of ObjectID, location and size of all the raster cells in all the raster layers. Afterwards each layer was converted from raster to points with one of the layers as base. I also made check of five specific locations in every point layer to ensure compliance for the attribute's location and ObjectID. Then one of the layers were used as a base and the actual values of all themes were joined to the base layer. Then the layer was converted into dbf, further in Excel converted to format xlsx and finally in Advanced XLS Converter converted to format csv.

4.4.3 Model selection

The main factors that I tested in the models, were habitat attributes /land cover and distance to these, both suitable and not suitable habitats. All layers were converted to raster by the cell size 1000x1000 meters, and then they were each converted into layers of points with the value of the center of each cell. By using the tool Join Field, I joined them into one layer which was converted into table format dbf and then in Excel converted to format csv.

According to Burnham & Anderson (2002) I followed the principle of simplicity or parsimony regarding number of factors. I defined several candidate models. After performing correlation analyses, see Appendices 20-22, I re-evaluated the models and ended up with seven models. To figure out different models I used both

1) previous knowledge described in Chapter 3,
2) exploring the geographical data described in Table 1,
3) the results of estimating the expansion rate in Chapter 5.1,
4) the results of the correlation analyses, and
5) testing by excluding and including factors in the first selected models to improve them into candidate models.

In total at least 15 models were tested for each target. In every model I have emphasized to avoid overlapping factors if it's not benefitting the analyses, and each model is named after superior focus of the terms:

- Land cover is based on the five main groups of land cover based on CLC 2018.
- Human & Forest is a model focusing human influence and presence and forest. Forest is implemented as a positive bear habitat factor.
- Nature & Conflict is based on factors of nature, human impact and presence and terms scoring high on the Potential Conflict Index, PCI, ref. Chapter 3.
- The models named Expert are models mixing terms specifically based on the background knowledge, ref. Chapter 3 and 5.1, exploring the geographical data, estimations, the results of the correlation analyses and testing by excluding and including factors.

The correlation analyses in Appendix 20-21 have shown that models of neither all nor no factors are correct, so those two models are excluded. The model Full including all the factors in Appendix 20 and 21 showed the best score, ΔAIC_c=0 and AIC_{cWt}=1, though it's an illogical model because quite many several overlapping factors causing overfitting. The model Full was therefore excluded.

The factors included in each model are listed in Table 3. The prerequisites for the models are as follows where the factors are equally weighted 1xfactor except where two factors are multiplied showed by *:

Land cover: Open + Forest + Mountain + Artificial + Agriculture

Human & Forest: Forest + Agriculture + Artificial + Human_density + Roadandrail+ Rein_no

Nature & Conflict: Forest + Mountain + Spring_no + Percent_ca

Expert: Forest + Roadandrail + Percent_ca + Class_unsuit +

Expert4: Forest + Mountain + Percent_ca + SpringM + Roadandrail*Forest

Expert32: Forest + Roadandrail + Percent_ca + SpringM_no + Unsuitable

Expert62: Forest + Roadandrail + Percent_ca + SpringM + Class_unsuit + Forest*Roadandrail

Table 3. Factors and targets in the final models. Factors included in each model is marked by x.

Name of factor layer	Land cover	Human & Forest	Nature & Conflict	Expert	Expert32	Expert4	Expert62
Open	x						
Forest	x	x	x	x	x	x	x
Agriculture	x	x					
Mountain	x		x			x	
Artificial	x	x					
Roadandrail		x		x	x	x	x
Percent_ca			x	x	x	x	x
Human_density		x					
Spring_no			x				
SpringM						x	x
Class_unsuit				x			x
Rein_no		x					
Unsuitable					x		

To find the most fit model among the selected models, I resampled the data 50 times in the software R to shuffle them to an even representativity. Then I split the resampled data in 80% and 20%, respectively training set and test set, by 5-fold cross validation.

By using the training set I evaluated my chosen models by estimating Akaike's Information Criterion (AIC) in R (Burnham & Anderson 2002; Brownlee 2019; MacDonald & Braun 2010). AIC is a method for scoring and selecting the best fitted model of the data among several models. In a test with different models AIC estimates the quality of each model relative to the other models. The lower the positive score, the more the model fits to the data.

To assure valid results I estimated both ΔAIC_c which is second order bias-corrected AIC difference values, and AIC_{cWt} which is second order bias-corrected AIC weights. The calculations were done within the frame of 95% confidence interval to interpret results of the comparing models.

To simplify the model to avoid overfitting and avoid penalty using AIC, the most parsimonious model was also tested by developing several Expert-models by including and excluding factors, followed by recalculating the AIC. By this performance, the relative importance of each factor and the composition of the model selected, in the most parsimonious model was in some degree evaluated.

The model accuracy of the most parsimonious model was by 10-fold cross validation estimated using the metric coefficient of determination, R^2, and correlation coefficient, r, on the test dataset. Both metrics quantify the strength of a linear relationship between the target and factors in each model.

5. RESULTS

5.1 Expansion rate

5.1.1 Using linear regression

By using linear regression, method 1, the H_0 hypothesis that there is no linear relation, is tested against the H_1 hypothesis that there is linear relation between distance from median center, y, and year, x.

The regression showed linear relationship in 17 of the 32 directions. By using linear regression by simplified data as a control, direction 5 in subpopulation SN turned from significant negative to no significance, and direction 6 in SS and SN turned into significant positive linear. Then the number of directions with no proven linear relationship was reduced to 14:

- 1, 2, 7 and 8 in subpopulation SS
- 1, 5 and 8 in the subpopulation SN
- 1, 2, 4, 5, 6, 7 and 8 in the subpopulation N

In the Southern subpopulation, S, the estimated expansion rate is significant in all directions. This means that there is a linear relation between x and y and H_0 is rejected in all directions. The significant expansion rate is the highest in the directions 2-3, 45 -135 degrees, from 3,314-3,479 km/year and the lowest in the directions 180-45 degrees; 1,224 – 1,800 km/year, see Table 4. In direction 4 the expansion rate is 2,3552 km/year.

Table 4. Expansion rates - results of the Southern subpopulation, S, using linear regression.

Direction	No. of obs., n	R^2	F-significance, α=0,05	H_o rejected if p< α	Expansion rate (95% conf.-interval), km/year
0.01-45 (1)	49	0.2949	Yes. 4.48	Yes	1.2243 (0.0601 – 2.3885)
45.01-90 (2)	56	0.6126	Yes. 32.44	Yes	3.4794 (2.2547 - 4.7042)
90.01-135 (3)	110	0.6696	Yes. 87.78	Yes	3.3141 (2.6130 – 4.0152)
135.01-180 (4)	106	0.5776	Yes. 52.06	Yes	2.3552 (1.7079 – 3.0026)
180.01-225 (5)	60	0.3238	Yes. 6.79	Yes	1.2906 (0.2994 – 2.2817)
225.01-270 (6)	40	0.3316	Yes. 4.70	Yes	1.3481 (0.0887 – 2.6074)
270.01-315 (7)	65	0.5414	Yes. 26.12	Yes	1.8003 (1.0963 – 2.5042)
315.01-360 (8)	91	0.5299	Yes. 34.75	Yes	1.4147 (0.9379 – 1.8916)

In the second-Southern subpopulation, called SS, the expansion rate is significantly linear in the directions 90-135 and 135-180; 5,157 and 3,2848 km/year respectively, see Table 5. In the directions 180-225 and 225-270 degrees the expansion is estimated to 1,360 and 1,381 km/year respectively. In the other directions there are no proven linear expansion.

Table 5. Expansion rates - results of the second-Southern subpopulation, SS, using linear regression.

Direction	No. of obs., n	R^2	F-significance, α=0,05	H_o rejected if p< α	Expansion rate (95 % conf.-interval), km/year
0.01-45 (1)	37	-	No	No	-
45.01-90 (2)	34	-	No	No	-
90.01-135 (3)	79	0.7254	Yes. 85.52	Yes	5.1565 (4.0461 – 6.2668)
135.01-180 (4)	99	0.7564	Yes. 129.61	Yes	3.2848 (2.7123 – 3.8573)
180.01-225 (5)	68	0.5359	Yes. 27.00	Yes	1.3602 (0.8377 – 1.8827)
225.01-270 (6)	37/33	- 0.5222	- Yes[1]. 11.62	 Yes	- 1.3809 (0.5548 – 2.2070)
270.01-315 (7)	35	-	No	No	-
315.01-360 (8)	20	-	No	No	-

[1] Significant result when using the ten outermost locations in each of the 7 periods.

In the second-Northern subpopulation, SN, the expansion rate is significantly linear in direction 45-90, 90-135 and 225-270 and 270-315 degrees, respectively 2,793, 1,733, 1,931, 2,485 and 1,191 km/year, see Table 6. The simplified data regression for control showed no linear relationship in direction 5.

Table 6. Expansion rates - results of the second-Northern subpopulation, SN, using linear regression.

Direction	No. of obs., n	R^2	F-significance, α=0,05	H_o rejected if p< α	Expansion rate (95% conf.-interval), km/year
0.01-45 (1)	13	-	No	No	-
45.01-90 (2)	43	0.6430	Yes. 28.91	Yes	2.7934 (1.7441 – 3.8427)
90.01-135 (3)	86	0.4318	Yes. 19.26	Yes	1.7325 (0.9474 – 2.5176)
135.01-180 (4)	58	0.4090	Yes. 11.25	Yes	1.9305 (0.7776 – 3.0833)
180.01-225 (5)	41/31	0.4824 0.3481	Yes. 11.83 No	Yes No	-3.1399 No significance[1].
225.01-270 (6)	39/28	- 0.5406	No Yes[1]. 10.73	No Yes	- 2.4846[1] (0.9258 - 4.0434)
270.01-315 (7)	51	0.3358	Yes. 6.23	Yes	1.1910 (0.2321 – 2.1499)
315.01-360 (8)	20	-	No	No	-

[1] Significant or not significant result when using the ten outermost locations in each of the 7 periods.

In the Northern subpopulation, N, the number of shot females are much fewer. It was not possible to achieve results in any of the directions except direction 90-135 degrees. The expansion rate in this direction was estimated to 1,483 km/year, Table 7.

Table 7. Expansion rates - results of the Northern subpopulation, N, using linear regression.

Direction	No. of obs., n	R^2	F-significance, α=0,05	H_o rejected if p< α	Expansion rate (95% conf.-interval), km/year
0.01-45 (1)	2	-	No	No	-
45.01-90 (2)	6	-	No	No	-
90.01-135 (3)	59	0.3763	Yes, 9.40	Yes	1.4828 (0.5144 – 2.4512)
135.01-180 (4)	7	-	No	No	-
180.01-225 (5)	2	-	No	No	-
225.01-270 (6)	0	-	No	No	-
270.01-315 (7)	6	-	No	No	-
315.01-360 (8)	7	-	No	No	-

5.1.2 Using Minimum Convex Polygon and circle area

The expansion rate from one period to another is calculated and the average is equivalent to the expansion rate estimated from Minimum Convex Polygon (MCP) of 1981-1983 to MCP of the period, 2014-2019, see tables 8 - 11.

In the Southern subpopulation, S, the average rate is the highest in the directions 45-90, 90-135 and 135-180 degrees; 4,337 – 4,539 km/year, see Table 8. The lowest rate is in direction 315-360 degrees; 1,859 km/year. In direction 0-45 degrees the rate is 3,197 km/year and in the directions 180-225, 225-270 and 270-315 degrees the rate is 2,305-2,641 km/year. In the Southern subpopulation there is a positive expansion all periods with few exceptions, and there might be stabilization in directions 270-315 and 315-360 degrees during the period 2014-2019.

In the second-Southern subpopulation, SS, the expansion rate in directions 45-90, 90-135 and 135-180 degrees is the highest; 3,387-5,083, see Table 9. It is the lowest in the directions 225-270, 270-315 and 315360 degrees, 1,017-1,714 km/year. There might be signs of stabilization in the last period 2014-2019 and 2008-2013 in some directions.

The highest expansion rates in the second-Northern subpopulation SN are in the directions 135-180, 180-225 and 225-270 degrees, 3,154-3,901 km/year, see Table 10. The lowest rates are in the directions 315-360 and 0-45 degrees, 1,160-1,176 km/year. The other rates are from 2,370-2,712 km/year. It seems like as if the rates are reduced during the last two period in several directions because the rates are generally negative or around 0.

Table 8. Expansion rates – results of the Southern subpopulation S, using MCP. Expansion rate km/year 1981-2019 from one period to the next and the average.

Angle	1984-89	1990-95	1996-2001	2002-07	2008-13	2014-19	Average, angle
0.01-45	13.2526	-4.4939	1.2805	5.8802	1.4075	1.8570	3.1973
45.01-90	4.1130	1.6822	18.6066	-8.3063	5.7425	4.1831	4.3369
90.01-135	0.0695	9.7901	13.2356	-2.7816	3.1688	3.7538	4.5394
135.01-180	-2.9327	7.7915	6.6787	1.0206	6.5661	6.9495	4.3456
180.01-225	0.1983	2.1595	6.4361	1.5767	2.6996	2.7736	2.6406
225.01-270	0.9219	0.9875	5.9848	-5.5545	0.0353	3.2770	2.3997
270.01-315	2.6368	0.1509	4.2006	6.4077	-0.0805	0.5153	2.3051
315.01-360	2.9614	2.1289	-5.5545	6.9612	4.3827	0.2764	1.8593

Table 9. Expansion rates – results of the second-Southern subpopulation SS, using MCP. Expansion rate km/year 1981-2019 from one period to the next and the average.

Angle	1984-89	1990-95	1996-2001	2002-07	2008-13	2014-19	Average, angle
0.01-45	11.4697	3.5800	-3.0748	6.6363	-4.2436	1.6948	2.6771
45.01-90	17.6048	-7.3420	12.2352	-1.3296	-3.4306	2.5828	3.3868
90.01-135	12.4610	-3.7775	15.4183	4.0033	3.5775	-1.1869	5.0826
135.01-180	8.9620	4.0587	5.2982	2.6223	2.3423	-0.8965	3.7312
180.01-225	6.3591	4.5521	-0.7971	-1.5550	4.2753	1.045	2.3132
225.01-270	2.9576	1.0008	1.0021	0.041	3.8627	-2.1706	1.1156
270.01-315	2.7138	0.1271	3.3572	-1.7456	6.6431	-4.9966	1.0165
315.01-360	4.5892	1.3125	1.3777	2.1741	0.2300	0.5978	1.7136

Table 10. Expansion rates – results of the second-Northern subpopulation SN, using MCP. Expansion rate km/year 1981-2019 from one period to the next and the average.

Angle	1984-89	1990-95	1996-2001	2002-07	2008-13	2014-19	Average, angle
0.01-45	-0.7541	4.3471	4.0183	-0.2071	0.1569	-0.5074	1.1758
45.01-90	-1.0279	8.0968	2.5594	0.9961	4.6241	0.3834	2.6053
90.01-135	7.5412	2.1615	-4.7700	10.7214	3.3656	-2.7464	2.7123
135.01-180	10.2763	3.4144	-2.9040	6.3946	7.9054	-5.2528	3.3055
180.01-225	16.6296	1.4366	3.1353	2.1745	-0.0662	0.0919	3.9005
225.01-270	15.0765	-8.7424	9.0915	3.7853	0.4176	-0.7061	3.1538
270.01-315	5.6085	-5.2180	9.8648	-2.5163	4.6456	1.8361	2.3701
315.01-360	0.7865	2.8195	2.0369	1.4901	2.7471	-2.9225	1.1596

The highest expansion rates in the Northern subpopulation, N, are in the directions 45.01-90 and 90.01-135 degrees, respectively 2.558 and 4.816 km/year. The expansion rate in this differs from the other subpopulations because in four of the directions, 135.01-315 degrees, the rates are negative from -1.505 to -0.438, which is due to no or some extent an overlapping with the minimum convex polygon of 1981-83 in 2014-2019. In direction 315.01-45 degrees the expansion is positive though below 0,6 km/year, Table 11.

Table 11. Expansion rates – results of the Northern subpopulation N, using MCP. Expansion rate km/year 1981-2019 from one period to the next and the average.

Angle	1984-89	1990-95	1996-2001	2002-07	2008-13	2014-19	Average, angle
0.01-45	0.8451	-1.8089	0	8.6019	5.6814	-9.7396	0.5967
45.01-90	3.2228	4.2237	-8.6355	17.0951	-3.6347	3.0792	2.5584
90.01-135	17.6277	-2.2213	6.4150	3.4941	-7.6570	11.2400	4.8164
135.01-180	11.2467	-6.1157	-6.7581	12.7381	-1.3195	-12.4199	-0.4387
180.01-225	6.3456	-7.8541	0	4.9810	-0.1102	-5.9893	-0.4378
225.01-270	0.9931	-4.1501	1.7493	1.0958	4.2023	-6.2964	-0.4010
270.01-315	-2.1193	-4.1781	-7.4864	10.9009	8.1574	-14.3041	-1.5049
315.01-360	-0.1076	-4.0480	-10.3019	16.3484	9.1886	-10.1421	0.1562

Only in the period of 2008-2013 the MCP of 1981-1983 is covered completely in the Northern subpopulation. In the periods of 1984-89 and 2002-07 the median center of the MCP 1981-83 is covered and the angle areas are partly or totally covered. The MCP of 1981-83 is only partly covered by the MCP of 1990-95 in the directions 45-180 and only partly in the MCP of 2014-19 in the directions 315-180 degrees. The MCPs of 1981-83 and 1996-2001 have no geographical overlap. The distance between the two MCP's are almost 11 km. The distance between the Eastern positions in 2008-13 and the female distribution of 2002-07 and 2014-19 is 40-50 km and 75 km, respectively. The same distances from the Western and the Northern positions in MCP of 2008-2013 to the Western distribution of the periods 2002-2007 and 2014-2019 are about 42-49 km and 43-77 km.

5.1.3 Summary and comparison

The results are based on separating the coherent brown bear in Norway, Sweden and Finland into four subpopulations. The results show average a positive expansion in the population in the study period 1981-2019 (*hypothesis 1a*) and it is possible to separate them into four subpopulations and estimate expansion rates in 8 angle area in each of them.

Table 12. Directional and average expansion rates, km/year, in the four subpopulations. Different angles and average. Using MCP.

Angle	Sub-population S	Sub-population SS	Sub-population SN	Sub-population N	Average, all sub-populations	Average for S, SS and SN
0.01-45	3.197	2.677	1.176	0.597	1.91	2.35
45.01-90	4.337	3.387	2.605	2.558	3.22	3.44
90.01-135	4.539	5.083	2.712	4.816	4.29	4.11
135.01-180	4.346	3.731	3.306	-0.438	2.74	3.79
180.01-225	2.641	2.313	3.900	-0.438	2.10	2.95
225.01-270	2.400	1.116	3.154	-0.401	1.57	2.22
270.01-315	2.305	1.016	2.370	-1.505	1.05	1.90
315.01-360	1.859	1.714	1.160	0.156	1.22	1.58
Average	3.20	2.63	2.55	0.67	2.26	2.79

The average expansion rate in the eight angles show the highest value in direction 45.01-180 degrees, 2.74 – 4.29 km/year. It is the highest in direction 90.01-135 degrees and this applies to three of the subpopulations and the second highest for the fourth. It is second and third from the top to respectively direction 45.01-90 and 135.01-180 degrees. It is the lowest in the directions 225.01-360 degrees, 1.05-1.57 km/year. Besides, the number of shot female bears, is varying from 0-250 individuals in the 45-degrees angle areas, is quite reflecting to the varying directional expansion rates.

The four subpopulations have a partly positive linear expansion in the study period (*h1b and c*). When using linear regression, significant expansion was positive and different in 18 of the 4x8 directions from 1.191-5.157 km/year (*h1d*). The only subpopulation with significant expansion rate in all directions, S, had in average an expansion rate of 2.028 km/year. When using MCP the average expansion in each subpopulation from North to South were, 0.67, 2.55, 2.63 and 3.20 km/year. The total expansion rate was 2.26 and when excluding the Northern, the average is 2.79, Table 12.

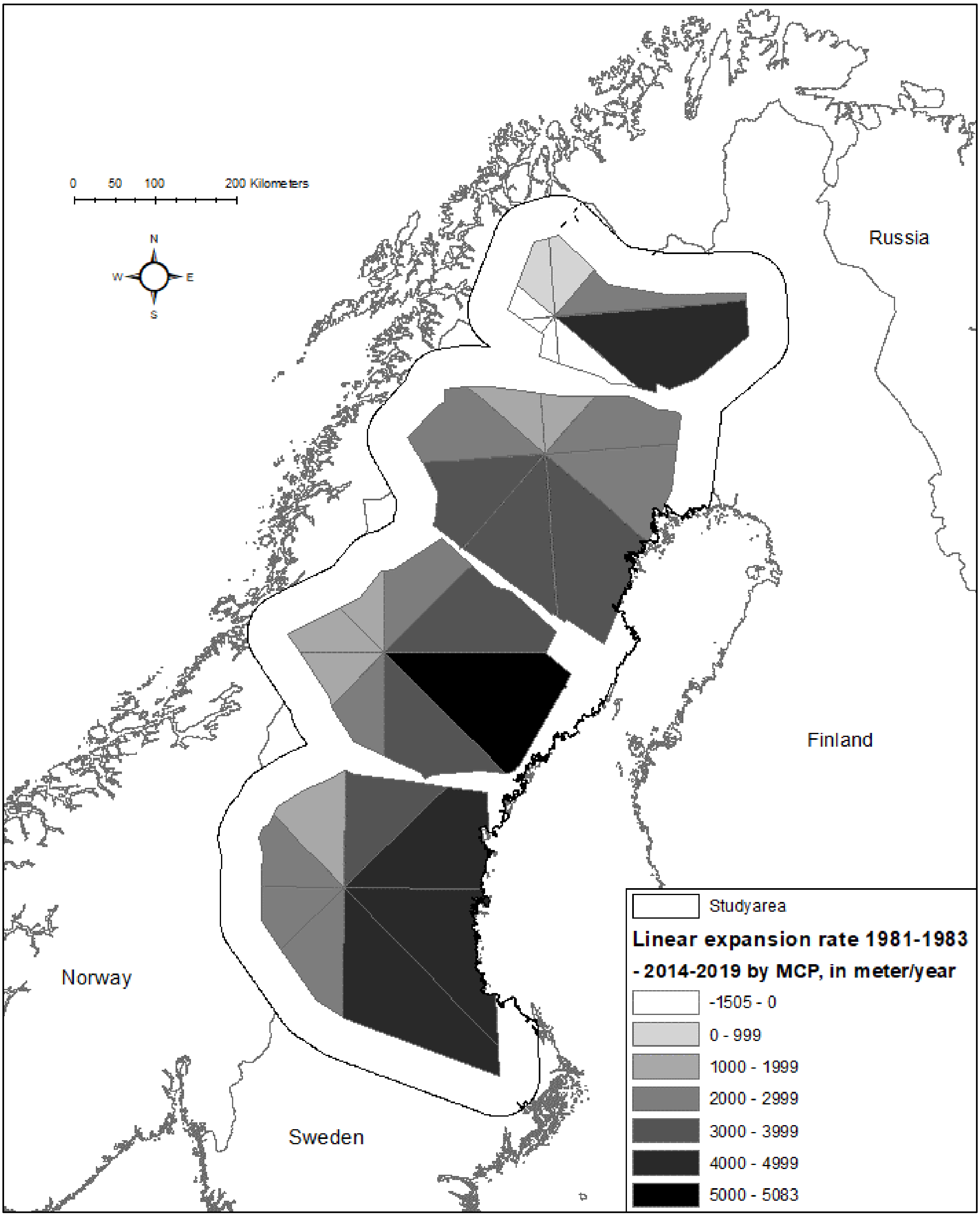

Figure 7. Expansion in meters per year in the four subpopulations in the study period 1981-2019 based on average distance estimated by using Minimum Convex Polygon in 1981-1983 and 2014-2019. The 50 km-belt is given the value -1.

When using MCP from the period 1981-83 to 2014-19 the expansion rate for the angle areas varied from -1.50-5.08 km/year, see Figure 7. In the Northern subpopulation the expansion rate was only significant in the direction 90-135 degrees and the amount of data was too low in the other directions, n≤7. The Northern subpopulation was the only subpopulation with negative expansion, and they were negative in four directions and lower than 0,6 km/year in two other directions.

Only three of the results using MCP are lower than when using regression, like 90-135 degrees in subpopulation SS, respectively 5.16 and 5.08 km/year.

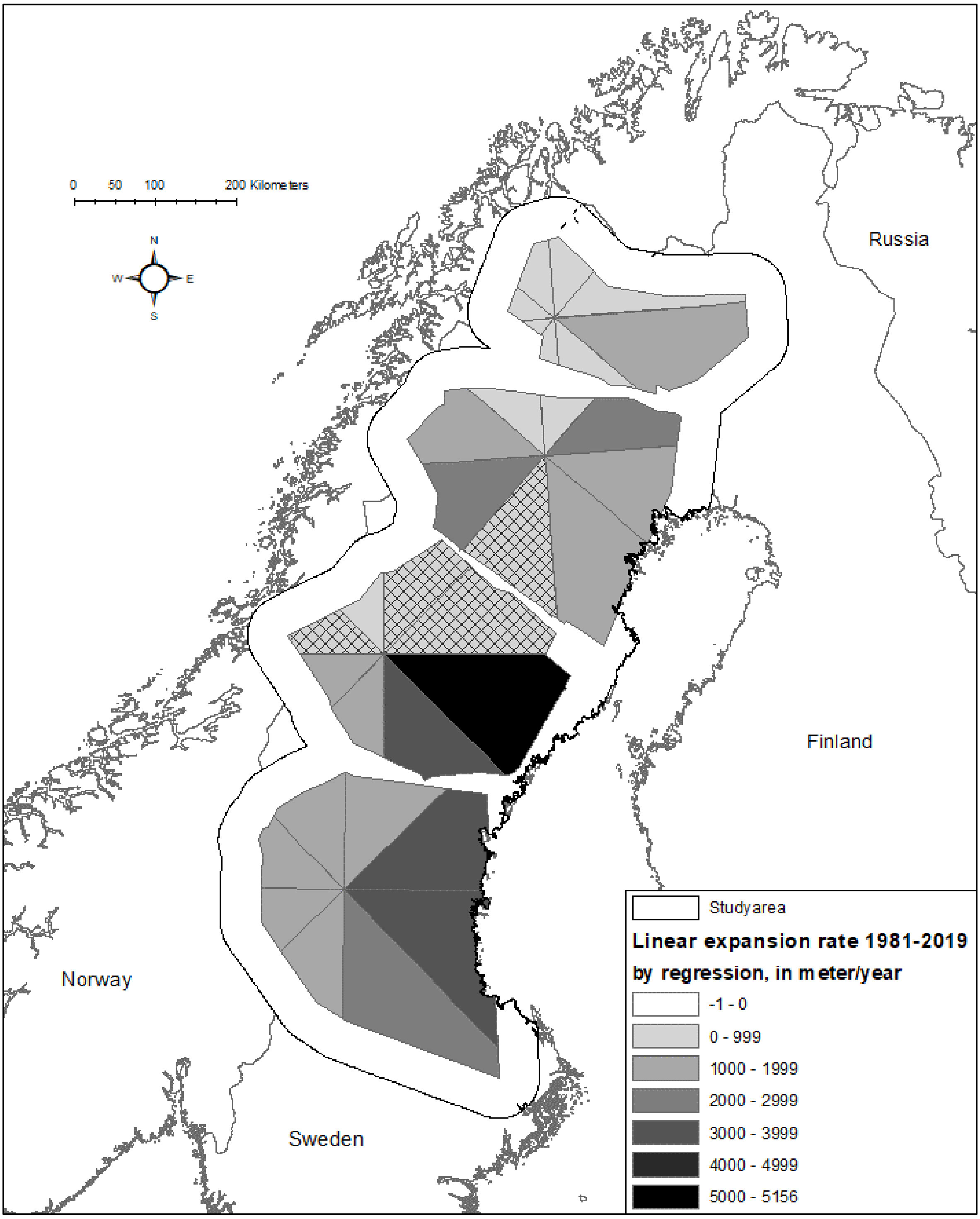

Figure 8. Expansion per year in the four subpopulations based on linear regression.
The cross-hatched areas have no significant linear expansion though there are >20 shot females.
Values of -1-0 are without registered shot females in the study period. In areas with ≤20 shot females the value was set to 100.

The results by using MCP show a higher rate than estimation by linear regression in 15 of 18 direction areas. Only three of them had a lower value than the result when using linear regression. In 50% of the 18 direction areas the results by using MCP were within the 95% confidence interval of the comparable significant values using regression:

- Subpopulation S: 45-90, 225-270, 270-315 and 315-360 degrees
- Subpopulation SS: 90-135, 135-180 and 225-270 degrees
- Subpopulation SN: 45-90 and 225-270

Totally, the expansion is the highest in the directions 45-225 degrees and in average it is the lowest in the directions 270-360 degrees, Figure 7 and 8. The highest expansion estimated by linear regression and MCP was in direction 90-135 in the second-Southern subpopulation, SS.

The distance between the two Northern subpopulations has not shortened during the 40 years in respectively North and South/Southwest direction and the expansion towards and in Norway is generally low, see Figure 9.

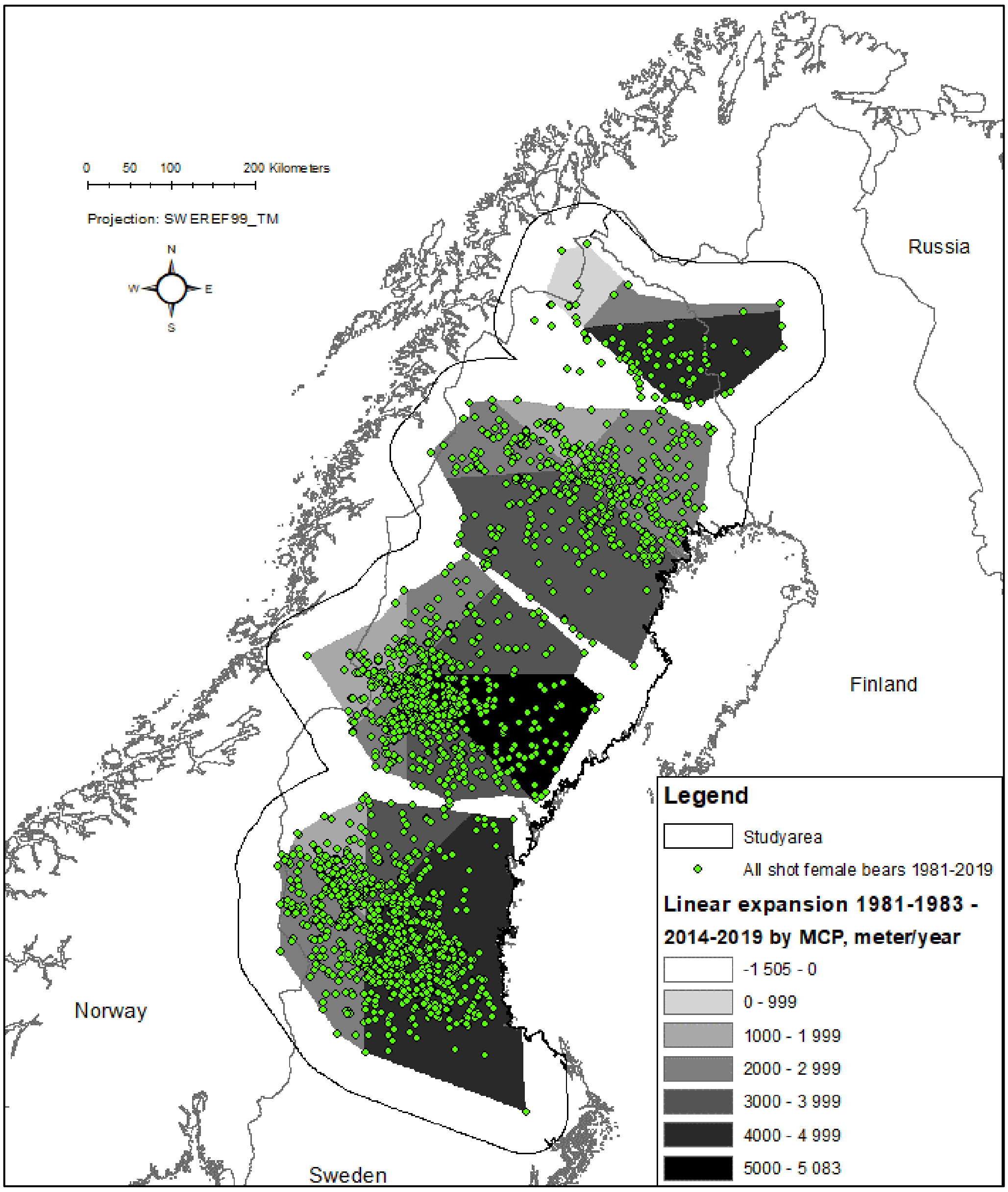

Figure 9. The concentration of the female bears shown by the positions of shot females 1981-2019. The background is the linear expansion in meters in each direction of each subpopulation by method Minimum Convex Polygon, MCP. The connectivity zones are indicated by the ellipse lines.

Though the female core areas were completely or quite isolated from each other in four subpopulations for decades in the study period, there are connectivity zones between the nearest of each of them. The female core areas have expanded during the study period visible in Figure 9 as areas with very dense locations of shot female bears 1981-2019. In the outskirts of the dense areas there are fewer shot females during the study period. Where the outskirts of the subpopulations are between the subpopulations within the distance of about ≤60 km, I call them connectivity zones where only DNA-analyses can show which subpopulation each shot female genetically actually belongs to. These female core areas, outskirt zones and connectivity zones are visible and shown in Figure 9. Out of the figure I also see that the expansion is very variable, as if the subpopulations have expanded more to the East/South-East than to the Southwest.

Based on the analyses the female core areas seem to have some connectivity:

- S and SS from the period 2008-2013 in direction 0-45 and 135-180 degrees, respectively.
- SS and SN in the late 1990's /beginning of 2000 in the directions 0-90 degrees and 135-270 degrees, resp. The connectivity zone is wide compared to the other connectivity zones.
- SN and N from the late 1990's or early 2000's in the direction respectively direction 45-90 degrees and 90-135 degrees.

The data analyses give no systematic results of expansion variation between the seven time periods but there is some logic, probable variation between the periods visible in the estimations of linear expansion by using MCP like expansion that have smoothened out or stabilized around 0 km/year for the last years.

The bear presence mentioned in Chapter 4.4, shows bear presence in the seven periods in a scale from 1-7 where 0 means no presence and 7 presences during all the periods, created by the Minimum Convex Polygon Hull of the seven periods. In each of the subpopulations except the one in the North, there are presence during all the periods in a central area of each subpopulation, Figure 10. The figure underlines the pattern of geographical linear expansion and regional and directional varying expansion.

The bear presence during seven periods in Figure 10 shows presence by periods which means that density within each period is not taken into account. The expansion front within each period is defined by the very outermost shot females within each period. By adding the polygons, the presence and expansion in the study period are visible. The pattern of expansion rate is very visible in for example the subpopulation SS in Eastern and Western direction. In contrast bear presence by Kernel Density, Figure 11, shows density of bears during the whole study period and every bear has the same magnitude. The density is emphasized and the expansion fronts during the period are not all visible or emphasized. And, the densest areas in the Northern subpopulation have about 80-85% less density, 0.0075, than the densest areas in subpopulation SS, value 0.0497, and S, 0.039 and 0.035. Most female bears have been shot in the core area of subpopulation SS and second most in subpopulation S where two core areas with very similar density are marked. The density in the second Northern subpopulation is 0.0194. In the Appendices 4-7 the density in a period of 10, 10, 10 and 9 years is shown, and the maps show considerable expansion into new areas compared to 1981-1990 and 1990-2000. They also show that core areas have changed into new areas and become larger but in the Northern subpopulation there isn't one core area in more than six periods. The density in the nine years 2011-2019 is as highest 0.02 in subpopulation SS, 0.018 in subpopulation S, 0.009 in subpopulation SN and 0.0044 in the subpopulation N. The densest areas in the subpopulations SN, S and N seem to have changed into a more Eastern location.

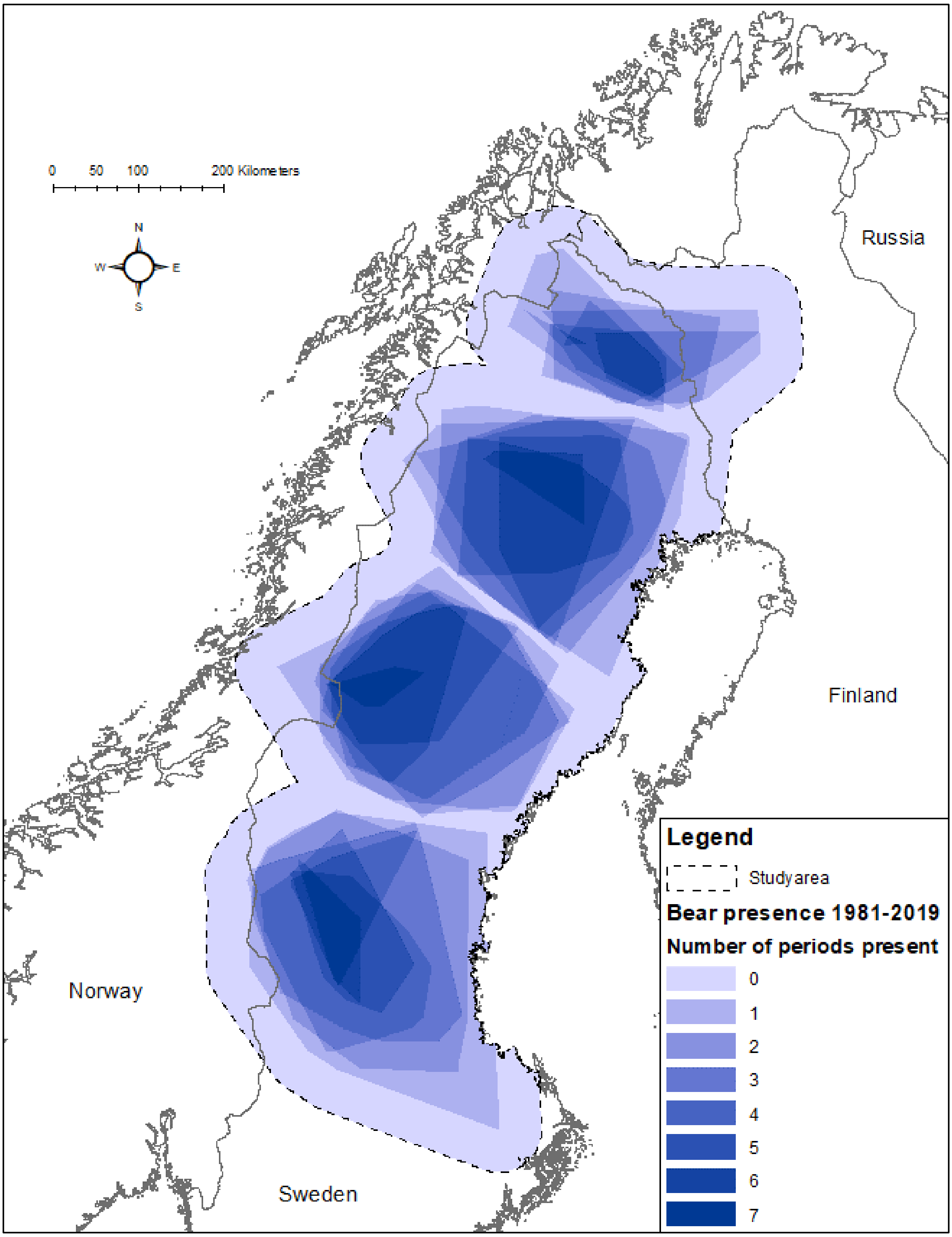

Figure 10. Density of bear presence over time during the period 1981-2019 in the Fennoscandian bear population created by the Minimum Convex Polygons of seven periods. Value 0 means no presence and up to value 7 which means presence in all seven periods.

The density during the study period differs between the subpopulations and Kernel Density gives another result, where the lower density in the two Northern subpopulations is more visible, Figure 11.

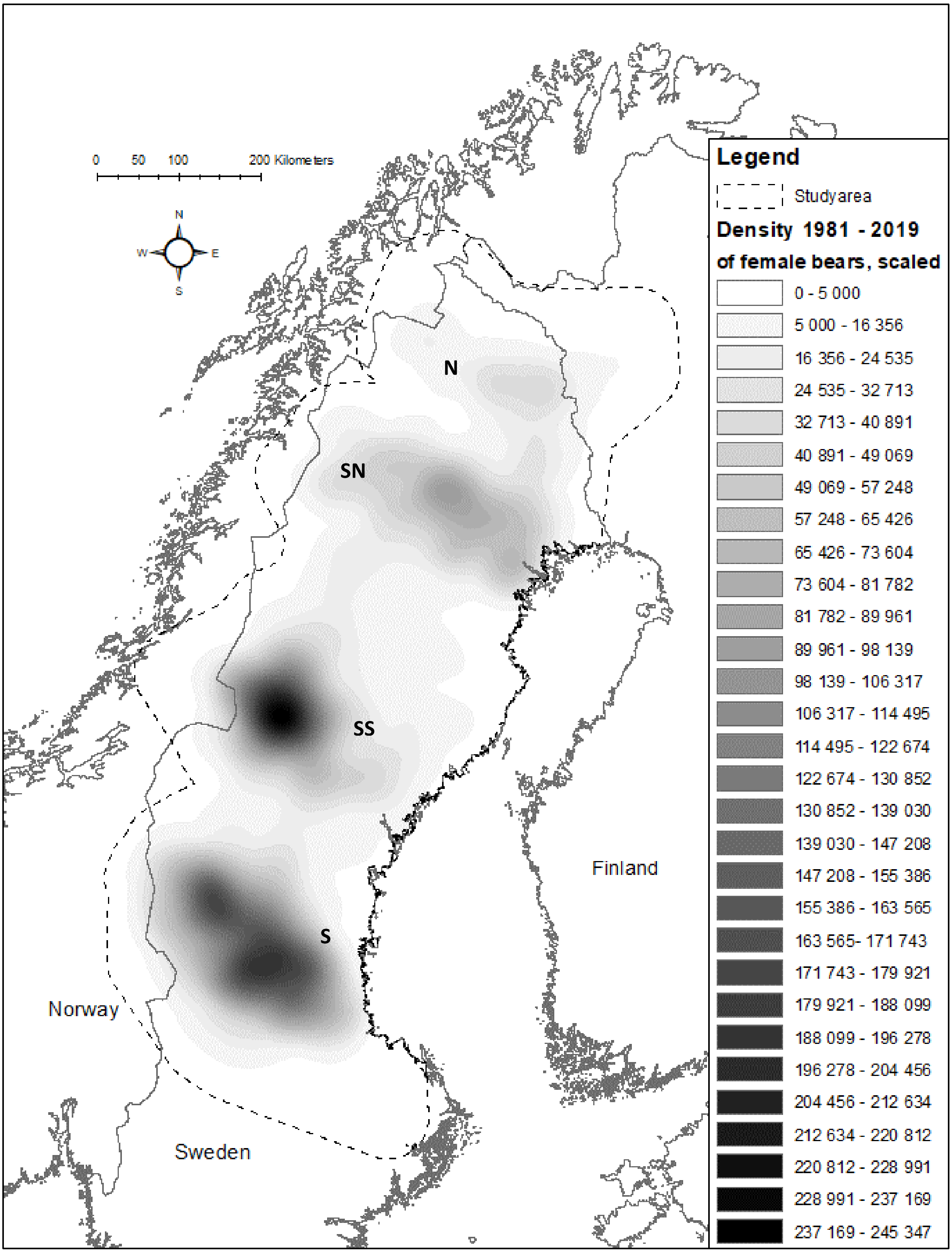

Figure 11. The density of shot females reflecting bear presence density in 1981-2019 created by the tool Kernel Density. The densest areas (darkest color) on a scale are the core areas in the two Southern subpopulations, SS and S. The connectivity zones are visible as lighter areas between the subpopulations. The scale is from 0 - 0,0497 with equal intervals. The letters label the subpopulations.

5.2 Analyses of factors that gain and hamper the population expansion

Correlation analyses show that the land cover group Forest is the only positive considerable factor impacting in all the models of expansion and bear presence verifying *hypothesis 2d*, see Appendices 20 and 21. The density of roads and railways is a quite considerable positive impact factor on the expansion parameters but not considerable for the bear presence or bear density parameters.

Of the negative factors there are several impacting negatively on all the four targets (*hypothesis 2a*). Landcover group Mountain and Percent calving area are the two single factors that impact most considerable negatively on all four targets. The second quite considerable and considerable negative factors in general are:

- The areas of protected nature areas in land cover groups Open and Mountain, Land cover group Mountain and spring pastures in reindeer husbandry, valued 0-1.
- The areas of protected nature areas in land cover groups Open and Mountain, Land cover group Mountain and spring pastures in reindeer husbandry, valued 0, 1, 2 and 3 multiplied with number of reindeer.
- The areas of protected nature areas in land cover groups Open and Mountain, Land cover group Mountain and spring pastures in reindeer husbandry, valued from 1-3.
- Calving areas in Sweden and areas used in spring in Norway and Finland.
- Spring pastures in the land cover groups Mountain and Open and Mountain.
- Calving areas in Sweden and spring pastures
- Number of reindeer before calving in spring pastures in land cover group Mountain.

The factor protected nature areas had a very poor correlation to the bear presence and density parameters and quite considerable impact negatively on the expansion parameters.

The factors that showed no or very low correlated impact are:

- Human density
- Land cover group Agriculture
- Land cover group Artificial areas
- Land cover group Open
- Spring pastures in land cover group Forest, except for the target bear presence by MCP's where the correlation was quite positive.

The *hypothesis 2b* was rejected because the artificial areas and density of inhabitants show low or no impact.. In contrary, vulnerable areas for reindeer husbandry like calving areas + spring pastures and higher number of reindeer in the same reindeer areas in the mountain have a negative impact (*hypothesis 2c*).

All the chosen models are explained in chapter 4.4.3. When running only the seven selected models the best score was for the y-model Expert4, which means
y=1*Forest + 1*Mountain + 1*Percent calving area + 1*Spring pastures in mountain + 1*Density of roads and railways * Forest,
ref. chapter 4.4.3 where all the models are explained. For all four targets the models emphasizing areas of very high importance to reindeer owners and high conflicting interests regarding presence of bears, mountain and forest give the highest score and correlation.

The very poor fit models for three of the targets were Landcover and Human & Forest, see Table 13-16. The model Human & Forest emphasize forest and human activity in general and Landcover only emphasize main nature and land use by CLC2018.

Table 13. Model output for bear presence 1981-2019 by MCP.

	ΔAIC_c	AIC_{cWt}	R^2	
Expert 4	0	1	0.19027	
Nature & Conflict	769	0		
Expert62	5882	0		
Landcover	7222	0		
Human & Forest	8069	0		
Expert 32	8722	0		
Expert	8876	0		

Table 14. Model output for bear presence 1981-2019 by Kernel Density.

	ΔAIC_c	AIC_{cWt}	R^2	
Expert4	0.00	1	0.13346	
Expert 62	930	0		
Expert 32	958	0		
Expert	1113	0		
Nature & Conflict	2292	0		
Landcover	12316	0		
Human & Forest	16647	0		

Table 15. Model output for linear expansion rate by regression.

	ΔAIC_c	AIC_{cWt}	R^2	
Expert 4	0.00	1	0.27795	
Nature & Conflict	684	0		
Expert32	686	0		
Expert 62	1078	0		
Expert	2188	0		
Landcover	38917	0		
Human & Forest	39489	0		

Table 16. Model output for linear expansion rate by Minimum Convex Polygon.

	ΔAIC_c	AIC_{cWt}	R^2	
Expert 4	0.00	1	0.35565	
Nature &Conflict	203	0		
Expert32	3939	0		
Expert 62	4768	0		
Expert	4282	0		
Landcover	33235	0		
Human & Forest	45048	0		

The accuracy by metric R^2 is 0.133-0.356, which means a correlation, r, of the respective models from 36.5-59.6 percent. The model with highest correlation is linear expansion by MCP, and secondly linear expansion by regression. This means in general that the targets have varying quality or correlation of linear relationship for the best fit model, ref. table 13-16:

- Linear expansion rate by MCP: 59.64% which in general statistical terms means slightly strong correlation
- Linear expansion rate by regression: 52.72% which in general statistical terms means solid moderate correlation
- Bear presence in the study period: 43.6% which in general statistical terms means moderate correlation

- Density of bears in the study period: 36.5% which in general statistical terms means weak correlation

According to general statistical theory the quality of strength of the linear relationship for the targets vs. the factors in each parsimonious model, can also be interpreted by the amount of data. The number of observations in the data by number of raster cells in each layer are more then 280 000 and the strength of the metrics can be considered higher than in general statistical terms.

The best fit models emphasize the highest potential conflict areas between bears and reindeer husbandry, forest as the best habitat to bears, and parameters for mountainous areas. It's noteworthy that beside the suitable bear habitat forest and the more unsuitable mountain, the factors are very closely associated with high potential conflict areas and activities in reindeer husbandry in mountainous areas during spring and early summer, including calving period, both in the AIC estimations and in correlation analyses.

6. DISCUSSION

6.1 Expansion – aim 1

In the Slovenian brown bear population Jerina et al. (2008) and Jerina et al. (2013) found that the expansion rate was estimated to be in average 1.6-1.9 km/year though the expansion and density varied. Their study was in approximately directions 225-360 and 0-90 degrees. I found the highest average expansion of 2.028 and 3.20 km/year in the Southern subpopulation using the two linear methods. Three of the subpopulations have quite the same or higher rates than the Slovenian study but the Northern subpopulation is diverging with a significantly lower expansion and a lack of expansion.

I have in this study revealed a very high variation in rate at subpopulation level and in different directions. The highest rates in my study are 5.156 and 5.083 km/year in direction 3, 90-135 degrees, in subpopulation SS. In directions with result by using both methods the lowest expansion rate is in direction 270-315 degrees in subpopulation SN, 1.191 and 2.370, respectively.

The reasons why the expansion in average is significantly higher in several of the directions and subpopulations in my study may be several. Brown bears in Swedish population have several times larger home areas and lower density than the Slovenian (Jerina et al. 2012; Swenson et al. 2010) so I claim that the geographic extent principally may increase more in Sweden at the same level of population growth, than in the Slovenian population. The density in Slovenia may exceed 40 bears/ 100 km^2 and in Sweden it has been below 2 bears/ 100 km^2 (Swenson et al, 1994; Jerina 2012). The highest density of adult female bears has the last decades been in the Southern half of the Fennoscandian population (Swenson et al. 1994; Kindberg et al., 2014, and Kindberg et al., 2018) and this is also confirmed in my analyses, ref. Chapter 5.1.3. Besides, the population growth in the Fennoscandian bear population has been the highest registered in the world among brown bear populations in 1981-2013 (Chapron et. al. 2014) and comprehensive population growth leads to recolonizing of new areas (Swenson et al., 1998; Jerina et al, 2008).

The results also confirm the presence of four geographical subpopulations in the study period, cf. Figure 7-10 and Appendix 1, which is supported by Swenson (1994, 1995). Manel (2004) has later defined three genetic female concentration areas, or core areas, because the two Northern ones were defined as one due to investigated genetic structure. The theory of three is supported in a study of genetic structure and gene flow in the brown bear population in the North of Europe (Schregel et al. 2015). My study confirms the theory of four geographical subpopulations by the four geographical female core areas and the genetic dispersal between them has been re-established at least the latest about 1-2 decades according to my analyses, ref. Chapter5.1.3. The most probable connectivity zones are defined in Chapter 5.1.3, and I suggest that the expansion front between some of the subpopulations in some directions, further will be difficult to interpret in a farther population growth.

Using median centers has given good accordance with all the subpopulations compared with the female concentration areas for 1981-1990, see Appendices 3-8. Except for the period 2008-2013 the core distribution area in NN seems to have changed to a more Eastern location, though biologically this is less possible so there must have been some female bears further East than the females shot in 1981-1983. Choosing median center of the polygons of 1981-1983 in this study instead of mean center of the location points gives a more accurately representative result. Using median centers and the method Generate Near Table in this study has led to significant results. To exceed the first period would not have led to more representative results because the method especially in the early periods with less data, is vulnerable to female bears dispersing farther away from their mother's home area than the average, so-called outliers.

The weakness of using Generate Near Table is that it only takes into consideration the shortest distance from a chosen point to each location. Some locations in the study can be outliers in one subpopulation though they are closer to locations in another subpopulation, or they are closer to one midpoint though they belong to the adjacent subpopulation. The sensibility for outliers or locations that may belong to another subpopulation, probably gave misleading results using linear regression by one occasion, subpopulation SN in direction 180-225 degrees. In 1984-89 a few locations in direction 45-90 degrees in SN are more than 90 km from other locations in SN but only about 39 km from locations in the N subpopulation. This might have reduced the estimated versus the real expansion in the directions. This is almost the same case in period 1984-89 in the subpopulation S, where one shot bear is more than 100 km from shot bear positions in the subpopulations SS and S but it is connected to the subpopulation S in the GIS operations and might be an outlier. Such outliers in early periods may cause lower expansion rate like direction 0-45 degrees in subpopulation S. An improved method where spatial autocorrelation or spatial dependence would be taken into account, may give a more precise result. Though is it important to remember that some of the locations definitely don't have a certain belonging to any subpopulation. I suggest the reasons why there are no significant linear relationship in some directions may be one or several:

- There are no linear relationship or expansion.
- Outliers in the first 10-20 years. The method has high sensitivity for outliers in the first 10-15 years due to few data in the same periods.
- Decline in subpopulation(s) from about 2005 to 2020.
- When using linear regression, the selection method when the data are quite few also include data that is not at all in the expansion front. This also indicates that estimated rates may be below the real rate.
- On a few occasions it seems that some data occur in the adjacent subpopulation. If such data occurs in an early period, they may lead to a lower coefficient of determination and no linear relationship.

The results in both methods regarding expansion support each other, underlining the importance of analyzing separately in different directions at subpopulation level to understand the expansion evolution of the Fennoscandian population since 1981. Method 1 may underestimate though significance leads to high value for validity. Method 2 secures results in all directions, and also discloses negative expansion by possible termination or underlining a very sparse density. Further, it is natural that the method using Minimum Convex Polygon Hull leads to higher rates and may be overestimated because it emphasizes only the very outer most locations of shot females like outliers. And, since the dispersal is inverse density-dependent, the density in the peripheral areas will always be low gaining the dispersal (Støen et al, 2006) and the expansion front will be uneven and not a concrete line. An improved estimation or modelling of expansion rates if such data had existed, could have implemented more data as systematically collected traces, signs, sights, DNA-analyses of female bears and habitat attributes, and maybe developed more detailed, complex, and different models due to different patterns in expansion, especially the Northern and generally direction 2-5 versus 6-1. Changes from one period to the next using method 2 by MCP leads to too unprecise results generally. Anyway, I claim that my analyses of expansion rates give a good and useful insight into the pattern of the four subpopulations.

Besides, the Northern subpopulation is differing in the meaning sparser and more clustered towards the West, Southwest and partly North and Northeast, strongly indicating very low density and unsystematic distribution within a larger area. There may even be some outliers among them. This is especially claimed by the period of 2008-2013 where several female bears are shot more than 50 km from shot females in the previous period and about 110 km from each other in Western Kiruna and the adjacent area in Norway. In 2008-2013 there were seven females shot in the directions 270-360 and 0-90 degrees and none in the directions 180-270 degrees in the Northern subpopulation. I therefore claim that the distribution in the Northern subpopulation mostly does not seem to follow a pattern that is logic according to bear biology or legal quotas for damage control and hunting. The clustered or sparsely pattern is also the fact in some Western and Northern directions in the other subpopulations. In 2008-13 the number of shot female bears was higher than previous periods due to damage control. Fløystad et al. (2021) show there are in total about 30 females in 2020 in the Norwegian areas Hedmark, Nord-Trøndelag and Troms in and just outside the study area and they are more protected resulting in low legal mortality. I generally therefore agree with Jerina (2008) that where there are no or very few data, the expansion is absent, but I also suggest as mentioned before that the distribution may be sparsely clustered and/or too sparse to give significant results.

6.2 Factors that have an impact on expansion – aim 2

I thought before analyzing factors influencing expansion that the supporting analyses of the targets density of bears in the study period and in seven periods would give more similar results to the expansion methods. The target Bear presence 1981-2019 by MCP emphasizes each shot female bear as equal independent of which year it was shot, and does not consider changes within time, which give a too poor correlation for analyzing the factors that influence. Presence in seven periods using MCP is a better target for analyzing factors than by Kernel density though the MCP's have some inaccuracy. I conclude due to accuracy score that they are not good as parameters for statistical analyses of the expansion. I think the two methods more than anything visualizes changes and pattern of expansion in the subpopulations and in the population as total. Both density methods contribute to the analyses of expansion and factors influencing but they cannot answer the analyses alone. It may be that a more time-weighting of the shot females in method of Kernel density could develop a better method using Kernel density but when I tried, the result was actually even weaker correlation to the factors. The estimated expansion rates magnitude the changes of distribution best in the study period. Most probably the correlation by using linear regression would have been higher and more similar to the correlation by linear method using MCP if more data on bears had been available with subsequent significant results of rates in more directions than 18 of 32.

Accuracy measured by the coefficient of determination, R^2, gave a solid moderate and slightly strong strength of quality for linear relationship of the best fit model for rate by linear regression and by MCP, respectively. Generally, with the amount and type of data in this study I consider the accuracy and significance as high for the most parsimonious model for rates.

The open land cover category is probably more negative close to and around mountain than patched in forest. The forest is probably also a more negative factor very close to the mountains. This means that including an elevation factor like areas in open and forest categories in example above 750 or 800 m.a.s. to exceed the mountain category to include both such open and forest land cover categories in subalpine areas, might improve the results.

In a larger project, effort could be made to improve the analysis accuracy by homogenizing each data layer of factors using the tool Spatial analyst – Generalization, though the used tool Dissolve includes some generalization. Generalization may improve the expression of real habitat suitability for bears in areas, in example close to the mountains in the West and in and close to the forested areas in the East and South. I could also or instead have used tools in R to increase the accuracy like ensemble prediction and tuning. I also think the belt of 50 km around the bear distribution area could have been dropped or reduced for areas where they haven't had the possibility to expand into yet in the South, or I could exceed the value of expansion of each angle area into the same angle in the belt. Forest is probably underestimated in the correlation analyses because of the belt included in the South without female bears, which is good and very good bear habitat. The belt of mountains and vulnerable areas to the reindeer husbandry could also been reduced but at the same time the analyses give very clear answers regarding the negative factors there and what seems to be a belt of barriers in the West and North. Anyway, I claim that my results give clear answers.

Anyway, the analyze results of proportion calving areas, spring pastures in mountain, mountains and forest strengthen the pattern in the results by using the two expansion methods. Though, percent calving area also is in some degree a combined layer because it also reflects mountainous areas in some degree. It is also remarkable that the combination 1) protected nature, 2) spring pastures in open land cover and mountains and 3) mountain both with value 0-1, 0-3 and 4) multiplied with reindeer numbers led to clearly negative factor in correlation analyses for all the four targets. There is no doubt that this belt in the West has hampered the expansion. This also means that all those four factors probably reinforce each other as negative factors, meaning they are in some degree additive.

The effect on population expansion of individuals dispersing longer from other females and may be creating small metapopulations, could be studied in areas with different habitat suitability and mortality risk. This pattern makes each female bear in Norwegian areas, very important alive in the purpose of achieving the national and regional population aims.

A regional variation in my study is supported by estimations of population growth. For example, Kindberg et al. (2011) found for the years 1998-2007 that the population growth varied from 0-10.2% in different counties in Sweden. In studies in North America and Southern Europe the expansion has also been revealed to be quite variable due to varying landscape features (Wiegand et al. 2004; Bjornlie et. al, 2014). On the other hand, the absent or small expansion in some directions and especially the subpopulation in North, is noteworthy. The data shows areas where female bears hardly or not seem to establish over time. Due to low natural density in those areas the female bears' reproduction and population are vulnerable to stochastic, demographic and human-caused termination and mortality. Even sexual selected infanticide, SSI, may have larger impact on expansion due to killing of dominating male bears in areas with low density. In the Fennoscandian bear population this is coincident in quite remote areas close to or in Alpine areas regarding bear presence and vulnerable reindeer pastures with high potential conflicts, see Appendices 10, 13 and 15-19.

Of the five land cover types in the study area is "Forest" dominating by 63.8% of the area and "Mountain" and "Open" come second and third, both by 16.5%. "Agri" and "Arti" are less than 3 and less than 1%, respectively. The mountain areas are dominant in the Western parts and forest is dominant everywhere else. Both artificial and agricultural areas are in mosaic with the natural land cover types, so I therefore claim that relatively small areas with cities and areas of agriculture haven't hampered the expansion or bear presence in a regional and national scale, and this is despite that they are unfavorable bear habitats, ref. Chapter 3.6.2.

Agricultural areas and artificial areas are more than average represented in the South-Eastern parts in Sweden outside the bear presence area, and this area might become a more negative factor towards expansion and presence if or when bear expansion reach those areas. Mountain is probably a negative factor in two ways, both unsuitable /less suitable habitat to the bears and areas connected to very high conflicts with reindeer activities like important spring pastures. The remote Alpine areas are by all means without roads and other public access, but the bears and bear tracks are very visible in the snow and the access to the bears are high for persons on snowmobiles with motivation of chasing and killing them, ref. BRÅ (2007) and Chapter 3.9.

Each year 1-2 weeks in spring-winter time the reindeer are conducted in specific tracks or areas several hundreds of kilometers from the coast to the mountainous areas for calving and summer pastures in Sweden. The movements from the coastal areas in Norway to the mountainous areas close to the border to Sweden is at the same time. During those movements, the reindeer are vulnerable to attacks from large carnivores, though most of the losses are in the calving period and early summer, especially from bears. It is noteworthy that the spring pastures including tracking areas seem to impact negatively on the expansion and even seem to partly be overrepresented in connectivity zones between subpopulations S and SS, SN and SS and partly N and SN, ref. Figure 9 and Appendix 19.

Besides bears, other large carnivores in the same area also cause stress to the present reindeer so that they spend less time on grazing and are split into several areas (Forsberg & Korsell, 2005). Calves may even be separated from their mother due to the stress. Tverraa et al. (2012) found that the predation of golden eagle *Aquila chrysaetos*, wolverine *Gulo gulo* and lynx *Lynx lynx* on reindeer in Troms and Finnmark are higher when the density and number of reindeer are higher. High density of reindeer lead to less body weight and condition due to high intraspecific competition of the winter grazing resources in winter barren land. The more reindeer, the less nutrition and condition. Variation in years like late onset of spring and low primarily production due to cold summer also seem to challenge the reindeer condition and production. The predation losses in Troms and Finnmark due to golden eagle, wolverine and lynx are mostly compensatory, meaning that a high proportion of the predated reindeer would have died of starvation. Weak reindeer are in general vulnerable to predators. Mattisson et al. (2014, 2015) found that both lynx and wolverine search for and predate specifically reindeer calves in summer, and in winter lynx select reindeer calves and wolverine predate calves according to availability. Contrary to bears' diet, the main diet of wolverines and lynx in Northern parts of the study area is semi-domesticated reindeer, though the wolverines are often mainly scavenging (Mattisson et al. 2016). Besides existence of bears, the total predator press may therefore cause inevitable challenges, stress, and losses of reindeer for the reindeer owners. The total predator press locally may cause and reinforce negative attitudes to large carnivores and higher acceptance for illegal hunting (Gangås et al., 2013). Even Jacobsen et al. (2012) found that there are areas in Norrbotten where radio-collared golden eagles simply quickly disappear without reasonable natural reason, indicated poaching. I therefore suggest that presence of large carnivores in Fennoscandia on both semi-domesticated calving ground and the other spring and early summer pastures for reindeer have an extremely high score on Potential Conflict Index, PCI, mentioned by Gangås et al. (2013). Such areas combined of a high amount of snow vehicles, and remote areas with low and very low public access and law enforcement, and the intolerance may cause high proportion of illegal mortality caused by support to or performance of illegal crime to bears, ref. Forsberg & Korsell (2005) and BRÅ (2007). I suggest that combined with a high number of reindeer, a higher number of snow mobiles close to the mountains since the 1980's and 1990's may indicate potentially higher illegal mortality the last decades there than in the previous decades, ref. the use of snow mobiles by Forsberg & Korsell (2005), BRÅ (2007) and Rauset et al. (2015).

National parks and other protected areas where hunting is and has been forbidden for decades, are in themselves supposed to impact positively on bear population expansion. In the areas of the large national parks Sarek, Padjelanta and Stora Sjöfallet, the expansion rate is negative or 0. Even though there is a mix of forest and mountain peaks the non-existing expansion is not natural, and the bear population is very sparse even though those parks in forested valleys naturally should have been hot spots for further expansion. The parks include forested areas as well and the factors that hamper the expansion must be very strong in those areas during the study period 1981-2019.

Illegal hunting as a regulating factor of bear population has been found in other bear populations. According to Kaczensky et al. (2011) illegal killings cause reduced expansion and recovery in the Eastern Alps. The expansion rate estimations and analyses of factors that hamper the expansion are very important for understanding the distribution of and low and lacking expansion into the Norwegian part of the population. Calving areas and mountainous areas on both sides of the border seem to have hampered the possibilities of increasing the brown bear population for decades in parts of Norway. In contrary, the expansion is both significant and positive into Hedmark in areas without comprehensive reindeer husbandry and with high proportion of forest and few mountain areas.

Previous studies from North America show that even gravel roads and trails give higher human access to areas for people that are intolerant to large carnivores and the access therefore may increase the illegal and legal killing (Benn et al., 2002; Merrill et al, 2000). The access by motor vehicles is therefore important regarding illegal hunting because of the higher possibility of approaching and chasing predators. The alpine areas in Fennoscandia have a high landscape visibility and the traces of bears in the snow reveal bear existence to humans. In the spring pastures including calving areas, the bears live within a dangerous frame of conflicting human interests and snow vehicles in areas with low public access. The analyses in this study by both estimated expansion versus no expansion and factors that impact expansion, both strongly indicate that reindeer husbandry has a high importance regarding bear distribution in areas with high score on Potential Conflict Index. I suggest that the road and railway density in the study area mostly reflects the road density and remote versus not remote areas, and roads means more public access which seem to be more positive to bear presence. In short, where there are roads, there is forest which is positive to bears. The gravel roads in forests are not fully included in the analyses but neither are they assumed to be physical barriers to expansion, though they might increase human access in some degree and lead to higher risk for illegal killing. In the mountainous areas the number and length of gravel roads are much fewer and not winter plowed. I therefore claim that gravel roads are not at all a comprehensive influencing factor on bear expansion in Fennoscandia.

The correlation analyses and the best fit models in my study support Swenson et al. (2011) who found illegal mortality at a peak in the period May-June in the Northern subpopulations regarding areas in or close to mountains. Swenson et al. (2010) concluded that the illegal killing of bears has been several times higher in the Northern parts than in the Southern.
My results of analyzing the factors that may impact, support that in areas with very low density and partly periodically local termination of female bears in the Western parts of Northern Norrbotten is not natural as I concluded in chapter 6.1, and I suggest possible compensatory and additive death reasons of damage control versus illegally shot females. This is supported by previous studies and work, among them BRÅ (2007). The females shot due to damage control may have improved the realistic view in my study of the bear presence though there is a possibility of termination at a local and regional scale in peripheral areas. I suggest that the phenomenon illegal mortality of bears in those areas may be comparable to the study of wolves by Liberg & Sand (2020) who found that the disappearance rate correlate positively to population size or density and negatively correlated to legal culling, though the difference in female presence in mountain and forest areas with potentially high losses of reindeer in spring, I also suggest that it may differ depending on if the motivation is termination or reduction of the presence of the bear population. This is underlined by the fact that the population centers have even changed from a more Western to a more Eastern location in the study period and even higher density of bears in a more Eastern location, which means from more mountainous areas to more forested areas away from areas with higher proportion of remote calving areas and spring pastures with low or no public access and low or no law enforcement.

Though, it is very important to underline that my results in themselves do not prove illegal killing of bears but they strongly support findings and conclusions in other studies and investigations regarding illegal killing of bears and other large carnivores, when I am finding impacting factors as percent calving area, spring pastures in mountain besides natural unsuitable and suitable areas in my analyses.

Other predators may also contribute to the habitat suitability. Brown bears may benefit the presence of wolves in the forests because brown bears in Sweden may kleptoparasite > 50% of the wolf-killed moose (Milleret et al., 2011). It is also known from other latitudes that brown bears may scavenge on up to 50% of the kills by Eurasian lynx *Lynx lynx* (Krofel et al. 2012). The presence of lynx and wolves may therefore positively contribute on the habitat suitability and thereby reinforce a positive effect on the expansion, but the bears' diet as omnivore may cause a neutral impact of other large carnivores on brown bear expansion. The factor of presence of other large carnivores therefore seems to be of less or no importance on the distribution of bears, though further studies may reveal if and how the bear population may benefit population of wolves and lynx in a large-scale expansion.

The spring pastures in the forested lowlands influence much less on expansion than the spring pastures in mountains. The reasons may be several. It is easier and more efficient to move fast by snowmobiles in bare mountains, sparsely forested areas in mountains and open areas. The unforested areas lead to more oversight in landscape and the bear traces are easier to track on snow, and there are more persons in the reindeer husbandry in the field during spring and spring-winter, ref. chapter 3.8. The reproduction of bears and potential expansion are much higher in forested areas due to forest as very suitable bear habitats. Bears prefer rugged forested areas (Nellemann et al. 2010) and the combination of ruggedness and forest results in higher bear reproduction and density. Though, emphasizing ruggedness in my study would probably not have an impact on the expansion rate on a large scale as the study area, though they may have an impact when studying individuals, ref. Chapter 3.6. Though rugged forested areas truly might impact positively on bears survival giving the bears shelter and nutrition (Nellemann et al. 2010) meaning that rugged forest may implicate density of bears and in less degree on population distribution area.

The more populated forested areas are less sheltered for visible common access. There it is less effective to go by snowmobiles and the reindeer husbandry may be performed in another way with less transport and more sheltered operations. The Finnish part of the study area and the areas for concession reindeer husbandry at the Swedish-Finnish border may be examples of areas with another kind of reindeer husbandry, especially in calving period, possibly in less conflict with presence of bears than reindeer pastures with a high number of reindeer in mountainous areas. The expansion rate in the directions towards East is considerable higher than the expansion in the directions towards West.

Military shooting practice areas are not included in the analyses. Only in Norrbotten there are several, up to 1650 km^2 each (Försvarsmakten, www.forsvarsmakten.se). One is between the roads E10 and E45 in the upper North of Norrbotten. The largest is West of E45 between Jokkmokk and Kåbdalis. The military shooting areas may influence in some degree on the bear distribution, but it isn't known whether they influence the expansion rate like a barrier that hamper the expansion. This could be studied on a more local scale in future. Anyhow, such barriers are probably not so large that it is impossible for the bears to live and disperse around them, and every military area may not be in use every year.

It is possible to expect the density of brown bears of both sexes to be different within the subpopulations and each county due to fluctuations in population size and mortality, ref. Chapter 3.5. I think therefore, that the density of bears may influence the expansion rates, as the high saturated density may lead to, higher geographic expansion. Due to the dispersal pattern and SSI the expansion rate may vary in some degree due to bear density. In forested areas where there might be saturation, there might be more geographic expansion into new forested areas (Støen et al. 2006). For the same reason, bear density may be a moderate to small reinforcing factor impacting in the study period like more negative or more positive, but I also think that bear density in some areas is of less considerable single value due to other factors influencing more. But as a consequence, higher natural geographic expansion towards South and South-East in the Southern subpopulation is to be expected.

Most of the bear presence implemented in the analyses, is in Sweden so I have chosen not to include density of about 2 million free ranging sheep in Norway in the analyses, though the presence of bears versus sheep husbandry leads to high local conflict situations in Norway (Knarrum et al.2006). In several municipalities adaptions in the sheep husbandry have been done and the possibilities of adaptions within sheep husbandry seem to be much higher than within reindeer husbandry (Hansen et al. 2020), which may have led to less conflicts in some areas in the study period though the lacking expansion in several Norwegian areas is noteworthy. The bear reproduction biology is complex regarding SSI in the peripheral areas of the population like Norway, but I assume that the situation with high mortality level in conflict areas in such peripheral areas, even SSI may complicate the bear cub survival and impacting the expansion, in a mix of reasons of illegal and legal damage control and hunting.

In Sweden the exceptionally thick snow cover in the mountains in the winter 2019-2020 and a late snowmelt in spring 2020, led to an all-time high when it came to the number of bears killed for damage control in reindeer husbandry during spring (M. Schneider, Länsstyrelsen Västerbotten, pers.comm.). Damage control in areas close to the mountains has been conducted in both Norrbotten, Västerbotten and Jämtland counties. In spring 2020, due to snow conditions, reindeer were not able to reach their traditional calving grounds in alpine areas. As a consequence, calving started when the herds were still in the forest close to the mountains, where bear numbers are higher than in subalpine and alpine calving grounds (A. Danell Savela, Länsstyrelsen I Norrbotten, pers.comm.). Until 25 May 2020, 132 bears had been reported killed in 2020 and 54 of them in Norrbotten (A. Danell Savela, Länsstyrelsen I Norrbotten, pers. comm.). In the spring of 2017 almost, similar conditions occurred with deep snow cover, low temperatures and delayed snow melt. During spring 2017, 42 bears were killed in damage control. The climate changes cause more variation within the year and from year to year and extreme periods and situations become more ordinary and even more extreme (Riseth & Tømmervik 2017; Loe et al. 2016). The calving areas in a warmer climate may change geographically from mountains to forest areas, underlining that the global climate changes may increase the potential conflicts between bears and reindeer husbandry, if the bears living in the forest are shot due to new conflicts in forested calving areas. Odden et al. (2018) conclude that a reindeer husbandry more adapted to live with the global climate changes locally of today and in future will be more robust to secure an acceptable degree of condition of the reindeer, especially the does and calves, less vulnerable to large carnivores. Improving the co-existence to large carnivores and adaption to future climate by management implications of presence of bears and reindeer husbandry, may reduce conflicts and potential poaching, if bear distribution and density is to be maintained in high conflict forested areas. My results show vulnerable areas for bear expansion, and adaption and co-existence may be important to landscape connectivity to secure bear distribution close to the border Norway – Sweden.

7. CONCLUSION

The two methods for estimating expansion rates supplement each other in analyzing the trends at a subpopulation level. I claim that the two methods together show changes and trends that are in high accordance with reality in the study period. Together with presence and density of bears in seven periods and the whole study period they supply new information about this bear population. The expansion was significant linear in 18 of 32 directions (hypothesis 1b), different in the subpopulations (hypothesis 1c) and directions and mostly positive (hypothesis 1a and 1d). The highest expansion rate was about 5.1 km/year in direction 90-135 degrees in the second-Southern subpopulation and in average highest in the Southern subpopulation 2.03-3.20 km/year and decreasing towards North.

The accuracy of estimated expansion rate from one period to another in the same angle is generally low (hypothesis 1c), though trends are indicated in some directions and periods. The value of using the rates for evaluating hunting quotas and strategies for a short period of time are therefore generally too low.

In this study based on the results and previous studies, there seem to be no factors to contradict the results and conclusions in my master thesis. Though, the accuracy of each factor's impact may increase or decrease in some degree by improved methods.

Spring and early summer pastures in reindeer husbandry, especially calving areas, in sub-alpine and alpine areas and partly winter-spring-move are barriers that hamper expansion of brown bear population (hypothesis 2c). Supporting previous studies, those areas seem to be high-risk areas for poaching of brown bears in Norway and Sweden. Higher number of reindeer in mountain in spring and early summer pastures also were a negative factor. Spring pastures in forest seem anyhow to have a neutral or low impact.

The mountains and open areas around the mountains reinforce human-caused barriers in those areas probably as a less or not suitable habitat for brown bears as expected in hypothesis 2a. As a paradox, road density seems to gain the bear expansion as the lower road density, the lower bear population expansion rate. In contrary to hypothesis 2b, cities and other settlements, human population density, and the land cover groups Agricultural, Artificial and Open areas at this scale have a neutral impact.
The expansion has been very positively influenced by forest areas (hypothesis 2d), the natural favorable main habitat of brown bears. Though, large, remote and protected nature areas where hunting has been prohibited, seem to have a negative impact and most of those are in or close to mountain and alpine and sub-alpine vulnerable reindeer husbandry areas close to the border Norway-Sweden.

The positive expansion rate in general towards East and Southeast seem therefore very natural due to the distribution of forest giving possibilities for shelter, nutrition and higher bear reproduction and with no or only few potentially high-risk areas for reindeer husbandry.

This study shows a high potential for considerable benefits in management by identifying the high-risk level areas for large carnivore poaching and additionally use improved targeted management incentives to reduce the mortality of bears.

The results of the study emphasize the importance of and may contribute to improve the 1) prediction of losses of reindeer, and 2) planning and performance of preventive and corrective actions in reindeer husbandry. The incentives in vulnerable areas for reindeer husbandry should create a win-win-situation to both encourage sustainable reindeer husbandry and esteem protection of bears and bear populations, to achieve predictability for both issues.

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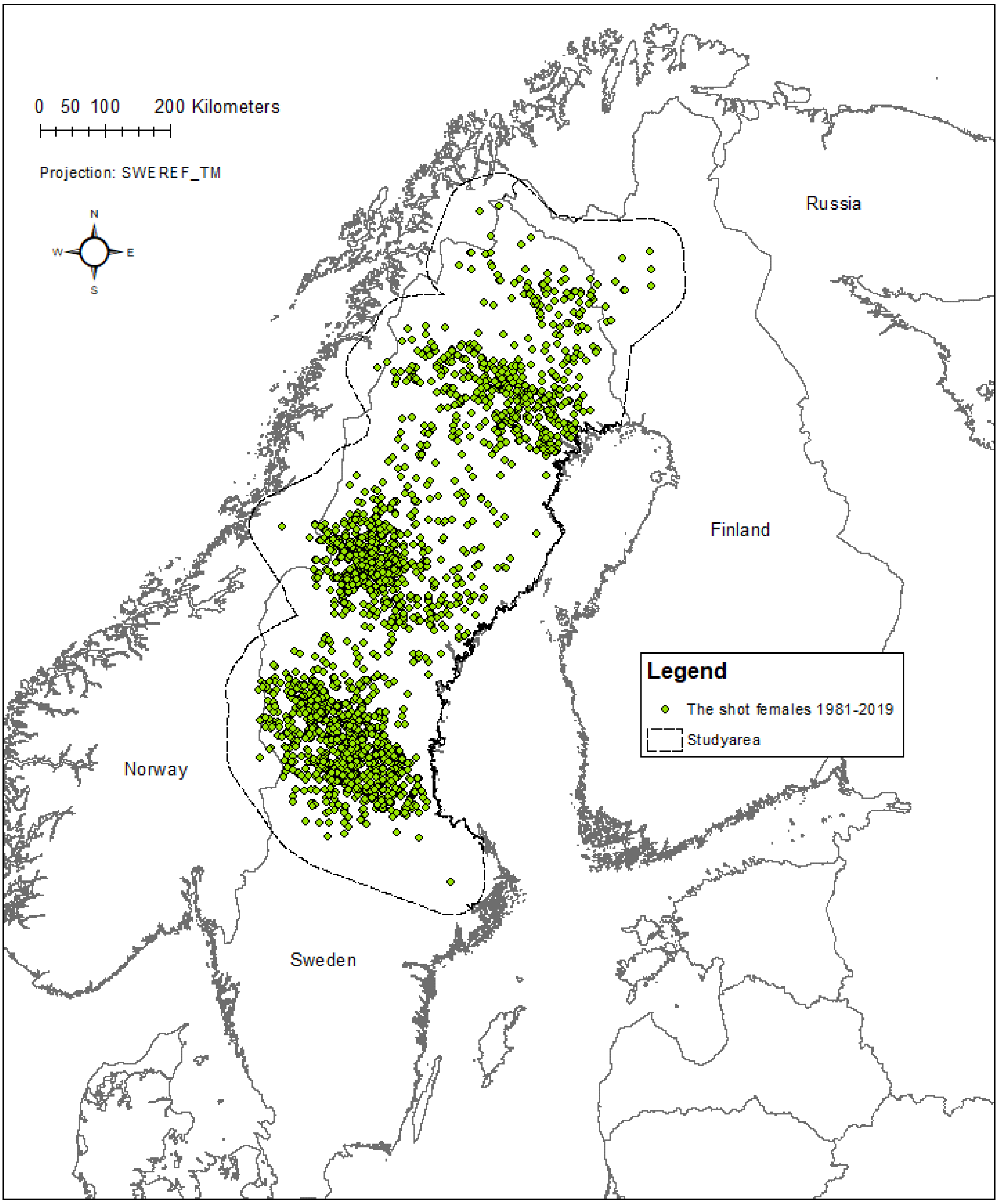
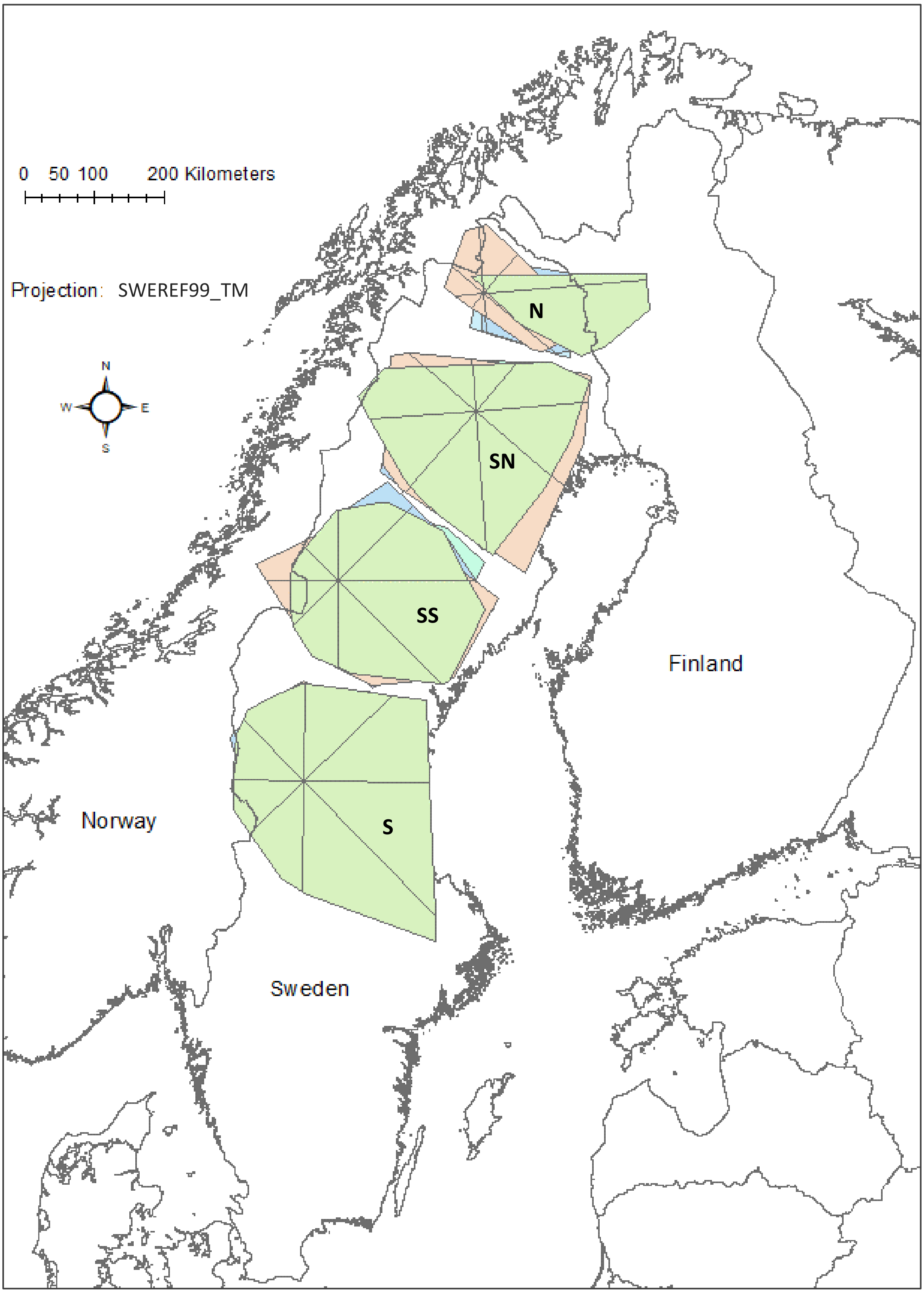
Appendix 1 The shot female bears in 1981-2019



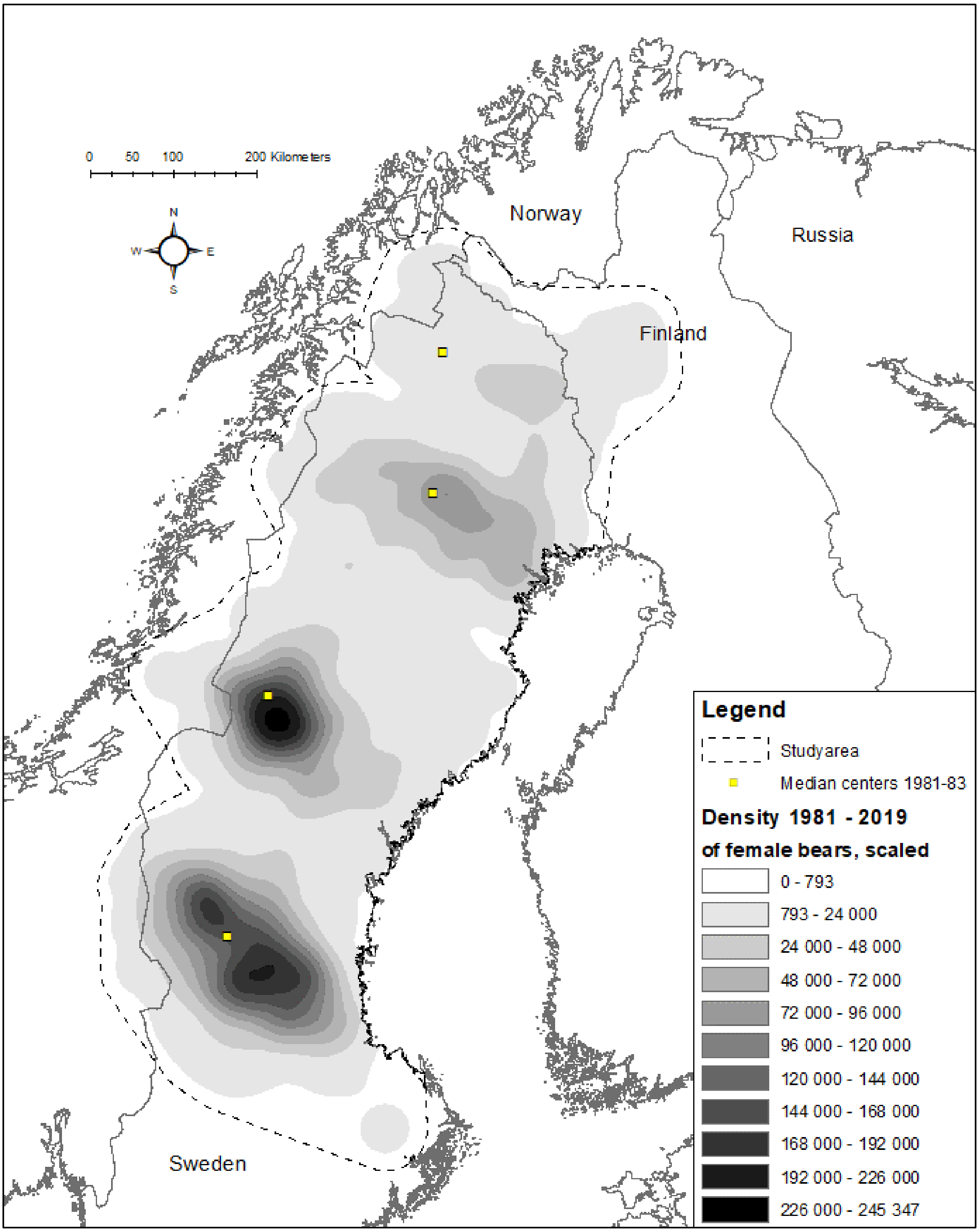
The shot female bears in the Fennoscandian bear population in the period 1981-2019 within the study area.

Appendix 2 Minimum Convex Polygon Hull of the subpopulations



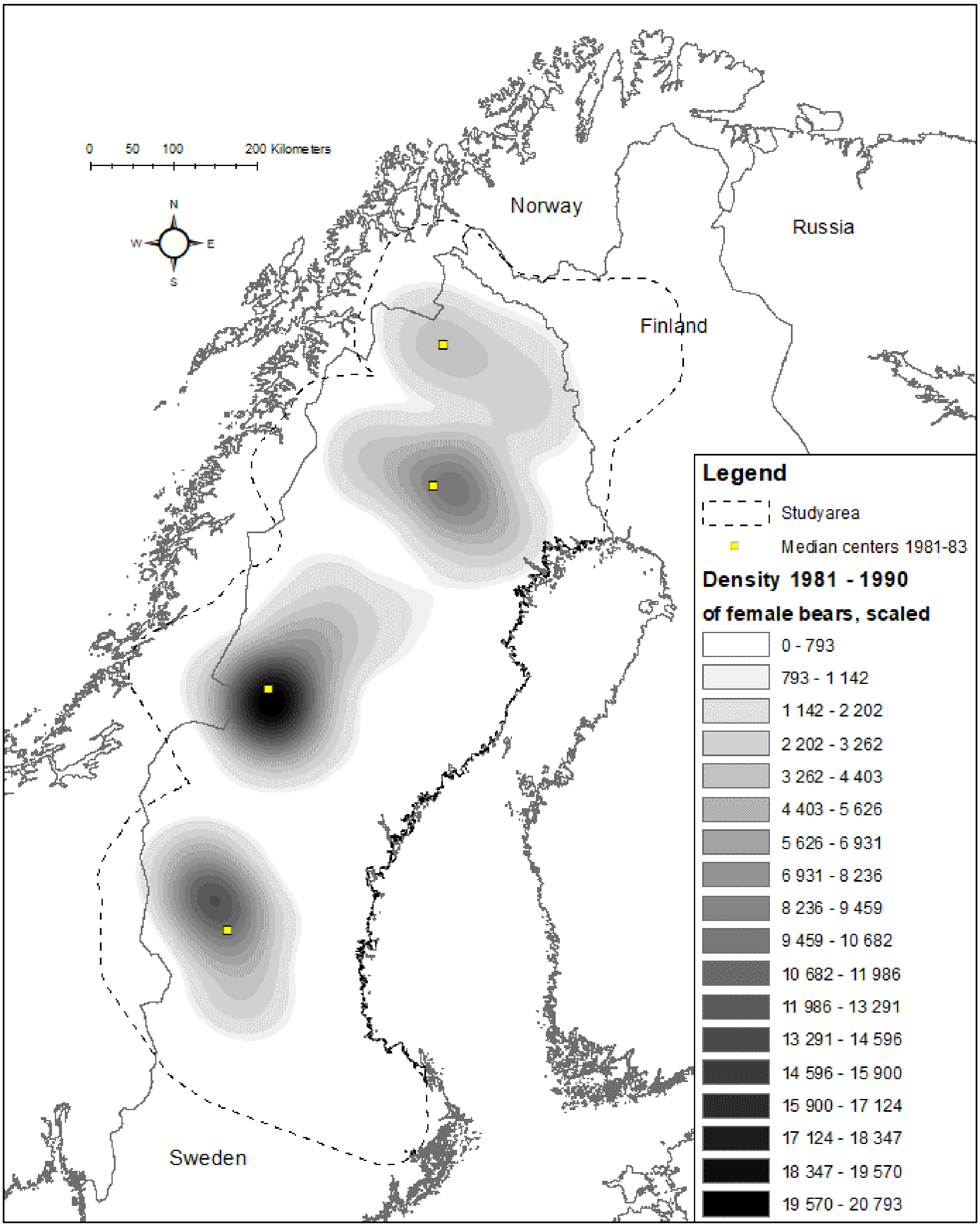
The estimated Minimum Convex Hull polygons of the four subpopulations. The latest periods are in front; 2014-2019 in light green, 2008-2013 in pink, and 1996-2001 and 2002-2007 in blue. The latest periods cover the earlier periods almost completely in subpopulation S, mostly in SN and SS, and partly in the Northern subpopulation, N.

Appendix 3 Kernel Density of shot females in 1981-2019 versus median centers of 1981-1983



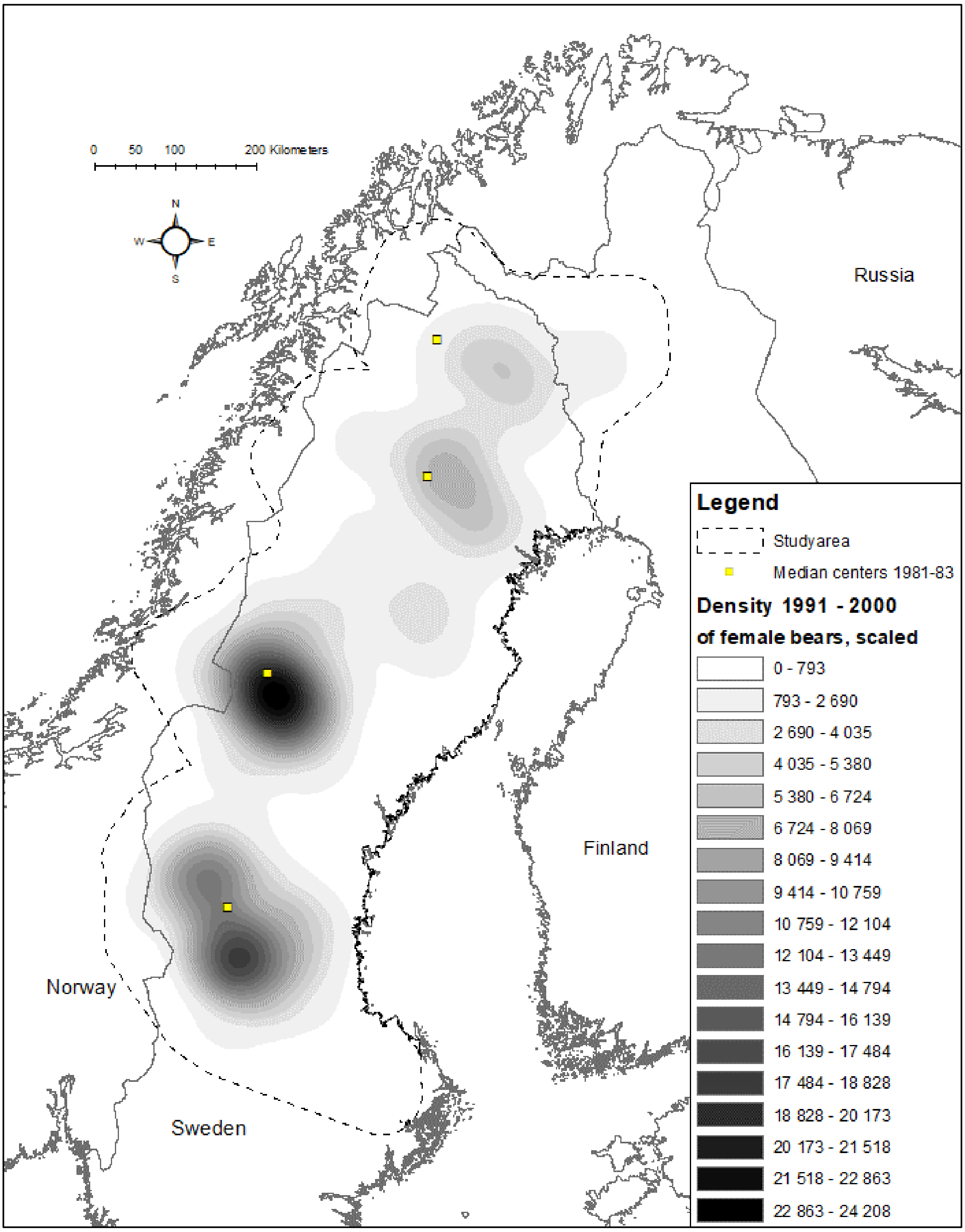
Shot females 1981-2019 representing bear presence in the study period. The darker color, the denser areas. The median centers of each Minimum Convex Hull of shot females 1981-1983 shown in yellow quadrats, indicate that good representativity in the densest areas except for the subpopulation in the North.

Appendix 4 Kernel Density of shot females in 1981-1990 versus median centers



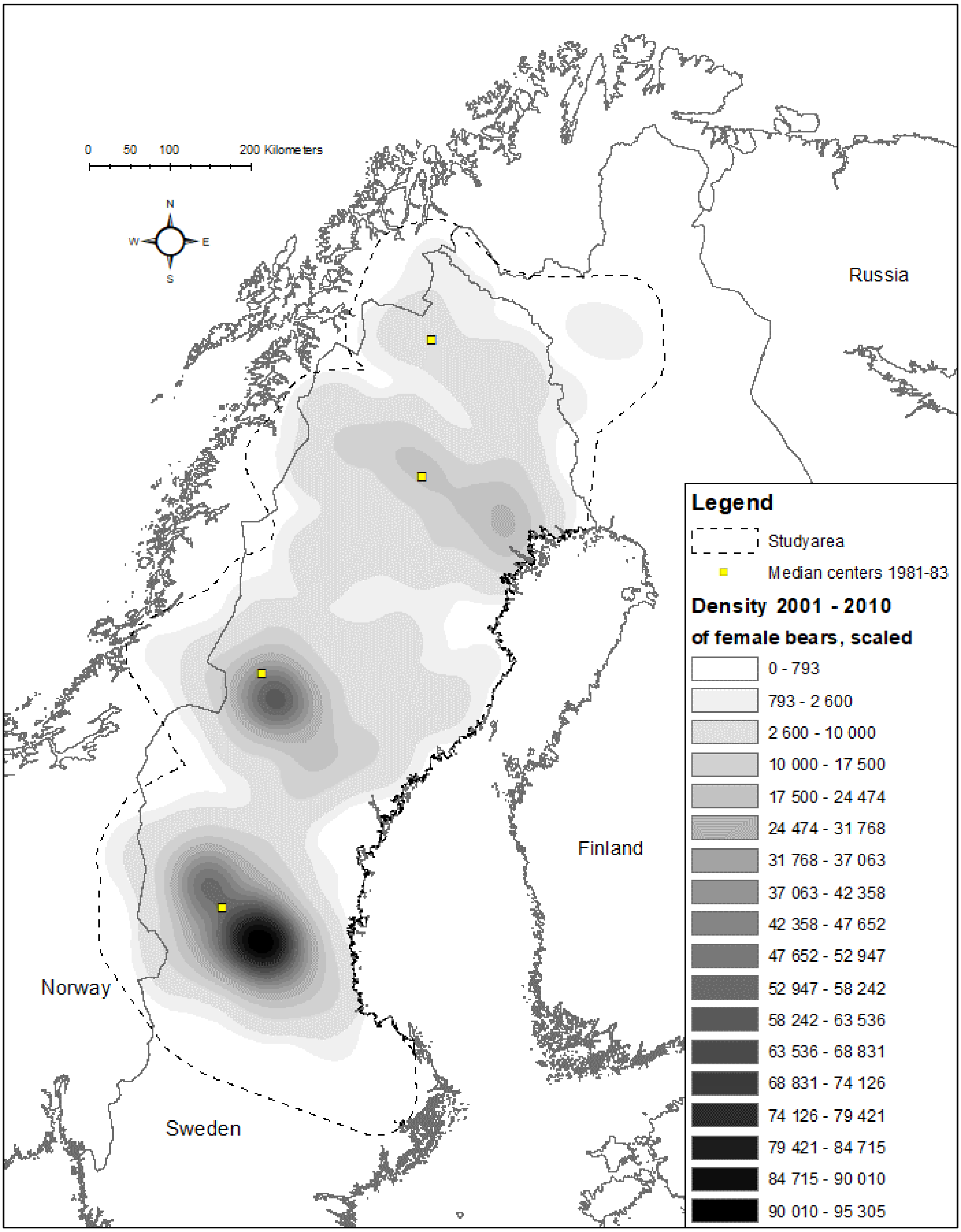
Density in the bear subpopulations in the period 1981-1990 based on the shot females in the same 10- year period, by the tool Kernel Density. The darker the color, the denser of female bears. The median centers of the Minimum Convex Polygon Hull 1981-1983 are shown as yellow points. The lighter colors between the subpopulations show connectivity zones.

Appendix 5 Kernel Density of shot females in 1991-2000 versus median centers



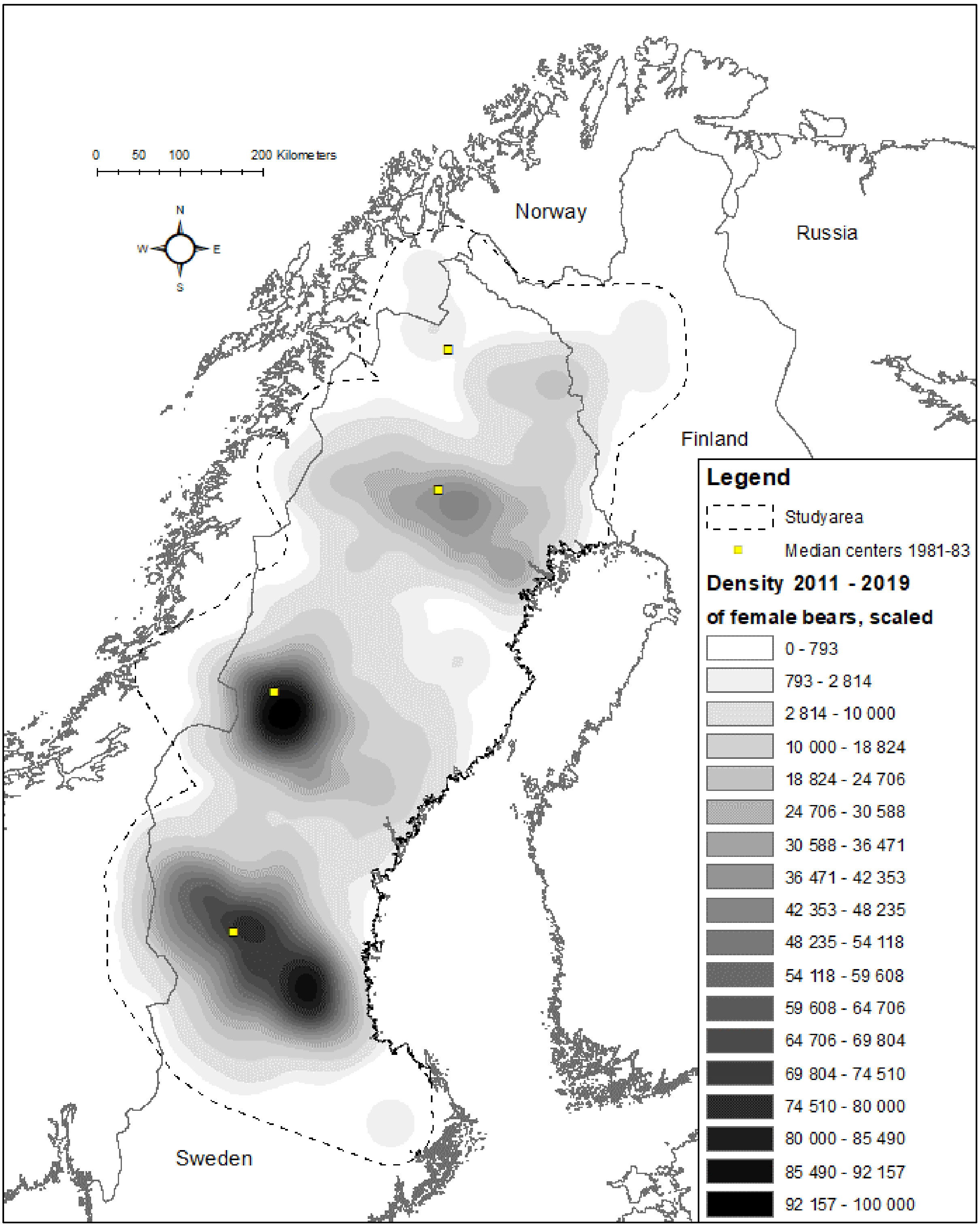
Density in the bear subpopulations in the period 1991-2000 based on the shot females in the same 10- year period, by the tool Kernel Density. The darker the color, the denser of female bears. The median centers of the Minimum Convex Polygon Hull 1981-1983 are shown as yellow points. The lighter colors between the subpopulations show connectivity zones.

Appendix 6 Kernel Density of shot females in 2001-2010 versus median centers



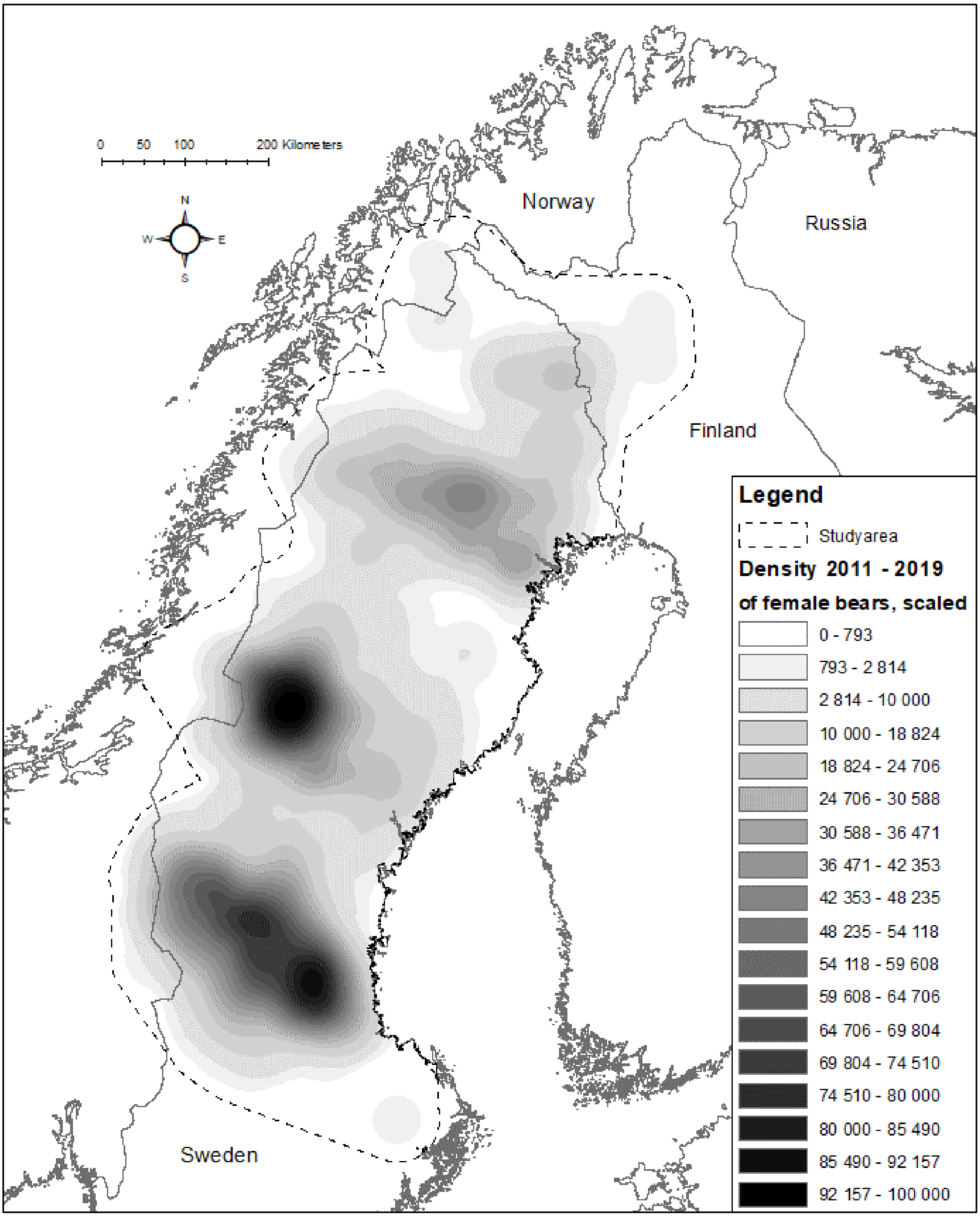
Density in the bear subpopulations in the period 2001-2010 based on the shot females in the same 10- year period, by the tool Kernel Density. The darker the color, the denser of female bears. The median centers of the Minimum Convex Polygon Hull 1981-1983 are shown as yellow points. The lighter colors between the subpopulations show connectivity zones.

Appendix 7 Kernel Density of shot females in 2011-2019 versus median centers



Density in the bear subpopulations in the period 2011-2019 based on the shot females in the same 10- year period, by the tool Kernel Density. The darker the color, the denser of female bears. The median centers of the Minimum Convex Polygon Hull 1981-1983 are shown as yellow points. The lighter colors between the subpopulations show connectivity zones.

Appendix 8 Kernel Density of shot females in 2011-2019



The density of shot females 2011-2019 reflecting bear presence density in the same 9-year period created by the tool Kernel Density. The densest areas (darkest color) are the core areas in the two Southern subpopulations. The connectivity zones are visible as lighter areas between the subpopulations.

Appendix 9 The layer names of targets and factors with a short description

Targets

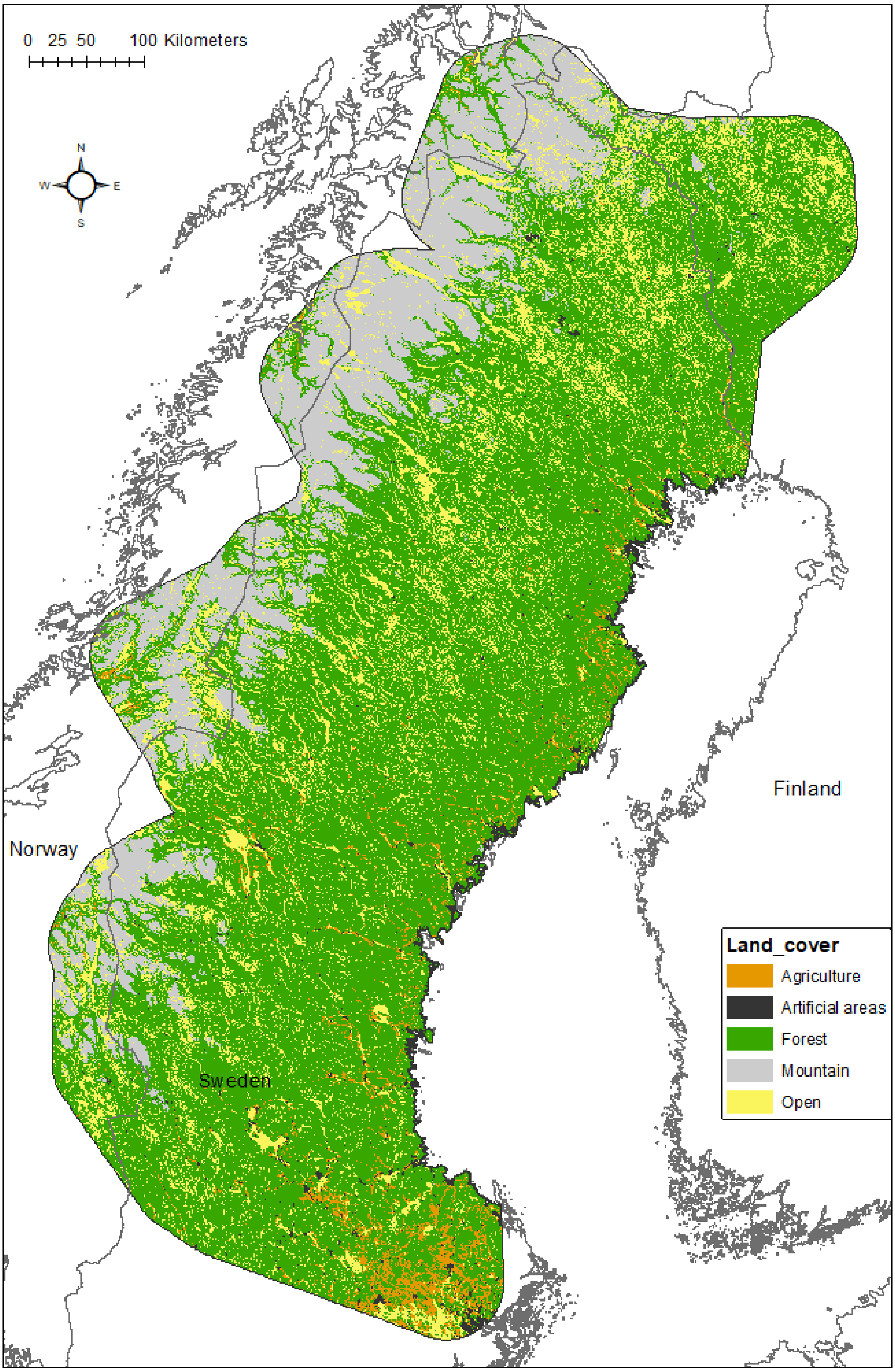
Name	**Description**
Beardiff	MCP for each of the periods layed upon each other summarizing the value by each of them, 1, giving the maximum value 7 present all periods and minimum value 0 not present at all in the study period, see figure 10.
Kernel	All shot female bears in the period 1981-2019 and then used the tool Kernel Density in ARGIC leads to values shown by map, see figure 11.
Exp_linear	The estimated significant linear expansion rate and substitute values in each direction and the external belt, see figure 8.
Exp_MCP	The estimated linear expansion rate and value in the external belt, see figure 7.

Factors

Name	**Description**
Agriculture	The layer includes agricultural areas with the code 211, 222, 231, 242-243 in the source data CorineLandCover2018, see map in Appendix 10.
Artificial	The layer includes artifical areas with the code 111-112, 121-124, 131-133, 141-142 in the source data CorineLandCover2018, see map in Appendix 10.
Forest	The layer includes forest and transitional woodland/shrubs areas with the code 311-313 and 324 in the source data CorineLandCover2018, see map in Appendix 10.
Mountain	The layer includes mountain areas with the code 321-322, 332-333 and 335 in the source data CorineLandCover2018, see Appendix 10.
Open	The layer includes open areas on land surface including freshwater and a few marine areas in Norway with the code 331, 334, 411-412, 421, 423, 511, 512, 521-523 in the source data CorineLandCover2018.
Roadandrail	The layer includes density of roads and railways.
Rein_no	The layer includes the number of reindeer within each Sapmi village, reindeer district and Finnish reindeer units.
Human_density	The layer includes density of human inhabitants, see map in Appendix 11.
Naturepro5	The layer includes nature protected but not protected areas less than 5 km^2, see map in Appendix 12.
Calvspring	The layer includes spring pastures in Finland and areas where the does calve and spent their time the first period after, socalled calving areas, and where the oxen spend their time in the same periode in Norway and Sweden.
Percent_ca	The layer contains percent area of the layer Calvspring in each chosen unit, see map in Appendix 15.
Springrein	The layer includes the spring pastures in Finland and Norway and the areas used by the reindeer in spring and early summer in Sweden.
SpringF	The layer includes spring and early summer pastures in Sweden and spring pastures in Finland and Norway in the land cover Forest.

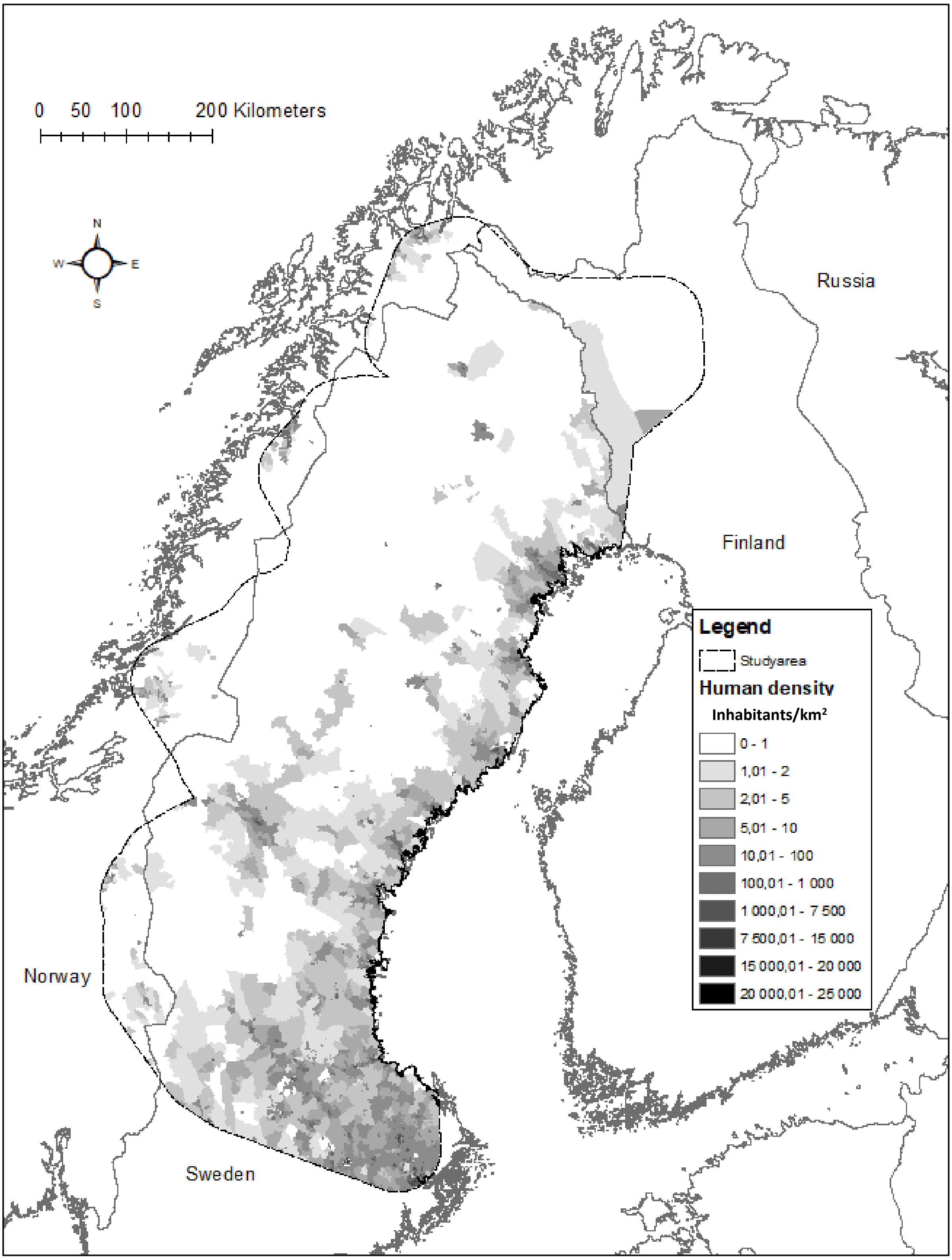
SpringOM	The layer includes spring and Swedish early summer pastures in the land cover Open and Mountain.
SpringM	The layer includes spring and early summer pastures in Sweden and spring pastures in Finland and Norway in the land cover Mountain.
Spring_no	The layer includes number of reindeer in the spring pastures in Finland and Norway and spring and early summer pastures in Sweden, see map in Appendix 16.
SpringMno	The layer includes the number of reindeer in spring and early summer pastures in Sweden and spring pastures in Finland and Norway in the land cover Mountain.
SpringOMno	The layer includes the number of reindeer in spring and early summer pastures in Sweden and spring pastures in Finland and Norway in the land cover Mountain.
Class_unsuit	The layer is a combined layer with values from 0-3. The layer is added by the layers of protected nature, spring pastures in the land cover groups Mountain and Open, and the land cover Mountain, see map in Appendix 17.
NatSprOMM	The layer is the layer called Class_unsuit multiplied with the number of reindeer in layer Rein_no, see map in Appendix 18.
Unsuitable	The layer includes the layer Class_unsuit but the values of 1-3 is given the value 1. The values of the layer are 0-1.

Appendix 10 Land cover in the study area



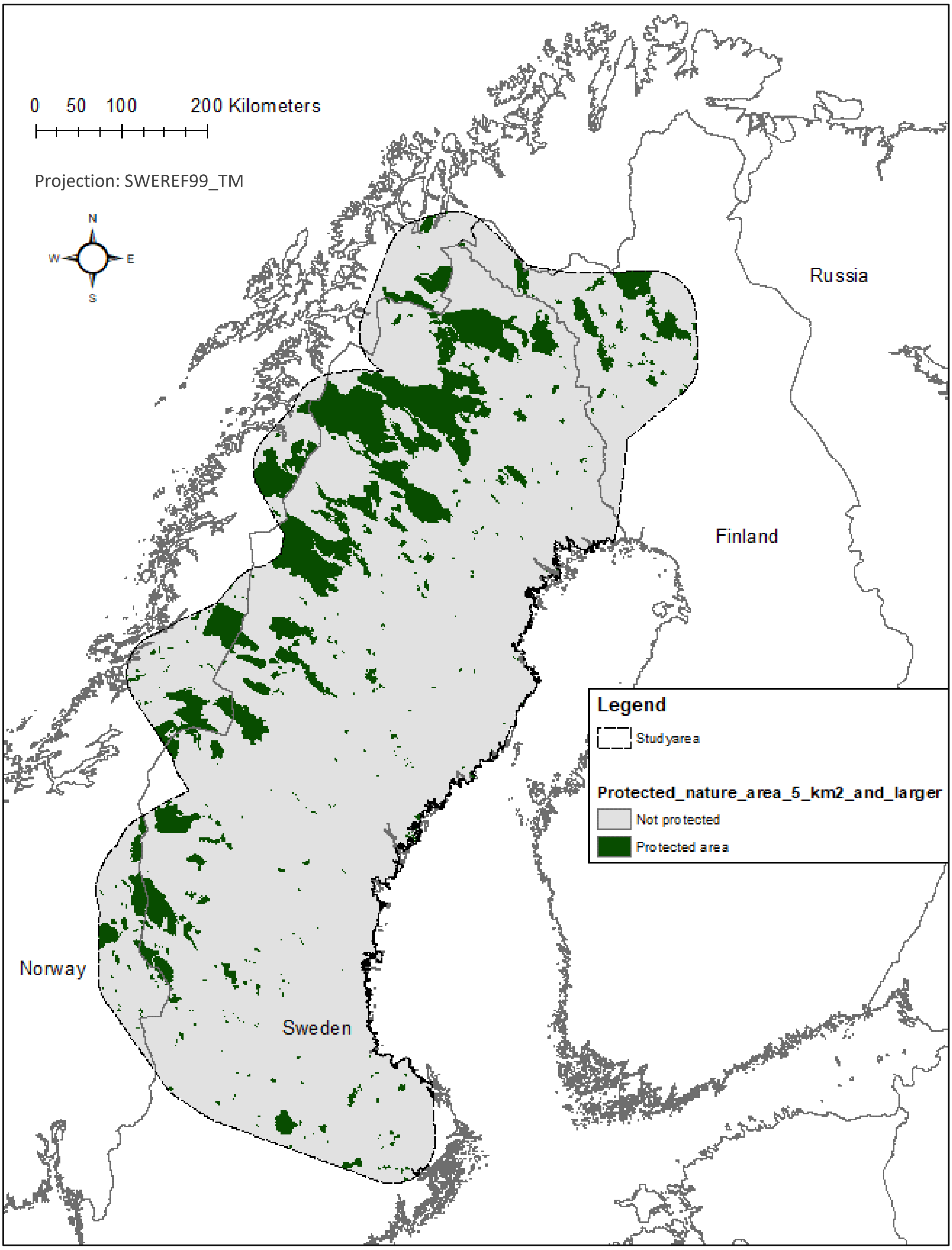
Forest is dominating in all parts of the study area except for in the West and the most South-Eastern parts. Both open areas, artificial areas and agriculture are in mosaic with forests or/and mountains.

Appendix 11 Human density per km^2



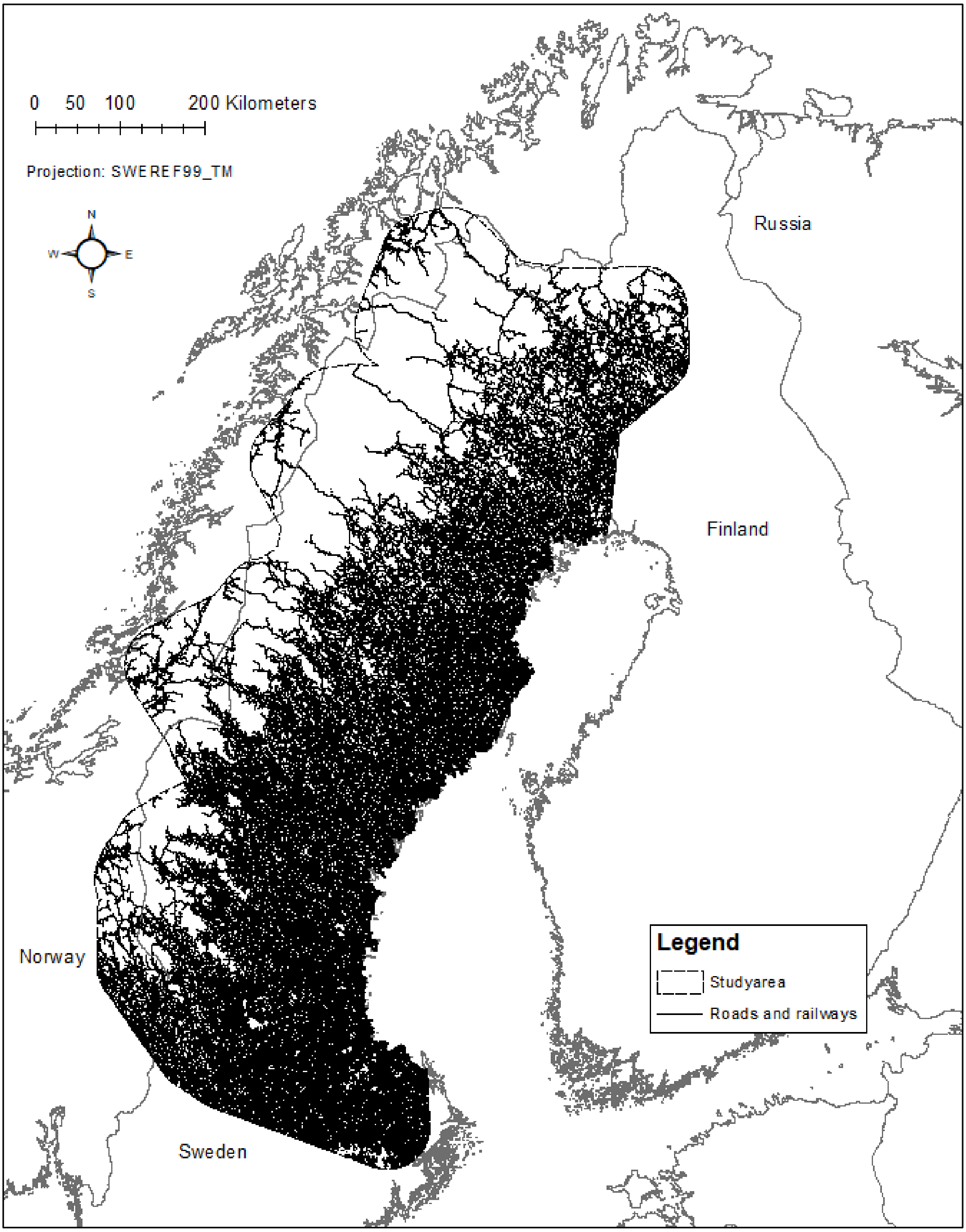
Number of inhabitants per km^2 within the study area on a scale from 0 – 25 000. Projection: SWEREF99 TM.

Appendix 12 Protected nature areas ≥ 5 km^2



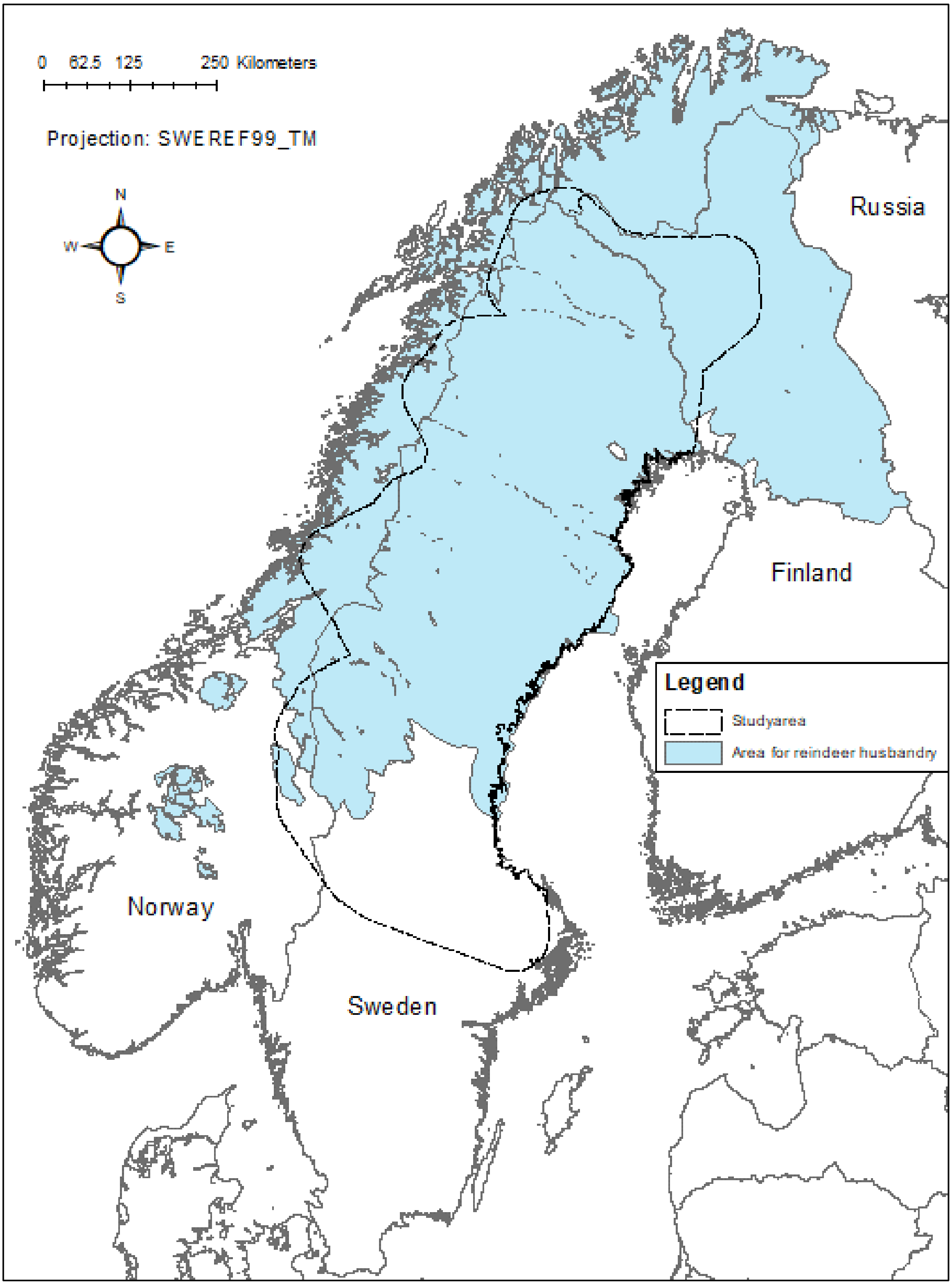
Areas with protected nature for conservation. Only areas > 5 km^2 are included.

Appendix 13 Road and railway net



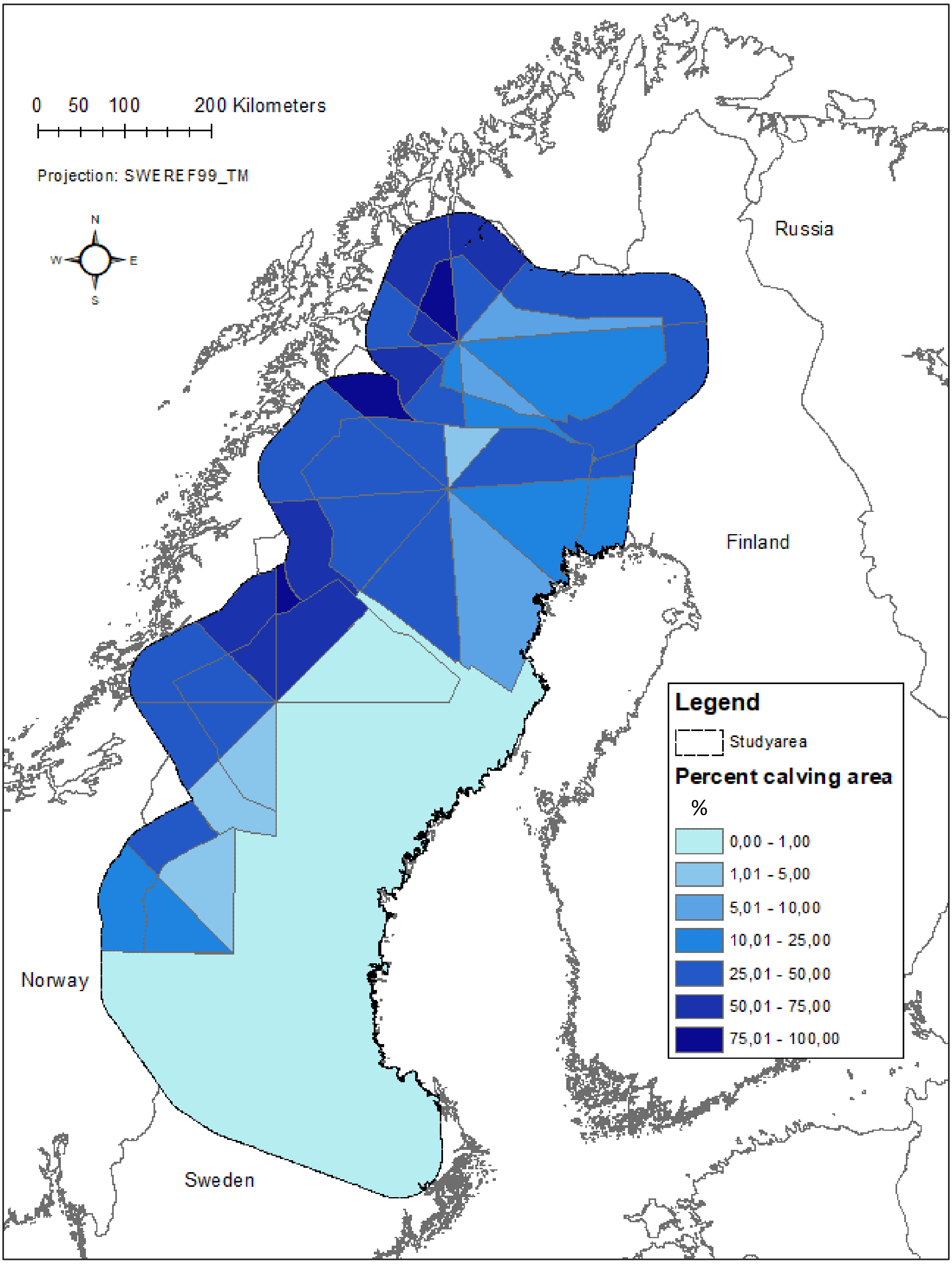
The roads and railways are shown in black lines.

Appendix 14 Area of reindeer husbandry in Norway, Sweden and Finland



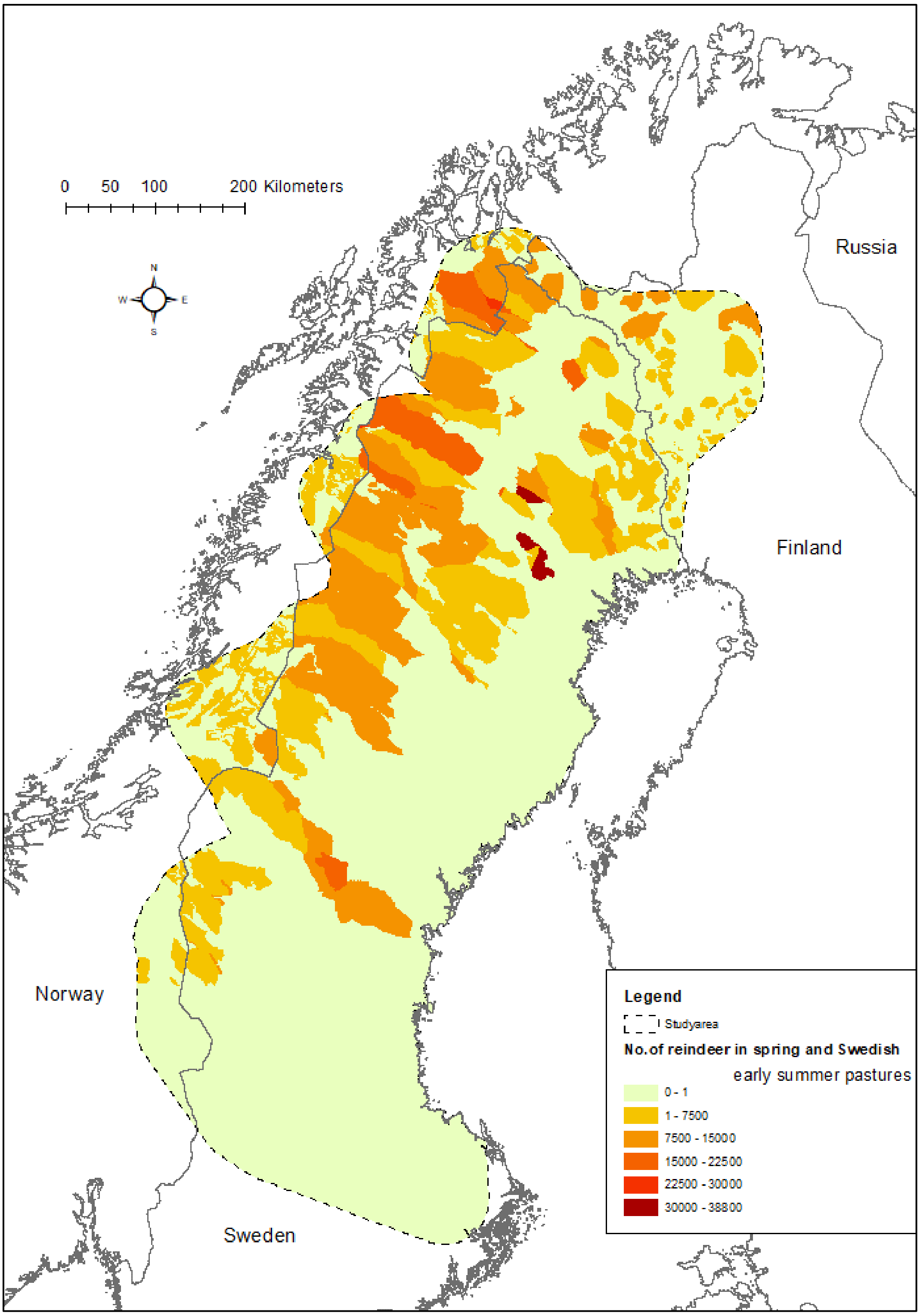
The total area for reindeer husbandry in Norway, Sweden and Finland. At the border between Norway and Sweden the map shows the Swedish area in Norway though it's overlapping in the convention areas.

Appendix 15 Percent of area where semi-domesticated reindeer graze in the calving period



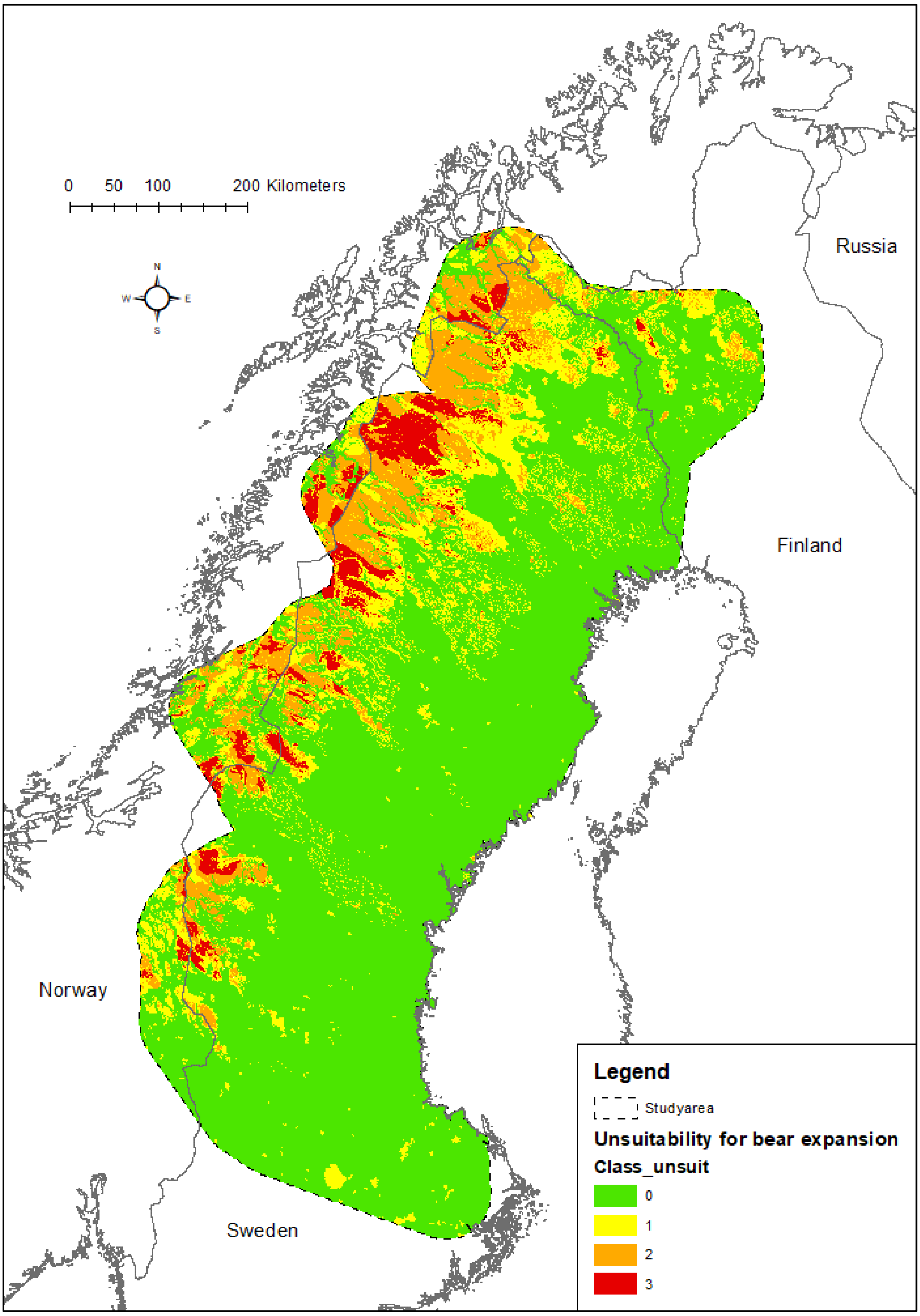
Percent of area where reindeer spend their time in the calving period within the study area. In Finland the spring pastures are used.

Appendix 16 Number of reindeer in the pastures of spring and early summer



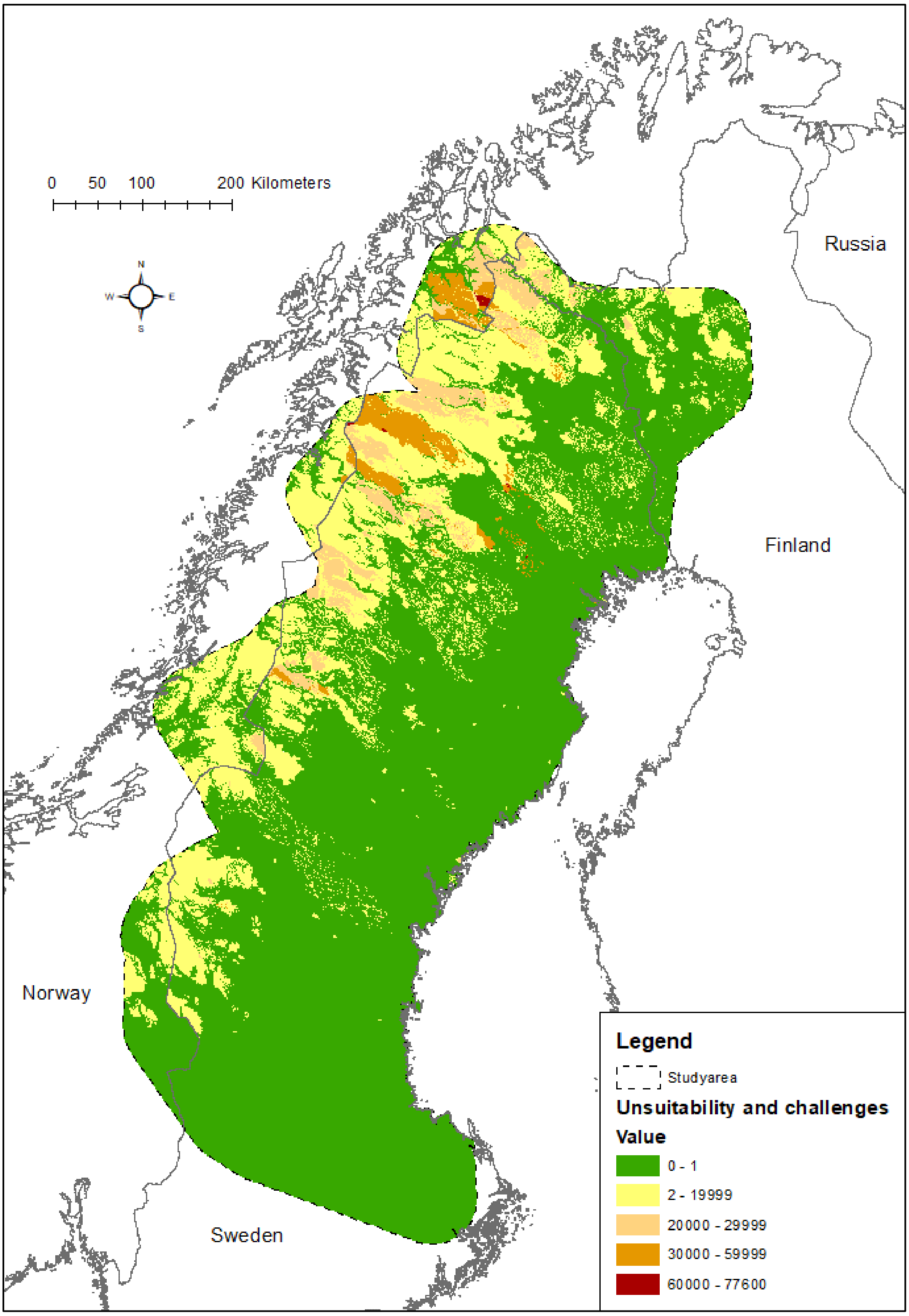
Number of reindeer in pastures of spring and in Sweden also of early summer in the study area. All the areas have high score on a Potential Conflict Index and the areas with high number of reindeer have a higher score than those with low number of reindeer. Number of reindeer in the spatial data within the study area varied from 0 – 38 800 though the number has varied within the study period in Norrbotten.

Appendix 17 Protected areas, mountains and spring and Swedish early summer pastures in open and mountainous areas



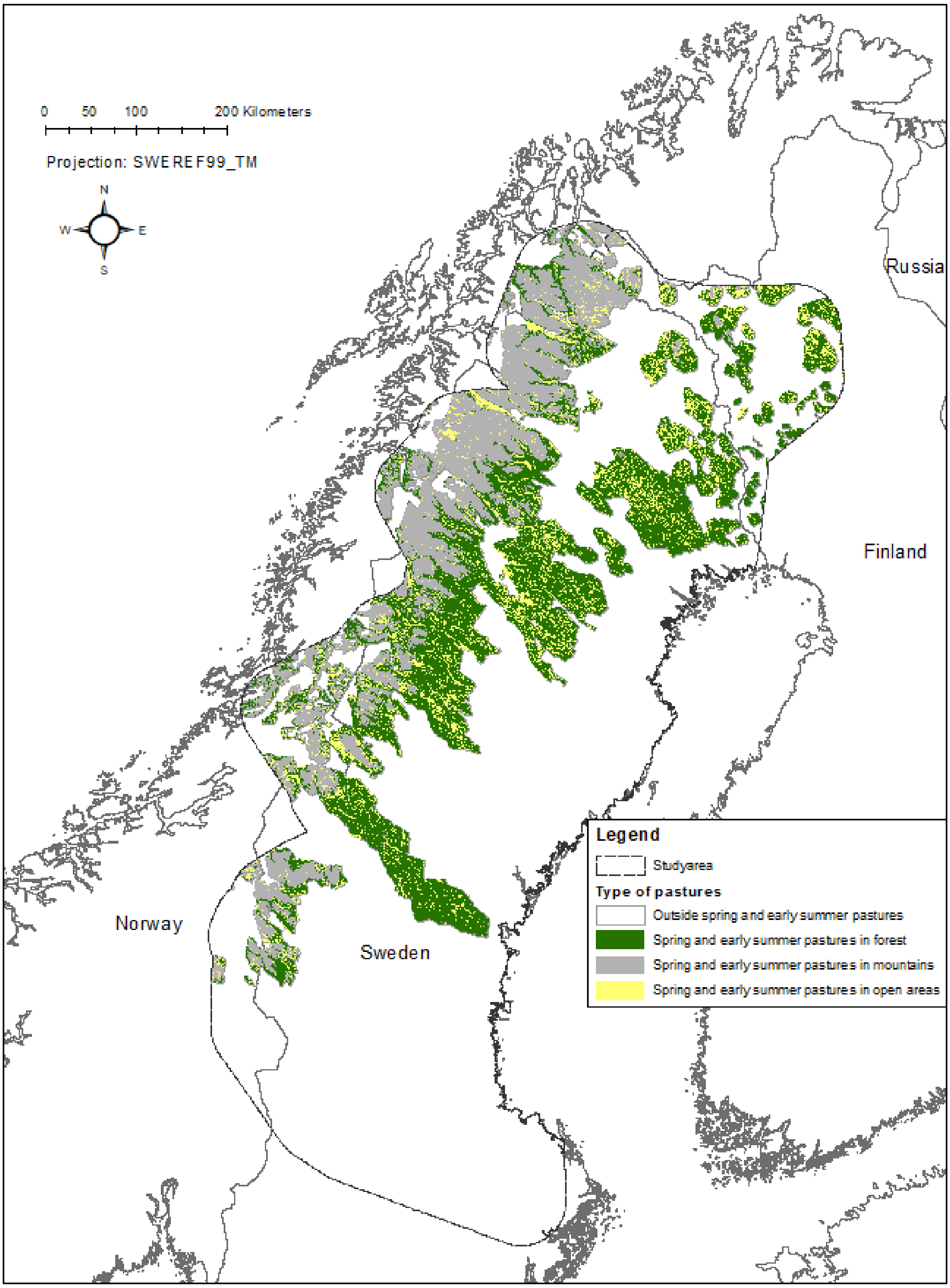
Categories of possible unsuitable habitats for the brown bears measured by adding the factors protected nature areas >5 km^2, spring and Swedish early summer pastures in open and mountaneous areas and the mountain areas.The higher value the potential less fit habitat for brown bears in the period 1981-2019. Projection: SWEREF99 TM.

Appendix 18 Protected areas, mountains, spring and Swedish early summer pastures in open and mountainous areas, and number of reindeer



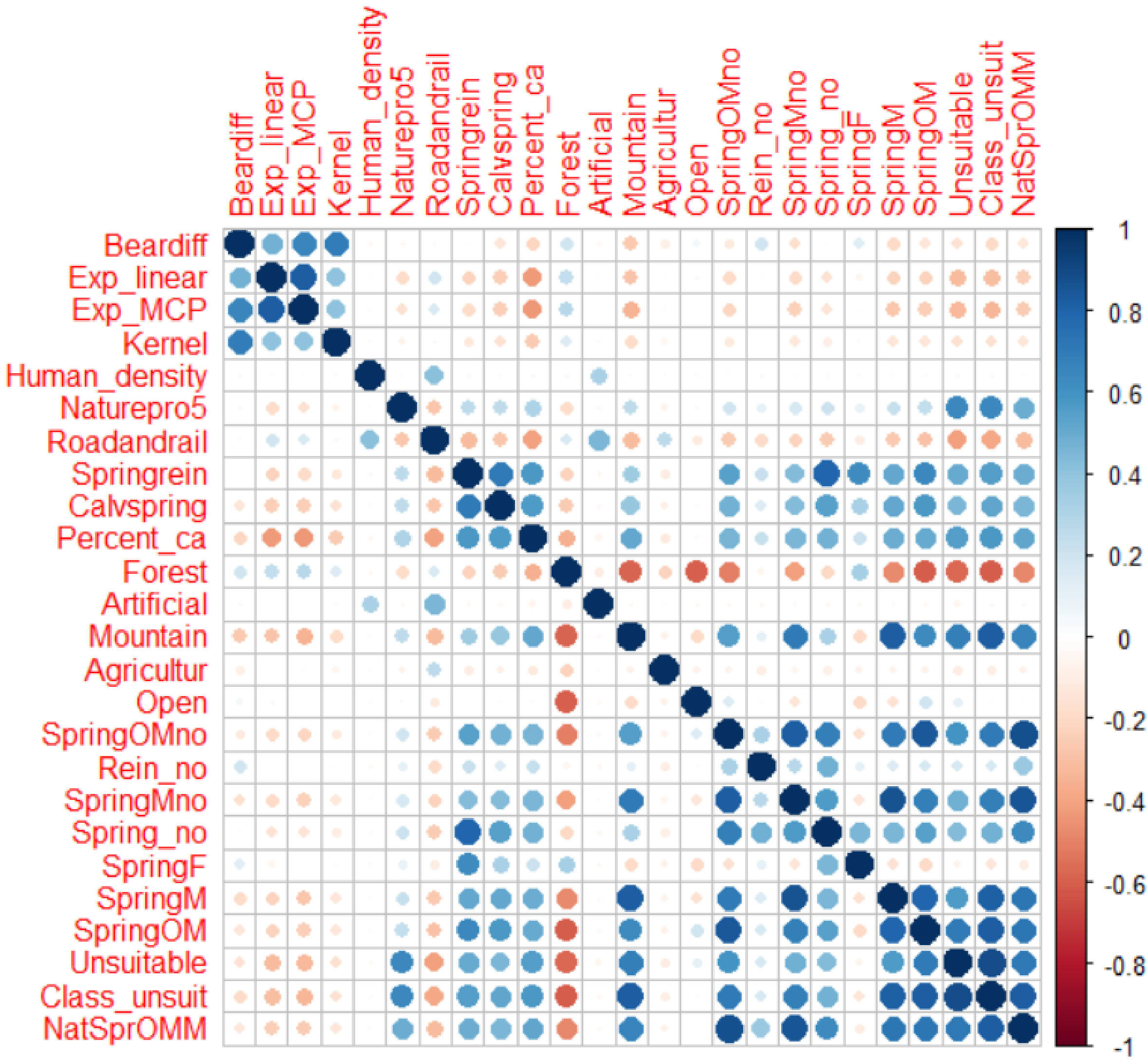
Another way of pointing at remote areas and areas with potential of conflicts, by adding the layers protected nature areas >5 km², spring pastures and Swedish early summer pastures in open and mountaineous areas and mountains, multiplied with number of reindeer.

Appendix 19 Spring and Swedish early summer pastures in forest, mountain and open areas



Spring pastures and Swedish early summer pastures in the land cover groups forest, mountain and open in the study area.

Appendix 20 Correlation plot



Appendix 21 Correlation table

Correlation table for the targets versus the factors and targets versus targets.

	Beardiff	Exp_linear	Exp_MCP	Kernel
Beardiff	1.00000000	0.475296509	0.651165656	0.696770593
Exp_linear	0.47529651	1.000000000	0.823355990	0.408664230
Exp_MCP	0.65116566	0.823355990	1.000000000	0.405991015
Kernel	0.69677059	0.408664230	0.405991015	1.000000000
Human_density	-0.03432612	-0.010909126	-0.017587161	-0.021446357
Naturepro5	-0.03633974	-0.180279261	-0.165951178	-0.068450691
Roadandrail	-0.02285378	0.191455431	0.169348875	0.036604248
Springrein	0.00102452	-0.228254759	-0.188814679	-0.122391949
Calvspring	-0.13300208	-0.240461037	-0.244104135	-0.155953232
Percent_ca	-0.21426635	-0.429148512	-0.435153005	-0.252782000
Forest	0.19684188	0.249843409	0.273914790	0.158260851
Artificial	-0.03317167	0.001096060	-0.003282714	-0.021422379
Mountain	-0.26447024	-0.287681634	-0.347862677	-0.180202891
Agricultur	-0.08965780	-0.001067897	-0.017942741	-0.055843938
Open	0.05375375	-0.038525868	-0.001727524	0.002757843
SpringOMno	-0.11135734	-0.193896492	-0.212828844	-0.118704490
Rein_no	0.19354078	0.005559078	0.007314017	-0.003026384
SpringMno	-0.17043479	-0.199378115	-0.236212497	-0.127867248
Spring_no	0.01575700	-0.158463241	-0.141955101	-0.096342064
SpringF	0.13831065	-0.057414949	0.012776682	-0.019395652
SpringM	-0.19965019	-0.227568018	-0.277697104	-0.139645940
SpringOM	-0.13448423	-0.229943806	-0.249368016	-0.133899719
Unsuitable	-0.15641523	-0.316870378	-0.325456267	-0.168347006
Class_unsuit	-0.19111702	-0.304183342	-0.333219783	-0.167394864
NatSprOMM	-0.12790991	-0.243944029	-0.257984471	-0.139129974

Appendix 22 Correlation table for factors

The correlation table of factors divided into five parts.

	Human_density	Naturepro5	Roadandrail	Springrein	Calvspring
Human_density	1.00000000	-0.01936533	0.4113136	-0.03400547	-0.02477988
Naturepro5	-0.01936533	1.00000000	-0.2753982	0.26469757	0.25287572
Roadandrail	0.41131362	-0.27539820	1.0000000	-0.31367027	-0.27599818
Springrein	-0.03400547	0.26469757	-0.3136703	1.00000000	0.70748205
Calvspring	-0.02477988	0.25287572	-0.2759982	0.70748205	1.00000000
Percent_ca	-0.04019455	0.30201314	-0.4031162	0.57203287	0.56051268
Forest	-0.03573069	-0.18609203	0.1627883	-0.22669436	-0.25043232
Artificial	0.32774542	-0.03313572	0.4566410	-0.04931621	-0.03832424
Mountain	-0.02210203	0.25731273	-0.3164322	0.35313669	0.38096912
Agricultur	0.01923658	-0.06576306	0.2690098	-0.10600350	-0.08007501
Open	-0.01181535	0.02110754	-0.1153366	0.00128155	-0.01011579
SpringOMno	-0.01934954	0.19259107	-0.2518456	0.54018392	0.47944383
Rein_no	-0.03645296	0.10787225	-0.1924590	0.22264866	0.14810468
SpringMno	-0.01601815	0.17543108	-0.2278553	0.43938630	0.43452984
Spring_no	-0.02715099	0.21373592	-0.2567433	0.79086225	0.54792812
SpringF	-0.02028561	0.09152804	-0.1072017	0.62077020	0.32177115
SpringM	-0.01848222	0.23075577	-0.2634476	0.51068902	0.51251717
SpringOM	-0.02272213	0.24362315	-0.2923581	0.64094472	0.57168338
Unsuitable	-0.03076982	0.64291612	-0.4131632	0.50785170	0.45010134
Class_unsuit	-0.02793746	0.64007539	-0.3844754	0.55184345	0.52812876
NatSprOMM	-0.02303638	0.49608545	-0.3159019	0.49033913	0.45788449

	Percent_ca	Forest	Artificial	Mountain	Agricultur
Human_density	-0.04019455	-0.03573069	0.32774542	-0.02210203	0.01923658
Naturepro5	0.30201314	-0.18609203	-0.03313572	0.25731273	-0.06576306
Roadandrail	-0.40311621	0.16278834	0.45664103	-0.31643222	0.26900982
Springrein	0.57203287	-0.22669436	-0.04931621	0.35313669	-0.10600350
Calvspring	0.56051268	-0.25043232	-0.03832424	0.38096912	-0.08007501
Percent_ca	1.00000000	-0.35845921	-0.05295616	0.51547197	-0.11688067
Forest	-0.35845921	1.00000000	-0.10814258	-0.58446427	-0.22421433
Artificial	-0.05295616	-0.10814258	1.00000000	-0.03586140	-0.01335559
Mountain	0.51547197	-0.58446427	-0.03586140	1.00000000	-0.07432593
Agricultur	-0.11688067	-0.22421433	-0.01335559	-0.07432593	1.00000000
Open	0.01807821	-0.59091995	-0.03606418	-0.19360228	-0.07506149
SpringOMno	0.46777033	-0.50765460	-0.03115659	0.55898120	-0.06457480
Rein_no	0.23017817	-0.05773156	-0.04290939	0.11062147	-0.09797321
SpringMno	0.45866381	-0.41267639	-0.02534281	0.70668774	-0.05252523
Spring_no	0.47563394	-0.20645966	-0.04028519	0.32328498	-0.08376034
SpringF	0.21365980	0.33067906	-0.03580463	-0.19250638	-0.07416536
SpringM	0.49036051	-0.47990339	-0.02945539	0.82136759	-0.06104891
SpringOM	0.50817752	-0.60263955	-0.03696825	0.63344556	-0.07661997
Unsuitable	0.55228571	-0.57127829	-0.05189440	0.68636481	-0.10529595
Class_unsuit	0.57922782	-0.60312991	-0.04609220	0.82866758	-0.09431073
NatSprOMM	0.52274146	-0.48391732	-0.03701746	0.66976665	-0.07674531

	Open	SpringOMno	Rein_no	SpringMno	Spring_no
Human_density	-0.011815345	-0.01934954	-0.03645296	-0.01601815	-0.027150987
Naturepro5	0.021107543	0.19259107	0.10787225	0.17543108	0.213735919
Roadandrail	-0.115336588	-0.25184559	-0.19245899	-0.22785526	-0.256743254
Springrein	0.001281550	0.54018392	0.22264866	0.43938630	0.790862246
Calvspring	-0.010115787	0.47944383	0.14810468	0.43452984	0.547928120
Percent_ca	0.018078210	0.46777033	0.23017817	0.45866381	0.475633940
Forest	-0.590919946	-0.50765460	-0.05773156	-0.41267639	-0.206459658
Artificial	-0.036064181	-0.03115659	-0.04290939	-0.02534281	-0.040285191
Mountain	-0.193602277	0.55898120	0.11062147	0.70668774	0.323284976
Agricultur	-0.075061492	-0.06457480	-0.09797321	-0.05252523	-0.083760341
Open	1.000000000	0.14041734	0.01919904	-0.13500493	-0.005844225
SpringOMno	0.140417338	1.00000000	0.32870420	0.82663145	0.683848590
Rein_no	0.019199039	0.32870420	1.00000000	0.27578681	0.480271594
SpringMno	-0.135004925	0.82663145	0.27578681	1.00000000	0.566608648
Spring_no	-0.005844225	0.68384859	0.48027159	0.56660865	1.000000000
SpringF	-0.195545368	-0.16691358	0.10943592	-0.13544106	0.455510518
SpringM	-0.158748107	0.70048128	0.15491483	0.86037938	0.454626102
SpringOM	0.194522861	0.84279330	0.17129642	0.68552918	0.542102175
Unsuitable	0.117063236	0.59632795	0.17000779	0.48505283	0.432194184
Class_unsuit	0.010984062	0.70201798	0.17014319	0.68923961	0.473280900
NatSprOMM	0.006223844	0.87106206	0.37339396	0.85260445	0.638159489

	SpringF	SpringM	SpringOM	Unsuitable	Class_unsuit
Human_density	-0.02028561	-0.01848222	-0.02272213	-0.03076982	-0.02793746
Naturepro5	0.09152804	0.23075577	0.24362315	0.64291612	0.64007539
Roadandrail	-0.10720168	-0.26344759	-0.29235809	-0.41316315	-0.38447545
Springrein	0.62077020	0.51068902	0.64094472	0.50785170	0.55184345
Calvspring	0.32177115	0.51251717	0.57168338	0.45010134	0.52812876
Percent_ca	0.21365980	0.49036051	0.50817752	0.55228571	0.57922782
Forest	0.33067906	-0.47990339	-0.60263955	-0.57127829	-0.60312991
Artificial	-0.03580463	-0.02945539	-0.03696825	-0.05189440	-0.04609220
Mountain	-0.19250638	0.82136759	0.63344556	0.68636481	0.82866758
Agricultur	-0.07416536	-0.06104891	-0.07661997	-0.10529595	-0.09431073
Open	-0.19554537	-0.15874811	0.19452286	0.11706324	0.01098406
SpringOMno	-0.16691358	0.70048128	0.84279330	0.59632795	0.70201798
Rein_no	0.10943592	0.15491483	0.17129642	0.17000779	0.17014319
SpringMno	-0.13544106	0.86037938	0.68552918	0.48505283	0.68923961
Spring_no	0.45551052	0.45462610	0.54210217	0.43219418	0.47328090
SpringF	1.00000000	-0.15775749	-0.19842859	-0.06964874	-0.13466659
SpringM	-0.15775749	1.00000000	0.79677546	0.56375268	0.81231324
SpringOM	-0.19842859	0.79677546	1.00000000	0.70754996	0.82622543
Unsuitable	-0.06964874	0.56375268	0.70754996	1.00000000	0.88583884
Class_unsuit	-0.13466659	0.81231324	0.82622543	0.88583884	1.00000000
NatSprOMM	-0.10596361	0.72190411	0.72083714	0.71256472	0.82305523

	NatSprOMM
Human_density	-0.023036384
Naturepro5	0.496085453
Roadandrail	-0.315901866
Springrein	0.490339129
Calvspring	0.457884486
Percent_ca	0.522741456
Forest	-0.483917323
Artificial	-0.037017457
Mountain	0.669766655
Agricultur	-0.076745309
Open	0.006223844
SpringOMno	0.871062060
Rein_no	0.373393958
SpringMno	0.852604454
Spring_no	0.638159489
SpringF	-0.105963608
SpringM	0.721904108
SpringOM	0.720837145
Unsuitable	0.712564720
Class_unsuit	0.823055233
NatSprOMM	1.000000000

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