Towards the Limits – Climate Change Aspects of Life and Health in Northern Sweden
Studies of tularemia and regional experiences of changes in the environment

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Till Örjan, Emric och Adele.
Det är roligt nästan jämt.

“Knowledge is a sphere with its surface towards the unknown”
(Blaise Pascal 1623-1662)
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Abstract

Background

Indigenous peoples with traditional lifestyles worldwide are considered particularly vulnerable to climate change effects. Large climate change impacts on the spread of infectious vector-borne diseases are expected as a health outcome. The most rapid climate changes are occurring in the Arctic regions, and as a part of this region northernmost Sweden might experience early effects. In this thesis, climate change effects on the lives of Sami reindeer herders are described and 30 years of weather changes are quantified. Epidemiology of the climate sensitive human infection tularemia is assessed, baseline serologic prevalence of tularemia is investigated and the disease burden is quantified across inhabitants in the region.

Methods

Perceptions and experiences of climate change effects among the indigenous Sami reindeer herders of northern Sweden were investigated through qualitative analyses of fourteen interviews. The results were then combined with instrumental weather data from ten meteorological stations in a mixed-methods design to further illustrate climate change effects in this region. In two following studies, tularemia ecology and epidemiology were investigated. A total of 4,792 reported cases of tularemia between 1984 and 2012 were analysed and correlated to ecological regions and presence of inland water using geographical mapping. The status of tularemia in the Swedish Arctic region was further investigated through risk factor analyses of a 2012 regional outbreak and a cross-sectional serological survey to estimate the burden of disease including unreported cases.

Results

The reindeer herders described how the winters of northern Sweden have changed since the 1970s – warmer winters with shorter snow season and cold periods, and earlier spring. The adverse effects on the reindeer herders through the obstruction of their work, the stress induced and the threat to their lifestyle was demonstrated, forcing the reindeer herders towards the limit of resilience. Weather data supported the observations of winter changes; some stations displayed a more than two full months shorter snow cover season and winter temperatures increased significantly, most pronounced in the lowest temperatures.

During the same time period a near tenfold increase in national incidence of tularemia was observed in Sweden (from 0.26 to 2.47/100,000 p<0.001) with a clear overrepresentation of cases in the north versus the south (4.52 vs. 0.56/100,000 p<0.001). The incidence was positively correlated with the presence of inland water (p<0.001) and higher than expected in the alpine and boreal ecologic regions (p<0.001).
In the outbreak investigation a dose-response relationship to water was identified; distance from residence to water – less than 100 m, mOR 2.86 (95% CI 1.79–4.57) and 100 to 500 m, mOR 1.63 (95% CI 1.08–2.46). The prevalence of tularemia antibodies in the two northernmost counties was 2.9% corresponding to a 16 times higher number of cases than reported indicating that the reported numbers represent only a minute fraction of the true tularemia.

Conclusions

The extensive winter changes pose a threat to reindeer herding in this region. Tularemia is increasing in Sweden, it has a strong correlation to water and northern ecoregions, and unreported tularemia cases are quite common.
Klimatförändringar är ett omfattande och komplicerat forskningsfält där ett allt större intresse ägnas åt konsekvenserna av den globala uppvärmningen.urfolk med traditionell livsstil, i synnerhet arktiska urfolk, har identifierats som extra särbara för dessa konsekvenser baserat på deras beroende av naturen för sin utkomst. Infektionssjukdomar av olika slag bedöms också öka på grund av klimatförändringarna; särskilt vektorburna zoonoser, det vill säga sjukdomar som sprids via exempelvis insekter och kan smitta både människor och djur. Förändringarna går snabbare i arktiska regioner än någon annanstans på planeten och norra Sveriges position på jordklotet medför att omfattande förändringar kan förväntas komma tidigt även här.

I detta avhandlingsarbete undersöks om klimatförändringar i norra Sverige har skett, om de varit märkbara för befolkningen och om klimatförändringar utgör ett problem för vårt svenska urfolk med traditionell livsstil, renskötande samer. En sjukdom svenska myndigheter har bedömt som klimatkänslig är tularemi, eller harpest. Den orsakas av en mycket smittsam bakterie som utlöser lokala utbrott och ger influensaliknande symtom med hög feber och svullna lymfkörtlar under flera veckor. Sverige har en av de högsta förekomsterna av sjukdomen i världen. Harpest har historiskt förekommit framförallt i Norrland och därför undersöks i avhandlingen också utveckling och utbredning av harpest i Sverige under trettio års tid, vilket är den period som motsvarar tiden när klimatförändringarnas effekter börjat bli allt mer påtagliga.

Den första studien var en kvalitativ studie av intervjuer med fjorton renskötande samer om deras erfarenheter av klimatförändringar. De beskriver hur de noterat allt varmare vintrar, kortare snösäsonger, långa våta höstrar, tidiga vårar och snabbt svängande temperaturer. Förändringarna har medfört stora konsekvenser för deras liv och leverne, konsekvenser vars hantering försvårats genom helt andra historiska och aktuella omständigheter som samtidigt påverkat renskötseln. Exempelvis ökande konkurrens från andra näringer, ständig krympande betesmarker, rovdjurspolitik och dålig ekonomi.

I skenet av klimatförändringarna framträdde bilden av en näring och en livsstil på gränsen till vad den klarar av och flera intvjuupersoner uttryckte oro och sorg över traditionell renskötsels framtid, de frågade sig om de var den sista generationen renskötare.

Några av de omfattande förändringar som beskrevs av renskötarna undersökt vidare med en uppföljande kvantitativ analys av väderdata från elva stationer i svenska Sápmi – Sameland. Trettio års information om temperatur och snömängd analyserades med statistiska analyser. Att kombinera två diametralt olika metoder på detta sätt kallas blandad metodologi (mixed-methods) och används för att ge en bredare, fördjupad och mer överförbar bild av en företeelse. Analyserna visade att temperaturen ökat signifikant i hela regionen och att det är de allra lägsta

Undersökningen av harpest gjordes med hjälp av tre olika kvantitativa metoder:

- En undersökning av alla harpestfall som rapporterats till Folkhälsomyndigheten mellan 1984 och 2012
- En utbrottsutredning som analyserade riskfaktorer för harpest.
- En studie där tecken på genomgången harpest i form av förekomst av antikroppar i blodet hos friska individer undersöktes.

De samlade undersökningarna visade att det under perioden anmälts 4 792 fall av harpest smittade i Sverige. Sjukdomen drabbede personer mellan ett och nittiofem år men var vanligast i åldrarna femtiofem till femtionio år. En tvåpucklig åldersfördelning sågs i båda patientmaterialen med en nedgång i antalet fall hos unga vuxna. Män hade högre risk att insjukna än kvinnor. Antalet insjuknade per invånare var åtta gånger högre i norra delen av Sverige jämfört med södra delen, däremot var ökningstakten nästan tio gånger så hög i södra delen. Mellan första och andra halvan av undersökningsperioden sågs en nära tiofaldig ökning av antalet fall per invånare. Denna ökning sammanfaller med perioden då klimatförändringar tydligt börjat märkas, vilket skulle kunna tyda på ett samband. Å andra sidan talar den mycket snabbare ökningen av harpest i södra Sverige jämfört med norra instinktivt
emot en klimatkoppling. Dessa två omständigheter tillsammans antyder att det finns mer än en faktor som påverkar förekomsten av harpest i Sverige, men dessa faktorer är okända.

Korrelationen mellan harpest och vatten visades på olika sätt i två av patientmaterialen. Harpest var vanligare i kommuner med mer ytvatten och att bo nära vatten liksom att tillbringa mycket tid vid vatten var två riskfaktorer för harpest. Sjukdomen var vanligare i regioner dominerade av barrskog än lövskog. När förekomsten av antikroppar i blodet undersöktes hos femtonhundra slumpvis utvalda personer från Norrbotten och Västerbotten sågs tecken på genomgången infektion hos tre procent. Översätts detta till fall så motsvarar det över niotusen personer med harpest vilket är sexton gånger fler än de som rapporterats i de båda länen.

## Dictionary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Adaptation</td>
<td>Adjustment</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td>Man-made</td>
</tr>
<tr>
<td>Anthropology</td>
<td>The study of aspects of humans within society</td>
</tr>
<tr>
<td>Armament</td>
<td>Militarization</td>
</tr>
<tr>
<td>Bimodal</td>
<td>A distribution with two different peaks</td>
</tr>
<tr>
<td>Bioterrorism</td>
<td>Weaponization of pathogens</td>
</tr>
<tr>
<td>Constructivism</td>
<td>Knowledge based on experience</td>
</tr>
<tr>
<td>Context</td>
<td>Situation</td>
</tr>
<tr>
<td>Denominator</td>
<td>A common characteristic</td>
</tr>
<tr>
<td>Dialectic</td>
<td>Art of arriving at the truth by the exchange of logical arguments</td>
</tr>
<tr>
<td>Discourse</td>
<td>The process of reasoning</td>
</tr>
<tr>
<td>Eco-region</td>
<td>Area defined by certain environmental conditions</td>
</tr>
<tr>
<td>Endemic</td>
<td>Prevalent in a particular region</td>
</tr>
<tr>
<td>Epidemiological transition</td>
<td>Changing patterns of mortality and population dynamics</td>
</tr>
<tr>
<td>Epistemology</td>
<td>How knowledge is produced</td>
</tr>
<tr>
<td>Frontier</td>
<td>Borderland</td>
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<tr>
<td>Incidence</td>
<td>Rate of occurrence</td>
</tr>
<tr>
<td>Incubation period</td>
<td>Time from pathogen exposure to symptom debut</td>
</tr>
<tr>
<td>Indigenous</td>
<td>Native to an area</td>
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<tr>
<td>Institutionalize</td>
<td>Systematize</td>
</tr>
<tr>
<td>Meta-inferences</td>
<td>Conclusions drawn from the combination of qualitative and quantitative results</td>
</tr>
<tr>
<td>Mitigation</td>
<td>Moderation</td>
</tr>
<tr>
<td>Mortality</td>
<td>Death rate</td>
</tr>
<tr>
<td>Perturbation</td>
<td>Disturbance of the regular</td>
</tr>
<tr>
<td>Positivistic</td>
<td>Fact based, excludes speculation</td>
</tr>
<tr>
<td>Prevalence</td>
<td>Part of population affected by a disease at a given time</td>
</tr>
<tr>
<td>Reservoir</td>
<td>Organism that can transmit a pathogen without being affected</td>
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<tr>
<td>Resilience</td>
<td>The ability of a system to cope with change</td>
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<tr>
<td>Term</td>
<td>Definition</td>
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<td>---------------------</td>
<td>---------------------------------------------------------------------------</td>
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<tr>
<td>Sami community</td>
<td>An economical and administrative union of reindeer herders</td>
</tr>
<tr>
<td>Sero-positive</td>
<td>An individual with certain antibodies in the serum</td>
</tr>
<tr>
<td>Sero-prevalence</td>
<td>The widespread presence of sero-positive individuals</td>
</tr>
<tr>
<td>Subsistence lifestyle</td>
<td>The very basic necessities of life</td>
</tr>
<tr>
<td>Traditional lifestyle</td>
<td>Subsistence lifestyle</td>
</tr>
<tr>
<td>Usufruct</td>
<td>Legal right to use something</td>
</tr>
<tr>
<td>Vector</td>
<td>A carrier of disease-causing microorganisms between hosts</td>
</tr>
<tr>
<td>Virulent</td>
<td>Infective</td>
</tr>
<tr>
<td>Zoonosis</td>
<td>Animal disease transmittable to humans</td>
</tr>
</tbody>
</table>
**Abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
</tr>
<tr>
<td>AR₅</td>
<td>IPCC Fifth Assessment Report</td>
</tr>
<tr>
<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
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<tr>
<td>TEK</td>
<td>Traditional Ecological Knowledge</td>
</tr>
<tr>
<td>TK</td>
<td>Traditional Knowledge</td>
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<tr>
<td>WGII</td>
<td>Working Group II</td>
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<tr>
<td>ACIA</td>
<td>Arctic Climate Impact Assessment</td>
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<tr>
<td>UN ILO</td>
<td>United Nations International Labour Organization</td>
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<tr>
<td>UNHRC</td>
<td>United Nations Human Rights Council</td>
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<tr>
<td>TBE</td>
<td>Tick Borne Encephalitis</td>
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<tr>
<td>SPP</td>
<td>Subspecies</td>
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<tr>
<td>ELISA</td>
<td>Enzyme-Linked ImmunoSorbent Assay</td>
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</table>
Original papers

This thesis is based on the following papers:

I


II

Furberg Maria, Hondula David, Saha Michael, Nilsson Maria. In the light of change: A mixed methods investigation of climate perceptions and the instrumental record in northern Sweden. (Submitted manuscript)

III


IV

Furberg Maria, Hjertqvist Marika, Liu Xija, Sellin Mats, Stenmark Stephan, Nystedt Anders, Eliasson Mats, Ahlm Clas, Johansson Anders. Tularemia in northernmost Sweden – sero-prevalence and a case-control study of risk factors (manuscript)
### Overview of the thesis

<table>
<thead>
<tr>
<th>Paper</th>
<th>Aim</th>
<th>Method</th>
<th>Material</th>
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</thead>
<tbody>
<tr>
<td>I</td>
<td>To explore climate change experiences and perceptions among reindeer herders in the Swedish indigenous Sami population.</td>
<td>Qualitative</td>
<td>Recorded in-depth interviews with 14 Sami reindeer herders about their perceptions and experiences of climate change were performed and analysed with qualitative content analyses.</td>
</tr>
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<td>II</td>
<td>To explore similarities and differences in human observations and instrumental weather data.</td>
<td>Mixed methods</td>
<td>Observations from Paper I were adopted to form hypotheses for a sequential quantitative analyses of instrumental weather data from 10 stations in northern Sweden during 1978–2007. Temperature distributions and variations, duration of cold spells and snow cover seasons were investigated. Meta-inferences were drawn from the combined results.</td>
</tr>
<tr>
<td>III</td>
<td>To describe the Swedish epidemic of tularemia and determine ecologic factors contributing to the spread and transmission of <em>Francisella tularensis</em>.</td>
<td>Quantitative</td>
<td>4,792 cases of tularemia reported 1984–2012 were analysed with descriptive epidemiology. 3,524 cases were assigned geographical coordinates and further analysed for spacial distribution, correlation to ecoregions and inland water.</td>
</tr>
<tr>
<td>IV</td>
<td>To establish tularemia sero-prevalence rates in northernmost Sweden, estimate the hidden burden of disease and investigate risk factors for tularemia contraction in this area.</td>
<td>Quantitative</td>
<td>11 years of reported tularemia cases were compared to sero-epidemiological data from 1501 random population samples in the same area. Risk factors were analysed through the investigation of a 2012 tularemia outbreak in northern Sweden.</td>
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<tr>
<td>Results</td>
<td>My work</td>
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<td>and add new challenges. Climate change was yet another stressor on an</td>
<td>analyses and wrote the paper with assistance of the coauthors.</td>
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<td>already stressed vulnerable traditional lifestyle, forcing the reindeer</td>
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<td>herders towards the limit of resilience.</td>
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<td>Increase in mainly winter temperatures and shorter cold spells. Two</td>
<td>Performed the qualitative work, participated in methodological</td>
<td>Furberg Maria, Hondula David, Saha Michael, Nilsson Maria. In the light of change: A mixed methods investigation of climate perceptions and the instrumental record in northern Sweden (Submitted)</td>
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<td>months shorter snow cover season at some stations. Observed changes</td>
<td>considerations and design of the sequential quantitative analyses that</td>
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<td>and instrumental data mainly converged. Increased temperature</td>
<td>were done by others. Wrote the paper with assistance of the coauthors.</td>
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<td>instability could not be seen in the weather data.</td>
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<td>common in men and the age distribution was bimodal with highest</td>
<td>geocoding. The geographical modeling and analyses were done by others.</td>
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<td>incidence in 55-59 year olds. From the first to the second half of the</td>
<td>Active in writing together with the coauthors.</td>
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<td>study period mean incidence increased tenfold. Eight times higher</td>
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<td>incidence in north vs. south of Sweden, though nearly ten times higher</td>
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<td>rate of increase in the south. A positive correlation to inland water</td>
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<td>was found, as well as to boreal and alpine ecoregions.</td>
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<tr>
<td>Seropositivity was found in 2.93% of the samples, corresponding to</td>
<td>Cleaned the outbreak investigation risk factor data. Performed</td>
<td>Furberg Maria, Hjertqvist Marika, Liu Xija, Sellin Mats, Stenmark Stephan, Nystedt Anders, Eliasson Mats, Johansson Anders. Tularemia in northernmost Sweden – sero-prevalence and a case-control study of risk factors (Manuscript)</td>
<td></td>
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<tr>
<td>9036 cases, a ratio of 16:1 compared to the 558 reported cases. Proximity</td>
<td>descriptive and statistical analyses. Performed parts of the ELISA test</td>
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<tr>
<td>to water and mosquito bites were identified as a risk factor for</td>
<td>and analysed the results. Wrote the paper, with coauthors assistance.</td>
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<td>tularemia and displayed a dose-response relationship.</td>
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Preface and methodological considerations

The first question I asked myself when beginning my PhD studies on the topic of climate change and health was “Is there a noticeable ongoing climate change in Northern Sweden where I grew up?” I could not find an answer in the literature back then in 2009. Answering this question provided the opportunity for me to get acquainted with qualitative research methods, a methodology that appeared completely incomprehensible to me being heavily trained in quantitative methods through medical school as I was.

Initiating my research training with qualitative methodology had a profound influence on me and my subsequent development as a researcher. I am a person who thinks in images and pictures and qualitative studies provide rich images, deep and informative illustrations of the subject under study that I could relate to. To fathom the process involved in qualitative analyses and how the results are grounded in the data made me abandon my previous understanding of quantitative research as the only evidence-based methodology. Today I weigh both methodologies equal; they simply answer different questions. Doing qualitative research is a bit like reading pure literature; you get to lead many lives at the same time. Learning qualitative methods really changed my view of science, it broadened my scope and opened my mind to all the various kinds of knowledge that’s out there.

The purposive sampling of qualitative methods then led me to the reindeer herding Sami who also happen to represent the Swedish indigenous people. The versatility of the climate change research field provided the opportunity to focus on some aspects that are related to both of my clinical professions, Family Medicine and Infectious Diseases. Mostly it is people that interest me, people and the different factors that influence and affect their lives. Climate change is affecting all of our lives and Arctic regions of the north are affected more rapidly than the rest of the globe. Infectious diseases are pinpointed as particularly important as a potential climate change health outcome and indigenous peoples with traditional lifestyles are identified globally as particularly sensitive to climate change impacts. So I could have studied climate change health effects by looking at an infection already labeled climate sensitive by the authorities, tularemia, and how this disease is distributed among indigenous and non-indigenous Swedes. Comparing notifiable disease data on Sami with other groups is, however impossible in Sweden; we do not have the ethnic denominator. Investigating climate change health impacts on the Swedish traditional indigenous population required a different methodological approach, asking different kinds of questions and led me to a more holistic view of climate change experiences and impacts.

I still wanted to study the presumed climate sensitive infection tularemia, an intriguing and fascinating disease that is clinically relevant to me in my daily work as a physician. Investigating the Swedish epidemiology of tularemia enabled insights into factors affecting the prevalence of this disease and the rate and direction of the increase perceived by doctors in the last decades. The picture is still not rich enough
to satisfy my holistic desires but I have been able to add a few more factors and
details to that image. Baseline data on disease prevalence is necessary in order to
study future climate change effects, and since there were no such data establishing
baseline sero-prevalence rates seemed like a good starting point.

Hence a combination of methodologies was used in my thesis to cover the different
topics and thereby provided me with a very comprehensive and inclusive research
education for which I am so very grateful.

Maria Furberg
Background

The earth is warming, given no alternative, in the hands of man. This thesis is about change; changes in people’s lives, changes in disease epidemiology and changes in climate and weather. Scientists need to monitor climate changes closely to enable adequate mitigation and adaptation measures in response to these changes. However, climate change research is an extremely extensive and far-reaching field that spans multiple topics and sciences. It is difficult to study, being an ongoing, long-term process makes it complicated to discern from other factors influencing the phenomena of interest. Researchers easily end up studying weather effects or weather variability effects instead of climate change effects. One way of facing these challenges is to investigate changes over longer time periods, i.e. disease development over decades, comparing old records with more recent ones, and establishing baseline knowledge to facilitate future climate change research and continuous monitoring.

Climate change science

The first IPCC (Intergovernmental Panel on Climate Change) Assessment Report was published already in 1990 [1]. Since then four additional reports assessing the current state of climate research have been published. IPCC is an international organization established in 1988 and membership today is held by all independent sovereign states in the world. Together the members provide thousands of experts and scientists that contribute on a voluntary basis as authors, reviewers and contributors to meet the challenges faced by climate change. According to their website the objective of IPCC is “to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts”. The website also states “Review is an essential part of the IPCC process, to ensure an objective and complete assessment of current information. IPCC aims to reflect a range of views and expertise”[2].

The Anthropocene

The term Anthropocene is suggested for the epoch covering the time when human activities began to significantly affect the ecosystems and geology of the globe. Although still under debate and formally not yet approved as a subdivision of geological time or as a cultural term like Neolithic, the term Anthropocene is frequently used and offers a way of describing the current time in a way that delineate the underlying cause of the ongoing changes and the central role of mankind in geology and ecology [3].

As of today there is an international scientific consensus that climate change is ongoing and that the anthropogenic or human–induced forces, consisting of increased levels of greenhouse gas emissions that cause radiative forcing, constitute an important driver of this change [4]. The most important greenhouse gas is carbon dioxide (CO₂), and the CO₂ increase primarily stems from the use of fossil fuels and to some extent also from changed land use. Fossil fuels originate from partially broken-down animal and plant remains that over millions of years have been transformed underground
into coal, gas and oil. When burning fossil fuels all the CO₂ bound in these organisms is released as a net contribution into the atmosphere. According to the IPCC AR5 (IPCC Fifth Assessment Report) there has been a 40% increase in atmospheric concentrations of CO₂ since pre-industrial times around 1850 (Figure 1)[5].

![Global anthropogenic CO₂ emissions](image)

**Figure 1: Global anthropogenic CO₂ emissions from forestry and other land use as well as from burning of fossil fuel, cement production and flaring. Cumulative emissions of CO₂ from these sources and their uncertainties are shown as bars and whiskers, respectively, on the right side and global emissions on the left side. (Republished from Climate Change 2014 Synthesis Report Summary for Policymakers. p.11) [5]**

The Arctic is warming at an even higher rate than the rest of the world, and early impacts of climate change effects are already seen in this region and are expected to increase [6, 7]. In the climate change context, the Arctic can be regarded as the “canary in the coal mine” and act as an early indicator of changes that can be expected on a global scale in the future. Overland and colleagues report a 2.9°C increase in Arctic annual surface air temperature anomaly since the beginning of the 20th century. The Arctic is warming at twice the rate of lower latitudes and shows no trend of the slowing increase in global temperature that is noted for the rest of the world during the last decade (Figure 2) [8].

Arctic warming is due to a phenomenon called “Arctic amplification” caused by the decreased reflective capacity of snow and ice melting into water and the subsequent increased absorption of heat by dark ground, also referred to as surface albedo feedback. In the Arctic, snow and ice reflect most of the incoming solar radiation while the ocean absorbs the majority [9]. Another contributing factor is warmer air being trapped underneath the clouds formed by water evaporating from the melting snow and ice. The colder atmosphere gets rid of excess heat from global warming less efficiently than other parts of the globe and warms faster [10].

The Antarctic on the other hand, displays a completely different development. In contrast to the Arctic, the sea ice around Antarctica is growing and reached a record high in 2014. However, the upward trend in the Antarctic is only a third of the magnitude of the rapid loss of sea ice in the Arctic Ocean. Antarctica is a large icy landmass surrounded by sea ice, and the Arctic is a semi-enclosed ocean covered by a floating icecap surrounded by land. Antarctic sea ice is seasonal to a greater
extent than the Arctic one and it melts away completely in the summer when drifting into warmer waters further north. Arctic sea ice on the other hand, trapped by the surrounding land forcing the formation of thick ice ridges, remains in the cold Arctic ocean and ice formed during the previous winter can continue to grow the following autumn. A little less than half of the Arctic winter sea ice remains after the summer melt season. This makes Arctic sea ice much more vulnerable to increasing ocean temperatures [11].
Sweden as an Arctic country

Sweden is a member of the Arctic Council and has been since it was established in 1996. The Arctic Council is a high-level intergovernmental forum for international cooperation between subarctic states, mainly on the themes of research, sustainable development, cultural and environmental protection and indigenous cultures and languages. Permanent participant status is held by eight Arctic states – Norway, Finland, Denmark including Greenland, Sweden, Iceland, Canada, Russia and the United States. To secure active participation of the Arctic Indigenous peoples, permanent participant status (though without the voting right) is also assigned to a number of indigenous organization among which the Saami Council is one [12]. With a background in exploration, research and strategic conflict a discourse on an Arctic region started to take form during the second half of the 20th century, eventually leading up to the first Swedish Arctic strategy ever being launched in 2011 [13]. The Arctic Council was established in the post-cold war era with the ambition of reducing and neutralizing tension in an area that during the cold war had been a region of continuous USSR and NATO armament that had involved all the current member states in one way or another. The formation of the Arctic Council institutionalized the concept of an “Arctic region”, but there are major differences between the North American and the North European Arctic contexts. Neither Sweden, nor Finland, Iceland or Norway share the frontier conception of the Arctic common in the US, Canada, Russia and Denmark in terms of Greenland. The frontier conception depicts a place where culture meets nature and refers to pure environment, indigenous peoples and subsistence lifestyles that simply do not apply to the Nordic countries. This frontier conception in the Arctic discourse in also prevalent in many official documents, for example, in the Arctic Human Development Report 2004, a fact problematized by Keskitalo in her extensive research on the development of the Arctic as a region [12]. Even though the definition of Sweden as an Arctic country can be contested, the geographical position of Sweden on the globe might entail early and drastic changes in terms of climate change. Northern Sweden as an Arctic region was therefore one of the entry points in this research.

Climate change is occurring now at a speed the world probably neither expected nor anticipated. The warmest February ever occurred in 2016 with a global mean temperature increase of 1.21°C above the 20th century average. February 2016 thereby exceeded the all-time monthly record set just two months earlier and became the 10th consecutive month a monthly global temperature record was broken (Figure 3) [14]. This trend continued through 2016, and August 2016 was again the warmest month since measurement began in 1880. Overall, 14 of the 15 highest monthly departures from the 20th century temperature average have occurred since February 2015. The Arctic region with its’ unprecedented rapid climate change holds several indigenous populations with traditional subsistence lifestyles. The Sami reindeer herders of northern Sweden constitute one of those populations [15].
Climate change and indigenous peoples

The dominating climate change and indigenous peoples discourse is that of vulnerability [16, 17], perhaps influenced by the fact that the vulnerability concept was used already in the UNFCCC (United Nations Framework Convention of Climate Change in 1992) where countries committed to promote adaptation directed towards vulnerable populations and regions [18]. Since then, indigenous peoples all over the globe have been identified as uniquely sensitive to climate change impacts due to their geographical location in climate sensitive areas, their strong connectedness to nature and land through traditional lifestyles, as well as by the expected disproportionate burden of climate change health impacts on indigenous populations [19, 20]. The Arctic indigenous populations will be particularly sensitive based on their dependence on climate-sensitive resources as well as climate sensitive infrastructure [7, 21].

Simultaneously, indigenous knowledge – often referred to as traditional ecological knowledge or traditional knowledge – has been emphasized as very important for adaptation and management of climate change effects [22]. There is increasing engagement with traditional knowledge but still the epistemological differences between scientific knowledge and traditional knowledge remain a challenge. Scientific knowledge is seen as objective and rigorous, while traditional knowledge is regarded as subjective, arbitrary and anecdotal.

Figure 3: Land and ocean temperature departure in February 2016 from the three decade average of 1981–2010. Available at www.ncdc.noaa.gov/sotc/global/201602. [14]
The “victim-hero frame” is a term used to describe how indigenous peoples’ knowledge and experiences are often portrayed in both popular and scientific contexts – victims in terms of vulnerability, and heroes due to the potential importance of indigenous knowledge in addressing the problem in question. This victim-hero framing of indigenous peoples was found by researchers to be common in the IPCC AR5 WGII (working group II) report as well. When investigating the representation of Indigenous peoples in the IPCC report, Ford concluded that the IPCC reports tend to prioritize positivistic science like modeling and scenarios at the expense of other knowledge systems, thereby making “climate change a problem for society as opposed to a problem of society”. As a consequence, the underlying cultural, social and economic circumstances causing climate change vulnerability in Indigenous peoples remain unexposed.

Theories on vulnerability

The definition of vulnerability varies greatly across disciplines and sciences. The different vulnerability frameworks cover essentially the same components, although these components are often named differently according to science or scholar. The basic components in the framing of vulnerability used in IPCC 2001 and ACIA (Arctic Climate Impact Assessment) are exposure – to natural events, climatic conditions or environmental hazards; sensitivity – how easily the system of interest is disturbed by an exposure and resilience or capacity to adapt – the ability of the system or people to handle and respond to the stimuli.

These basic components can be elaborated further and described in more detail, to increase understanding and facilitate discussion and application. Ford and colleagues offer a conceptual model of vulnerability in climate change research built on several previous vulnerability concepts from scholars of different disciplines. In this framework vulnerability is defined as a multifaceted entity composed by factors working both together and in opposition. On the one hand there is the exposure-sensitivity side, representing the systems susceptibility to the risk in question. This susceptibility is of course influenced by internal factors as well as features of the risk at hand. Examples of climate change risk features could be late ice formation or early ice break-up, below-freezing rains, more intense storms and wind from unexpected or unusual directions. Internal factors are influenced by community characteristics like socioeconomic circumstances, livelihood conditions, economic stress and time constraints. Susceptibility is of course variable between groups and individuals and over time within the same group or individual.

Adaptive capacity is placed on the other side of the model, opposed to exposure-sensitivity and it is equally variable reflecting the individual, group or systems’ ability to cope with, adapt to or handle the exposure-sensitivity. Some scholars would equal this with the term resilience. Adaptive capacity is influenced in part by the same factors as vulnerability – livelihood conditions, access to technology and machinery, economic circumstances and social networks affecting resource use options and management strategies to handle exposure effects. Adaptive capacity can however,
both mitigate and increase the exposure-sensitivity side of the model. Repeated exposure to the same risk can lead to system wear-out and exhaustion, thereby increasing the exposure-sensitivity. It can result in more experience and an elevated capacity to handle the exposure thereby working protective, but increased experience can also lead to more risk-taking behavior and increase the exposure-sensitivity.

The two core concepts of the model, exposure-sensitivity and adaptive capacity, are also affected by conditions on a wider scale outside the individual or the group like political decisions or national regulations (socio-economic, political) or climate changes’ continuous influence and change of the risk at hand (biophysical). (Figure 4).

A framework like this may facilitate understanding of the multiple factors affecting vulnerability. When assessing climate change vulnerability Ford et al [25] have used this framework to assess the human implications of climate change in Inuit in both Arctic Bay and Iqaluit, Nunavut, Canada. Frameworks like this offers a possibility to encompass the many various influencing factors to get a better picture of what can be done and how [25].

Füssel [26] on the other hand does not include either the word resilience or adaptive capacity in his framework. Here a vulnerable situation is first identified by depicting four fundamental components: the system of interest – e.g. a human-environmental system or population; the attribute of concern – health, certain practices, cultural identity; the hazard – storms, thin ice, unsustainable land use; and a temporal reference. He then argues that there are two different dimensions that need consideration when describing a systems vulnerability profile – the socioeconomic and biophysical domains, both divided into internal or external factors. The socioeconomic domain
includes internal factors like household income, social networks and information access and external factors like national policies or economic globalization. The internal factors in the biophysical domain are exemplified by environmental conditions or topography and the external factors are severe storms, earthquakes and sea level rise. According to Füssel these four categories represent the vulnerability profile of a specific system to a particular hazard at a given time.

One can see that Füssel’s framework represent the components covered in the Ford model although expressed differently and including a time reference. Füssel has a strong case in emphasizing the importance of a temporal reference when assessing vulnerability to an ongoing perturbation like climate change. The climate change effects are changing in character and scale over time, so are the system of interest and the attribute of concern, making the time frame essential in vulnerability assessments. According to Füssel the main purpose of this more elaborated framework is to allow for common terminology to be used in vulnerability communication, regardless of discipline, to review existing classifications and terminologies and to facilitate discussions on the differences between various vulnerability concepts [26].

In this thesis the assessment of the Sami Reindeer herders’ experiences was influenced by the above described theories.
The Sami population in Sweden

The Sami constitute the Swedish indigenous population. The trans-national community of Sápmi – traditional Samiland – covers northern Norway, northern Finland, northern Sweden and the Kola Peninsula in Russia. Historically, nomadic Sami herded their reindeer in this region without consideration of country borders (figure 5).

The Sami have their own language of finno ugric origin with four different official variations and the Sami language is more closely related to Finnish than the Swedish language, although all Sami in Sweden are native Swedish speakers \(^{[27]}\). Around 80,000–100,000 Sami live in Sápmi; 20,000–40,000 Sami live in Sweden, 50,000–65,000 in Norway, around 8,000 in Finland and 2,000 in Russia \(^{[28]}\). No registration by ethnicity is carried out since ethnic registration is prohibited by law in Nordic countries, so these numbers are approximations. In Sweden the numbers are based on a prospective calculation from 1975, where it was said that it is likely that the Sami in Sweden will amount to 20,000 in the year 2000 \(^{[29]}\). The traditional Sami trades include hunting, fishing, handicrafts and reindeer herding. Today about 10% of the Sami are occupied with reindeer herding, an extensive land-use practice based on usufruct prescribed since time immemorial, dependent on the free grazing of traditional Sami land \(^{[30]}\). Work as a reindeer herder involves extensive traditional skills based on the lived experience of oneself and ones ancestors. Reindeer graze for forage and are constantly exposed to weather, traffic and predators. They are not fenced in and how they roam the land depend on complex interactions between weather, grazing and herder decisions. Reindeer herding have been identified by the Swedish government as sensitive and vulnerable to climate change effects \(^{[31]}\). The Sami calendar year has eight seasons, all with a main focus on what is important for the reindeer in each and every period. The reindeer and their herders live with and

Figure 5: Sápmi – traditional Sami land. Picture by Anders Suneson/Samiskt Informationscenter.
by the weather, which explains the utmost importance climate change can have on their livelihood.

In 1977, the Swedish Parliament recognized the Indigenous status of the Sami, and since 2011 the Sami are explicitly recognized as a people, as opposed to a minority, in an amendment of the Swedish constitution. However, the UN ILO 169 Convention on Indigenous and Tribal Peoples in Independent Countries (1991) has still not been ratified by Sweden, a circumstance criticized by the UNHRC [32]. The epidemiological transition of the Swedish Sami population has been extremely rapid during the 19th and 20th century, as illustrated by figure 6 [33]. The Sami people are today exceptionally well integrated and assimilated in the Swedish society, however, the cost of the sociocultural and contextual loss accompanying this process is not easily calculated or estimated.

Figure 6: Here 72 year old retired reindeer herder Per Jonasson is in front of the cot where he grew up with his mother, father and four siblings. The whole family lived in the cot to the left; the middle part and the cot to the right were added to house tourists. Today Per shares the same standards as most Swedes, he lives in a villa, owns two cars and several snowmobiles etc. Grönvallens sameviste, Vallbo, Undersåker. Picture by the thesis author from 2010, published with Pers kind permission.

Sami health

The main body of Swedish Sami health knowledge comes from the construction of a Sami cohort by the work of Hassler, Sjölander and colleagues [34]. The cohort was based on reindeer herders registered in the Swedish business directory and Sami individuals eligible to vote in the Sami parliament, defined as “Index-Sami”, including the registered relatives of these two groups. More details on the construction of this inclusive cohort counting almost 40,000 people and how it was compared to a four times as big demographically matched non-Sami control population have been
described elsewhere. Research on Sami health and wellbeing is limited in Sweden, a circumstance criticized by the UN in 2006 [35] and again in a recent Lancet review this year of Indigenous and Tribal Peoples’ Health [36]. The existing studies on Sami health have focused on cardiovascular diseases, cancer and mental health. The research shows very small differences in terms of Sami overall life expectancies and mortality rates compared to the general population [37]. Socioeconomic characteristics like education and medium net income (with male reindeer herders excluded who have considerably lower annual income) showed very small differences in comparison with non-sami [38].

Research specific to reindeer herders have focused mainly on musculoskeletal problems and shows a high risk of hand/wrist and lower back symptoms compared to other blue-collar occupations, symptoms associated with high work demands [39]. Male reindeer herders also display a significantly higher risk of dying from vehicle accidents and poisoning, tentatively caused by increased socioeconomic pressure and extensive use of terrains vehicles in reindeer herding, making commercial reindeer management one of the most dangerous occupations in Sweden [40]. Additional research on mental health and suicides among Swedish reindeer herding Sami have also been conducted and shows a higher load of anxiety and depression especially among middle-aged reindeer herders [41]. The Sami population has a higher exposure to suicidal behavior, different types of suicidal problems and actual suicides, as compared to non-Sami [40, 42, 43]. Compared to a reference population no general increase in alcohol use was seen among reindeer herders, although subgroups with a higher proportion of total abstainers was seen as well as more hazardous drinking related to stress and anxiety [44]. On the other hand, a questionnaire study on health among Sami youth have also showed a slightly better health compared to non-Sami young Swedes, except regarding stress and worries [45].

Due to the lack of ethnic denominators in Swedish public registers, studying climate change health outcomes in reindeer herding Sami compared to the general populations is not possible as of today [46].

Health aspects in climate change research

The initial IPCC reports were mainly focused on the technical science exploring trends in temperature, precipitation and other physical factors, as well as discussing and developing scenarios and mitigation strategies. Over the years, the consequences and impacts of climate change to human health such as infectious diseases, socioeconomic factors, lost work capacity and reduced labour productivity due to heat exposure have received increased attention, and in the IPCC Fifth Assessment Report (AR5) health issues receive much more attention than they did previously. Today adaptation is another important focus of the IPCC [47]. A recent review concluded that between 1990 and 2006 very few studies were published on climate change and health, but since then the increase has been almost exponential. The number of publications on the topic of climate change and health in the two databases PubMed and Science Direct has increased from 1,329 in 1990, to 5,651 in 2006, and to 23,474 in 2014.
Still the subject of health is receiving less attention than other climate change related research sectors in terms of publication volumes [48]. The increase of studies on climate change and health is reflected in the more recent IPCC reports, AR4 and AR5. The AR5 concludes that the evidence points towards that negative effects of climate change will outweigh the positive effects on a global scale. It also concludes that research modelling consequences of climate change alongside projected economic and social changes suggest that climate change might counteract other health gains in the poorest countries. The IPCC states that the most effective adaptation measures remain implementation and improvement of basic public health measures [47].

Despite the increased attention on the effects of climate change, the typical climate change illustration remains a curve displaying the change in mean temperature during the last century, compared to the 20th century average, sometimes also involving the corresponding increase in CO₂, despite the fact that an illustration like this gives no idea about what impact the effects might have (Figure 7).

The many different ways by which climate change can affect population health are visualized in an illustration from a Lancet review describing present and future climate change risks [49]. In this thesis two different health effects described here are studied – changes in infectious disease geography and epidemiology, and threats to the traditional livelihood of Sami reindeer herders (figure 8).
Climate change and infectious diseases

How infectious diseases are transmitted is affected by many factors such as the underlying populations health status, socioeconomic conditions, health care access, environmental conditions, etc. [51]. Some infectious diseases are considered particularly sensitive to climatic conditions through the influence on geographic range and conditions for reservoir species and vectors, increasing vector abundance and biting rates, suitable environment limitations, and pathogen replication rates. These diseases include mosquito-borne, tick-borne and water-borne infections such as malaria, dengue fever, TBE and schistosomiasis, among many others [49].

In the 2007 government report “Sweden Facing climate change – threats and opportunities” a risk assessment was made of infectious diseases of particular interest for Sweden (see figure 9). In this report vector-borne diseases were identified as carrying the highest climate change risk effects and the tick-borne diseases TBE (Tick Borne Encephalitis) and borreliosis (Lyme disease) were mentioned in particular. Diseases like dengue, West Nils fever and visceral leischmaniasis were also mentioned but are hitherto not endemic to Sweden. Another identified vector-borne infection associated with risk was tularemia, a notifiable disease of considerable public health importance for northern Sweden (figure 9) [31].
Tularemia

Tularemia is a zoonotic, vector-borne disease caused by the highly contagious intracellular, gram-negative coccobacillus *Francisella tularensis*. Studies have shown that it may take less than 10 bacteria to cause disease and laboratory contamination is not unusual [52]. There are four subspecies of *Francisella tularensis* and the two main strains causing disease in humans and animals are spp. *Tularensis* (type A) and spp. *Holarctica* (type B). Tularemia type A is found almost exclusively in North America and is the one associated with bioterrorism with a mortality as high as 30% if untreated. Type B tularemia is the one present in Sweden and occurs all over the temperate regions of the Northern hemisphere, however, with great geographical variations. It is less virulent than the type A and mortalities are very rare [53].

Sweden has, together with Finland, the highest tularemia incidences in the world, with local incidence rates during epidemics reaching the levels of common infections like influenza or chlamydia trachomatis [54]. Considering well known risk factors for tularemia such as hunting, farming, living in heavily forested areas, working with wildlife and mosquito bites [55, 56], reindeer herders could constitute a high-risk group in terms of tularemia exposure. In one mountain Sami community there was in fact an outbreak a few years ago with at least three cases (Personal communication: Stephan Stenmark, County Medical Officer, Västerbotten County Council, 2014). Considering the size of a Sami community the number of cases was disproportionally high. One of these patients was treated for occulo-glandular tularemia, which is the rarest clinical manifestation comprising less than 1% of the cases. However, in the first Spanish tularemia outbreak where 11.3% of the cases were hunters, oculo-
glandular tularemia was found in 4.2% \[57\]. Due to the lack of ethnic denominators in Swedish public registers, detecting an overrepresentation of tularemia in reindeer herding Sami is today not possible.

Tularemia can infect more than 300 species of mammals, reptiles, insects, fish, birds and humans and cause epizootics in hares, rabbits and rodents who are important sources of human infections and may act as reservoirs, vectors and amplifiers \[58\]. Tularemia is called rabbit fever or harpest in Swedish, due to the fact that it is a disease often seen in sick hares and symptoms resemble that of a plague with fever and swollen buboes. The most important vector in Sweden is mosquitoes, although other arthropods like ticks, wasps, deer and horse flies of the Tabanidae family, can act as transmitters of the disease as well.

Clinical features include high fever, headache, muscle ache, chills, malaise, infected wounds, regional lymphadenopathy, dry cough and pneumonia. Disease symptoms vary with the route of infection; insect bites cause ulceroglandular tularemia, the most common clinical presentation in Sweden. Inhalation of infected dust causes pneumonia or oropharyngeal disease which can also be caused by the ingestion of infected water. There is also the so called typhoid form with no focal symptoms. Ocular tularemia exists as well and several other organ manifestations. The incubation period is around 3–5 days ranging between 1–21 days. Tularemia is treatable with antibiotics such as Ciprofloxacin or Tetracyclines but with a two week delay of adequate treatment from symptom onset the risk of lymph node suppuration is 30–40% and recovery without treatment can take weeks or even months \[53\].

**Tularemia immunity**

Tularemia is considered to create lifelong immunity and reinfections are very rare \[59\]. Nonetheless, Dr Edward Francis (1872–1957), who discovered and named *Francisella tularensis*, managed to acquire tularemia at least three times, deliberately exposing himself by performing autopsies on tularemia infected animals without wearing gloves \[60\]. Immunization of laboratory personnel with a live vaccine strain reduced the number of laboratory-acquired pneumonic tularemia dramatically although the incidence of ulceroglandular cases remained unchanged \[59\]. A Finnish study of humoral immunity after natural tularemia infection showed that nine tested individuals still displayed detectable ELISA titers 11 years after the acute infection \[61\]. Another study of humoral and cell-mediated immunity investigating persons who had tularemia 25 years earlier revealed declines in antibody levels with low serum agglutinin titers, and only 15 (28%) of 53 persons had an ELISA IgG > 200, the upper limit of the reference range for IgG in the laboratory at that time. Only three persons had IgG value > 400. The T-cell medicated immune response however, was still potent indicating that the individuals still displayed protective immunity against reinfection, despite the antibody response declines into low or non-detectable levels \[62\].
Tularemia ecology

The lifecycle of tularemia is not well understood. A connection to water has been mentioned in the literature since the 1950s although this has never been scientifically proven. The distribution of the disease is patchy; *Francisella tularensis* causes local outbreaks and once established in a location repeated cases are seen, sometimes with many years or even decades separating the subsequent cases indicating a local tularemia reservoir of unknown nature. It has not been possible so far to identify where *Francisella tularensis* resides in nature between outbreaks.

Aims

The overall aim of this thesis is to increase the knowledge on climate change relevant aspects of life and health in northern Sweden during three decades from the 1980s and onward. The specific aims are to:

1. Describe climate change effects in northern Sweden.
2. Investigate if climate change is of any concern for the Swedish Indigenous Sami people leading traditional lifestyles.
3. Explore the Swedish tularemia epidemic over the last three decades, on the national level and with a special focus on the Swedish Arctic region.
4. Establish a baseline sero-prevalence rate for tularemia and estimate the hidden burden of disease in the Swedish Arctic region; as well as investigate if correlations exist between tularemia and water, altitude or eco-regions.
Materials and methods

This thesis applies a multi-methodological approach to enable the use and combination of several diverse sources of knowledge and information to fulfill the aims and to obtain a deeper understanding of different aspects of life and health in the climate change context. The approach moves from a strictly qualitative interview study in paper one, to a mixed-methods investigation in paper two that combines the qualitative data with quantitative instrumental weather data, and then to strictly quantitative data collection and analyses in papers three and four.

Interview data – papers I and II

The aim of the initial qualitative study was to investigate if there were climate change effects that were noticed or experienced by people in northern Sweden over the last three decades. The qualitative methodology provided the best option to get an in-depth understanding of the lived experiences of changes in the environment. Sami reindeer herders were chosen as the interview target population since they were considered most knowledgeable in terms of long time environmental climate change effects. The basis for the reindeer herders’ intrinsic environmental knowledge is their total dependence on the landscape, weather and environment for their livelihood, working outside every day all year round.

This was a descriptive qualitative study where interviews were chosen in favor of focus group discussions for the following several reasons: to enable a geographical dispersion (see figure 11 for details), to facilitate active herder participation, to reduce participant inconvenience and to allow more sensitive issues to be discussed. Support from the Sami parliament was secured as well as research board ethical approval.

Purposive sampling was applied in the selection of the 14 Sami reindeer herders in aim for maximum variation in respect to age, sex, length of reindeer herding experience and a widespread geographical distribution to get as broad and deep understanding as possible. Convenience sampling enabled the first recruitment of interviewees during the Jokkmokk Winter Conference – “Changing Climates: The new political and environmental reality for Northern Communities” in January 2010. These interviewees, along with a number of Sami community leaders that were also contacted, then gave recommendations on additional persons to contact, so called snowballing technique. In addition to the Sami interviewees, two farmers and one fisherman were included to discern whether they had different experiences as compared to the herders. All interviews were conducted in Swedish during spring 2010 by the author of this thesis, most in the informants own homes. All but two approached informants agreed to participate, and the most likely reason for this success was the direct, personal telephone contact that was taken. Several interviewees mentioned that they would have declined if they were simply sent a letter asking about them to participate.
A simple guide was used during the interviews and all informants were asked to reflect upon what they knew about climate change, their experiences of changes in the environment, their thoughts about these changes and about the future for reindeer herding. Open ended questions were used, all interviews were audio recorded and impressions and thoughts preserved in brief research notes. Interviews were transcribed verbatim, five of them by the author of this thesis during the interview process as part of the emergent design, and when the data appeared saturated the interviews were terminated. No new or deviant information emerged during the three interviews with non-Sami participants which lead to the conclusion that transferability was good enough with solely the Sami. The decision was thus made to exclusively include the reindeer herders to preserve the contextual integrity of the analyses.

The analytical approach was descriptive content analyses employed to capture both the *manifest content* – what is stated in the words, and the *latent content* – underlying significations and unspoken meanings [63, 64]. All interviews were listened to and read through several times and then divided into meaning units and coded using the free Open-Code software [64, 65]. Codes were grouped to form sub-categories and categories. In this part the analytical process moves to a higher logical level and proceeds from organizing data to organizing ideas generated by the data, thereby moving the analyses toward a higher degree of interpretation. Continuous peer coding, peer review and discussions about the latent content were carried out to ensure inter-coder agreement and concordance in the interpretations, thereby increasing credibility and trustworthiness. Throughout the entire process codes, sub-categories and categories were continuously developed by moving back and forth through the material, from the whole to parts of the text, sometimes all the way to the original interview, and then back again. An example of the analytical process is illustrated in figure 10.

**Mixed-methods design – Paper II**

To meet the challenges posed by climate change complexity and in order to get a more comprehensive, complete and broad description of climate change effects in northern Sweden, a mixed methods approach was employed. The reasons behind this decision...
were as follows: triangulation purposes – for corroboration, to show that human observations and instrumental data are complementary and enable generalizability and further increase validity of the qualitative study; complementarity – to elaborate and illustrate the observed changes with numbers; and initiation – to discover any paradoxes, contradictions or unexpected results. The philosophical position here is dialectic as well as pragmatic, bridging the gap between the constructivist stance of qualitative methodology and the postpositivistic stance in quantitative research [66, 67].

An exploratory sequential mixed-methods study design with an interactive level of interaction was applied. This was a two-phase design where the initial exploratory qualitative phase results were followed by quantitative data collection and analyses to test or generalize the initial findings. The qualitative and quantitative strands were integrated through this direct interaction where the design and conduct of the second phase is based on the initial phase findings [67].

In this study reindeer herders experiences were considered more regional than local in scale since reindeer herding takes place over large geographical areas, i.e. moving twice a year from summer grazing areas in the mountains to winter grazing areas on the coast, a distance of over 300 km for some. Four specific observations from the qualitative study (paper I) were chosen for further investigation with quantitative measurements, based on the specific impacts these changes have on the reindeer herders’ work and daily life:

- **Wintertime temperatures are increasing.**
- **Rapid fluctuations in temperature are becoming more common.**
- **Snow arrives later and departs earlier in the season.**
- **Long stable cold periods are becoming less common.**

A number of quantitative measurements were selected to investigate and elaborate on these observations and to visualize and illustrate the regional trends of climate alterations in northern Sweden. After the quantitative analyses had been carried out meta-inferences were drawn from the combined results of the qualitative and quantitative phase studies.

**Instrumental weather data – paper II**

Ten weather stations located in proximity of the areas where the study subjects live and herd their reindeer were selected, (see figure 11 for an overview of the locations of the interviewees, their grazing lands and the corresponding weather stations). Detailed data from each station on maximum and minimum temperature and snow depth between the years of 1978 and 2007 – corresponding to the relevant time frame of the interviewees experiences – were downloaded from NOAA (National Oceanic and Atmospheric Administration) [15]. Illustrations were made using R version 2.13.2. and analyses were conducted with MATLAB version 7.10.0. A multitude of different statistical analyses were used to elaborate on, test and illustrate the observations selected.
Temperate activities and physical processes might be affected differently by particular temperature distribution changes. To determine trends in temperature distribution shifts and specific distribution proportions a total of 2000 regression slopes were calculated on maximum and minimum temperatures for each station over the time period, and temperature percentiles for the start and end of the time period were modeled and the density distribution approximated. Daily mean temperature was calculated as the average of daily minimum and maximum temperatures. Periods of more than ten consecutive days with daily mean temperatures

Figure 11: Reindeer herder interviewees’ residences (red triangles), weather stations (blue stars) and colored grazing areas used by the interviewees. Striped areas are shared. DVD–Dividalen, PAJ–Pajala, KVK–Kvikkjokk, ARJ–Arjeplog, LUL–Luleå, GUN–Gunnarn, GAD–Gäddede, JUN–Junsele, STO–Storlien, FRO–Frösön.
below the annual 25th percentile were defined as cold periods and the number of days within cold periods each year was calculated.

The observation of increased temperature fluctuations was assessed by three different methods. Daily variations were investigated, as well as up to five day period variations to cover the possibility that the perceived rapid changes occurred over a prolonged period of time. Due to the obvious circumstance that an increase in temperatures pending around 0°C, strongly affecting the freeze-thaw cycle, would manifest in a very evident way, temperatures pending around 0°C were also looked into.

**Snow depth**

To investigate the length of the season with persistent snow cover a 21-day centered moving average smoother was applied to the daily snow depth data. This procedure excludes early– and late-season snowfalls surrounded by no snow cover. ”Snow season” was defined as a period of 50 or more consecutive days in which the smoothed snow depth data exceeded 25 mm. The choice of the 25 mm threshold was based on its ability to allow herding on cross-country skis or snow mobiles. Start date, end date and duration of each year’s snow season was calculated and tested for trends in each variable.

**Tularemia epidemiology – papers III and IV**

Tularemia has been mandatory reportable since 1968 under the Swedish Communicable Disease and Prevention Act. The data collection systems have changed a number of times since 1968, the last two changes were made in September 1984 and 1996. The case report form includes multiple variables but only some of the variables are mandatory and the quality of the data varies.

For the purpose of these studies, data on all 4,792 cases reported infected in Sweden from September 1984 to December 2012 were collected from the national data base. These included information on patient age, sex, home address, suspected date and place of disease contraction, onset of illness, diagnosis and report date. Data on land, water and population were retrieved from Statistics Sweden and used in incidence calculations[68]. Each recorded case of tularemia was assigned geographical coordinates (latitude and longitude) for the probable or certain place of disease contraction. Each case was assigned a quality code grading the quality of the information on location in six levels. Data on disease onset was either available directly in the data set or calculated based on the exposure date and known *Francisella tularensis* incubation period. Disease onset data were also quality coded in three levels from A to C. To enable analyses with a high level of spatial and temporal certainty only cases with quality codes one and two for disease location were used; these correspond to code one for a certain or probable unmistakably named place of small size like the place of residence and code two for the persons place of residence if the reported place of disease contraction was within the same municipality. Only quality codes A and B for disease onset date were used, referring to A for a reported disease onset date
and B if only an exposure date was reported and the disease onset date had to be approximated. This selection resulted in 2,534 cases for the subsequent analyses.

An outbreak was defined as more than four cases in one municipality under a 30–day period. The spatial tularemia case distribution was compared to a map constructed as if tularemia was a geographically evenly distributed disease. An eco-region is an area defined by its environmental conditions like climate, soil, distribution of flora and fauna, and pre-defined eco-regions were used [68]. A municipality was considered part of an eco-region if the municipality centroid was located within that region. We used the *limes norrlandicus* definition to delineate northern and southern Sweden where northern Sweden is boreal forest and southern Sweden is mixed deciduous and coniferous or broad-leaf forest. ArcGIS and R software version 2.9.1 were used in the statistical analyses and to visualize the geographical data.

**The outbreak and sero-prevalence investigations – paper IV**

The outbreak investigation was performed by the Public Health Agency of Sweden under the Swedish Law for Communicable Diseases Control (SFS 2004:168). Each reported case of tularemia in the Norrbotten and Västerbotten outbreak was assigned six controls retrieved from the Swedish population register SPAR, matched by place of residence, age and sex. The power calculation was based on a previous outbreak. A questionnaire on symptoms and risk factors was created and mailed to the 242 cases and corresponding 1,452 controls, including one reminder, during November and December of 2012. Data were cleaned and logistic regression was used in univariable analyses and the p<0.10 threshold was used to identify variables to be included in the subsequent multivariate analysis. All analyses were conducted using IBM SPSS statistics version 23.

A random population serum sample collected in the MONICA 2014 survey was used to analyse the prevalence of tularemia antibodies in the populations of Norrbotten and Västerbotten. The northern Sweden MONICA study is a population based survey aimed at the study of cardiovascular risk factors where subjects are randomly selected from population registers, and stratified for age 25–74 years and gender. Two hundred and fifty men and women from each 10–year age group in both counties were invited to participate [69]. In 2014 the standard MONICA questionnaire also included a question about previous tularemia diagnosis.

An ELISA method was used to identify individuals that had been exposed to tularemia prior to the testing. A total of 1,503 serum samples were analysed using the routine tularemia diagnostic serology of Umeå University Hospital Clinical Microbiology Laboratory (a Swedish national tularemia reference lab). The diagnostic procedure has been described elsewhere [70]. One-fifth of the analyses were performed by the author of this thesis, and the reminder by laboratory personnel. Two samples were discarded due to technical reasons. The decision on a 100 relative ELISA titer as the cut-off was based on this being the upper limit of the reference range for antibodies to *Francisella tularensis* in the laboratory. The unique Swedish personal identification number was
then used to investigate if any of the individuals in the MONICA 2014 sero-prevalence investigation had been reported as a tularemia case in the period of 1989 to 2014.

Since tularemia antibodies can still be detectable at least eleven years after the acute infection [61], the sero-prevalence was used to calculate an estimated number of cases in the region based on the underlying population in the same strata. Population data for Västerbotten and Norrbotten for the 25–74 year strata at the end of 2013 were retrieved from Statistics Sweden [71]. All reported cases in the area during the eleven years prior to the MONICA 2014 sampling were used to calculate a reported prevalence for comparison. The cases were summed up and divided by the underlying population in the same strata, thereby possibly overestimating the reported prevalence since reported cases are found also outside these age strata.
Results

Climate change human and instrumental experiences

The qualitative data provided a rich description of the reindeer herders experiences of changes in their environment over the last three decades; changes that the herders started noticing in the middle of the 1980s and that had been accentuated during the ten years prior to the interviews in 2010. The data displayed how these changes have affected the everyday lives of the herders but also how their ability to adapt has been restricted by outside circumstances. In the analyses one core theme emerged that connected the different sub-categories and categories developed in the analyses, i.e. in the face of climate change reindeer herding is facing the limit of the resilience (paper I). Within anthropology the concept of resilience refers to a dynamic systems capacity to absorb disturbances, adapt successfully and still remain essentially the same [72]. Figure 12 gives an overview illustrating the main finding including the relationships between key concepts covered in the interviews, the sub-categories, categories and the core theme developed. The weather data analyses tested and illustrated the changes observed by the herders and provided a scale of the changes as a reference to relate to (paper II). Below is a description of the results where sub-categories from paper I are marked in bold.

![Figure 12: The core theme with the categories and sub-categories.](image-url)
The environmental changes in weather and climate described by the reindeer herders were many. Autumnns were perceived as longer, warmer and very wet – Nights with below-freezing temperatures in the early fall seldom occur nowadays resulting in the persistence of mushrooms in the forests which scatter the reindeer who are willing to stray far away to access these treasures, making them difficult to gather for the herders. The lack of cold nights also prevents the reindeer from initiating the annual migration themselves, thus lingering in the summer grazing areas. The wet weather can lock the grazing under a thick ice layer that prevents the reindeer from accessing the food, and this problem remains throughout the winters under the worst circumstances, with the subsequent need for continuous movements or supplementary feeding. Ice is thin and established much later; this hampers passage over rivers and lakes especially under the annual migration in fall and spring (paper I).

Snow arrives later and the snow season is shorter. This circumstance was evident form the instrumental records as well with a shortening of the period with persistent snow cover by two full months over three decades in Gunnarn and Froson stations, and more than one full month in another four stations. Only one station showed a slight increase in snow season duration. In six out of ten stations with statistically significant (p>0.05) trends of shortening snow season duration, the season grew shorter by 1.2 to 2.2 days every year (paper II).

Warmer winters were apparent in both data sets. The long cold stable periods were perceived as more or less disappeared by the reindeer herders. These periods represent a time when the grazing is stable with no need to move the herd, providing an opportunity for the herders to do other tasks that are not feasible during the rest of the year (paper I). Quantifying the number of days per year in extended cold periods revealed a sign of the trend consistent with a decline in all ten stations. In the early period of the record some winters had over 100 days per year classified as parts of an extended cold period and more than 60 days was common. In the more recent data almost every year had less than 50 cold period days (paper II).

Weather was perceived as more extreme and intense as well as more unstable, unpredictable and varying by the reindeer herders. Old rules no longer held true and to predict the coming weather had become increasingly difficult. They did not recognize themselves any longer: the tree line is climbing and vegetation is changing from lichen to grass and shrubs (paper I). An increase in rapid temperature variability was emphasized by several herders, although no evidence of this could be found in the instrumental record data with the three different methods applied. If any, a sign of decreasing day-to-day temperature changes could be seen (paper II).

An area that emerged and became prominent in all of the interviews was the variety of different climate-unrelated circumstances limiting the herders’ room for manoeuvring and ability to adapt. The interviewees described how the pressure on reindeer herding increased constantly. Grazing lands are continuously decreasing: Lost to infrastructure, forestry, tourism, mining, wind– and hydro power plants. Poor economy and a loss of competence and traditional knowledge posed huge threats to the future of the trade. The predator policy of the Swedish Government was strongly
emphasized as problematic. Being experts on adaptation climate change predictions communicated through media and the authorities were by some herders perceived as an even heavier burden than the changes themselves (paper I).

The Chernobyl accident was spontaneously brought up by several participants in the interviews and the memories of how that situation was handled by the authorities shape how the reindeer herders relate to climate changes today; they are the first ones affected though feel the least responsible. The herders’ impression was that reindeer herding is not appreciated in Sweden and several had little hope for the future of the trade with limited possibilities for their children to inherit the traditional lifestyle. A sense of grief for the future was a latent content running throughout the whole material (paper I).

There were opportunities in climate change effects identified by the informants as well. Warmer winters could, for example, favor reindeer herding depending on how the warming is manifested, and increased vegetation could result in better grazing conditions during the summer period (paper I).

The meta-inferences from the mixed-methods investigation, that is conclusions and interpretations drawn from the separate quantitative and qualitative strands of the study as well as across them, were also assessed. Apart from the abovedescribed findings the support of three out of four observations adopted from the qualitative study was illustrated. Convergence of the results supported the hypothesis of human perceptions being highly sensitive to climate change effects. Complete corroboration of the results was, however, not the case with contradictory findings regarding the observations of rapid fluctuations in temperature becoming more common (paper II).

The tularema investigations

Epidemiological characteristics

An increase in tularema cases was evident on both the numerical and geographical scale, and was pronounced during the second half of the study period of 1984–2012. Results from the large epidemiological investigation revealed an overrepresentation of men (58.2%) among the 4,792 patients infected in Sweden during the time period. Age ranged from 1 to 95 years with a mean of 47.6 (±19.5) years with small gender difference (47.8 years for men, 47.2 for women) (paper III). The 2012 local outbreak in Norrbotten and Västerbotten displayed similar features with 55.3% male cases, age ranging from 1 to 89 year, a mean age of 47 years (48.6 for men and 45.1 for women) and a median age of 53 years (55 for men and 50 for women) (paper IV).

In the analyses of incidences, the 3,524 cases with sufficient data quality on disease contraction time and location based on quality criteria were used. The age group distribution of tularema mean annual incidence displayed an apparent bimodal distribution with a decrease in the early twenties. The highest incidence was found in the age group of 55–59 years (2.75 cases per 100,000 population). A similar
age distribution tendency was visible also in the 2012 outbreak in Norrbotten and Västerbotten (papers 3 and 4) (figure 13).

There was an incidence gender difference of 0.44 cases per 100,000 persons and year (p<0.001) with the relative risk of contracting tularemia being 1.39 times higher for males than females, ranging from 1.15 to 4.28 for all ages except very small children. The incidence was significantly higher for men than women in all age groups above 55 years of age (paper III).

In the outbreak investigation factors associated with a statistically significant increased likelihood of being a tularemia case in the uni-variable analyses were living within 100 m from water mOR 2.86 (95% CI 1.79–4.57), daily time spent by water
mOR 3.11 (95% CI 1.60–6.05), living within 100 m from forest mOR 1.88 (95% CI 1.16–3.06), working with hay daily mOR 3.18 (95% CI 1.10–9.22) and other agricultural activities mOR 2.29 (95% CI 1.36–4.54), as well as daily gardening mOR 2.86 (95% CI 1.36–6.02). In univariable analyses the risk factors living close to water, spending time by water and agricultural activity displayed a dose response relationship to tularemia. Mosquito bites showed a strong dose-response association to tularemia mOR 7.16 (95% CI 2.79–18.42). No association between tularemia and cat ownership, hunting, fishing or picking berries or mushrooms was found (paper IV).

Tularemia infections in Sweden are highly seasonal. The 3,524 cases were symmetrically distributed around week 32 when the cumulative number of cases peaks. The majority of the cases appear between weeks 29–35, corresponding to mid-July to late August. There were no significant differences between outbreak period and length when comparing northern and southern regions of Sweden (paper III).

Spatial and temporal tularemia case distribution

The geographical uneven distribution of tularemia infections was evident in all three data sets. Most cases of tularemia were reported from the north where approximately 20% of the Swedish population lives. See figure 13 for an illustration of the increase in incidence seen in Sweden for 1984–2012 with Norrbotten and Västerbotten counties outlined (paper III). In the year 2012, the number of cases in the Norrbotten and
Västerbotten outbreak was 242, which equals 43% of all the 564 cases reported in Sweden that year. The population in this area only constitutes 5.3% of the Swedish population (paper IV). The particularly local distribution of tularemia is evident from the case map of the outbreak (figure 14).

The 2012 cases were reported from outbreaks occurring in novel areas as well as areas that had only seen sporadic cases previously (Luleå, Älvsbyn, Robertsfors). Most cases were reported from Boden (n=53), Norrfjärden (n=18) and Piteå (n=43). One case was infected in Örträsk where the only known previous case was reported in 1985, 17 years earlier. Östra Blisterliden, with no known previous cases, reported 2 cases (paper IV).

Not all 290 municipalities in Sweden reported tularemia cases during the period 1984 – 2012; 101 municipalities had no cases at all while some communities reported 921 cases/100,000 persons in Ockelbo in 2000, 588 cases/100,000 in Malung in 2008 and 429/100,000 in Ljusdal in 2008. Repeated outbreaks were common in some municipalities; Örebro experienced nine outbreak years from the year 2000 and onwards. Some years had no outbreaks and the maximum number of local outbreaks in a year was twelve. The number of local outbreaks corresponded with the mean annual incidence (paper III).

When comparing the first half of the study period (1984–1998) to the second half (1999–2012) the nationwide annual mean incidence increased almost tenfold, from 0.26 to 2.47/100,000 persons/year, (p<0.001). However, it was mainly during the second half of the study period that tularemia began to be reported more frequently from the southern region. See figure 15 for the national incidence distribution per five year interval (paper III).

When comparing the northern and southern regions of Sweden the increase rate of case reports was 9.6 times higher in the south as compared to the north (p<0.001). Still the global incidence was significantly higher in the north, with 4.52 cases/100,000 persons/year as compared to 0.56 cases/100,000 persons/year in the south (paper III).
Tularemia cases were mainly reported from the boreal forest regions. There was a statistically significant overrepresentation of cases in the combined boreal and alpine regions (incidence of 4.61 cases/100,000/year and a significant underrepresentation of cases in the nemoral (0.02 cases/100,000/year) and boreo-nemoral regions (0.80 cases/100,000/year), as compared to an even disease distribution based on the 3,524 cases which corresponded to a mean incidence of 1.56 cases/100,000/year (p>0.001) (paper III).

Investigation of altitude showed that the incidence was higher than expected at altitudes >100 meters and lower than expected at altitudes <50 meters. This corresponds with the negative correlation to seawater found in the analyses (Spearman ρ -0.28, 95% CI 0.40 to -0.15; p<0.05). No correlation to the four largest lakes was seen, whereas a positive correlation between tularemia incidence and the area of the municipality covered by inland water was found (Spearman ρ 0.36, 95% CI 0.23–0.47; p<0.001), (paper III).

A correlation to water was also found in the risk factor analyses of the 2012 outbreak investigation (described above), where the risk factors “living close to water” and “spending time close to water” displayed statistically significant dose-response relationships (paper IV).

**Outbreak investigations and sero-prevalence**

In the 2012 Norrbotten and Västerbotten tularemia outbreak case-control investigation 63.7% (121/190) of the patients had had an infected wound, 64.7% (123/190) had swollen lymph nodes and 8.9 % (17/190) were diagnosed with pneumonia. Forty-two of the cases were hospitalized during a mean duration of 5.95 days (median duration was 5 days).

In the sero-prevalence investigation 44 (2.93%) of the 1503 serum samples had relative ELISA titers of 100 or more which correspond to the definition of historical tularemia exposure in this study. A larger proportion of samples was positive in Norrbotten at 3.6% (28/777) compared to Västerbotten at 2.2% (16/726); see figure 16 for the spatial distribution of positive and negative samples. The ages among the sero-positive individuals ranged from 35 to 74 years of age. During the 11 years prior to the serum collection a total of 558 cases of tularemia were reported from the two counties together, corresponding to a sero-prevalence of 0.13% when divided by the underlying population. The number of cases represented by the investigated sero-prevalences would be 5,312 cases in Norrbotten and 3,724 cases in Västerbotten, a ratio of 16:1 in comparison to reported cases (paper IV).

The correlation between self-reported tularemia diagnosis and positive serology was poor – 3 out of 29 individuals who stated previous tularemia infection had a positive serology. The investigation into previous reports of tularemia diagnosis among the 1,501 individuals that provided blood samples revealed only two reported tularemia cases in this group during the period from 1998 up to 2014 when the samples were collected; there was one case from each county. However, one of these cases was reported as an acute infection one year after the samples were collected.
Strengths and limitations

Each paper in this thesis has its strengths and limitations. In paper I, the main strength is the richness and detail in the observations of climate changes in northern Sweden, as well as the in-depth knowledge provided about the consequences these changes have on reindeer herding. One limitation is that only reindeer herders were interviewed. Many other perspectives and observations may have thereby been overlooked. Transferability and confirmability of the results could also be contested based on the very specific context of reindeer herding.

The main strength in paper II is the use of weather data to scale the changes experienced by the herders, increasing the generalizability of the qualitative findings. The complementary nature of mixed-methods research conducted in paper 2 illustrate another important strength, particularly in triangulating and confirming phenomena described by the herders. A limitation of paper II is that only a few of the herders’ observations were tested. Further investigation into the modes of the decrease in the coldest temperatures, for example if the very coldest days are appearing more sporadically, may provide additional knowledge potentially useful for adaptation.

Figure 16: Sero-positive samples marked with green dots and negative ones as black dots. The orange color denotes the 2003–2012 incidence in the respective communities.
The very large sample size and long study period represent fundamental strengths in *paper III*, which enabled evaluation of disease development over time and in space, that had not yet been described in such detail. Unfortunately, some limitations are inherent to a study with such scale reliant on surveillance data. Potentially disease surveillance data may suffer from underreporting and/or various other kinds of reporting biases, in addition to issues relating to data quality, which resulted in the exclusion of many cases.

In *paper IV*, the outbreak investigation is marred by the classic case-control study limitations of participation loss, potential recall-bias and misclassification. However, using a case-control study design is suitable to investigate a rare disease like tularemia and controlling for age, sex and place of residence increases the statistical precision. A main strength of the sero-prevalence study in *paper IV* is the use of a randomized and large regional population sample. The restriction in age with inclusion of 25–74 year olds only, is a limitation since the disease appears in all ages. The lack of knowledge on the correct serological cut-off and how existing antibodies correlate with actual disease experience is another limitation. Using the personal identification numbers as a link to investigate if the study participants had been previously reported as tularemia cases, represents a unique opportunity within a global context and constitutes another strength of *paper IV*.

The main strength of the thesis is the multi-methodological approach with its combination of quantitative and qualitative data. Researchers, who do not embrace the mixed-methods paradigm, might consider this a limitation. Triangulation is another strength with both climate changes in northern Sweden and tularemia epidemiology investigated by more than one method. The multidisciplinary approach used in this thesis inquiry provides a breadth of scientific perspectives, although perhaps at the cost of not completely unfolding some important details of the research topics.
Discussion

Northern Sweden has experienced some major changes in climatic conditions in the last three decades as illustrated in this work, and the scope and consequences of these changes still remain to be disclosed. This thesis gives a numeric illustration of some of the climatic alterations and sheds light on the quite vast effects the changes have already had on the lives of Swedish reindeer herders. It also provides additional pieces to the ecology puzzle of the presumed climate sensitive infection of Francisella tularensis. The work describes the extent of the Swedish tularemia epidemic so far, providing a baseline for future tularemia surveillance in the Swedish Arctic region. This thesis shows a rapid increase in tularemia during the last three decades, concurrent with the time frame of substantial climate changes most pronounced in the Arctic regions. Tularemia is increasing in numbers as well as spreading geographically including emerging in previously unaffected areas. The reasons behind this increase are unknown and merit further investigation.

Reindeer herders’ vulnerability to climate change

*Paper I* subcategories indicated in *bold italics*. The consequences for the reindeer herding trade so far are described in the qualitative data analyses (*paper I*).

When applying the vulnerability model on the qualitative data, a pattern appears indicating that the reindeer herders’ climate sensitivity is mainly influence by social, economic, political and biophysical processes operating at scales beyond the reindeer herding system [26]. As experts on adaptation, the Sami reindeer herders would be able to handle climate change effects, provided they had the means to do it. Adapting to changes in climate, weather and grazing circumstances have always been an essential part of the reindeer herding profession and adaptation is executed through moving the herd to different grazing areas as well as changing the herd’s size or structure. The herders know their grazing lands in detail by lived experience; they know where to move the herd under any circumstances. This implies having enough grazing lands in terms of diversity as well as size – grazing lands are shrinking. If all pasture land has been “locked” by ground ice from winter rains and the herder no longer have access to old forests with arboreal lichen due to logging, the adaptive strategies are limited and the option left, supportive feeding, is expensive and considered untraditional – *supplementary feeding is a reluctant emergency solution and costly.*

The way the two modes of adaptation – mobility and diversity – have been compromised is described in *paper I*. The results mirror how the colonial-driven transformations of Sami human and natural systems constitute the foundation for reindeer herders’ climate change vulnerability today. The Swedish government laws and regulations of Sami life and culture have tied all Sami rights to reindeer herding, as well as placed the burden of the Sami cultural heritage on the shoulders of the reindeer herders – *the individual having great responsibility*. The laws of the late 19th century (1886 and 1898) clearly implied that the reindeer herders were the only Sami entitled to Sami rights. This was further emphasized in the 1928 law excluding...
all but reindeer herders from the Sami context; focus thereby moved away from
the people towards the trade instead to avoid accusations of racism [75]. Reindeer
herding became an industry instead of a lifestyle, austerity programs were imposed
during the decades following the 1960s followed by streamlining processes since the
1990s [76]. Today the trade is regulated in law and supervised by the authorities and
the everyday herding is directed to a greater extent by factors outside the trade, in the
past, the reindeer were the focal point.

"You can no longer pursue reindeer herding in the old way, it has to be more
economic...you can’t ride three or four snowmobiles to herd 500 reindeer.
We used to do that on skis, but it was different back then, the grazing
circumstances were good. Today it’s completely different." herder 10

In the 1970s the government made redundancy payments to herders who chose
to quit the trade and relocation grants were provided to Sami who moved to take
up another profession – reindeer herding is not valued [75]. These integration and
streamlining processes have increased the size of the herds and reduced the number
of herders – loss of traditional skills and knowledge. Large herds make it more difficult
to make full use of forests patchy from forestry cutting and logging and thereby
increase the competition for grazing land. Forage shortage result in the need for even
larger herds for economic survival – poor financial conditions. However, the number
of reindeer in each Sami community is limited and the number is decided externally
by the County Administrative Boards – reindeer herding always been up against it.

"If this (the climate changes) continues it is going to be very hard to herd
reindeer, with more of these bad falls and winters. There is no economic
room for that...you are going to need such a large herd to make it." herder 16

The adaptation possibilities are also limited by the constant de-prioritization of Sami
interests in the favor of other sectors – competing businesses are increasing. Loss of
pastures due to encroachment and fragmentation of pasture land is a serious challenge.
No new land is given when historical grazing lands are lost to competing industries
like wind– and hydro power, roads, mines, car-testing arenas etc., undermining the
foundation for the whole trade – grazing lands are continuously shrinking. In her
thesis analyzing Swedish reindeer husbandry governance Annette Löf showed how
the adaptability of Swedish reindeer herders is being challenged by political limits
and barriers and how the adaptive space is shrinking from accumulated pressure
from competing land use, predator pressure and institutional limitations [76]. She
concludes that “reindeer herding has an inherent resilience, but as reindeer herding
has become imaged in terms of an industry, that is reindeer husbandry, resilience has
decreased and vulnerability is reinforced by the governing system” [77].

The Sami parliament, established in 1993, is constructed as a representative body
elected by the Sami people and at the same time it is a government agency under
the Swedish state. This dual role constitutes a structural obstacle to Sami self-
determination. It was initially a deliberate construction in order to increase the Sami
influence without creating self-determination, however this basic construction still remains [78] – powerlessness in the face of the authorities.

In cultural anthropology hope is one of the most important determinants of resilience. The hope or “meaning making” that is referred to entitles the belief that the future matters more than the adversities and setbacks in the past [79]. Hope was not a prominent feature in the interviews when talking about climate change and the future for reindeer herding. In contrast, climate change was yet another stressor for the trade, there was a sense of grief for the future and many expressed deep concerns about the prospects for the trade and doubts about their children’s possibilities to inherit the profession – the last generation. Instead of hope a pressure to stay hopeful was described – pressure to be positive:

"The future for reindeer herding…well…I have children who believe in it. And I try to think – well, to think positively for their sake too. And for my sake as well. It’s just that I can’t be negative and pessimistic; it would undermine their hope and belief and future prospects. So you just have to bear it and keep on fighting.” herder 9

As described in the background, mental health issues and suicidal exposure are not uncommon in the Sami reindeer herding society. In a recently published study of the cultural meaning of suicide among Swedish Sami, a current situation is described where committing suicide might be used as a way of strengthening one’s Sami identity when it is threatened [43]. Research has also shown that Swedish Sami reindeer herders’ confidence in health care is significantly lower for primary care and psychiatry compared to a control population. The lack of confidence was based on the experience of health care staff being poorly informed about Sami culture and reindeer herding resulting in culturally inappropriate treatment and recommendations [80]. In view of these circumstances climate change, as yet another stressor, potentially pose a threat not only to health but to the lives of reindeer herders

Assessment of climate changes in northern Sweden

One hypothesis for the mixed-method study was that human perceptions, especially indigenous peoples leading traditional lifestyles, are highly sensitive to climate change effects, and meteorological instrumental records would support their observations. The results supported this hypothesis. The herders reported extensive changes, some of which they started noticing already in the 1980s. The quantitative analyses supported three out of four descriptions but despite some numerical trends reaching a near 50% or more reduction as was the case for days in prolonged cold periods in Storlien, trends were still not statistically significant in all stations (paper II). Statistical analyses are constructed to reduce the importance of outliers and extreme events thereby rendering them a lower sensitivity to small and slow changes over a prolonged time period; it simply takes much more data over a prolonged time period to discern such trends. Hence these methods are not ideal for early change probing. The descriptions by the herders of dramatic changes in weather and climate were not at all as visible in the weather data, and the magnitude and impacts of these changes were impossible to
discern in the statistical analyses. On the other hand, the instrumental weather data provide a scale that anyone can relate to. A less context-bound measurement of the observed changes also increases generalizability outside the reindeer-herding situation. A two full month shortening of the snow cover season is easy to apprehend, and the consequences of such a change on any outdoor winter activity becomes obvious. In addition, communication of intelligible images is key to success when trying to change the public opinion or behavior. In relation to the changes described here the surface albedo feedback mechanisms of the Arctic climate change may very well be under operation also in northern Sweden.

The changes in winter temperatures described in this thesis are going to have important consequences for northern Sweden, a region where the winters constitute a substantial and important part of the whole year. The unexpected change in temperature distributions with a much more rapid decrease in the very coldest days with a less pronounced increase in the warmest temperature and the subsequent compression of the temperature distribution center is particularly worrisome. Activities like downhill as well as cross-country skiing, snowmobile driving, ice fishing and ice-skating are impossible without snow or ice. Important industries such as winter car testing and winter tourism are dependent on stable winter conditions. In Arjeplog, for example, the population doubles every year when 3,000 engineers arrive to test cars in the harsh winter conditions. The estimated economical value of this trade is 150 million euros each year for the local economy [81]. In a study of climate change effects on Alpine skiing in Sweden published in 2007, the monetary loss of the predicted decline in the number of skiing days due to modeled climate change effects was estimated to an amount larger than the total current national ski-ticket sales [82].

Another hypothesis in the mixed-methods study (paper II) was that human perceptions might also be able to discover ongoing (hitherto not reported, recognized or studied) climate change effects. The contradictory finding regarding the observations of rapid fluctuations in temperature becoming more common was especially compelling but could represent such an effect. This phenomenon of increased weather and temperature variability has been reported from many indigenous peoples all over the world in Arctic as well as non-Arctic populations. Examples of Arctic populations who have reported this are Russian Nenets, Alaska natives, Canadian Inuit and Finnish reindeer herders [7]. How grave these changes appear to the indigenous peoples is illustrated by the following quote by Heikki Hirvasvuopio, now a retired reindeer herder for life, in Snowchange [83]:

"Today we can have almost 30 degrees of variation in a very small time frame. In the olden days the Sami would have considered this almost like an apocalypse if similar drastic changes had taken place so rapidly."

Several of the observations articulated in the interviews are shared by many Arctic indigenous peoples, i.e. the warmer winters, the lack of cold spells and the early abrupt spring followed by the return of colder weather, to name some. Increased weather unpredictability and more extreme weather conditions are shared observations as well [7]. These phenomena are equally difficult to assess with experimental weather data but raise concerns about the underlying causes.
Tularemia’s climate change sensitivity status is based mainly on its vector-borne transmission routes and natural hosts habitat limitations. The very rapid tularemia increase rate in the southern boreal forest region of Sweden documented by this work intuitively contradict a causal relationship to climate change. On the other hand, the most pronounced increase in incidence is occurring in the mountainous areas in the northwest. This concurrent expansion of tularemia in the southern boreal forest region and the Arctic/alpine region indicate that there may be multiple mechanisms involved in the disease expansion. The lack of knowledge on tularemia ecology and on levels of disease exposure in inhabitants in these areas prevents identification of those mechanisms and how they are affected by climate alterations. The climate change sensitivity status of *Francisella tularensis* might have to be revisited once we know more.

Tularemia is widely distributed over age groups from the very young to the very old although the incidence increases with age. The bimodal age distribution found it the large tularemia dataset was visible as well in the much smaller subset of the 2012 outbreak. The same age distribution was seen in a study of 190 tularemia cases between 2000 and 2007 in Missouri, USA. Similar bimodal age distributions have been identified for other infections. One example of a disease displaying a similar distribution is Lyme disease or borreliosis, caused by the spirochete *Borrelia burgdorferi*. This is a frequent vector-borne disease that is less common in the northern part of Sweden although it is currently increasing as the vectors – *Ixodes ricinus* ticks – are moving north along with the warming winters. Lyme disease includes the clinical manifestations of erythema migrans, neuroborreliosis and Lyme arthritis. In a German study of 18,894 cases notified from 2009 to 2012, the case age distribution displayed incidence peaks in the age groups of 5–9 years old and adults 60–69 years, with the lowest incidences among 20–24 year olds. A Danish study investigating the presence of the intestinal protozoon Dientamoeba fragilis using the PCR technique in 22,000 faecal samples also found a bimodal age distribution with the lowest carriage rates in 20–24 year olds. The reason for this bimodality is unknown and could reflect behavioral or immunological factors or a combination of these factors.

The connection between *Francisella tularensis* and the presence of natural waters such as streams and lakes has been suggested but not scientifically evaluated before, in this thesis correlation analyses are presented. The correlation of tularemia incidence and inland water found in the large epidemiological investigation together with the dose-response relationship found in the investigation of risk factors during an outbreak (paper IV) provide strong evidence of a connection. The nature of this relationship, however, remains undiscovered. The presence of *Francisella tularensis* in natural waters has been shown in a number of studies but the nature of a bacterial host in water reservoirs and the way the bacteria enters the disease transmitting vectors are unknown.
Tularemia has a well known markedly uneven geographical distribution visualized by three methods applied in this thesis. First in the investigation of the 3,524 cases over a 29 year period that were geographically analysed, then in the outbreak investigation and finally through the sero-prevalence investigation, however the distribution of sero-positive samples were also affected by the sampling procedures. Once established in a locality it seems to reappear at varying time intervals. National tularemia incidence correlated with the number of local outbreaks suggesting that there is some common factor that triggers tularemia outbreaks in many different locations at the same time during outbreak years.

A previous study of tularemia distribution has also indicated a very rapid geographical expansion, although on a much larger scale. Investigations into the genetic diversity of *F. tularensis* subspecies showed that subspecies holarctica was genetically monomorphic and genetical analyses of isolates from the United States and Sweden indicate very recent common ancestors in spite of their great geographical disparity. The authors concluded that *F. tularensis* spp. *holarctica* is likely to have recently expanded across the northern hemisphere and suggest that one reason for this rapid expansion could be spp. *holarctica* ability to infect a very wide range of host species without killing them [58]. The possibility of several different reservoir species could potentially explain the simultaneous southward and Arctic/alpine expansion of tularemia shown in this thesis.

The serological investigation revealed a high number of sero-positive individuals compared to the number of reported cases. With the level of sero-positivity set to 100 relative ELISA titers we found positive tests corresponding to 16 times more cases than the ones reported under the eleven years prior to the investigation. The 100 cut-off equals what is considered a positive level during an acute infection. For a serological investigation with the purpose of estimating the prevalence of past disease in the population a lower cut-off would probably be more accurate. Based on the distribution of the ELISA titers, a strictly mathematical statistical model suggests the optimal cut-off would rather be somewhere around a relative ELISA titer of 40 or even less in our study sample. This however implies using data affected by the well-known extensive background “noise” of ELISA results in the lower intervals. Applying that cut-off on our data suggests a sero-prevalence of 12 % (181 samples had ELISA titers over 40). This percentage would correspond to over 37,000 cases of tularemia in Norrbotten and Västerbotten; a number that seems extremely large given that tularemia is considered a disease connected to distinct acute symptoms that should cause infected individuals to seek healthcare. How sero-prevalence corresponds to actual past infections varies greatly with different diseases and the behavior of the antibodies over time varies as well. None of these phenomena are very well studied, for tularemia as well as for most diseases. To further explore and evaluate the best cut-off for sero-prevalence investigations would be of great value for the future monitoring of climate sensitive infections.

There are several possible interpretations when finding a higher than expected number of sero-positive individuals. Tularemia is considered to create life-long immunity, which means that you only get the infection once, although reinfections can
occur at exposure to extremely high infection doses as described in the background. Previous studies have shown that tularemia antibodies can remain detectable as long as 11 years after the acute infection [61]. How long the antibodies can actually persist needs to be further investigated; in this study two individuals displaying positive titers above 100, reported being infected with tularemia more than 30 years ago (1969 and 1970). If the antibodies are still detectable after 30 years or more, the sero-prevalence would represent cases accumulated over a longer period of time than taken into consideration in this thesis.

Some antibodies can cross-react with antigens other than the one of interest. Antigen cross-reactivity of \textit{F. tularensis} is rare but the possibility of cross-reactivity cannot be ruled out as a cause of high levels of sero-positivity. "Antibody boosting" could also explain titers remaining for a prolonged time period, like in the case of the two individuals in the sero-prevalence study. Re-exposure to the infectious agent by a person carrying protective antibodies could possibly amplify or “boost” the existing antibodies, thereby raising levels in an individual with low levels. Another more plausible explanation is that there might be a large number of subclinical cases among the sero-positive individuals. Subclinical disease means that you contract the disease but the immune system cures it without any evident symptoms, hence you develop antibodies without actually being sick. We do not know how many, if any, subclinical cases there are for each clinical case of tularemia. Finally there is the obvious possibility that the antibody titers actually represent a previous tularemia infection in all sero-positive individuals although very few of them were reported. This would imply a very substantial burden of disease for Norrbotten and Västerbotten counties. Considering the rate of increase in tularemia incidence, a public health authority focus on mitigation strategies could be recommendable, including attempts to identify high-risk groups and areas.

\textbf{Tularemia and reindeer herders}

Considering the well-known tularemia risk factors of hunting [57] and mosquito bites, together with the risk factors of living close to water and forest identified in this thesis, it would be interesting to conduct a tularemia sero-prevalence study on reindeer herders. Tularemia sero-prevalence has been studied in indigenous hunters and gatherers in Alaska where both tularemia type A and B exists. A study in the 1960s of 793 men from three indigenous groups of Alaska Natives showed an overall detection rate of 18\% [89]. Another survey in 1974 tested two different groups of Alaska Natives and found 4\% and 7\% sero-positivity, respectively [90]. A thorough serological investigating of reindeer herders paired with interviews about historical clinical symptoms could add important information on the hidden burden of disease as well as about subclinical disease. Reindeer herders’ access to and confidence in health care is limited by social and geographical factors as well as by the nature of their occupation [80]; hence only very grave symptoms would make a herder seek medical attention and a large proportion of undiagnosed cases could be suspected. Serological investigation of the populations in some of the most pronounced high-risk communities is another interesting option to further investigate the burden of hidden disease.
Conclusions

The overall pattern of evidence supported by the studies contained in this thesis suggests impacts of climate change on well-being are emerging in northern Sweden. The extensive effects of climate change on northern Swedish winters pose a threat to the health and well-being of the traditional reindeer herders of Sweden. The underlying circumstances that constitute the foundation for the reindeer herders’ vulnerability seem to be mainly societally, legally and politically induced. Further adaptation to present and future climate changes, as well as adjustments of the current rules, regulations and attitudes towards reindeer herding are necessary to facilitate resilience, crucial to managing vulnerability among those most impacted. Examples of such adjustments could be mandates, which increase Sami influence on decisions regarding land use in regions where reindeer herding is being practiced, for example, in determining areas for the establishment of new mines and wind park installations. Land lost to competing industries could be compensated. Increased influence on logging and deforestation to preserve forests with arboreal lichen in the winter grazing areas and along migration routes are other options.

The nature and extent of the changes to northern Swedish winters warrant further and more detailed local and regional weather data monitoring and analyses. The unexpected more rapid decrease in the very coldest temperatures, as well as the diminishing snow cover season are alarming and might require strong adaptation measurements in the coming decades by communities, who depend heavily on winter activities and/or winter tourism.

The investigations into tularemia epidemiology revealed a rapid and quite substantial geographical and numerical increase in tularemia cases during the three decades investigated. Even though this increase coincides with the equally rapid concurrent climate changes, this thesis provides no direct evidence for an assumed Francisella tularensis climate sensitivity itself. There are climate factors that govern transmission in terms of vector dynamics, which do impact when and where persons may become exposed. However, here are also other factors unrelated to climate and climate change known to impact transmission patterns as well, which may be changing simultaneously. Climate and weather may have impacts on individuals’ exposure to vector-borne disease in a variety of ways; however, disentangling the net contribution of climate change to observed disease increase is difficult to attribute in isolation. The correlation to water, identified using two different methods, further supported by the correlation to certain eco regions, suggest that tularemia transmission is closely tied to certain micro-environments. We have detected an expansion of disease transmission locations and numbers, consistent with other evidence from vector-borne disease ecology associated with changing climates.

Future research on the relationship between tularemia and climate change should focus on identifying these higher risk micro-environments, understanding the factors that trigger local and regional expansion, and the extent to which outbreaks of tularemia are climate or weather-driven. The uneven distribution of the disease with
very high incidence in some communities suggests that preventative measures could be developed, if the outbreaks could be predicted. The tularemia disease burden appears to be much higher than expected indicating a large number of undiagnosed or sub-clinical cases. Increased disease awareness among doctors and other health care staff could lead to more cases being found and treated. Future sero-prevalence studies in high-incidence communities and risk groups are recommended. Enhanced clinical detection and surveillance in combination with information gained from sero-prevalence could be combined with eco-epidemiological evidence to contribute further understanding of environmental determinants of tularemia and development of more sophisticated prevention and control strategies.

Towards the Limits

The title of this thesis refers to a common theme of change, movement and stretching boundaries in all four studies. *Paper I* shows how the reindeer herders – in the face of climate change – are facing their limit of resilience. *Paper II* describes the ways winters of northern Sweden are approaching the limit of being winters, as we know them. *Paper III* illustrates how tularemia is expanding its limits both in geographical and numerical terms, and finally *paper IV* reveals that tularemia in northernmost Sweden is not as limited as we think.
Personal reflections over my PhD process

The following quote comes from a paper published by Brace and Geoghegan in 2010. In just a few words this paragraph manages to encompass the complexity of problems surrounding the concept of climate change that I have become aware of since I started working on this thesis [91]:

“‘Climate change’ is an ideologically charged phrase, a thorough unpacking of which is beyond the scope of this paper. Nevertheless, we wish to acknowledge the inconsistencies and ambiguities that stalk the phrase, along with the intellectual ideological loading, the assignment of cause, the attribution of blame and the patina of doubt that surround the term”

From the very beginning of my medical studies some things about the biomedical paradigm chafed me – the lack of humility, the claims of absolute truth, the complete faith in randomized controlled studies as well as in evidence based medicine and the lack of self-criticism that occasionally characterize natural science in general and medical doctors in particular. Where were the individuals, the lived experience, the nuances, and the people I was interested in, in all of this? I still remember the first time I learned about the concept of paradigms in medical school; it was a true Eureka moment since it could in part explain my discomfort and helped me understand that there are other ways of seeing things than the medical perspective provides.

The PhD process has given me the opportunity to discover many different paradigms and ways of approaching the truth and has also helped to establish a domicile more comfortable for me within the field of science. Most enriching throughout this process was the aspects brought in by the selection of reindeer herders as interview subjects for my qualitative work. At first, as ignorant as so many scientists before me and probably most Swedes in general, I simply saw the reindeer herders as the most knowledgeable providers of the information I wanted; i.e. climate change effects. My interviews opened up a completely new world to me and it was an amazing experience. I soon discovered how extremely political everything concerning Sami was, and that surprised me. Being brought up in Piteå in Norrbotten I viewed reindeer herders as any professionals. Learning about the Sami context, culture and society and discovering the total silence surrounding it and how it sits within the major Swedish society has been a true journey for me. Norrsam is a loose network of young researchers from any faculty at Umeå University with a research connection to Sami and it is dominated by political scientists, historians and PhD students and post-docs from mainly non-medical faculties within the university. The discussions and seminars held in Norrsam sessions have been extremely valuable and increased my critical attitude, enhanced my scientific knowledge and augmented my academic curiosity.

The lack of political connotations of tularemia has been a relief since climate change research has vast political implications and everything concerning the Sami people
is very political. Getting to know the different cultures characterizing the unit of Clinical Microbiology as well as Epidemiology and Global Health has been fruitful for me as a researcher too. The two cultures are very different and navigating here has been an interesting challenge.

I am so very grateful to have been given the opportunity to do a PhD and continue learning, developing and experiencing new things on a daily basis, having fun almost all the time and expanding my sphere of knowledge into the lovely exciting unknown.
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