A thesis submitted to the Department of Environmental Sciences and Policy of Central European University in part fulfilment of the

Degree of Master of Science

Modeling and Assessment of Current and Future Changes in Reindeer Habitat in Finnmark, Norway, Using Remote Sensing, GIS and Indigenous Knowledge

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ABSTRACT OF THESIS submitted by:

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for the degree of Master of Science and entitled: Modeling and Assessment of Current and Future Changes in Reindeer Habitat in Finnmark, Norway, Using Remote Sensing, GIS and Indigenous Knowledge

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Reindeer husbandry in Norway comprises around 40% of the whole country's surface area. Livelihood of indigenous herders Sámi almost fully depends on the well-being of their herds. The majority of the herds is concentrated in the northernmost county of Norway – Finnmark. Current climate conditions in the Arctic bring warmer and longer summers that enhance plant productivity and reduce the duration of the period of snow cover. However, at the same time some pastures are being overexploited by infrastructure development or simply overgrazed. In the following research the author tried to identify and assess the current changes in land use / land cover with the help of remote sensing, to model transition potential and predict future land cover of the study area, and to model reindeer habitat suitability of current and future pastures. It was found that the area of mountain birch forest has been expanding as well as the barren land area with very sparse vegetation at high elevations of summer pastures. On the opposite, the area of mountain heath and shrubs has been decreasing. In terms of reindeer habitat suitability, there are no significant changes happening. However, the unsuitable area is slowly expanding. Also, the developed methodology showed how remote sensing and GIS-based modeling can be essential tools in assessment of reindeer habitat suitability.

Keywords: Reindeer herding, Finnmark, remote sensing, GIS, land change modeling, LULC, spatial modeling, habitat suitability

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List of Abbreviations

DEM – Digital Elevation Model

GIS - Geographic Information System

GPS – Global Positioning System

HS – Habitat Suitability

LCC – Land Cover Change

LULC – Land Use / Land Cover

ROS – Rain-On-Snow

RS – Remote Sensing

1. Introduction

1.1. Background and problem statement

Reindeer husbandry in Norway occupies around 40% of the whole country's surface area. Traditional herding in the area goes back to the 17th century when indigenous people of the North Saami domesticated reindeer. The livelihood of the Sámi almost fully depends on the well-being of their herds. Herders have been migrating annually following the same routes for centuries, which is an important part of their traditional nomadic way of living (Forbes et al. 2006). The majority of the herds are concentrated in the northernmost county of Norway – Finnmark. This area, as well as the Arctic as a whole, has been experiencing more pronounced changes in annual temperatures than the planet globally (Førland et al. 2009). Current climate conditions in the Arctic bring warmer summers that enhance plant productivity and increase soil mineralization. However, increased occurrence of locked winter pastures will have a negative effect on the reindeer populations (Turunen et al. 2016). At the same time pastures are being overexploited by infrastructure development or simply overgrazed due to unsustainable reindeer management practices. These changes in the reindeer habitat influence the livelihoods of the local communities (Pape and Löffler 2012). Regardless of the impact of climate change in the region, the Norwegian government also assumes that the number of reindeer in Finnmark during the recent decades was too high and pastures have been degrading. The current legislation focuses on setting the highest allowable number per district and Saami herders must reduce their herd sizes. Hence, reindeer husbandry in Norway is a social-ecological system where all actors are interrelated and the adaptive capacity of whole system depends on the dynamics of environment, resources, actors and government (Käyhkö and Horstkotte 2017).

The following research will try to evaluate the state of reindeer habitat in Finnmark, the current and potential future changes in its land cover and will attempt to analyze the sustainability of the population size.

1.2. Research questions and objectives of the study

The following research questions were formulated:

- What are the current and future changes in land cover and reindeer habitat suitability (HS)?
- How can remote sensing (RS) and GIS modeling help in assessment of reindeer habitat suitability?

To answer these research questions, the following objectives were set:

1. To review the existing literature on reindeer habitat in Finnmark, Norway.
2. To overview different RS and GIS modeling tools and methods used in LULC change and modeling and HS assessment.
3. To analyze the land cover changes in the region in the last two decades.
4. To model and analyze potential future Land Use/Land Cover.
5. To identify and analyze the environmental variables and their link to the ecological niche of reindeer.
6. To create a cartographic model of current and potential future reindeer habitat suitability.

1.3. Thesis outline

The thesis paper consists of 8 chapters. **The first chapter** provides background information, problem statement and introduces the aim and objectives of the study. **The second and third**

chapters comprise a literature review. In the second chapter, the author describes specifications of reindeer husbandry in Finnmark and its importance for the region, gives the overview of the area, the evidence of habitat changes, and existing knowledge on the populations' resilience to these changes. In the third chapter, the author introduces the possibilities of the application of remote sensing and GIS tools for habitat suitability assessments, Land Use / Land Cover change modeling and ecosystem management. A detailed overview of these methods is essential to understand the rational of the approach of this research. Also, an overview of the previous research done on application of remote sensing tools for reindeer habitat assessment is presented in this chapter. **The fourth chapter** presents research design and the key steps and methods applied. **The fifth chapter** is dedicated to the description of the particular study area and its characteristics that are important for the habitat suitability modeling. **The sixth chapter** describes the field work data collection. **The seventh chapter** presents the analysis of the data collected and processed. First of all, the satellite images were processed and classified in order to assess the land cover change within the last 17 years. Later these classifications were imported into the modeling software to assess the changes, to identify future transition potential and correlations with various external factors and to map the potential future land cover. Based on the land cover maps and other weighted factors, a habitat suitability assessment was performed. In the final, **eighth chapter** discussion of the results is presented, and the overview of the research and achieved results forms the conclusions section. Also, the author found it important to write about future research directions based on this methodology or the presented results due to the limited time or resources the research has been narrowed down to a small study area.

All maps, figures and tables, presented in the thesis paper were prepared and produced by the author if not stated otherwise.

2. Reindeer populations in Finnmark, Norway: husbandry, habitat and resilience to changes

2.1. Saami herders and semi-domesticated reindeer populations in Norway

The total territory occupied by reindeer husbandry in Norway is 146,451 km^2 which is around 40% of the country's surface area. The total numbers of semi-domesticated reindeers in the country were approximately 242,000 in 1990, 172,000 in 2000, 243,000 in 2007, 258,000 in 2012 and 211,700 in 2016 (Agricultural directorate 2016). According to the report published in 2016, there are 3 185 people involved in reindeer herding in Norway. Saami reindeer herding area is divided into six reindeer pasture areas and into 90 districts (78 summer pasture districts and twelve - autumn and winter). The six areas are East-Finnmark, West-Finnmark, Troms, Nordland, Nord-Trøndelag and Sør-Trøndelag/Hedmark with the highest numbers and densities of reindeers in the first two (Agricultural directorate 2016; Jernsletten and Klokov 2002). Each reindeer pasture area and each summer reindeer herding district has its maximum number of reindeers set by the governmental authorities (Agricultural directorate 2016). Numbers for the areas are presented in the *Table 1*. The winter pastures are shared between several 'summer' districts and are considered as common (Benjaminsen et al. 2015).

Area	Maximum number of reindeers	Gross area
East-Finnmark	71,000	30,757 km^2
West-Finnmark	78,000	25,925 km^2
Troms	13,000	18,277 km^2
Nordland	18,200	32,613 km^2
Nord-Trøndelag	15,900	22,300 km^2
Sør-Trøndelag/Hedmark	13,600	8,598 km^2

Table 1 Allowed number of reindeers per reindeer pasture area and the total area. Source: Resources of reindeer husbandry (Agricultural directorate 2016).

The biggest population of semi-domesticated reindeer herds has always been in Finnmark, the largest and northernmost county in Norway almost fully represented by reindeer pastures (*Figure 1*). In 2016 there were 2398 registered reindeer owners in Finnmark which is 75% of all herders in Norway and 146,246 reindeers which is 69% of semi-domesticated reindeer populations in the country (Agricultural Directorate 2016). According to this data, the average density of reindeer per km^2 in Finnmark is 2.44 reindeer/km^2 as the total area is 59,757 km^2. But the density is not the same in different districts and municipalities within Finnmark (Tømmervik and Riseth 2011). In 2016 herd composition in Finnmark was 5% males, 77% females and 18% calves. This is mainly due to the fact that young male reindeers are culled. In 2016 in East Finnmark 26530 reindeers were slaughtered (40% of the herd) and in West Finnmark 30584 (39% of the herd) (Agricultural Directorate 2016).

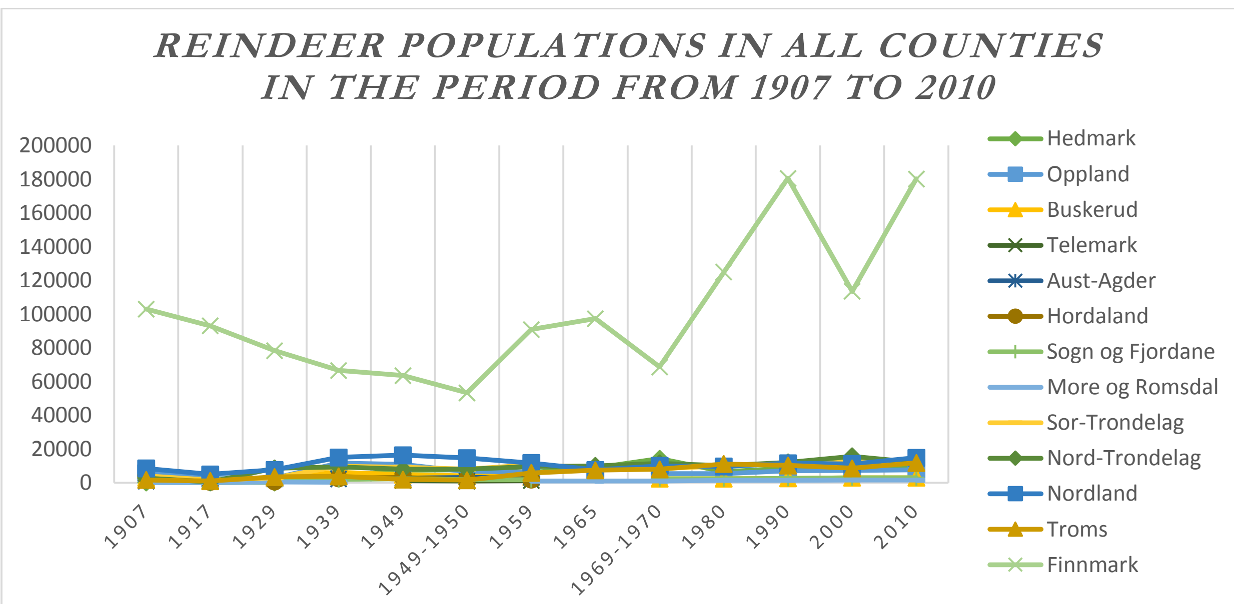

Figure 1 Reindeer population in all counties in the period from 1907 to 2010. Source: Tømmervik and Riseth 2011.

Finnmark reindeer herds migrate twice a year - from winter to summer pastures and back. In spring herds start to move to the mountainous coastal pastures (*Figure 2*). During spring their diet mainly consists of lichens while they are moving towards the calving pastures. In the beginning of summer when the calves are born females need to restore their energy and feed predominantly on emerging vegetation and young birch and willow leaves. However, after losing antlers in spring, females are extremely sensitive to disturbances and if frightened, might move to less nutritious vegetation but further from disturbance factors. During summer reindeers need to fill up their reserves for winter so they feed on various forbs and grasses in the rich summer pastures of Finnmark (Käyhkö and Horstkotte 2017; Tyler et al. 2007; Forbes et al. 2006). Also, it is known that higher quality summer pastures are at gentle slopes and depressions (Pape and Löffler 2012).

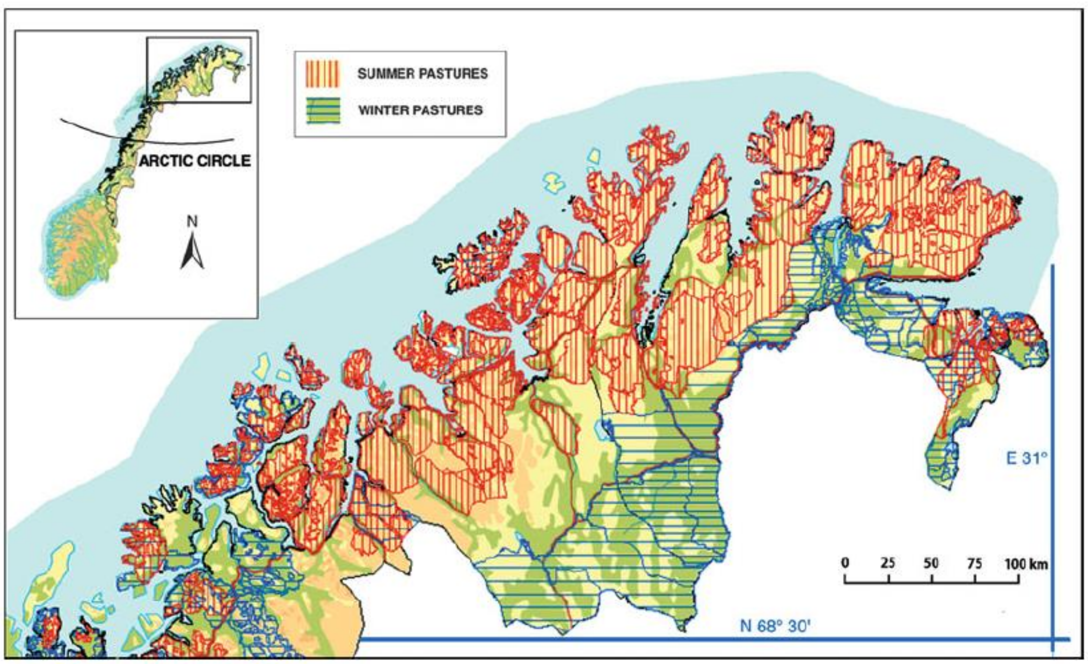

Figure 2 Finnmark with summer (red) and winter (blue) pastures. Source: Benjaminsen et al. 2015.

In the end of September reindeers start to move to autumn and winter pastures. Continental winter pastures are mostly represented by birch taiga with some wintergreen forage for reindeers and by boreal forests. Mean winter snow depth in Finnmark ranges from 8 to 140 cm and the deepest snow pack can be found along the coast (Tveraa et al. 2007). With snow layer accumulation reindeers move to higher elevations to a thinner snow layer where they can easier dig for lichens. According to various research papers, a typical reindeer winter diet is comprised of up to 80% of lichens (Pape and Löffler 2012). But as they are rich in carbohydrates and low in protein, it cannot be the only feed for animals during the season. The availability of winter forage is crucial for reindeer's calving success and survival, so the quality of winter pastures might be considered the most important factor affecting reindeer husbandry (Käyhkö and Horstkotte 2017; Tyler et al. 2007; Forbes et al. 2006). The climate pattern determines this traditional migration. Winter on the coast is wet and severe, snow pack is dense and icy, and reindeers would not be able to reach to forage and would starve (Tyler et al. 2007).

In research done in another reindeer herding area (Russian Acrtic, Nenets Autonomous Okrug), the authors suggest that the maximum sustainable density for reindeer should not exceed about one or two animals/km^2 (Rees, Williams, and Vitebsky 2003). According to the research made by Danell, Holand, Staaland, and Nieminen in 1999 on reindeer's forage needs, reindeer daily intake in summer is up to 2.5–2.9 kg of dry matter. During winter reindeer adapt to forage lower in protein and their intake becomes 1.6–1.7 kg dry matter per day (Pape and Löffler 2012). Few studies claim that the lichens biomass has been declining since 1970s and that it has been happening because of the increased number of reindeer in Finnmark and overgrazing of winter pastures (*Figure 3*) (Riseth, Johansen and Vatn 2002).

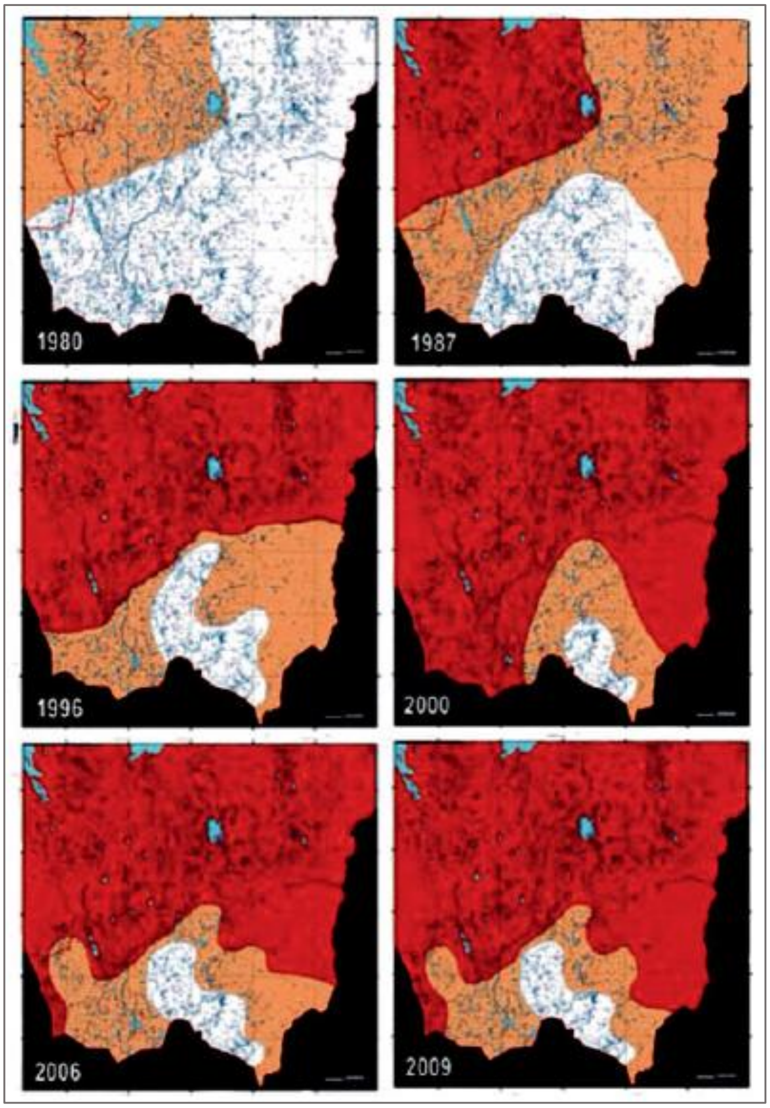

Figure 3 Overgrazing on the winter pastures in Finnmark; red = overgrazed, orange = moderately grazed; white = intact. Source: Benjaminsen et al. 2015.

2.2. Trends and threats for reindeer habitat in Finnmark

Even in Finnmark, territory almost fully represented by reindeer herding areas, some pastures are being lost due to encroachment and intrusions such as mining, infrastructure growing, wind power development and other activities. Also, according to the review of multiple regional research papers made by Vistnes and Nellemann, the majority of the reindeer population reduced the use of territories that are 1-5 km close to development area by 45-95%. However, reindeer still may be met close to infrastructure (Vistnes and Nellemann 2007).

Predators are one of the major threats for reindeer herds on a daily basis and is the reason for greatest losses. According to statistical data published, from 20 to 22% of herds was lost in 2015/2016, out of which up to 93% was due to predators (Agricultural Directorate 2016). The biggest impact is caused by wolverines and golden eagles. According to NINA's report lynx eats from 8 to 22,5 reindeer per month (Tveraa et al. 2013).

Another important threat to reindeer habitat mentioned in a lot of research papers from different perspective is a pronounced climate change in the region. Climate change may affect reindeer habitat both negatively and positively. One of the research papers summarized possible effects and consequences of climate variability for reindeer herds (

Table 2):

Pasture	Change	Effect	Consequence
Summer	Prolonged growing season and higher temperatures	Increased plant productivity Changed nutrient quality in plants Changes in vegetation Trophic mismatch Increased insect harassments Changed balance between summer and winter pastures	Positive: more forage available Ambiguous Ambiguous Negative: less forage available Negative: higher energy expenditure Ambiguous
Winter	Higher temperatures, increase in freeze-thaw cycles, increase in precipitation	Decrease in overall snow cover Increased probability of locked pastures Risk of lichens being out-competed	Positive: more forage available Negative: less forage available Ambiguous

Table 2 Climate change effects on reindeer pastures and resulting consequences. Source: Pape and Löffler 2012.

Longer summers with increased plant productivity and decreased snow cover might make the conditions better and increase reindeers' growth rate. It has been discovered through NDVI (Normalized Difference Vegetation Index) that between 1982 and 2012 about a third of the terrestrial Arctic has greened (IPCC 2014). But there are a lot of other factors to take into account such as increased insect harassment or more unpredictable extreme weather conditions. One of the crucial consequences of climate change affecting reindeer habitat is the increased frequency of rain-on-snow events. When mild weather with rain is followed by a colder period, a layer of ice is formed. This phenomenon is called rain-on-snow. Later when the snow falls, this ice layer gets thicker and can become impenetrable for animals and blocks their access to food. When this happens in the area of reindeer winter pastures, animals do not have access to forage and if there is not enough supplementary feed, they starve. Hansen et al. conducted research that empirically proved that rain-on-snow events reduce reindeer population growth rates. Also, their model predicted that these events will be increasingly common (Hansen et al. 2011). The object of their research was Svalbard wild reindeer populations. However, their findings are relevant to other reindeer populations since it is the same species. The fact that Svalbard populations are wild give a better understanding of the correlation between the frequency of rain-on-snow events and population trends as there is no supplementary feeding that could affect the accuracy of the findings.

3. Remote sensing and GIS modeling for ecosystem management

3.1. Remote sensing: environmental application

The opportunity to send satellites to space and receive the space-born digital imagery have enabled an endless number of new research approaches. The term *remote sensing* refers to observing the Earth from a distance through satellite sensors or aerial photography in order to detect and classify various aspects of Earth's surface and to obtain the information about the state and condition of an object (Chuvieco and Huete 2010). Remote sensing also comprises processing, interpretation and analysis of the digital images that give an opportunity to monitor the state of ecosystems and changes happening on the Earth's surface. Such data can be used for a wide range of environmental applications such as the monitoring of natural resources or disaster risk analysis. What makes remote sensing data invaluable is a global coverage with series of consistent and comparable information, capability to acquire data over the nonvisible regions of spectrum (infrared, near-infrared, shortwave infrared, ultraviolet), and prompt transmission of imagery (particularly useful in disaster management) (Lloyd 2006).

To identify various types of vegetation canopies is one of the important challenges for remote sensing. Specific biochemical and biophysical attributes of leaves determine the reflectance of the vegetation cover and their spectral properties differ too. The spectral domains that are able to differentiate vegetation optical properties are visible region, near-infrared region and shortwave infrared region (Wang and Weng 2013). For example, by spectral rationing of near-infrared and red bands the user can analyze the amount of green vegetation as the larger the contrast between these values in one pixel, the bigger amount of green vegetation there is (*Figure 4*).

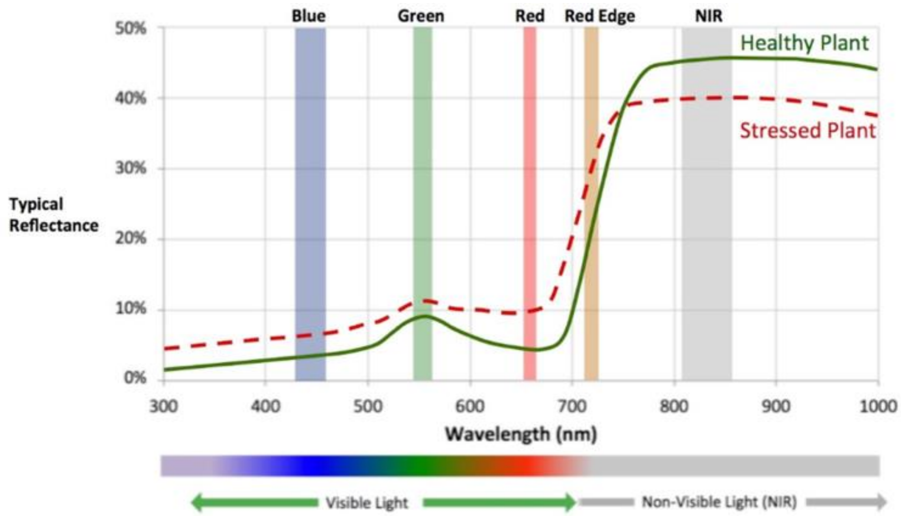

Figure 4 Typical reflectance of plants across the visible and non-visible light spectrum. Source: Chuvieco and Huete 2010.

Landsat satellites have provided continuous high-quality imagery of Earth's landcover for over 40 years that has a global coverage and is available in open access. Onboard Landsats there are multispectral scanner (MSS), thematic mapper (TM) and enhanced TM Plus (ETM+) (Wang and Weng 2013). Starting from Landsat 4 and 5 these satellites had an improved multispectral scanner sensor designed specifically for detecting and monitoring the vegetation cover.

3.2. Image processing: Classification methods, change detection techniques and analysis of land cover pattern

Nowadays satellite imagery is the ultimate tool for systematic land cover change monitoring. Digital image classification is a way to assign each pixel to a particular thematic category and that is a way to create a thematic map. The common procedure of working with a satellite image is presented on *Figure 5*. The first step is to define the research objectives and assess the availability of time and resources. The next step is to collect the data about the study area, its environmental characteristics and associated land use patterns that could be helpful for the image selection, and field work during which the ancillary information can be obtained that will be used later during the image interpretation or analysis.

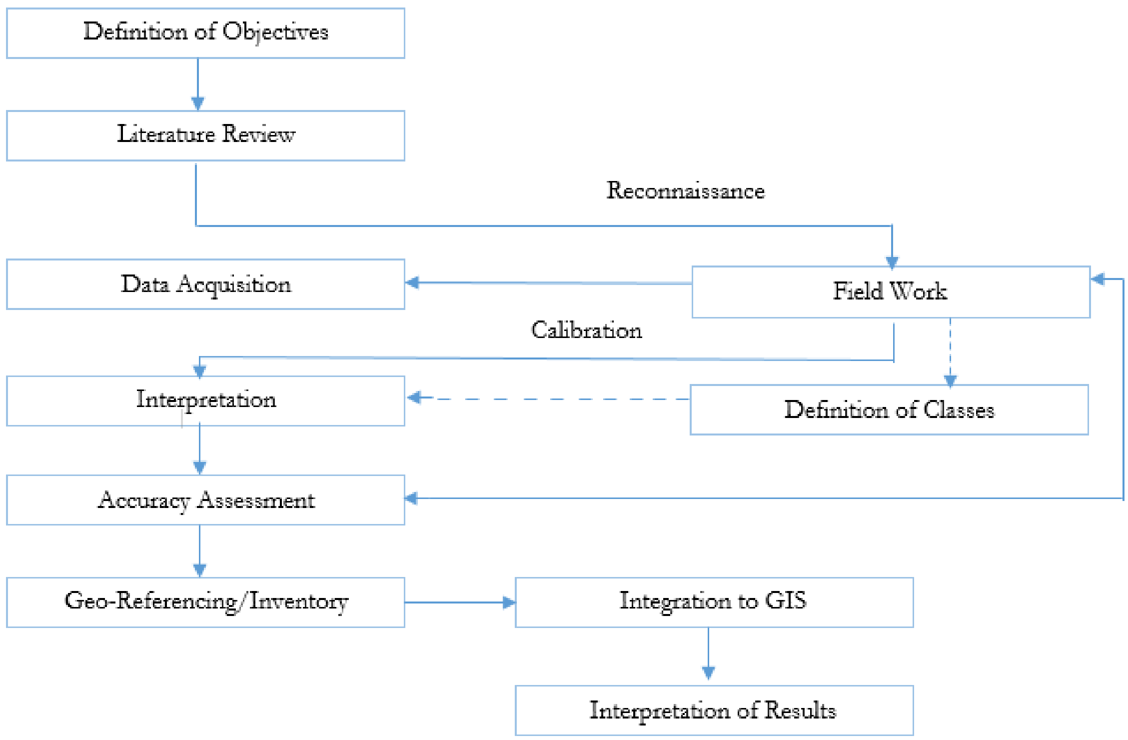

Figure 5 Common procedure for the interpretation of remote sensing imagery. Source: Chuvieco and Huete 2010.

The closer the field work to the date of acquisition of the image, the higher the accuracy of interpretation. After the data about the study area is collected and processed, the satellite images should be selected based on the knowledge of what sensors are needed for the research, what dates, number and area covered should be presented. The human analyst must define the land cover categories also based on the knowledge about the study area and then interprets the images (Chuvieco and Huete 2010). After the accuracy of the classification has been verified and the geometric correction performed (if conversion to a standard system is needed), the results are integrated into the GIS project. The last step is the interpretation of the results – quantitative or qualitative, as a final product or incorporated with other spatial information (Brimicombe 2009).

Classification of two images of the same area but from different dates allows users to evaluate the changes happened in the land cover within that period. Moreover, an accurate classification of two or more satellite images allows to make a quantitative analysis of such processes as deforestation, oil spill expansion, urban growth and any other land cover transitions. There are three main approaches to classify a satellite image: supervised, unsupervised and mixed classification (Wang and Weng 2013). In case of supervised classification an interpreter needs to know the categories of a few sufficiently representative zones within the image area and to use them as training fields for classification. It is very important that the reference information used for training of the system is as close as possible for the data acquisition. The categorization process (assigning each pixel to a category) can be done through such approaches as minimum distance, parallelepiped and maximum likelihood classifiers. The method of unsupervised classification resides in the grouping of image's pixels with similar digital levels into spectral classes. Here the interpreter does not need to train the system with reference training fields. His job is to assign the resulting groups to a thematic category (Bossler et al. 2010). Both methods have their advantages and disadvantages. Supervised classification can be biased as the interpreter sets the categories without taking into account the spectral characteristics of pixels, the unsupervised method comes with a risk of meaningless classes as similar spectral characteristics sometimes can belong to different categories. That is why interpreters are working on introducing mixed methods that would reduce the risk of mistakes. One of such mixed approaches is an unsupervised classification of the image pixels by their spectral values into clusters and then supervised guiding of each cluster to the known thematic categories. There are other methods such as the decision tree classifier, neural networks, fuzzy classification, etc. but within this research these approaches were left out of discussion (Steinberg and Steinberg 2015).

3.3. Transition potential and future land cover modeling with TerrSet (geospatial monitoring and modeling system)

Modeling of transition potential is assessing the likelihood of land cover change from one category to another based on the presence of driving force and suitability of area for the transition (Maguire, Batty, and Goodchild 2005). Modeling of the potential future land cover is based on the transition potentials of the land cover categories. One of the most widely used modeling approaches for predicting future LULC and dynamical spatial modeling for GIS is the Cellular Automata (CA) model. In a cellular automaton, each pixel of the raster is assigned to one of the categories. In one time step the category of the cell can change depending on neighbor cells' categories and the transition suitability of the cell (Maguire, Batty, and Goodchild 2005). In CA modeling decisions and transition suitability are specified locally for each cell and change patterns of the land cover are created bottom up (Andrew Crooks 2017). Markov Chain analysis is another transition probability model/mathematical system based on the process where one state of the process (a set of values) can be changed to the next one based on the previous and the model defines the probability of this change to happen (Maguire, Batty, and Goodchild 2005). Land Change Modeler in TerrSet has integrated both of these models. TerrSet software is a Geospatial Monitoring and Modeling Software developed by Clark Labs in 2015 based on IDRISI GIS (Clark Labs 2015). CA_Markov is a modeling tool in TerrSet software, which combines Cellular Automata and Markov Chain modeling. Based on those two schemes TerrSet software allows to create from two LULC maps of the same area a raster file of transition potential of pixels: higher or lower possibility of each pixel to undergo transition from one class to another. This raster is created based on variables – imported raster files that up to the human analyst's knowledge might be correlated to the change happened earlier. Those variables can be static or dynamic. Just one, few or all sub-models (transition from one specific category to another specific category) can be incorporated into the transition potential modeling. Subsequently, based on the transition potential map, the predicted land cover map can be created for the specified year considering the same influencing variables will be taking place (Eastman 2015).

3.4. Habitat suitability modeling

Spatial data analysis is a process of manipulating attribute data related to exact coordinates. A chain of various spatial operations and functions consisting of calculations with input data attributes allows to address a lot of questions such as species habitat or wind/solar power farm suitability (Bolstad 2012). The key approach to habitat suitability spatial modeling is analysis of various environmental variables affecting the habitat and wellbeing of the species, and extracting/classifying these quantitative or qualitative information through calculations with the gridded data. Some researchers use the terms of habitat suitability modeling and ecological niche modeling interchangeably. Environmental variables most commonly are land cover type, distribution and distance to disturbances, physical and biological characteristic of the optimal/unsuitable habitat, etc (Hirzel and Lay 2008). Such modeling needs to be based on the extended research on species' ecological niche characteristics so the modeler can select the appropriate variables, assess interactions between them and assess the fitness response of the species to those variables. The spatial operations used in almost every spatial habitat suitability model are Boolean algebra, reclassification, proximity functions, buffering, overlaying. Boolean algebra operates by conditions AND, OR and NOT and is used to create spatial selections. Reclassification allows the reassignment of parcels from the original set of classes to another one based on set of conditions. It can be a binary classification, equal interval classification, equal area classification, natural breaks classification or manual based on the decision of the human analyst (Bolstad 2012).

3.5. Overview of the previous research on reindeer habitat and remote sensing

Some research has already been done regarding application of remote sensing and GIS to reindeer habitat state analysis. In this subchapter, the previous research done in this field is reviewed. Unsupervised maximum likelihood classification with five classes was performed using LANDSAT images in the research on cumulative land cover changes in Kyro reindeer pastures district in Northern Finland where deforestation was the main cause of habitat fragmentation (Kivinen 2015). Mixed type of classification of a satellite image was applied in the research of the reindeer herding area in Nenets region, Northern Russia, as well as for Saami herding regions (Rees, Williams, and Vitebsky 2003; Kayhko and Horstkotte 2017). One of the studies presented a methodology of estimation of forest and lichen biomass and its change in Northern Fennoscandia using vegetation maps produced by remote sensing. There the authors correlate those vegetation cover maps with existing biomass estimation tables for different vegetation types (Tømmervik et al. 2008). Another research on estimation of pastures biomass was performed for Finland herding area (Colpaert, Kumpula, and Nieminen 2003). Few researchers assess arctic greening by performing Normalized Difference Vegetation Index (NDVI) (Nordberg and Allard 2002). Some studies propose different ways of lichen cover change detection in different regions (Nordberg and Allard 2002; Kumpula et al. 2014; Rickbeil et al. 2017; Falldorf et al. 2014; Casanovas et al. 2015). Assessments in changes of snowpack in the reindeer herding areas can be found in a few research papers (Maher, Treitz, and Ferguson 2012).

4. Methodology and data sources

4.1. Research design

The research discussed in this thesis consists of data collection, data processing and data analysis steps (*Figure 6*). Within data collection the primary and secondary sources were gathered and reviewed. As primary sources, two conversations with herders were held and the participatory mapping approach was utilized. In addition, an important part of satellite image classifications are field observations and collecting geolocations of field sites that could be associated with the points of the satellite image. Few ground truth points were registered.

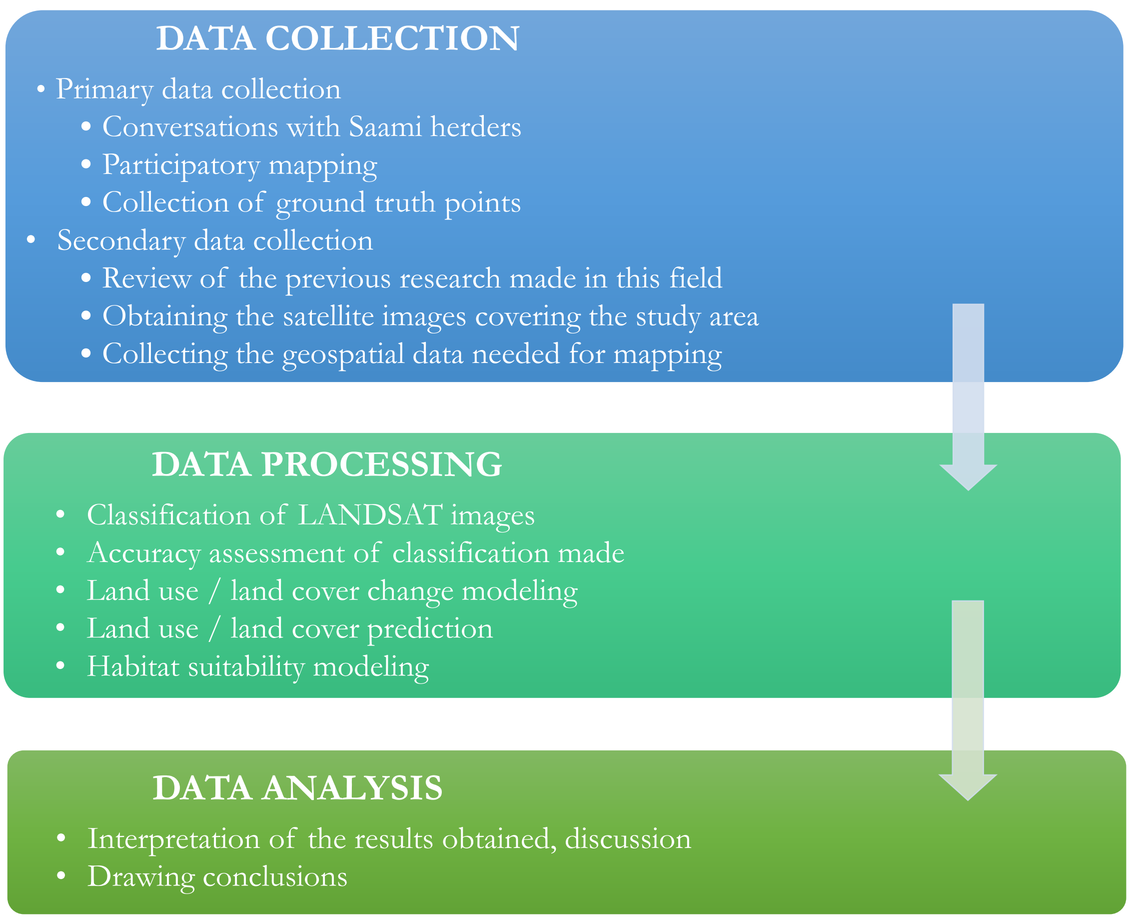

Figure 6 Scheme of the research design of the thesis.

The data processing is the most extensive part of this thesis due to the complexity of the methodology used. The 'hybrid' of supervised and unsupervised image classification with 300 classes was used. After the processing of the images was complete, an accuracy assessment of classifications was performed. Using the TerrSet geospatial modeling software the LULC change analysis was performed and a change prediction for 2070 was made. Based on those maps the habitat suitability assessment was performed for both current and future pastures. The results of this modeling approach were interpreted, analyzed and served as the basis for the research conclusions. The detailed description of the research steps can be found in the following sections of this chapter.

4.2. Primary data collection

4.2.1. Interviews with herders and participatory mapping

The objective of participating in the interviews with Saami herders of the region was to identify the factors affecting the reindeer habitat in Finnmark that can be used later for habitat suitability modeling. Also, some of the questions addressed the current state and perspectives of reindeer husbandry of the region. As part of this research only two short interviews/group conversations were conducted with two herders' families. That was considered to be sufficient for identifying the key factors affecting the reindeer habitat in the area. During the conversations, some topics needed to be discussed supported by background maps. Participatory mapping is a widespread approach to data collection from local communities. Such mapping, so called sketch mapping, is a complimentary tool for the interviews and workshops with local people (Di Gessa, Poole, and Bending 2008). For this research a map was generated and printed to be used during the interviews. The respondents were asked to show on the map the places of their herds' activities. The study area was chosen based on their mapping. Also, the results obtained through the conversations and participatory sketch mapping were used later in modeling.

4.2.2. Ground truth points collection

There are different ways to collect coordinates of ground truth points for satellite image classification. The author used GIS cloud (smartphone application), Collector for ArcGIS (smartphone application) and GARMIN eTrex GPS model (*Figure 7*). Alongside with registering coordinates it was needed to make notes describing the land cover at the point and to take a photo.

Figure 7 Summer pastures of the study area, Finnmark, 2017. Using GARMIN eTrex GPS during the field work. Photo made by the author.

At the end, for the current research data collected with Collector for ArcGIS was used. The reason for that is that the data obtained through this application is already in a form of a dataset that can be imported into the ArcGIS Online and ArcMap project where the classification will be performed.

Also this application allows to take notes and photos associated with the coordinates. This method could only be used for the classification of the latest image used in this research (17-SEP-16).

4.3. Secondary data sources

For the research, remotely sensed and geospatial data sources were collected and incorporated into the analysis. All datasets were of high quality from credible sources, the resolution of raster datasets was 30m, 50m and 1000m (only climatic datasets). WGS 1984 UTM Zone 34N was chosen as a spatial reference for all the datasets. WGS 1984 is a standard world geodetic system and Universal Transverse Mercator (UTM) is a standard global coordinate system which divides the planet into 60 zones in the northern and 60 zones in southern hemisphere and each of them is six degrees wide in longitude (Bolstad 2012). Zone 34 North covers the study area of this research.

4.3.1. LANDSAT Satellite imagery

Satellite imagery was downloaded from The Earth Explorer by the United States Geological Survey (USGS 2017). Both images used in the research were obtained through Landsat satellites. The images that would cover the study area needed to be from path 195 and row 11. For the accuracy of land cover change analysis, only images with the cloud cover <10% could be used. So partly the years chosen for this research and modeling were determined by the availability of satellite images that would meet the described criteria. The images used were acquired on July 14th, 1998 (Landsat 5) and September 17th, 2016 (Landsat 8) (*Figure 8*). The images do not belong to the same season but both have the least snow cover and cloud cover. Also, each type of the land cover was subsequently assigned manually to LULC categories, so the mistake that could be caused by difference in leafy vegetation cover was avoided.

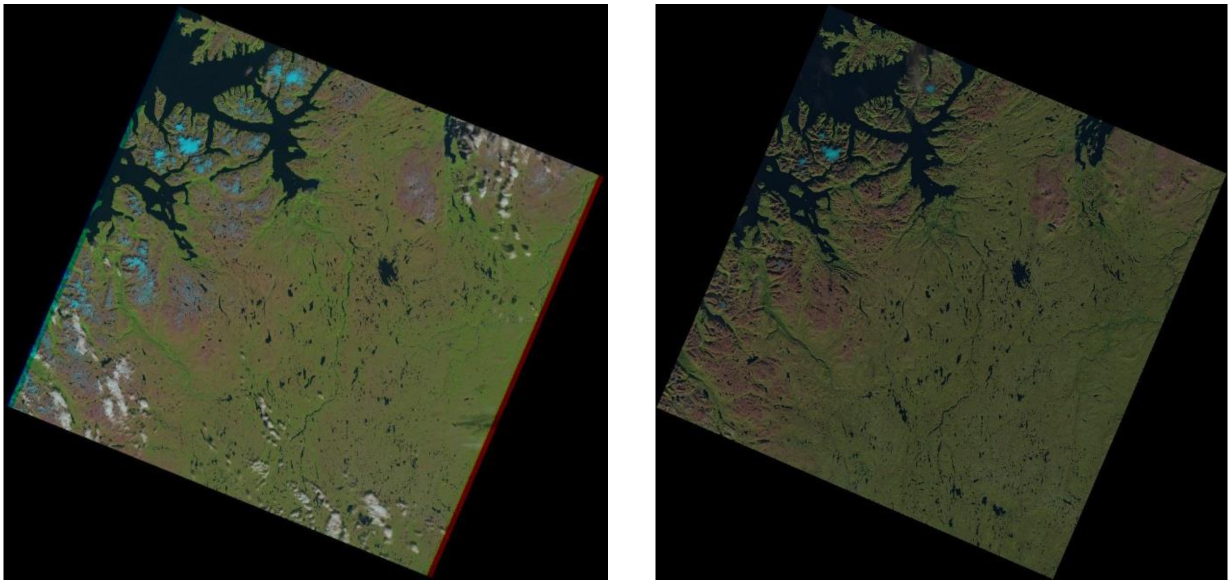

Figure 8 Chosen LANDSAT images: LT05_L1TP_195011_19980714_20161223_01_T1 and LC08_L1TP_195011_20160917_20170321_01_T1.

4.3.2. Geospatial data on reindeer husbandry and infrastructure

There is a wide range of geo-referenced datasets available on the internet open resource of The Norwegian Institute of Bioeconomy Research (NIBIO). This institute is one of Norway's largest research institutes (Nilsen 2011). The data collection is divided into five sectors: general information about the area, landscape, soil, forestry and reindeer husbandry. For this research the following vector datasets were downloaded and integrated into analysis: reindeer seasonal pastures, Saami reindeer districts, reindeer migration routes, cabins and fences, and roads. Also, administrative borders of Norway were taken from Global Administrative areas and datasets with water sources was found in the database of European Environmental Agency (Global Administrative areas; European Environmental Agency).

4.3.3. Digital Elevation Model (DEM)

Digital Elevation Model (DEM) represents Earth's surface elevation in raster format where each cell contains a value of the point's elevation. This data is invaluable for quantitative analysis of terrain as such factors as height, hillshade, aspect, slope, solar radiance, flow length, profile curvature can be assessed with the help of just one DEM dataset (Bolstad 2012). DEM with the largest coverage is generated and published in open access by ASTER, NASA's Earth Observing System. That data has a 30m resolution, and is widely used in GIS analysis. Unfortunately, for the study area of this research their data has significant defects. It turned out to be challenging to find a high resolution high quality DEM dataset for Finnmark. However, on the official website of Norwegian Mapping and Cadastre Authority Kartverket this data can be requested (Nilsen 2011). Thus the DEM dataset utilized in this research has 50m resolution and covers the whole study area with no defects.

4.3.4. WorldClim - Global Climate Data

Climatic variables are important for modeling vegetation change. Variables chosen for this research were temperature and precipitation. It was decided to use the data of the coldest month in the area – February and the warmest – July. The only high quality and high accuracy data for these variables was published by WorldClim – gridded Global Climate Data. These datasets have about 1000m resolution (Global Climate Data. 2017).

4.4. Processing of the satellite images

4.4.1. 'Hybrid' supervised and unsupervised classification

Out of various methods of satellite image classification, for this research it was decided to use the "hybrid" supervised-unsupervised approach. The author of the thesis tried to utilize the supervised classification method but it was found inaccurate for the number of classes needed to be identified (14 classes). After trying all the existing methods up to the author's knowledge the unsupervised classification with 300 classes per image was found to be the most accurate one. Each of the 300 classes was identified one by one and compared with high-resolution images and Google maps photos with specified GPS coordinates and assigned to one of the 14 LULC types identified in the study area. Manual assigning classes of the unsupervised classification of the latest satellite image (2016) was also significantly based on the data of collected ground truth points.

4.4.2. Accuracy assessment

Quality and usefulness of the performed classification of remotely sensed data can be evaluated through accuracy assessment. The accuracy assessment is based on the comparison of the obtained classification results and ground truth data at the time when the satellite image was acquired. Accuracy assessment consists of the following steps (Chuvieco and Huete 2009):

- Choosing the sampling method
- Collecting the reference data
- Comparing classification results with the reference data using statistical techniques
- Analyzing the distribution of errors

It is important to choose a proper reference source. For this research is was needed to assess the accuracy of the image obtained in 1998 so neither conventional statistical sources, nor ground truth observations could be used. It was decided to use the same satellite image for sampling as well as higher resolution images from Google Earth Pro database acquired in 1998 or close to that year. There are different sampling methods for reference points: simple random sampling, stratified random sampling, systematic sampling, systematic non-aligned sampling and cluster sampling (Rossiter 2004). In this case the author utilized stratified random sampling: set minimum number of sampling observations per classification category. The sampling unit was one pixel. Through comparison of classification points and reference points a confusion matrix was created to show agreements and disagreements between them. Total accuracy of classification can be evaluated through a simple formula: number of agreements / total number of reference points. However, there might be an error in this assessment due to the fact that some agreements were reached by chance. To assess the actual agreement and remove the effects of random factors there is a need of performing Kappa analysis (Chuvieco and Huete 2009). The equation of Kappa index is

K = (Total*Sum of correct) – Sum of all (Row total*Column total/

(Total squired – Sum of all (Row total*Column total)

For the 1998 image the reference points were created, 60 points per LULC type. Then the confusion matrix was created and Kappa test performed. For the 2016 image accuracy assessment was not made as the ground truth points were used during the classification.

4.5. Analysis of current Land Use/Land Cover change and modeling of the future land cover.

For LULC change modeling an "integrated geospatial software system for monitoring and modeling the earth system" TerrSet was used. One of the packages in this software is a Land Change Modeler (LCM), a tool for land change analysis and prediction (Eastman 2015). It allows to analyze the land cover change and simulate future scenarios. Land Change Modeler allows for the performance a three steps analysis: historical change analysis, transition potential modeling and change prediction. TerrSet performs change analysis and generates graphs of gains and losses, net change, persistence and specific transitions. Based on the historical change and variables integrated into the model manually, modeling software creates a transition potential raster file. Subsequently, based on the transition potential, TerrSet generates soft and hard prediction maps for the specified year. For these research the prediction year of 2070 was chosen (Eastman 2015).

4.6. Spatial modeling of reindeer habitat suitability

Next step in the research was mapping current and future reindeer habitat suitability. This rational of the methodology is described in Chapter 3.4. Using a combination of geospatial data layers with the information about spatial distribution of factors affecting suitability of the habitat were included into the spatial model. The variables integrated into the model were distance to roads and cabins, distance to water sources, elevation, aspect and steepness of the slope. Based on those factors and LULC maps for 1998, 2016 and predicted 2070 the map was produced with the following classes: optimal niche, suitable, marginal and unsuitable land cover. Spatial modeling was fully performed in ArcGIS software. Analysis of the quantitative results was performed in Microsoft Excel.

5. Positioning of the study area

For this research, the author aimed to analyze the state of those pastures that are on the migration route of a particular herd. Hence, the study area was chosen based on the conversation with the herder. His reindeer herd migrates annually through three reindeer herding districts in West-Finnmark: 22 – Fiettar (summer pasture), 23 – Seainnus/Navggastat (summer pasture), 30C – Ostre sonne (winter common pasture). The study area is presented on the *Figure 9*:

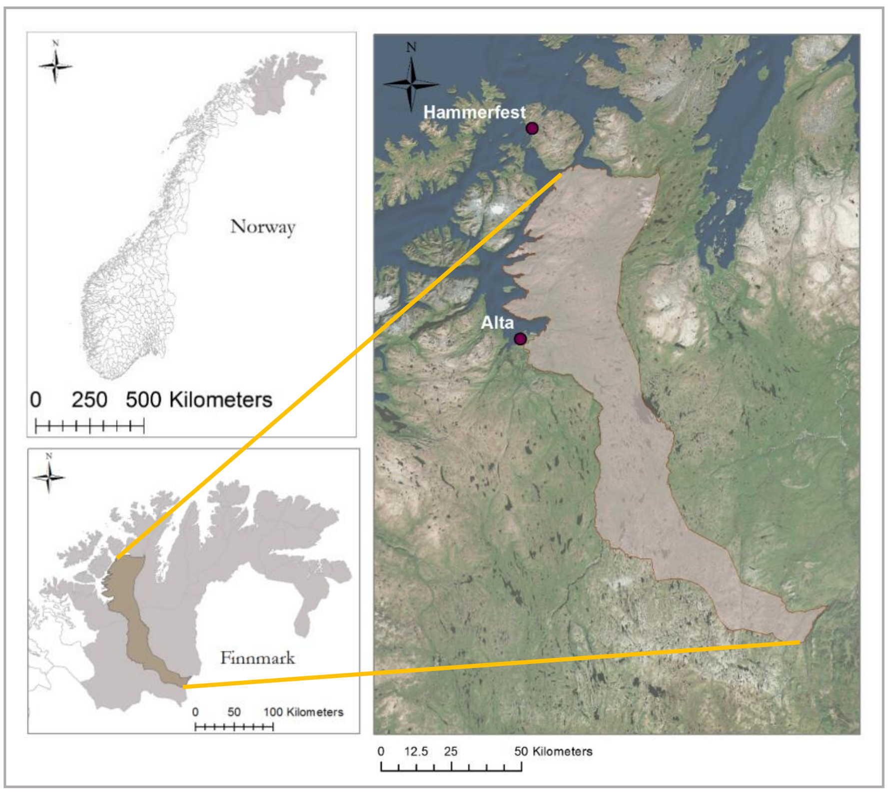

Figure 9 Study area. West Finnmark, reindeer herding districts 22, 23 and 30C.

The study area is in the Sub-Arctic region and most of it is characterized by continental subarctic climate. Most of the area is represented by mountain birch forest, mountain heath and closer to the winter pastures birch forest. The inner-continental part is characterized by low precipitation and significant seasonal variation between temperatures (*Figure 10*). The coastal area has higher levels of humidity with lower seasonality in temperatures (Tømmervik et al. 2012).

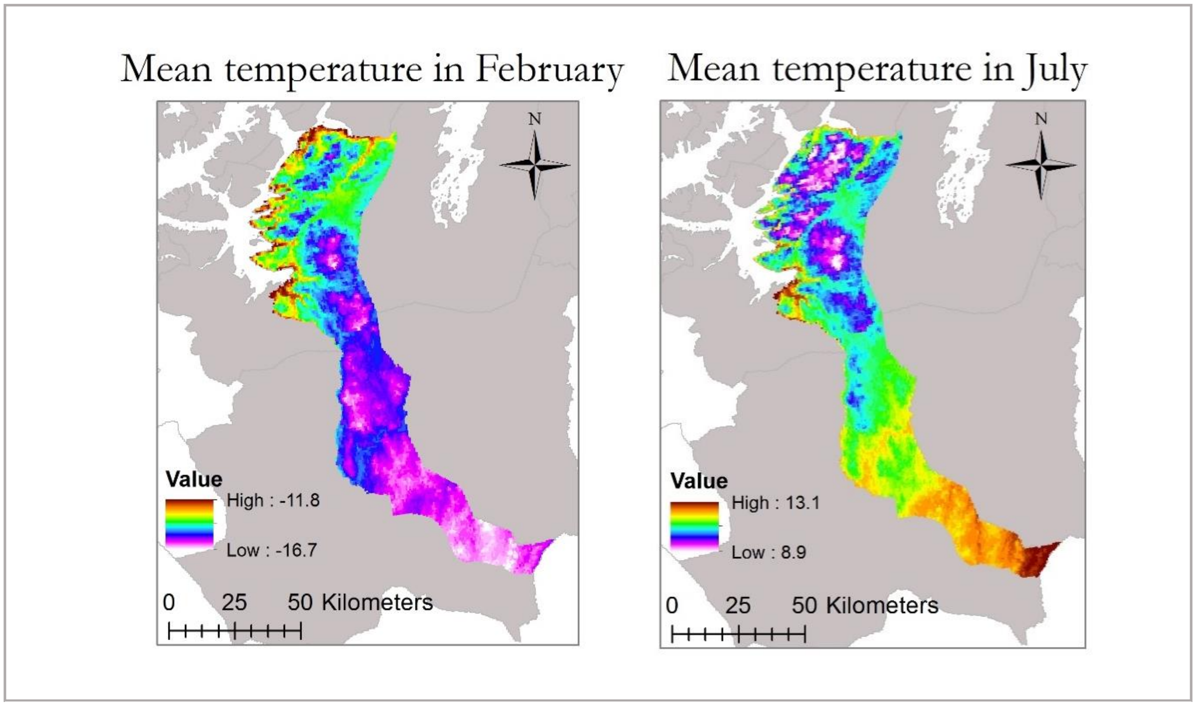

Figure 10 Mean temperature in the warmest (July) and coldest (February) months, in °C. Data source: Global Climate Data 2017.

Also, it can be seen on the graph, built on the data obtained through Giovanni NASA, that the climate in the region is actually changing and the annual mean temperature is rising (*Figure 11*).

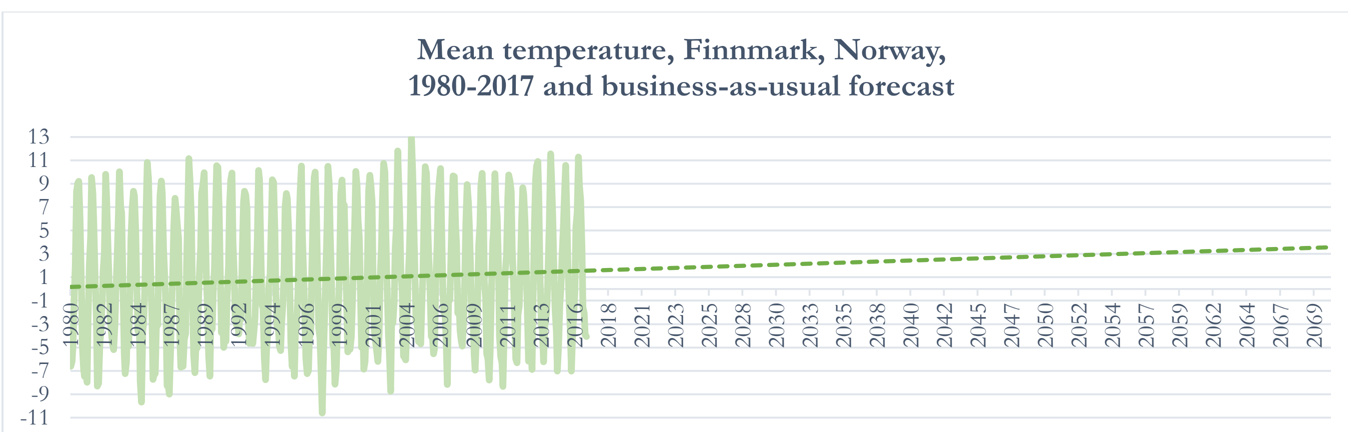

Figure 11 Mean temperature, Finnmark, Norway, 1980-2017 and business-as-usual forecast Data source: Giovanni NASA 2017.

Speaking about the land use patterns in the study area, in the following table and figure, the maximum number of reindeers set by government and the actual size of population per district of the study area is presented (Figure 12,

Table 3). According to the Reindeer Herding Act, allowed reindeer population numbers are set only for summer pastures where herds are registered (Ministry of Agriculture and Food 2007). That is why there is no set number for district 30C where same herds migrate every year for the winter season.

Number of district	Allowed number of reindeers per district	Area
22	4900	990 km^2
23	6600	1178 km^2
30C	-	3077 km^2

Table 3 Allowed reindeer population numbers per district. Source: Resources of reindeer husbandry (Agricultural directorate 2016)

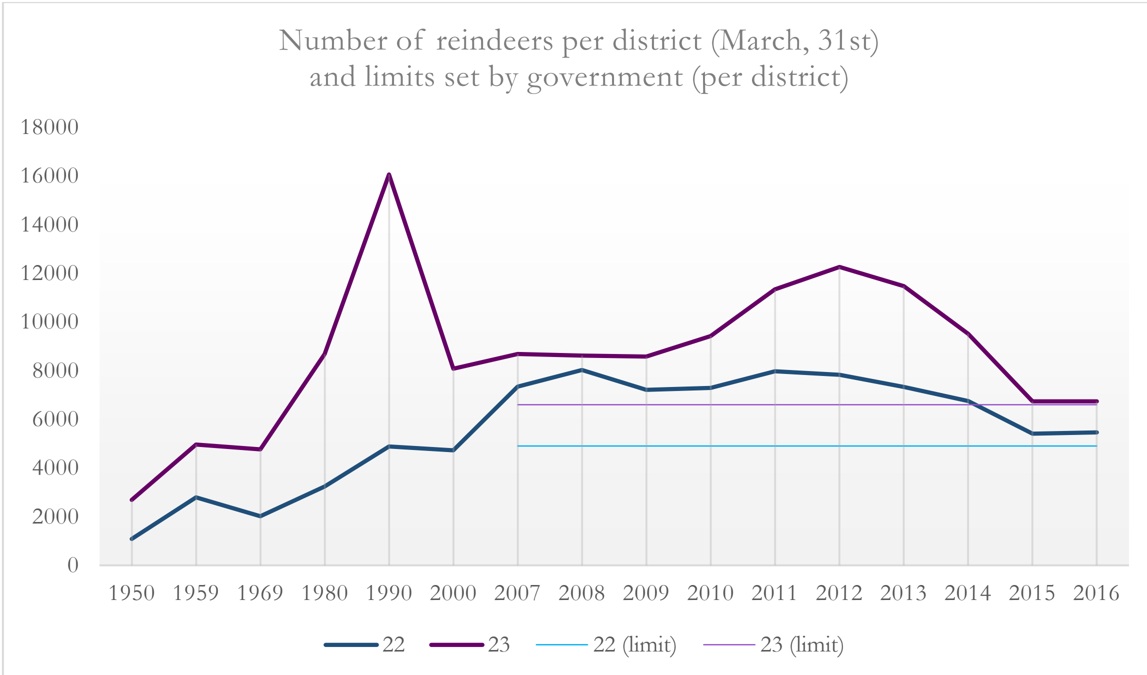

Figure 12 Number of reindeers and population limits per district. Based on data from: Tømmervik and Riseth 2011; Agricultural directorate 2016.

As it can be seen from the graph, although the reindeer population numbers in the districts of study area are decreasing since the enforcement of Reindeer Herding Act, they still exceed the allowed maximum number. The limit was set from the standpoint of overgrazing and degrading state of pastures (Benjaminsen et al. 2015).

6. Field data collection

6.1. Results of the interviews and participatory mapping

In July 2017, the author visited the study area in order to collect validation points for image classification and to participate in semi-structured interviews with the herders to know more about reindeer husbandry in the study area and specifications of reindeer behavior. *Figure 13* illustrates a photo of reindeers in the study area.. Mostly adult male reindeers were seen during the fieldwork.

Figure 13 Photo made in Finnmark, reindeer herding district 22, 04.07.2017. Male reindeers stay in the valleys close to human disturbance area as they need to obtain forces for the rut. Taken by the author.

During the field work two interviews were conducted with two families. The interviews were parts of bigger conversations in which a group of researchers participated. From those conversations, the following conclusions were made:

1. The main summer pasture predators in the area of summer pastures are lynx, eagle and wolverine. Sometimes brown bear is also hunting in the region. This is particularly affecting the herd in summer pastures due to spring calves being an easy asset for predators.

2. Only summer and autumn pastures have restricting fences. The winter pasture is a common pasture.

3. The reindeers are not particularly afraid of the road and cars on it but what they are trying to avoid is summer cabins. It becomes more popular among Norwegians to build their houses and small cabins in Finnmark and visit in summers with their dogs. Reindeers avoid encounters with dogs. The scared females with calves usually get higher in the mountains to be further from those cabins. The females feel defenseless since they lost their antlers in spring. Pastures at higher elevations are much poorer, the forage is less nutritious but reindeers move there anyway.

4. Male reindeers are interested to gain energy before the autumn rut and do not move to higher elevations, remain in close vicinity to the cabins and roads as the vegetation is richer there (*Figure 14*).

5. It is not regulated by law that the Saami herder of the district is represented in the municipality committee. Thus, there is no authority that could confront the infrastructure development plan while these are these pastures that belong to Saami herder get affected. One of the herders shared an example of mine development plan in a district of Kvalsund. In those municipality committees where the herders are represented such plans have a chance to be omitted (example of Kautokeino).

Figure 14 Reindeers met in the valley close to summer cabins. Most of them are males. Finnmark, summer pastures, 2017. Photo made by the author.

6. The preferable aspect for reindeers is south-facing. The snow melts faster and the fresh green highly-nutritious vegetation appears earlier.

7. The widespread misconception is that in winter reindeers can live on lichens and the quality of winter pastures is defined by the abundance of reachable lichens. However, lichens mostly consist of carbohydrates and cannot be the base of a reindeer diet.

8. According to the indigenous herders, availability of forage defines the quality of pastures. If the "good quality vegetation" is covered by a thick layer of snow or ice, it does not have any value for a herder, his reindeers will starve to death. The availability of a low nutritious forage gives a herd a better chance to get through the winter with fewer losses. Saami herders have a special word for "good pastures" meaning available pastures.

9. Currently feed supplements play a significant part in reindeer winter diet.

10. Some years moth outbreaks damage the birch forest which is the territory of reindeer summer pastures. It also occured in the last couple of years (*Figure 15*). However, according to the herders, they would not suggest that the defoliation of the birch forest affects the reindeers grazing in the area. On the opposite, the lower layer of the forest (grasses, shrubs) obtain more sunlight and grow more intensively. Reindeers prefer those grasses to birch leaves.

Figure 15 Photo of defoliated mountain birch forest, summer pastures of study area, photo taken by the author, 2017.

11. Reindeers are very selective in the plants they consume.

12. According to herders' knowledge, reindeer consumes around one kilogram of biomass per day in winter and around three kilograms per day in summer.

Alongside with the interviews the method of participatory mapping was utilized. Prior to the field work the map was created in ArcMAP. The following datasets were used: reindeer herding districts, major roads, settlements, municipality centers and administrative borders, lakes and rivers. Satellite imagery was used as a base map. It was prepared keeping in mind that the person being interviewed could easily orientate in the map and sketch the location of required objects as accurately as possible. The template of the background map used during the interviews can be found in Appendix I. The respondents were asked to show on the map the migration route of their herd – current and historical if changed, the reindeer accumulation areas, the boundaries of their territory, summer and winter pastures, calves' marking area, disturbance area (such as a planned infrastructure development points) and other relevant information about the land use in the region. This information was analyzed and integrated into habitat suitability modeling and land cover change analysis. The boundaries of the study area were defined based on the results of participatory mapping. This helped to avoid possible mistakes in analysis as the factors mentioned by herders in the interviews might only be relevant for their own pastures only.

6.2. Collection of ground truth points

In order to collect the ground truth points for future classification of LANDSAT 8 image Collector for ArcGIS was utilized. To use this application, before collecting the coordinates, a new geodatabase was created using ArcCatalog. For convenience, the author generated in this geodatabase one domain with a set of choices of LULC types they can choose from while working and one text domain for making descriptive notes. The LULC types included into the geodatabase were the same ones as the categories of the classified image (Fu 2015). During the field work detailed observations were made and geolocated so that they could be integrated into the processing of the satellite images. The interface of the Collector for ArcGIS and example of the collected ground truth point are presented in *Figure 16*.

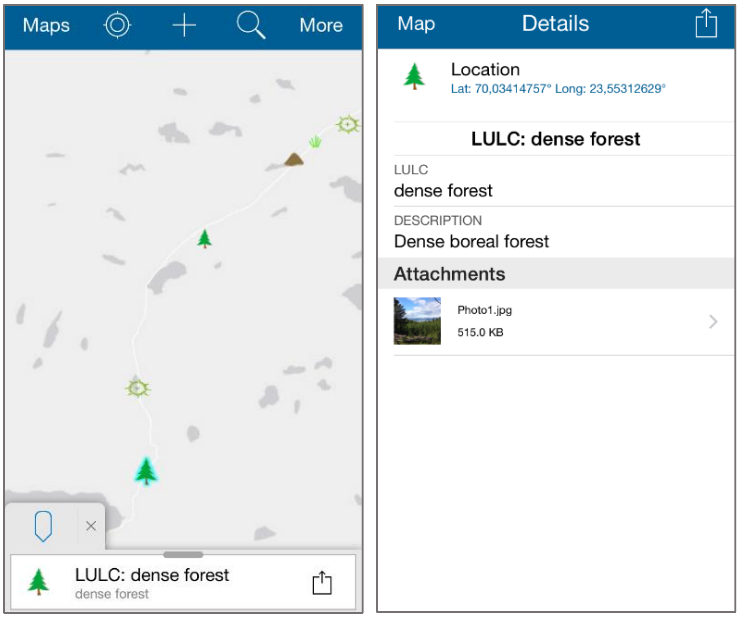

Figure 16 Example of the collected ground truth point for boreal forest with specified coordinates and attached photo.

The coordinates and photos of 50 indicative ecosystem sites with vegetational homogeneity were collected. All the sites from Collector for ArcGIS were automatically synchronized with the online map at ArcGIS Online and then imported into the working project in ArcMAP. Examples of these points with photos can be found in Appendix II and be seen on the *Figure 17*.

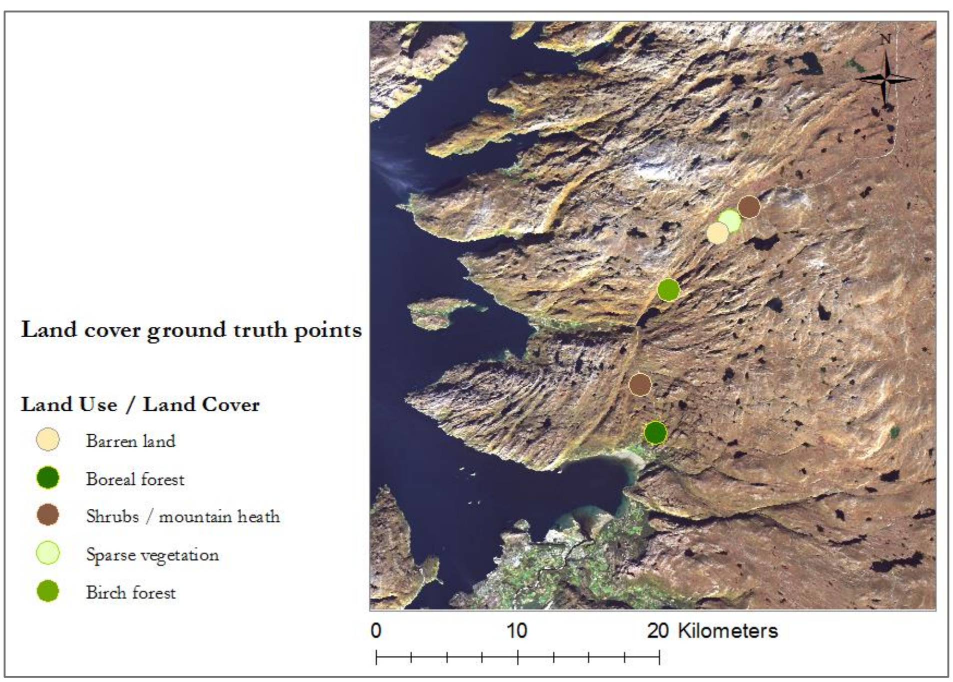

Figure 17 Part of the study area with some of the ground truth points collected through Collector for ArcGIS (LC08_L1TP_195011_20160917_20170321_01_T1, 17-SEP-16) and imported into the ArcMap project.

7. Assessment of Land Use / Land Cover changes in the study area and habitat suitability modeling

7.1. Land Use / Land Cover classification of satellite images

7.1.1. LULC classification of LANDSAT 4-5 image, 1998

The method of combined supervised and unsupervised classification was used. This method has been applied before in a few studies such as (Sandström et al. 2004). First step of this approach was to use the ArcToolBox Spatial Analyst tool "Iso Cluster Unsupervised Classification". The cells were grouped into classes based on the spectral clustering of the satellite image. The image was classified by 300 classes (*Figure 18Figure 18*).

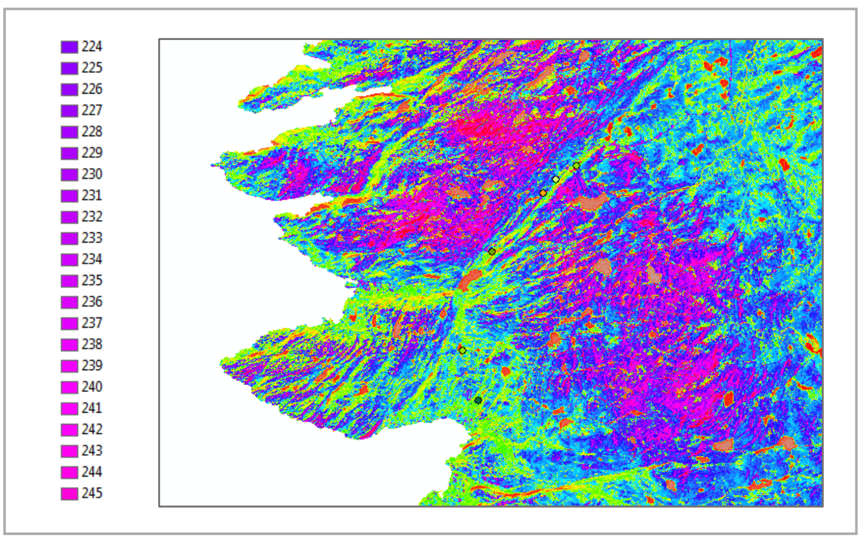

Figure 18 Example of one part of the study area. Unsupervised classification, 300 classes.

Second step was to identify each class and assign it to the LULC type represented in the area. For that purpose, high-resolution imagery of the year of 1998 (also two years earlier and two years later) was used. The sources of images were Google Earth Pro, Digital Globe and ArcGIS Online (satellite imagery basemap). The coordinates of at least five cells of each class were verified by exact points on the high-resolution images. Each class was assigned to one of the 13 types: water, barren land, sparse vegetation / mosses, shrubs / mountain heath, mountain birch forest, birch forest, boreal forest, built-up area, cultivated area, snow, image cells with no data, hill shaded area, cloud. Due to low quality resolution of the satellite images it is difficult to differentiate between water bodies and areas in the shadow. Even classification with 300 classes could not give an accurate result so it was decided to exclude those areas from the analysis and modeling as small areas with snow cover and clouds on the image.

7.1.2. LULC classification of LANDSAT 8 image, 2016

Approach to classification of the most recent image available for the study area with the least cloud cover was generally similar to the classification of the 1998 image. However, the accuracy of classification of the latter image can be guaranteed because of being significantly based on the collected ground truth points. Also, Landsat 8' image has two additional spectral bands: a deep blue visible channel and a new infrared channel. The data quality is claimed to be higher than images from previous Landsat missions. Therefore each class out of 300 clusters automatically generated by the software based on the surface's reflectance was manually assigned firstly – based on the collected ground truth points, secondly – verified through the same sources as the previous image classification (high resolution satellite imagery of the same year on Google Earth Pro, ArcGIS Online basemap) and through photos from Google maps that are assigned to the exact coordinate on the map. Example of a high-resolution image from ArcGIS Online Basemap with a clear view of classes boundaries is presented on the *Figure 19*. Boundaries of water, barren land and mountain birch forest can be seen on this image.

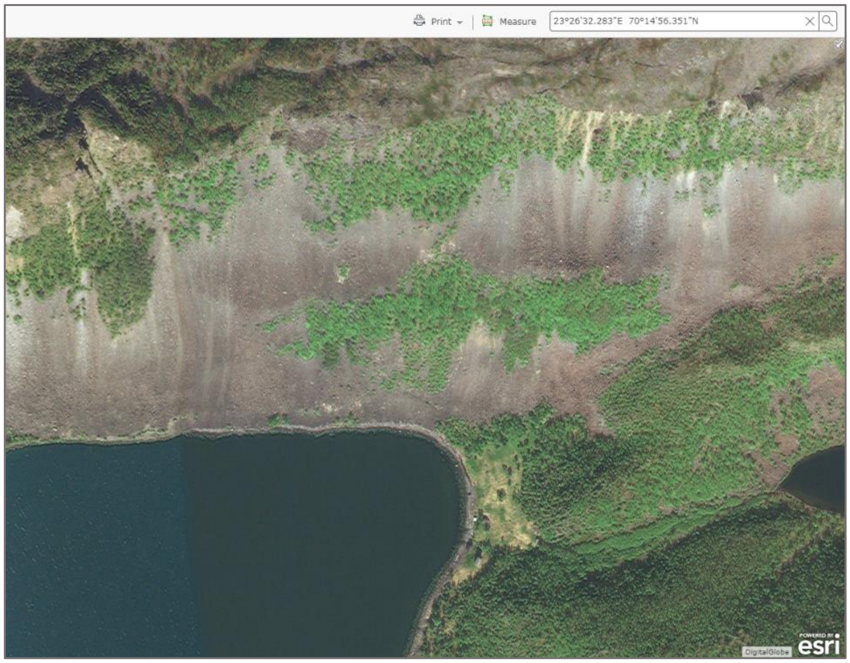

Figure 19 Example of a high-resolution satellite image (23°26'32.283"E 70°14'56.351"N) used as a reference for class assignment.

The process took a considerable period of time allocated for the research as overall 600 classes needed to be accurately analyzed through few reference sources and at least few points. Any other available method was also tested but the accuracy was found insufficient. The result of the 'hybrid' classification of both LANDSAT images is presented on *Figure 20*.

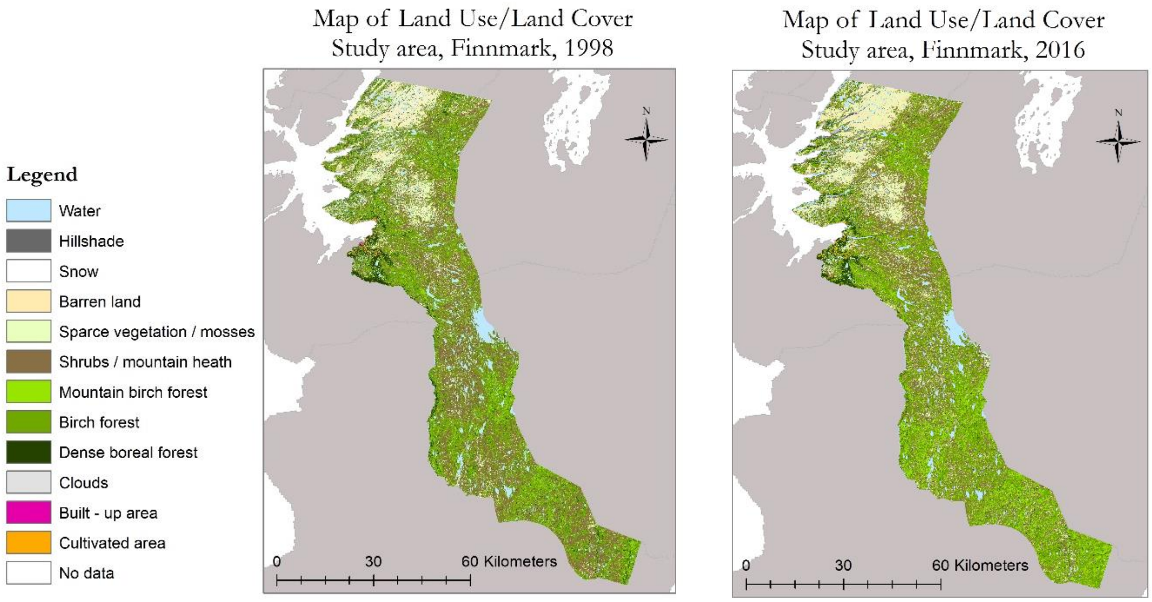

Figure 20 Classified LANDSAT images for study area for years 1998 and 2016.

7.1.3. Accuracy assessment

As described in the methodology chapter, to analyze the quality of image classification an accuracy assessment was performed. Stratified random sampling method was undertaken. It was decided to make 60 reference points per category excluding the "no data" category. To reduce the bias, the reference points were required to be well distributed within the study area. Firstly, a new shapefile for reference points was created. The attribute table consisted just of two fields: text field for LULC and short integer field for class number. Reference points were created category by category and then the shapefile was converted to raster (*Figure 21*).

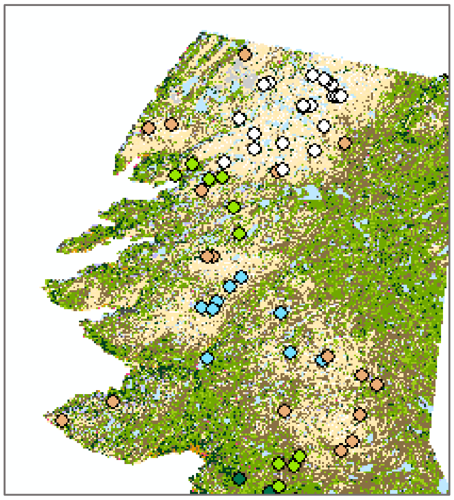

Figure 21 Example of reference points used for accuracy assessment matrix for the classification of the image 1998. The colors correspond to categories for convenience.

Using the Spatial Analyst Tool "Combine", classification raster and reference points' raster were merged. To create a proper confusion matrix the attribute table was exported from ArcMap using the "Pivot Table" tool. The exported table was imported into Microsoft Excel and was adjusted to the format of confusion matrix. Confusion matrix is a cross-tabulation of assignments performed through classification and assignments done as references to classes point by point (Chuvieco and Huete 2009). Confusion matrix shows agreements and disagreements between classification and reference points. One column of the table represents reference points assigned to one class. One row of the table represents all the classification classes. The diagonal cells are correctly assigned classes while the others are classification errors. The confusion matrix is presented in Appendix III.

The total accuracy is calculated by relating the diagonal cells of the matrix (correctly assigned reference points) to the total number of reference points. The total accuracy of the classification of 1998 image is 0.906. However, this formula does not exclude the agreements expected by random chance. That is why Kappa index should be used to assess just classification accuracy. The formula of Kappa index was shown in the methodology chapter. Therefore, here is the calculation.

Kappa index = 720*652-(60*62+60*60+60*62+60*61+60*63+60*66+60*56+60*60)/720*720-(60*62+60*60+60*62+60*61+60*63+60*66+60*56+60*60) =0.897

Kappa higher than 0.8 is considered to show a desirable agreement (Chuvieco and Huete 2009). Therefore, it is concluded that the classification of the 1998 LANSAT image has a high accuracy and is suitable for the modeling.

7.1.1. LULC change modeling and mapping potential future land cover

Two harmonized classified satellite images provide an invaluable opportunity to evaluate the actual change occuring with the land cover and also model the future scenario. As discussed in Chapters 3.3 and 4.5, TerrSet software has a Land Change Modeler extension designed specifically for this purpose. The flow of the modeling analysis performed in this chapter is presented on the flowchart (*Figure 22*).

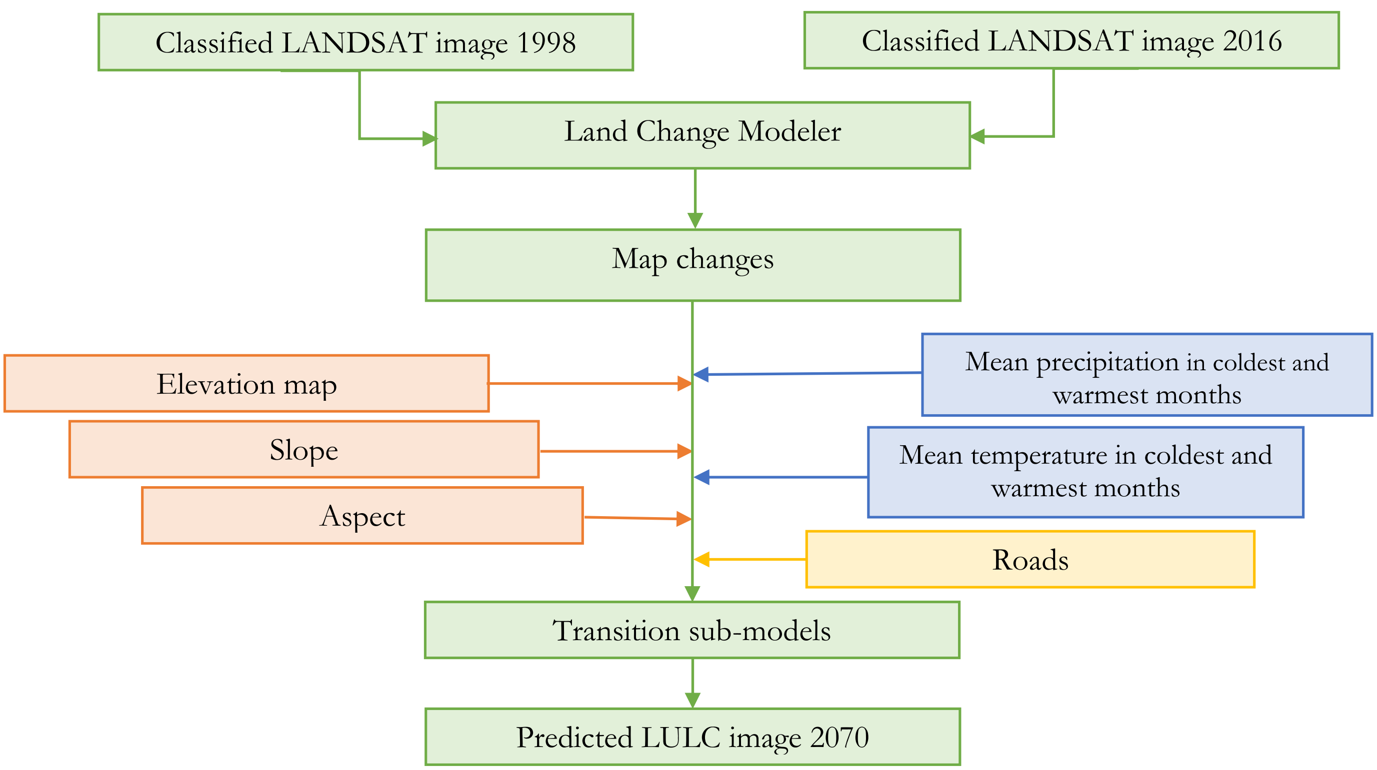

Figure 22 Flow chart of Land Change Modeler methodology.

As TerrSet is developed on the basis of IDRISI GIS, to operate in the software the prepared image classifications were converted from arcraster to ASCII and then to IDRISI raster format. Furthermore, the images were processed so that the legends, categories, backgrounds, spatial dimensions were same and sequential. As it was described above, not all the categories were included into the modeling. First step was the historical land cover change analysis. The results are presented on the following graphs in square kilometers (*Figure 23*):

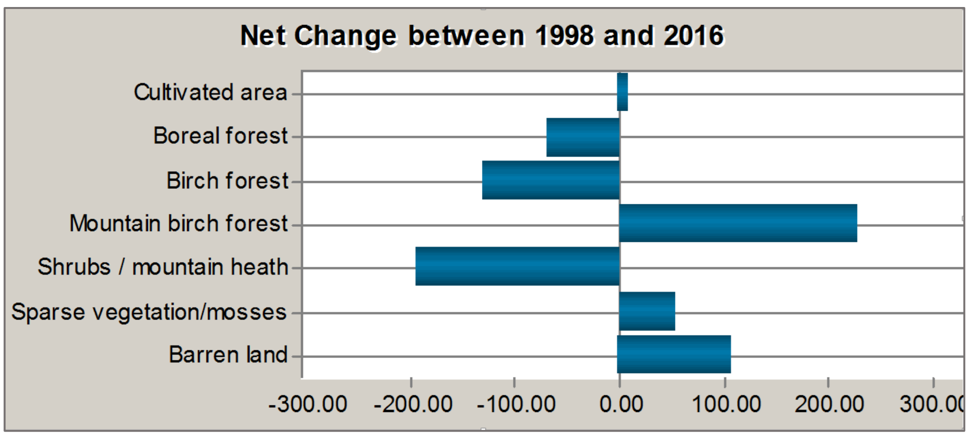

Figure 23 Net change between 1998 and 2016 in km^2.

From this graph it is easy to identify the changes occured in the area covered by a particular LULC category. According to it, the area covered by mountain birch forest and barren land became significantly bigger. The areas identified as mountain heath, birch forest and boreal forest were reduced. In more detail these changes can be seen on the graphs presenting contribution to net change in each category by other classes in Appendix VII. In the body of the chapter two of them are presented as examples (*Figure 24*).

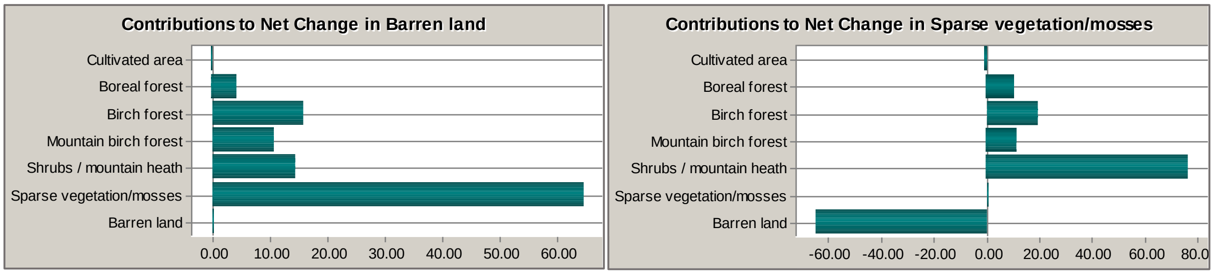

Figure 24 Contribution to Net Change in Barren land class and Sparse vegetation/mosses by other categories between 1998 and 2016.

It should be acknowledged that some of the transitions are not absolute even though they seem to be as per the graph. The pixel/group of pixels might be represented by a mix of ecosystem types with a predominance of one of them so that the spectral scanner registered it as predominant one. However, the dominance could be changed in the 17 years of the study period. That is why the changes on the graphs are indicative. In addition, according to the herders, in the last few years birch moth outbreaks took place, so there was defoliation of the mountain birch and birch forests and that could slightly affect the accuracy of the classification, as the reflectance of those classes on the latter image was different from the reflectance of the image from 1998.

The change analysis step is important for the modeling as the human analyst can identify the dominant transitions that should be integrated into the transition modeling. The following main loss/gain trends were identified:

- Sparse vegetation / mosses to barren land transition
- Mountain heath / shrubs to sparse vegetation / mosses transition
- Mountain heath / shrubs to mountain birch forest transition
- Birch forest to mountain birch forest transition
- Area of boreal forest to birch forest transition

After the key transitions have been identified, the next step was to generate a sub-model where these changes were included (*Figure 25*). Transition sub-model is a collection of land cover transitions that might share common drivers of land change. Grouped together they represent the main input for the model.

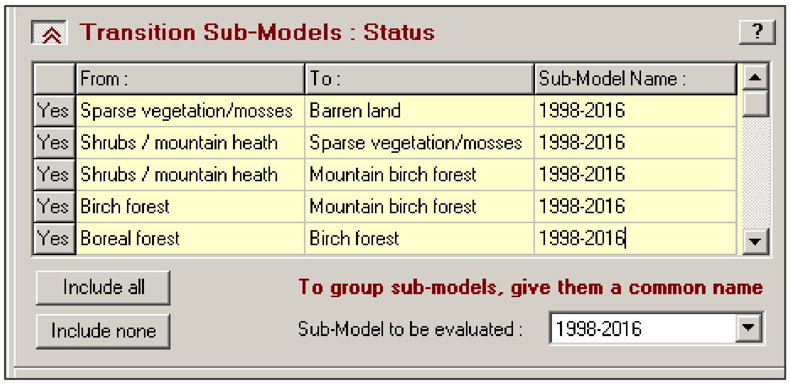

Figure 25 Process of creating the Sub-Model for mapping transition potential

Next step before running transition potential sub-model was to select, create and test the driver variables for the model. For the current research slope, elevation, aspect, mean temperature and precipitation of the warmest month (July) and mean temperature and precipitation of the coldest month were chosen (February).

In Land Change Modeler, all imported variables must have the same spatial extent, resolution, and spatial reference data. All the datasets obtained for this model had different spatial characteristics so they needed to be processed. That was performed in ArcGIS software. The classification had the 30m cell size, climate data had 1000m size and DEM data had 50m cell size. To align the output of the processing of these data to the spatial extent of the classified images, coordinates were specified in the Geoprocessing – Environments – Spatial extent. Then raster grids of these datasets were resampled to 30x30 meters and extracted by the mask of the classified image once again. The last step was to convert them back to IDRISI format, insert to the sub-model, test their explanatory power and verify that they fit into the modeling (*Figure 26*). In some models to specify constraints would also be needed. Constraint factor should be mapped in Boolean format: where the transition cannot happen, pixel value is 0, and classes that could potentially change – had a value 1. However, in case of this model the areas where transition cannot happen have been clipped out of the classifications prior.

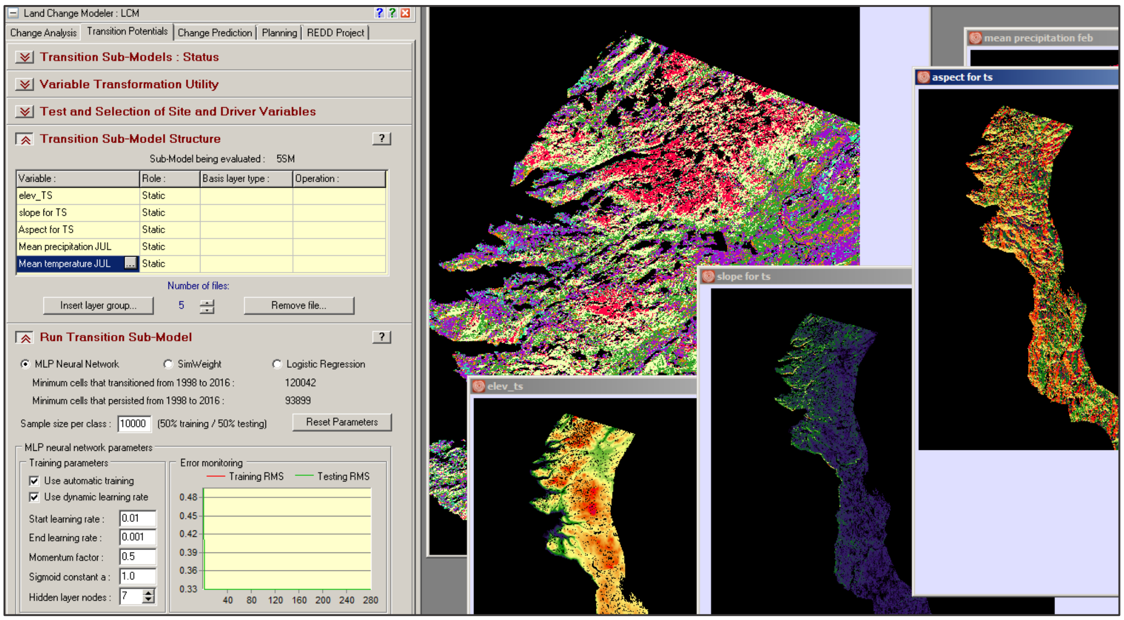

Figure 26 Interface of the transition potential tab in the Land Change Modeler with the list of few sub-model variables as example.

After all the variables are specified and tested, the sub-model needs to be run to train the multi-layer perceptron (MLP) neural network. The sample size per class was 10000 with automatic training and dynamic learning rate. The result of this processing is a number of transition potential maps for each class transition chosen and inserted into the sub-model and summarized map (*Figure 27*, *Figure 28*).

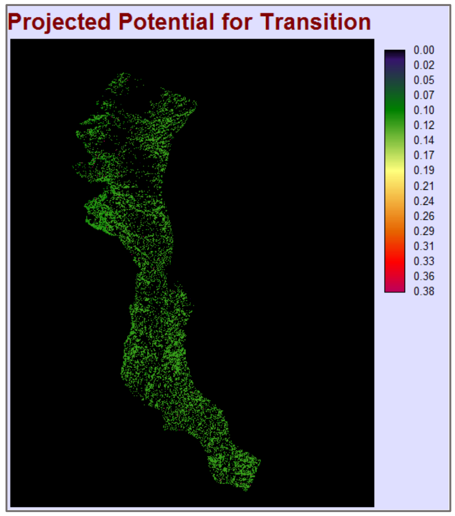

Figure 27 Summarized projected potential for

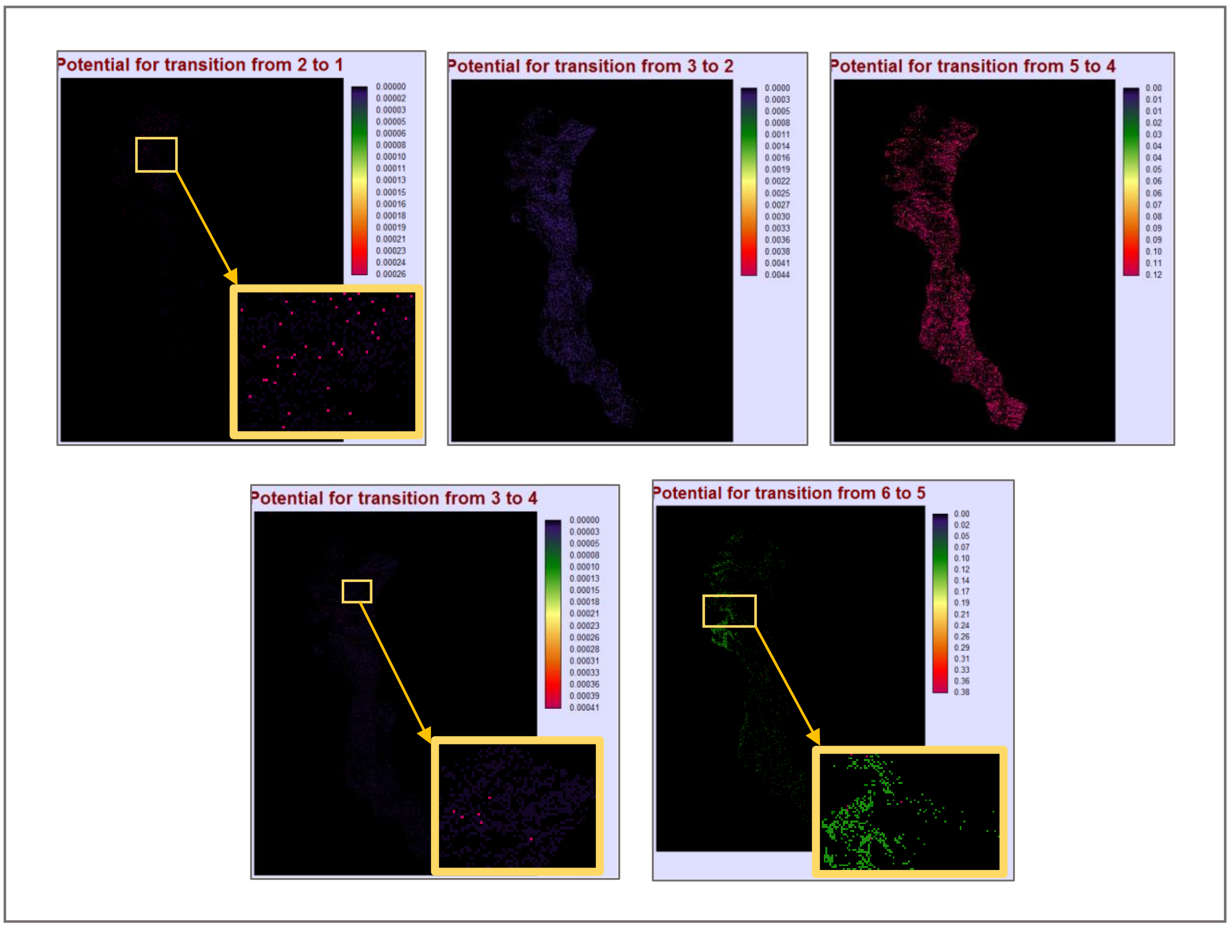

Figure 28 Transition potential maps by each transition. From 2 to 1: Sparse vegetation / mosses to barren land transition; From 3 to 2: Mountain heath / shrubs to sparse vegetation / mosses transition; From 3 to 4: Mountain heath / shrubs to Mountain birch forest transition; From 5 to 4: Birch forest to Mountain birch forest transition; From 6 to 5: Boreal forest to birch forest transition.

For change prediction Markov Chain method was chosen. Prediction date was specified as 2070. Transitions to be considered for end-point generation were the same as in sub-model. It is critical that all the transition potential datasets were created prior to running the prediction model. There are two basic models of change – soft prediction and hard prediction. Soft prediction is recommended for habitat assessments as it generates a map of vulnerability for the transitions chosen and is a better tool for comprehensive analysis (Eastman 2015). However, within this research the map of hard prediction was used in the analysis as this research aimed to compare the Land Use / Land Cover of different years (*Figure 29*).

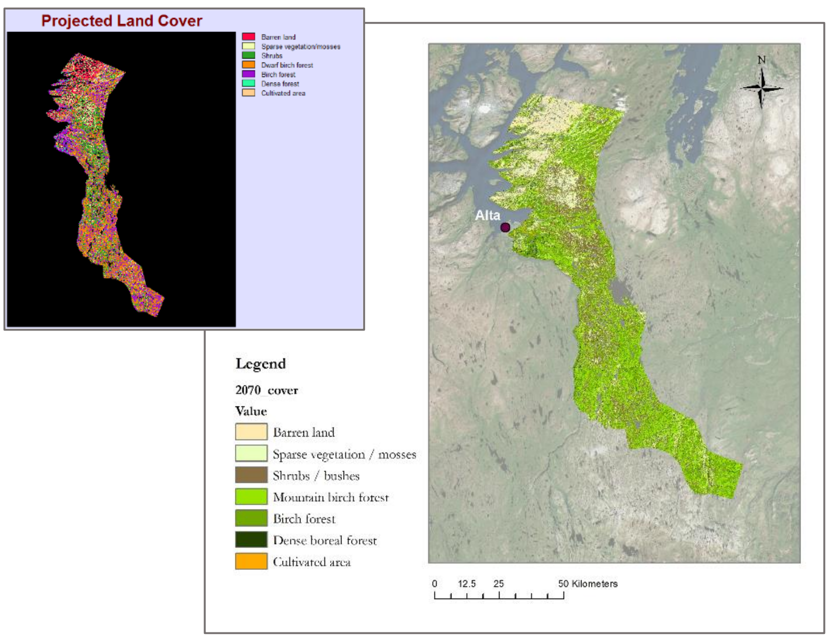

Figure 29 Projected land cover for 2070

After creating a map of potential land cover for 2070, the changes in areas of different land cover types could be quantitively compared through years 1998, 2016 and 2070. As the pixel size was 30m, then to account the territory covered by one category, the number of pixels belonging to one category extracted from the attribute table needed to be multiplied by 30x30 to get the area in m^2 and then multiplied by 1e-6 to get areas in km^2. This way the following graph with values for three different years was created (*Figure 30*). The area of mountain birch forest will continue to expand while the areas of mountain heath and birch forest are decreasing.

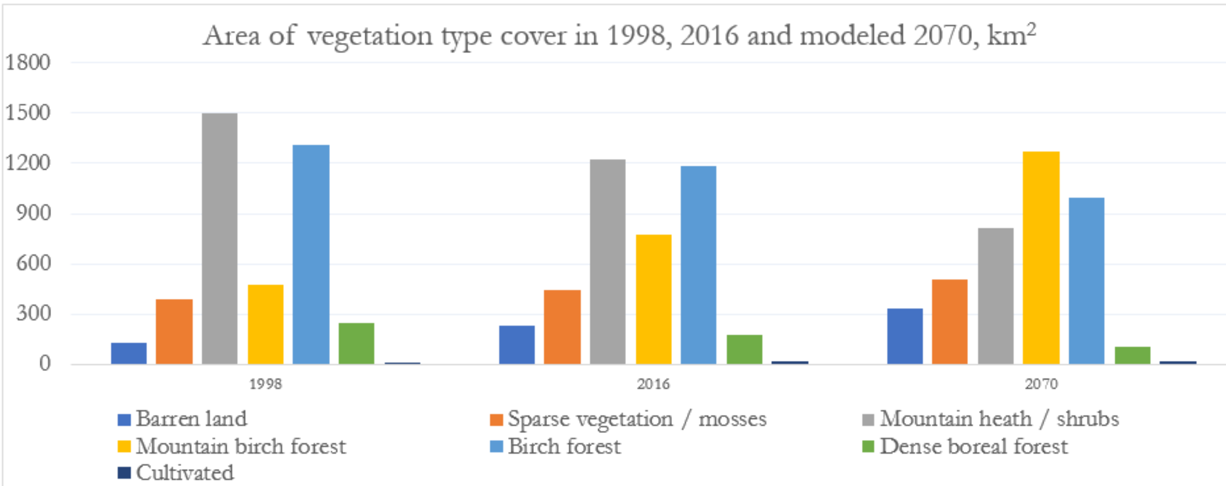

Figure 30 Area of vegetation type cover in 1998, 2016 and modeled 2070, km^2

7.1.2. Modeling reindeer habitat suitability of current and future graze lands

Creating a spatial cartographic model is manual map analysis based on mathematical relationships. The output of such modeling is nominal or ordinal. In the case of this research the aim is to obtain the maps for various year with such ordinal categories as Optimal, Suitable, Marginal and Unsuitable land cover. The analysis is based on the combination of spatial datasets and operations with them. As described in chapter 3.4, habitat suitability spatial model is based on the environmental variables determining the suitability of the land cover for reindeer in the study area. Based on the data reviewed regarding the factor of reindeer habitat, the following variables were included into the model:

- Elevation
- Aspect
- Slope

- Distance to water sources
- Distance to roads and cabins
- LULC

The factor of snow depth influencing the winter habitat of reindeer in Finnmark was not included as the high quality spatial data on snow cover was not found in public sources.

To integrate these factors into the cartographic model a set of criteria should be generated. The challenge is to translate the qualitative data into quantitative to be able to process it through map algebra such as "reindeers prefer a gentle slope" or "middle to high elevation is optimal". Hence, the criteria integrated into the model is based on the assumptions on suitability ranking but with the least bias. These are the key assumptions that were implemented in this spatial analysis (*Table 4*):

Factor	General criteria	Refined criteria			
		Unsuitable	Marginal	Suitable	Optimal
Elevation	Prefer middle to high elevation. Primarily good forage is concentrated in valleys (Forbes et al. 2006).	>700	600 - 700	0 – 300, 550 - 600	300-550
Aspect	Snow melts faster on the southern slope, richer forage in summer. In winter thinnest snow is at western slope (Skarin et al. 2008)	-	N, NE	E, W, NW	S, SE, SW
Slope	Optimal slope is 20º (Falldorf 2013). Best forage is mainly concentrated in valleys (Forbes et al. 2006)	> 45	-	30 – 45	0 - 30

Distance to water sources	Based on the conversations with herders	> 7km	5 – 7 km	1 – 5 km	< 1km
Distance to roads and cabins	Few studies point at the fact that with the infrastructure development reindeers abandon those territories up to the radius of 3km (Pape and Löffler 2015)	0 – 100m	100 – 1500m	1500 – 3000m	> 3000m
LULC	Generally: best forage is in mountain heaths, and mountain birch forest (Forbes et al. 2006). Lichens cover was not evaluated within these satellite image analysis.	barren land, cultivated area	sparse vegetation / mosses; boreal dense forest	birch forest	mountain heath; mountain birch forest

Table 4 Qualitative data converted into quantitative measures for spatial modeling

Unsuitable class would have value 0, marginal value 1, suitable value 2 and optimal value 3. A series of spatial operations needed to be done to perform the analysis with the described criteria which is presented on the flowchart (*Figure 31*). However, on this flowchart only part without LULC is presented.

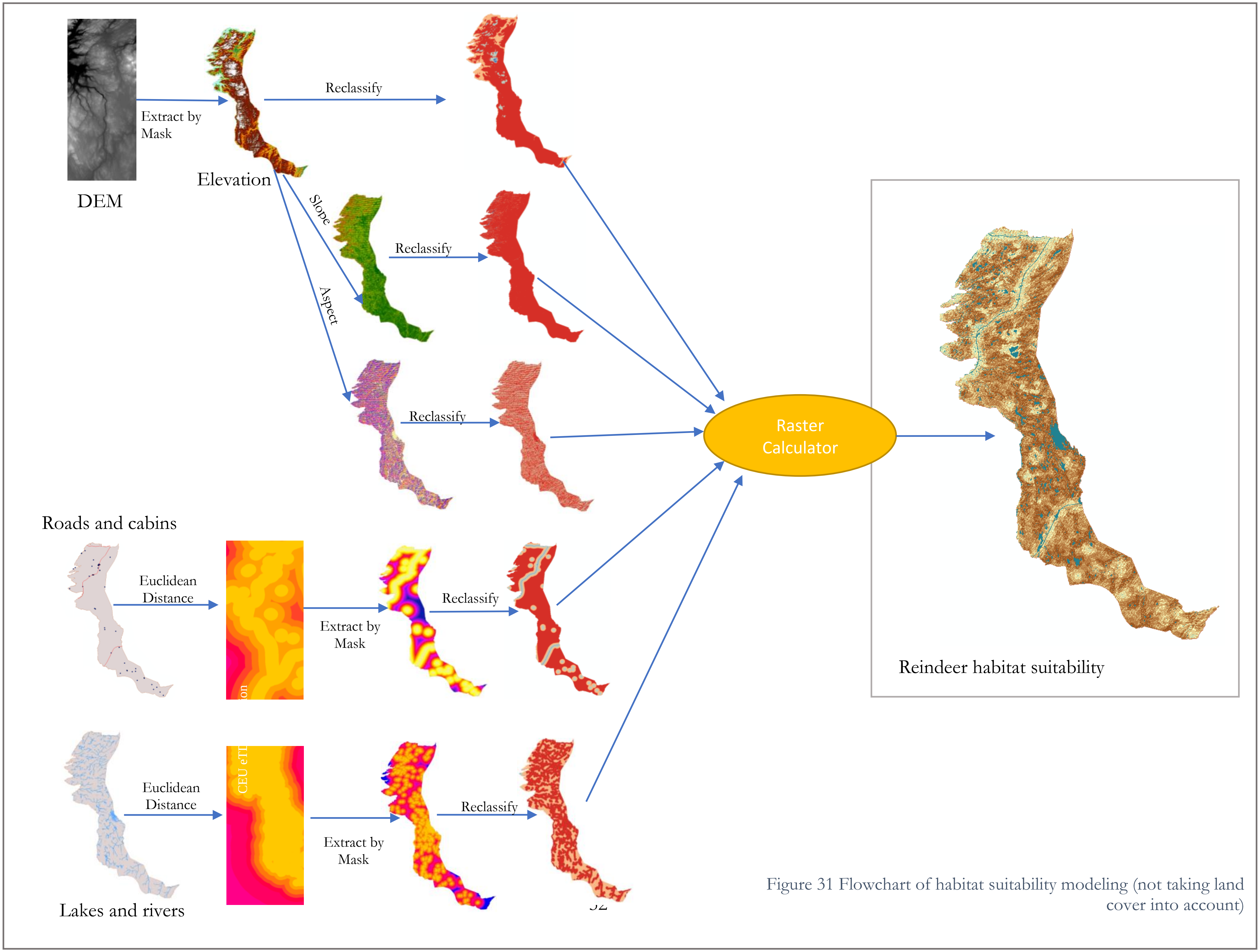

Figure 31 Flowchart of habitat suitability modeling (not taking land cover into account)

As described in the Chapter 4.3.3 dataset of elevation, slope and aspect were created based on the DEM dataset with the help of ArcMAP tools "Aspect" and "Slope". All of these datasets were reclassified into the classes with the values specified in the *Table 4*. To reclassify such factor as distance to disturbance or water source, the Euclidean distance tool was used. Example of one of the model's variable processing is presented on the *Figure 32*.

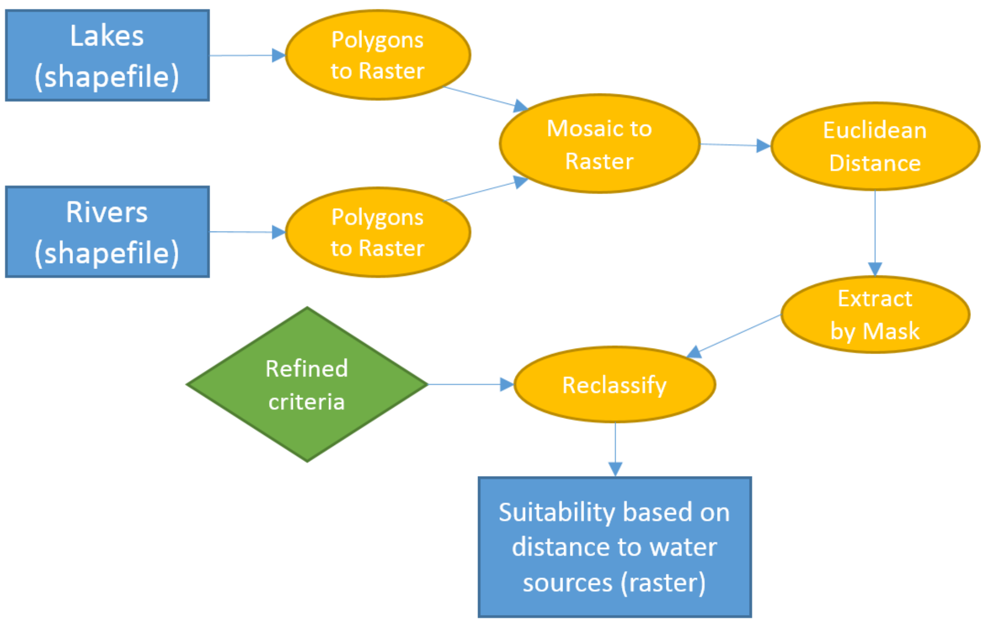

Figure 32 Flowchart of suitability map creating process (based on proximity to water sources)

After all the factor maps were created, the habitat suitability analysis was performed. Firstly, the general one without LULC was created. Through Raster Calculator the maps were summarized. This way the highest suitability were at the areas where most of the factors had the optimal value, and the least – where the factors had marginal/unsuitable value. To exclude each of the unsuitable area from the summarized map, all the factor maps were reclassified to Boolean maps – unsuitable class still had 0 value, all other classes – value 1. Subsequently, the summarized suitability map was multiplied with each Boolean map and this way all the zeros (unsuitable pixels) were excluded from the final map. Also, lakes and rivers needed to be "clipped out" from suitable area. This way the following map was generated (*Figure 1Figure 33*).

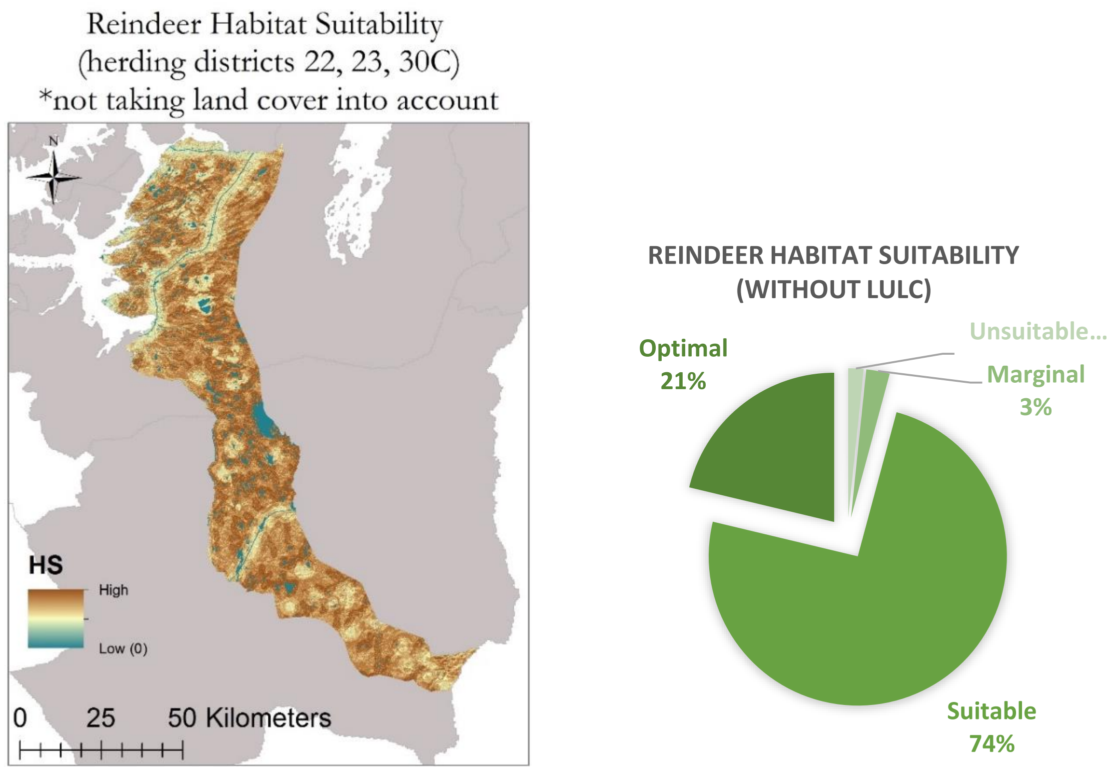

Figure 33 Reindeer habitat suitability for the study area (without land use /land cover variable) and the proportion of categories.

On the *Figure 33* the proportion of categories can be seen. Around 21% of the considered study area has optimal conditions for reindeers, 74% is suitable, around 3% marginal and 2% unsuitable. All the maps created for each criteria to be integrated into the cartographic habitat suitability model are presented in the Appendix VI.

Next step was to integrate the prepared earlier classified LULC maps for years 1998 and 2016 and the predicted LULC map for 2070 in to the habitat suitability analysis. For each year the maps were generated through the formula

Final LULC = (LULC + HS)*(Boolean map of LULC)*(Boolean maps of HS)

These are the final maps of reindeer habitat suitability of the study area (*Figure 34*).

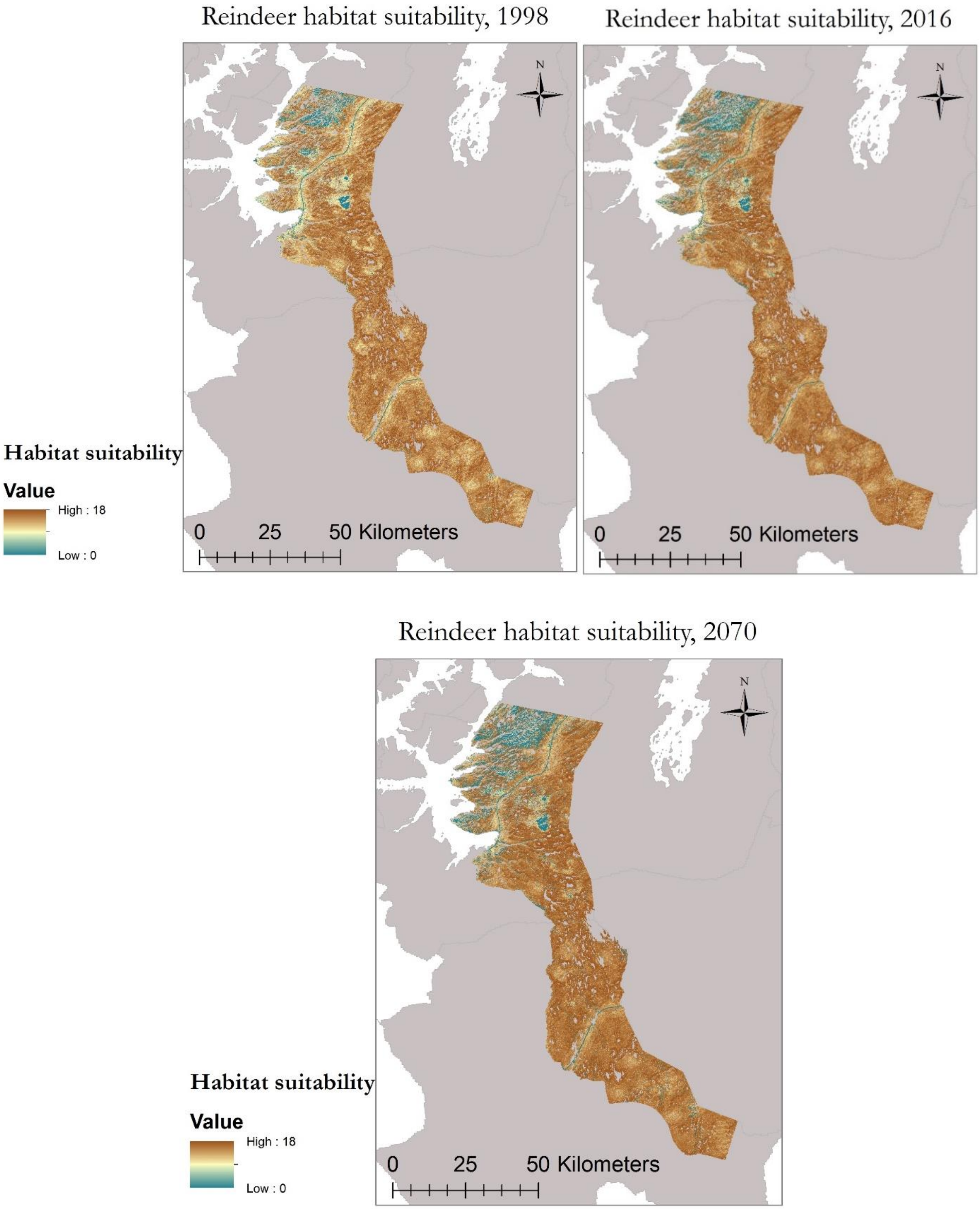

Figure 34 Reindeer habitat suitability for years 1998, 2016 and predicted 2070.

What can be seen from these maps and their attribute tables is that the changes happening are not significant (*Figure 35*). There is a trend of expansion of the unsuitable area (such as barren land and cultivated area). However, at the same time the area of optimal habitat for reindeers is also growing (due to the increase of mountain birch forest area). The area where suitability is decreasing mostly lies on the territory of summer pastures.

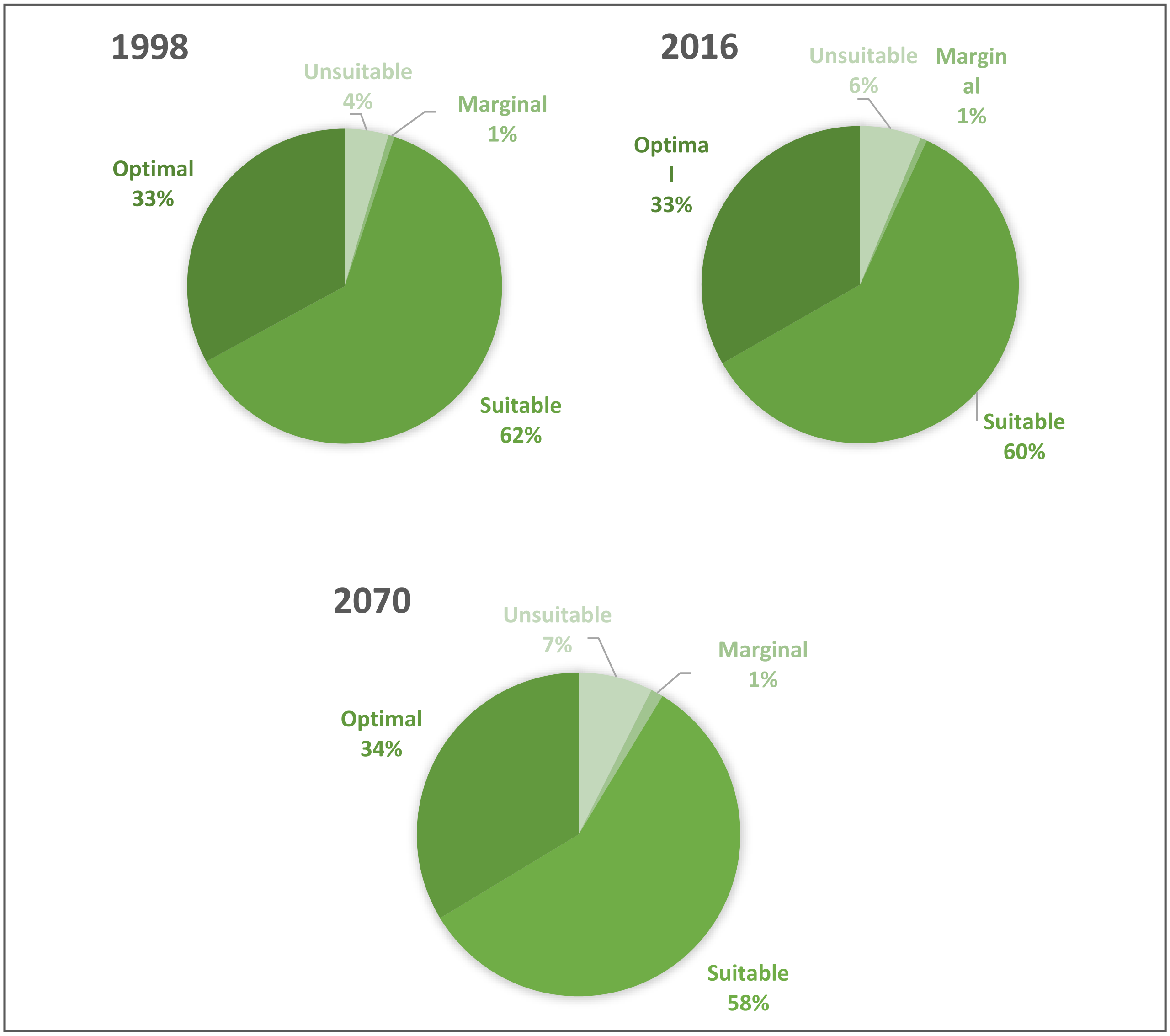

Figure 35 Proportion of Optimal, Suitable, Marginal and Unsuitable land cover for reindeers in the study area.

7.2. Limitations

Due to the limited time of the research period and the student's lack of previous experience of working with a software, this research has some drawbacks that could be addressed in a further research. As such, the number of ground truth points collected during the field work might not be sufficient for high confidence in the accuracy of classification. For this research only 50 points were collected but according to some sources there should be 10 times more ground truth points than there are classes in the classification. Following this scheme, there should have been 140 ground truth points per class. Unfortunately, there was no opportunity to travel enough around the study area and collect this number of sites. Nonetheless, methodology of this research can still be a model for making another classification with a higher level of confidence. Another limitation of this analysis is that habitat suitability model does not include the snow depth and predators' densities while these are important environmental variables affecting the population significantly according to the herders. The reason is that a high quality and high-resolution snow data for these factors was not found in open access.

8. Discussion

This section outlines the main steps completed and represents the final discussion of the results of the research. Data collection comprised of extensive literature review of both semi-domestic reindeer populations and habitat in Finnmark, and remote sensing and GIS research methods and functions; conversations with Saami herders involving participatory mapping approach; collection of ground truth points. The majority of the previous research on the quality of reindeer winter pastures was focused primarily on lichens cover. However, according to herders, lichens are not a nutritious forage and cannot solely define the quality of winter pastures. More and more supplementary feeding is included into the winter diet of reindeers. That is why in this research the author did not focus on lichens cover assessment. Local climate change, that has already been taking place in the last two decades, will affect the quality of the winter pastures as even if the snow cover season will be shortened, more pastures will be blocked due to higher frequency of rain-on-snow events and more reindeers will starve. Speaking about summer pastures, it was important to mention during the conversations the reindeer's avoidance of cabins with dogs so this factor was included into habitat suitability modeling. To prevent the future pasture fragmentation, urbanization and increasing number of summer cabins should be limited in the area of seasonal pastures of Saami's herds. During field work some reindeers were spotted close to roads and cabins, so not all of them avoid them but, according to various sources mentioned above, the majority of reindeers avoid the areas close to infrastructure (Figure 36).

Speaking about technical part of the research, different methods of performing land cover classification were evaluated and the 'hybrid' method was decided to be the most accurate for the study area. However, there are some notable constraints in this method of creating thematic maps such as subjectivity of the human analyst. Performing the ground truth validation of the latest image is considered to reduce the error.

Figure 36 Photo of a reindeer spotted at night close to the main road in the region. Finnmark, 2017. Photo taken by the author.

Regarding habitat suitability modeling, human factor might also be a constraint when the qualitative criteria is translated into mathematical values for the model. But here the author reviewed various published studies to refine the criteria most accurately. The key limitation of the HS model created was absence of snow cover input, as well as densities of predators' populations. However, the created spatial model present a viable basis for further research and the results are assumed to be representative.

The results of comparing image classifications for 1998 and 2016 showed that the most significant changes happened with categories of mountain birch forest, mountain heath, birch forest and barren land. While the area of barren land and mountain birch forest expanded, the area of birch forest and mountain heath and shrubs decreased. The prediction model showed the same trends up to 2070. As the goal of the research was to assess the consequences of these changes in a context of reindeer habitat, it is important to analyze them through the lens of suitability of different land cover types for reindeers. Comparing habitat suitability maps of different years it could be seen that the biggest area falls into

'Suitable' category (58-62%). Second biggest category is 'Optimal' and it is slowly expanding (33-34%). Although, 'Unsuitable' land cover comprised only 4% in 1998, by 2070 it would grow up to 7%.

The reindeer population density is already very high in the study area. As it was mentioned above, in the reindeer herding district 23, for example, that was included into the study of this research, the maximum allowed density is 5.6 animals per km^2. And just in 2012 the density was 10.4 animals per km^2. According to some studies on wild reindeer populations, the sustainable density is between one and two reindeers per km^2. If the suitable area of these pastures continues decreasing as the model has shown it, then alongside with overgrazing it will have significant consequences for the state of the summer pastures and the herds. Furthermore, if infrastructure in this area also continues developing, the indigenous herders will have to reduce their herds and search for means of living elsewhere. Thus, an opponent of infrastructure development on the territory of Saami pastures should be presented in each municipality committee.

As reindeer husbandry in Finnmark is a social-ecological system it should be managed in ecologically sustainable way from the side of herders who pursue saving the traditional way of living and increasing their family's income, as well as administrated by government as it is also their responsibility and the degradation of pastures would have consequences for all the actors. Over centuries Saami herders have been proving their resilience to changes and adaptive capacity of their reindeer herds (Riseth, Tømmervik, and Bjerke 2016). However, if external pressure comes both from natural environment and pasture encroachment imposed by infrastructure development, indigenous culture and traditions might be forced to undergo significant changes.

9. Conclusions and future directions

Performing this research the author aimed to identify the changes in land cover in Finnmark; to try to predict future transitions based on various environmental factors; to build a spatial model of reindeer habitat suitability; and to assess the value and opportunities of remote sensing and GIS tools and methods for performing current analysis. To meet this goal, the following research questions were formulated:

RQ1: What are the current and future changes in land cover and reindeer habitat suitability?

RQ2: How can remote sensing and GIS modeling help in assessment of reindeer habitat suitability?

To address these questions, a series of sequential steps was completed. First of all, extensive literature review and analysis of reindeer habitat in Finnmark was performed. In addition, various modeling and processing methods and software were reviewed and the opportunities of their applications were identified. Furthermore, a short field trip to Finnmark took place. Conversations with herders and participatory mapping were found to be effective methods of evaluating the significance of environmental factors affecting their herds and obtaining understanding of spatial distribution of different reindeer densities.

Regarding satellite image classification, ground truth validation alongside with ecosystem observations was found to be very helpful for defining categories and accuracy of classification and as it is the basis of the land cover analysis. Creating thematic land cover maps with the same land cover categories for different years allowed to analyze the land cover change in the study area between years 1998 and 2016. Using a modeling software TerrSet helped to identify areas with higher transition potential and to create future land cover map. The spatial data of six inserted variables needed to be processed and tested before the model was run. Subsequently, based on transition potential maps created and classified images, a map of projected land cover for 2070 was created (hard prediction). Hence, the changes in land cover that happened between 1998 and 2016 and those that might happen in the next 50 years could be visualized and analyzed. Finally, based on the created LULC classifications, modeled future LULC map and other environmental variables defining ecological niche of reindeer, reindeer habitat suitability modeling was performed and the changes in reindeer habitat suitability over the research period could be analyzed.

Speaking about future directions of the research, the first and foremost would be to assess the carrying capacity of the reindeer habitat based on the LULC datasets developed. This way the quantitative analysis would be performed that would help to link these results with the local policies and assess whether the population limits set by government are sustainable or not. Also, this research might be used as a model for analysis of the whole Finnmark and the conclusions could be drawn at the county level. Other potential future extension of the work developed could be separating spatial habitat suitability models by seasons. This way it would be possible to describe in better detail suitable/optimal vegetation cover and to include the snow depth and ROS occurrence for winter pastures

Further elaboration of habitat suitability modeling results would comprise of identification of the areas of higher suitability and adjusting the pasture boundaries so when the herd is most vulnerable (calving period or summer period when calves are still very young) they would graze on the territory of optimal suitability. The developed methodology, based on remote sensing tools and GIS-based operations, and the chain of sequential steps allowed to identify and assess the current and future changes in land cover and reindeer habitat suitability of the study area. Overall, remote sensing and GIS-based modeling were found to be invaluably useful tools in assessment of reindeer habitat suitability though there are some shortcomings and the broader analysis would be needed to draw conclusions on a county or country level.

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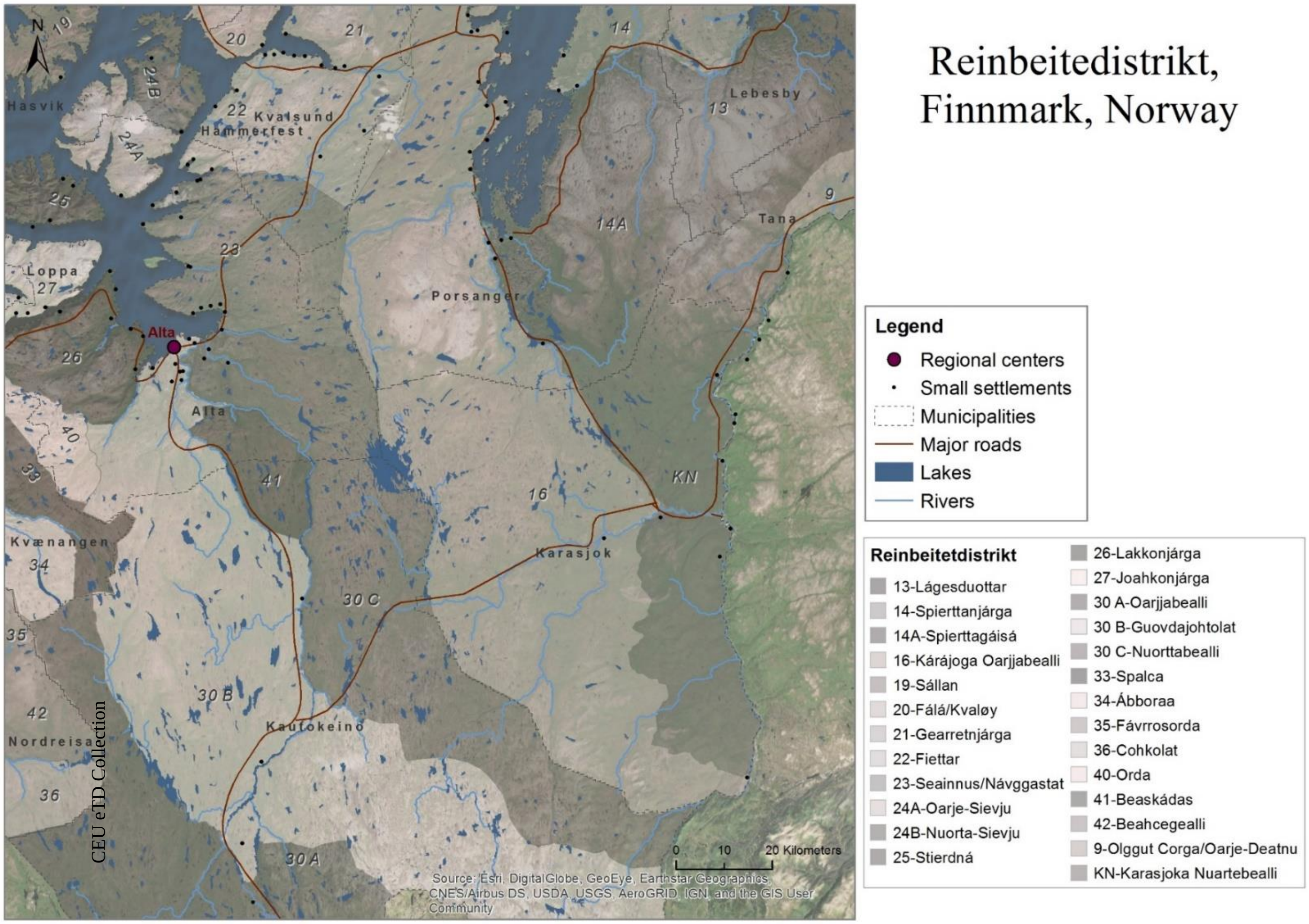
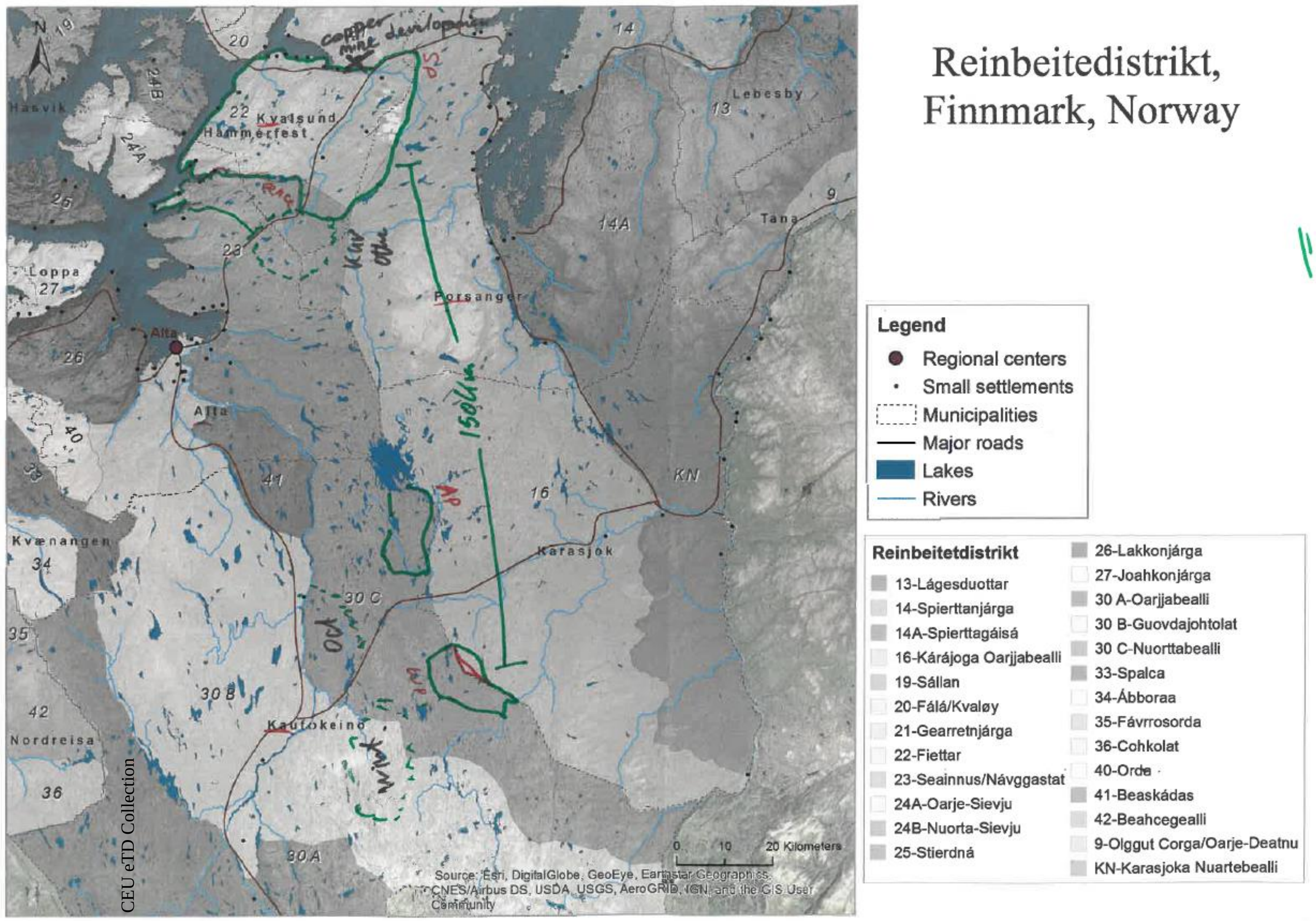
Appendix I. Template of the background map used for participatory mapping during the conversations with the herders.



Appendix II. Background map used for participatory mapping during the conversations with the herders.



Appendix III. Ground truth points used for the accurate supervised classification of the LANDSAT 8 image.

Point No.	Coordinates		Description	Photo
	Latitude	Longitude		
1	70,34306126°	24,33507307 °	Mountain birch forest defoliated by moths in 2016	
2	70,33896327 °	24,34004293 °	Mountain birch forest defoliated by moths in 2016	

3	70,33887240 °	24,34016780 °	Mountain birch forest defoliated by moths in 2016	
4	70,33781483 °	24,34444714 °	Bog surrounded by mountain birch forest; shrubs and grasses.	
5	70,33753542 °	24,34121632 °	Tundra; grasses, mountain heath surrounded by mountain birch forest.	

6	70,30809904 º	24,21632529 º	Bog; grasses.	
7	70,30728963 º	24,21484057 º	Bog	
8	70,30681460 º	24,22304084 º	Birch forest	

9	70,30576394 °	24,22543941 °	Upland tundra, high elevation, rocks, mosses.	
10	70,29861616 °	24,17817157 °	Birch forest	No photo
11	70,17100263 °	23,78684700 °	Mosses, grasses.	
12	70,16436596 °	23,74891697 °	Mountain heath	

13	70,15731373 º	23,72433388 º	Rocks, barren land on the slope	
14	70,12613105 º	23,62099189 º	Birch forest, large area	
15	70,06695764 º	23,54311511 º	Boundary point: East from the road – mountain birch forest, west from the road - shrubs	

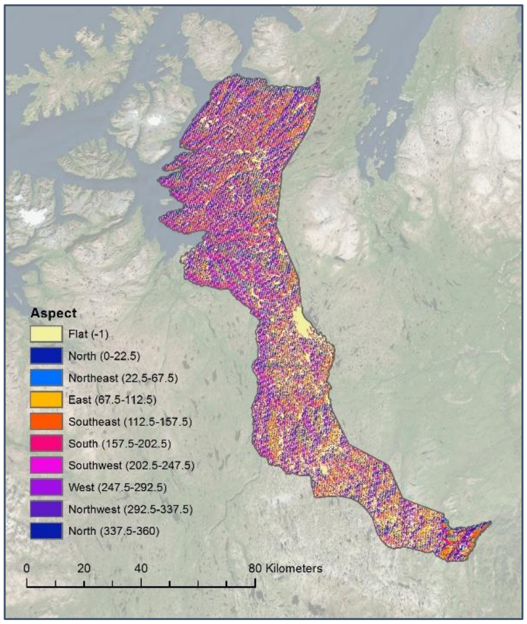
				
16	70,03414757 °	23,55312629 °	Boreal forest	
17	69,43164454 °	23,62223007 °	Dense tall birch forest	

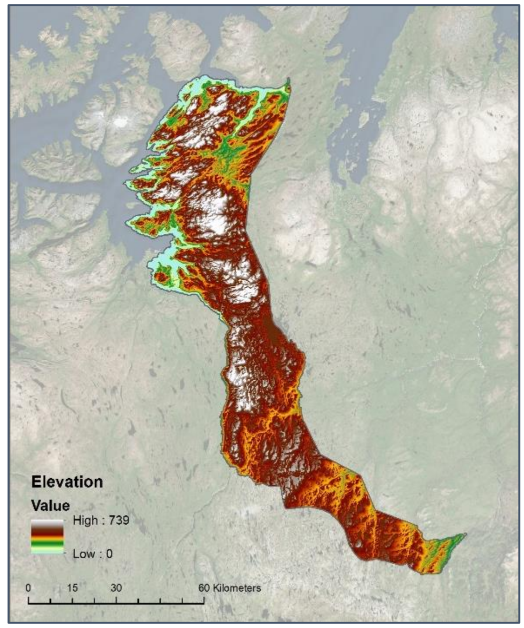
18	69,37663407 o	23,63697780 o	Dense tall birch forest	
19	69,24304631 o	23,60581959 o	Dense tall birch forest	No photo

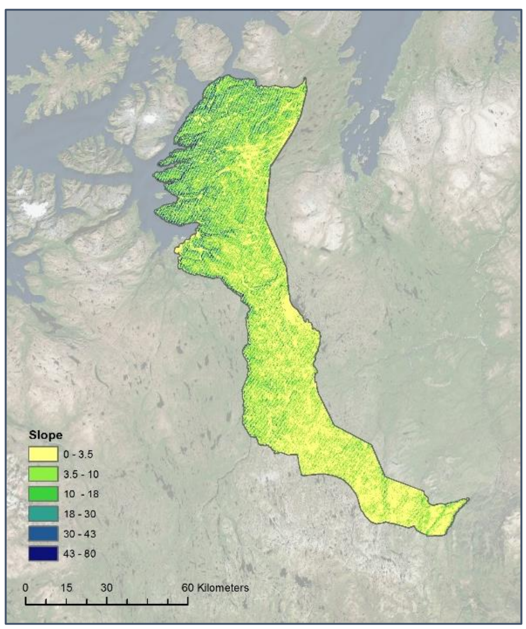
Appendix IV. Accuracy assessment of the 1998 image. Confusion matrix.

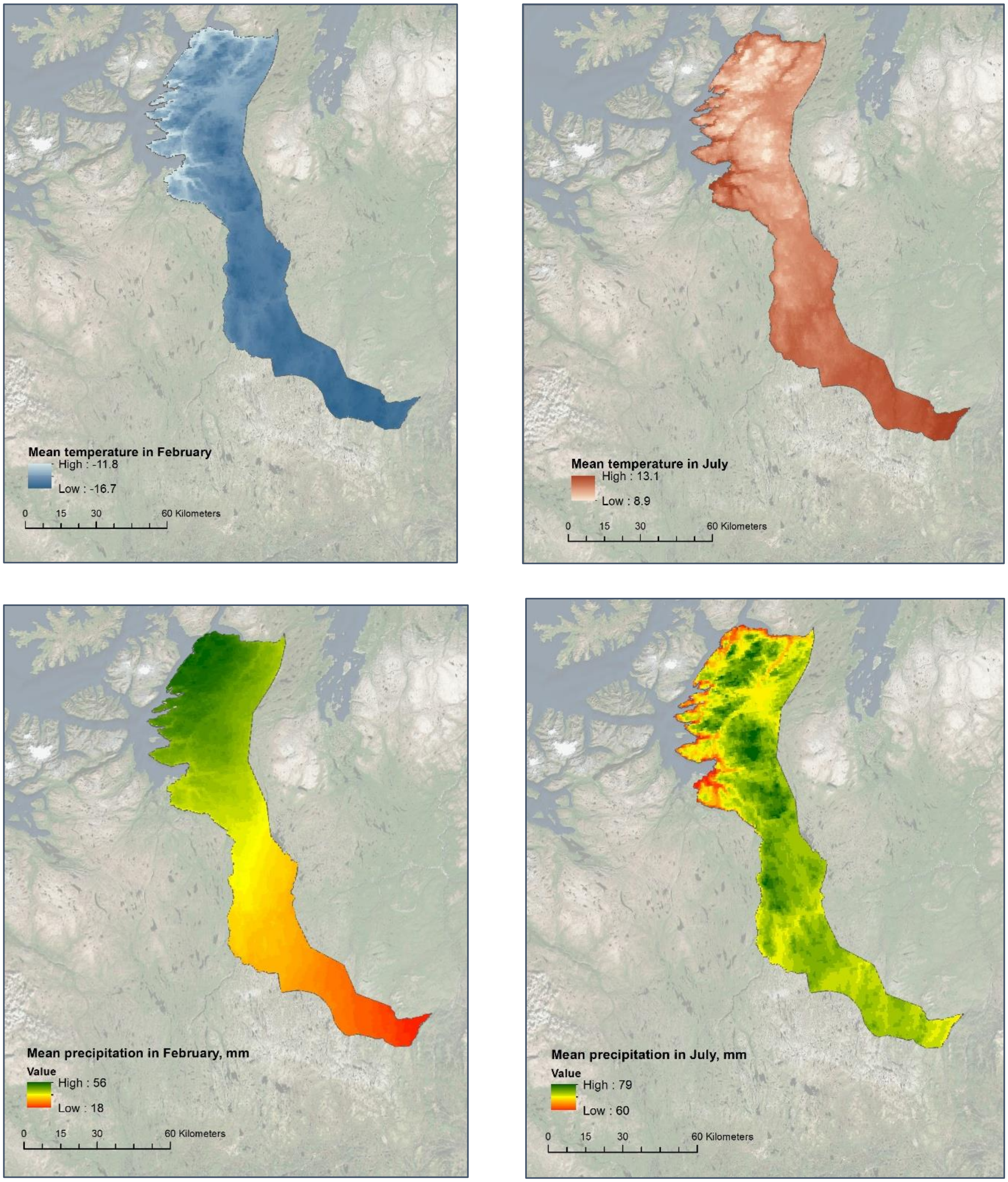
		Ref 1	Ref 2	Ref 3	Ref 4	Ref 5	Ref 6	Ref 7	Ref 8	Ref 9	Ref10	Ref11	Ref12	Total
1	Water	57	0	0	0	0	0	0	0	0	0	5	0	62
2	Barren land	0	54	4	0	0	0	0	0	0	2	0	0	60
3	Sparse vegetation	0	5	55	0	0	0	0	0	2	0	0	0	62
4	Shrubs	0	0	1	49	8	1	0	2	0	0	0	0	61
5	Mountain birch	0	0	0	7	50	6	0	0	0	0	0	0	63
6	Birch forest	0	0	0	3	2	53	6	2	0	0	0	0	66
7	Boreal forest	0	0	0	0	0	0	52	0	4	0	0	0	56
8	Built-up	0	0	0	0	0	0	0	55	0	0	0	0	55
9	Cultivated	0	0	0	1	0	0	2	1	54	0	0	0	58
10	Snow	0	1	0	0	0	0	0	0	0	58	0	0	59
11	Hill-shaded	3	0	0	0	0	0	0	0	0	0	55	0	58
12	Cloud	0	0	0	0	0	0	0	0	0	0	0	60	60
	Total	60	60	60	60	60	60	60	60	60	60	60	60	720

Appendix V. Maps of variables for TerrSet modeling





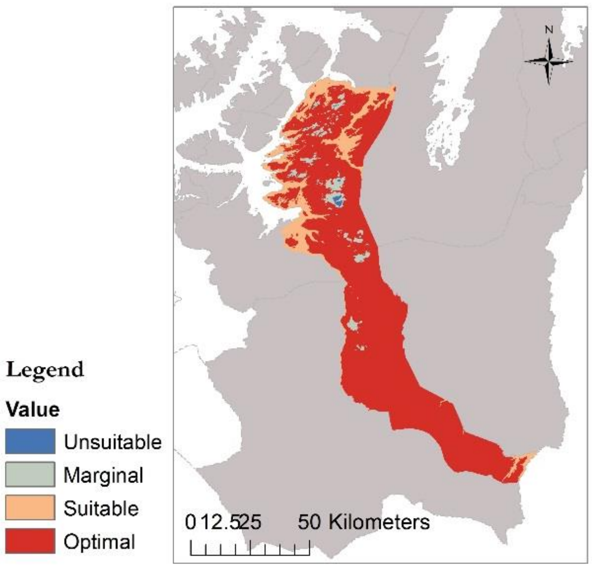




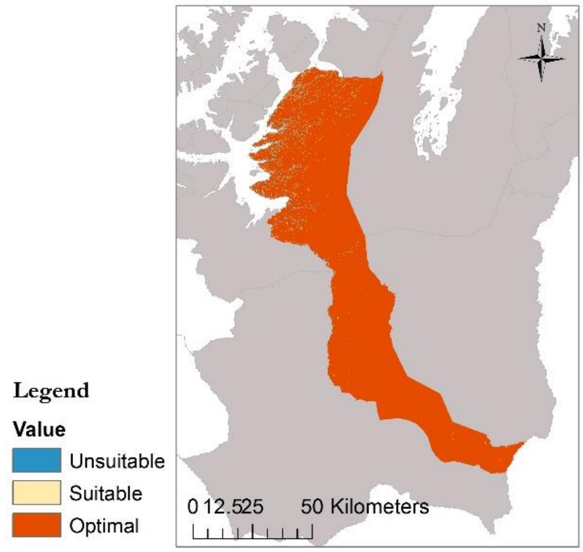
Mean temperature in February
High : -11.8
Low : -16.7
0 15 30 60 Kilometers
Mean temperature in July
High : 13.1
Low : 8.9
0 15 30 60 Kilometers
Mean precipitation in February, mm
Value
High : 56
Low : 18
0 15 30 60 Kilometers
Mean precipitation in July, mm
Value
High : 79
Low : 60
0 15 30 60 Kilometers

Appendix VI. Suitability maps created for performing habitat suitability analysis

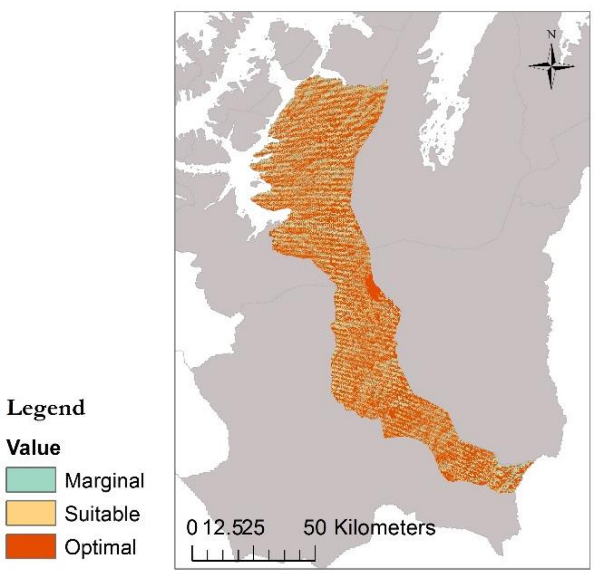
Suitability based on elevation



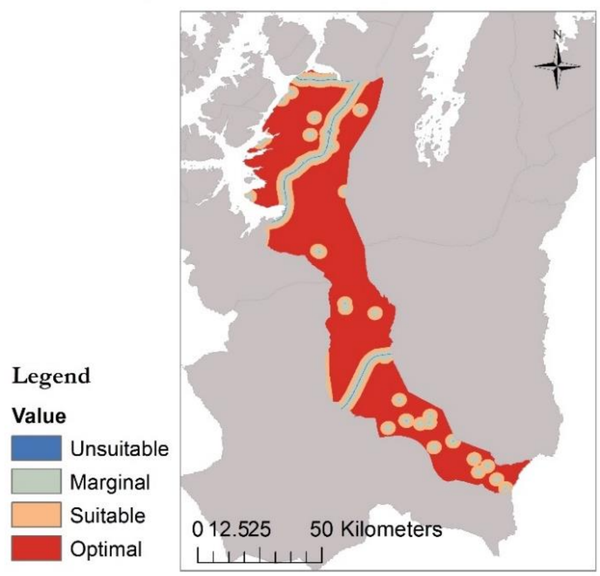
Suitability based on slope



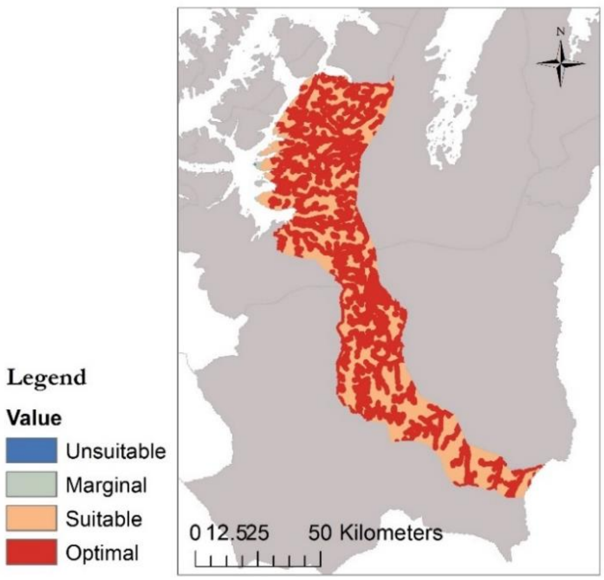
Suitability based on aspect



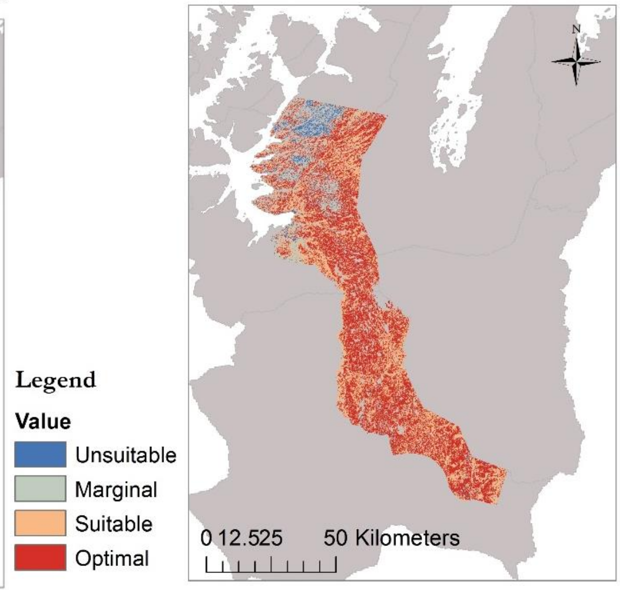
Suitability based on distance to roads and cabins



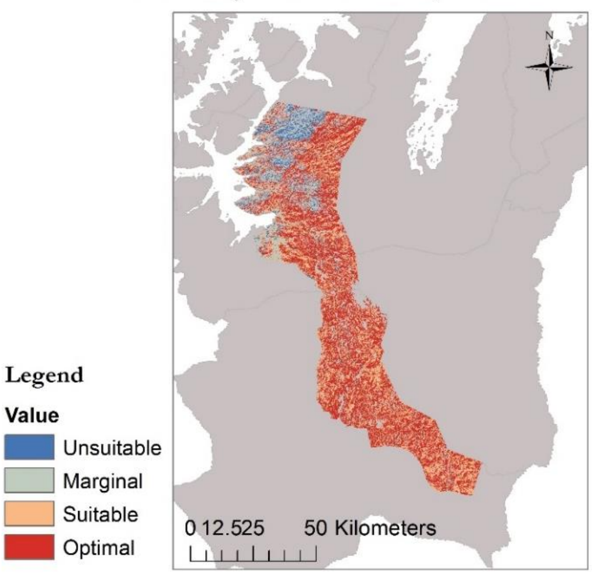
Suitability based on distance to water sources



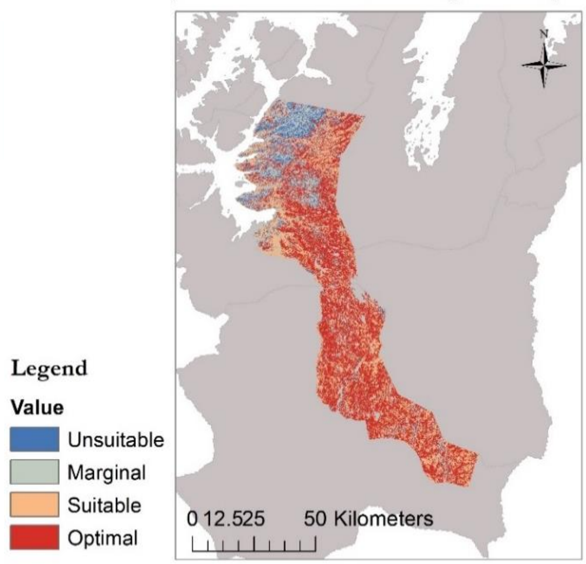
Suitability based on LULC, 1998



Suitability based on LULC, 2016



Suitability based on LULC, 2070 (predicted)



Appendix VII Contribution to Net Change in each category by other classes between years 1998 and 2016