Patterns of Mixed Land Use on Remote Eurasian Rangelands

Dissertations in Social Sciences and Business Studies No 12

TIMO KUMPULA

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Publications of the University of Eastern Finland
Dissertations in Social Sciences and Business Studies
No 12

Itä-Suomen yliopisto
Yhteiskuntatieteiden ja kauppatieteiden tiedekunta
Joensuu
2010

Juvenes Print - Tampereen Yliopistopaino Oy
Tampere, 2010
Sarjan vastaava toimittaja: FT Kimmo Katajala
Myynti: Itä-Suomen yliopiston kirjasto

ISBN 978-952-61-0263-4
ISSN 1798-5749
ISSNL 1798-5749
ISBN 978-952-61-0264-1 (PDF)
ISSN 1798-5757 (PDF)

Kumpula, Timo
Patterns of Mixed Land Use on Remote Eurasian, 137 p.
Itä-Suomen yliopisto, Yhteiskuntatieteiden ja kaupptieteiden tiedekunta, 2010
Publications of the University of Eastern Finland,
Dissertations in Social Sciences and Business Studies, no 12
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ISSN 1798-5757 (PDF)
Summaries in English and Finnish
Dissertation

ABSTRACT

Land use on remote Eurasian rangelands was studied in this thesis. Research has been conducted in four different areas: Jauristunturit (in Finnish –Norwegian border), Dzoge Eastern Tibetan plateau in China, Toravei and Bovanenkovo area in Arctic Russia. In all sites animal husbandry (reindeer or yak) practiced by indigenous people and based on natural pastures has been the traditional the primary form of land use. Remote sensing has been used in detecting land cover and land use. The evaluation of land use on vast rangelands requires the use of remote sensing and GIS. Traditional land use has changed in all areas, especially in the Arctic Russian research sites recent petroleum industry expansion is changing Nenets reindeer herding. In Jauristunturit and Dzoge changes in land use are in changes of herding practices. In this research multidisciplinary approach has been used to combine remote sensing, geographical ecological, social and local knowledge to create comprehensive understanding of combined social and environmental impacts on changing rangelands.

Key words: land use, remote sensing, reindeer, yak, indigenous people, multidisciplinary.

ABSTRAKTI

Tutkimuksessa tarkastellaan laidunmaiden maankäyttöä Euraasian periferisillä alueilla. Tutkimuksen kohteena oli neljä aluetta: Jauristunturit (Suomen ja Norjan rajalla), Dzoge Itä-Tiibetin ylängöllä (Kiinassa) sekä Toravein ja Bovanenkovon alueet (arktisen Venäjän alueella). Kullakin alueella perinteisenä maankäyttö-muotona on ollut alkuperäisväestön harjoittama luonnonlaitumiin perustuva eläintalous (poro- tai jakkitalous). Tutkimuksessa käytettiin kaukokartoitusta maanpeitteen ja maankäytön kartoittamiseen. Perinteinen maankäyttö on muuttunut kaikilla tutkimusalueilla. Muutokset maankäytössä ovat tapahtuneet erityisen nopeasti arktisen Venäjän alueella, jossa öljy- ja kaasuteollisuus levittäytyvät kohti pohjoisia nenetsien porolaidunmaita. Jauristuntureilla sekä Dzogessa maankäytön muutos liittyy pääasiassa laiduntamistapojen muutokseen. Tässä tutkimuksessa lähestyttiin laidunmaita monitieteisesti yhdistämällä maantiede, kaukokartoitusmenetelmät, ekologia, antropologia sekä tutkimusalueiden asukkaiden paikallistietämys. Näin pystyttiin arvioimaan sosiaalisten ja ympäristöllisten tekijöiden vaikutusta muuttuvilla laidunmailla.

Avainsanat: maankäyttö, kaukokartoitus, poro, jakki, alkuperäiskansat, monitieteinen.

Acknowledgements

This thesis took me to many wonderful places and on great adventures that I would probably not have experienced without participating in these diverse projects. It all began in Professor Olavi Heikkinen's inspiring physical geography lectures in Oulu University. Olavi was also the first supervisor of this long-lasting PhD student career until I moved to Joensuu in 2004. I would also like to thank my teachers and colleagues in Oulu; Dr. Seppo Luomaho, Dr Jyrki Autio and Pertti Vuolteenaho.

Professor Alfred Colpaert has been a tolerant PhD supervisor for all these years waiting for a positive outcome. I started work as a masters student in the Finnish reindeer pasture inventory project in 1995 under Alfred's supervision, in Oulu. He introduced me to the fascinating world of remote sensing and GIS. This project familiarized me to Jauristunturit during the fieldwork in Autumn 1995. Special thanks to the pasture inventory project's reindeer specialists Dr. Jouko Kumpula and Docent Mauri Nieminen from Kaamanen FGRI reindeer research station. Then research on pastures took Alfred and me to the Eastern Tibetan plateau. I am deeply grateful to the late Dr. Angela Manderscheid, who was the project leader of the Eastern Tibetan rangeland project. In Dzoge Dr. Wang Qian from Chengdu Institute of Botany was the most valuable botanical expert of grasslands, not to mention a most pleasent field companion.

I met Professor Bruce Forbes (Arctic Centre, University of Lapland) first time during the annual Poropäivät event at Kaamanen research station and consequently a valuable contact was established and our common interest in very high-resolution satellite imagery developed. Later Bruce provided with an opportunity to build a remote sensing workpackage into the RENMAN project application, which was later funded by the EU in 2000. Then RENMAN took me back to Jauristunturit beginning in summer 2001. During the RENMAN project Dr. Benjamin Burkhard, at that time a PhD student, became an utterly important partner; the Fenno-German partnership was re-established on the Norwegian border. The visits to Benjamin and Professor Felix Müller in the Ecology Center of Kiel University have always been intellectually stimulating experiences. Thanks also to Professor Manfred Bölter from Institute of Polar Ecology, Kiel for giving valuable comments to improve my chapter in the RENMAN book. Sakari Kankaanpää from the Forest and Park Service helped with field logistics in the Näkkälä and Lappi herding districts. Docent Timo Helle, also a RENMAN associate, always gave me wise comments about reindeer husbandry and pastures.

When ENSINOR project was launched in 2004 Bruce, as the project coordinator, became my second supervisor. Bruce has been the most supportive and warmhearted supervisor, always full of inspiring ideas when it comes to research. ENSINOR took us to the Russian Arctic, which I had dreamed about. We cooperated as a good team with Anu Pajunen, Florian Stammler, Elina Kaarlejärvi, Nina Meschtyb and Tuula Tuisku. Co-authoring with Bruce, Anu, Florian, Elina and Nina was a valuable example of fruitful interdisciplinary research.

A few side projects during my PhD were established from which Changing Landscape Management of Northern Finland CLMIRF must be mentioned here. CLMIRF was a researcher exchange project between Benjamin Burkhard and myself. It was supported by the Finnish Academy and DAAD. Many Finnish projects evolve in the sauna. So did this one. The project grew soon when we met Petteri Vihervaara during a sauna in Beijing. Ari Tanskanen also joined the project. He deserves special thanks for being a valuable colleague in our department's RS-GIS laboratory. Although CLMIRF prolonged my thesis, it was a valued experience and introduction to the world of ecosystem services. CLMIRF!

When I came to Joensuu Professor Markku Tykkyläinen was the head of the department. He supported the development of a GIS curriculum and reminded me occasionally about my PhD. Markku also gave useful advise when finishing the thesis. The subsequent head of the department, Professor Jarmo Kortelainen, continued to support my work. The head of the new Geography– History coalition, Professor Jukka Korpela, has not mentioned the PhD in our conversations. Thank you for that! Docent Heikki Vesajoki has been a pleasant colleague whose experience I appreciate. Olli Lehtonen has been devoted to GIS teaching. Thank you for valuable discussions in that field. The warmest thanks to all colleagues in the department. Special cheers also to co- and ex-PhD students: Minna P,, Kenneth M., Sarolta N., Mattias S., Jussi S, Katja P., Kati P., Moritz A., and Evgenia P.

There was, fortunately, some life outside of the PhD project. A great deal of energy has been gained from music. Armas Kesäketo ja Kohteliaat Kukkaispojat (AKKP), also known as Ari Kähkönen, Jussi Tomberg, Esa Härmä, Mika Moilanen, Pasi Ruotsalainen, Jani Salmu and Markku Jurva provided me with a great scene to be "a rock star". At least in my own head, as you might have noticed. Lately AKKP sessions have been seldom and lonesome blues has filled our living room. I would also like to thank my Oulu student colleagues and UKKI comrades Dr. Jani Vuolteenaho, Dr. Mika Rytkönen, Dr. Mervi Tervo, Dr. Juha Ridanpää, Heikki Hellsten, Mika Paakkanen, Matti Tapaninen, Harri Lundell, Ilkka Immonen, Vesa Juntunen., Sami Kolamo, Timo Rossi, Mika Hytönen and Aki Nurmesniemi to name a few.

Warmest thanks to my dear parents Asko and Pirkko for their patient support. Our hiking and fishing trips beginning in my childhood gave me the inspiration to study remote Eurasian rangelands.

As they say last, but definitely not the least, the warmest thanks go to my dear companion Hanna. You have accompanied me during the whole ten year project. There is no better field companion in rangeland research than my beloved botanical advisor. We spent summers in Jauristunturit, Yamal and Varandei seeing wonders of nature from *Gulo gulo*, *Alopex lagopus*, *Thymallus arcticus* to *Arnica angustifolia*.

Joensuu, 16 November 2010
Timo Kumpula

Preface

This thesis consists of the summary and the following articles, which are referred to in the text by their Roman numerals (I-V) in the text.

I Kumpula, T., Colpaert, A., Wang, Q. & A. Manderscheid (2004). Remote sensing in inventory of high altitude pastures of the eastern Tibetan Plateau. Rangifer, Special Issue No. 15:54-64.

II Kumpula, T. (2006). Very High Resolution Remote Sensing Data in Reindeer Pasture Inventory in Northern Fennoscandia. In: Forbes, B.C., Bölter, M., Müller-Wille, L., Hukkinen, J., Müller, F., Gunslay, N. & Y. Konstantinov (eds.): Reindeer Management in northernmost Europe. Ecological studies 184. Springer 167-185.

III Kumpula, T., Forbes B.C & F. Stammler (2010). Remote Sensing and Local Knowledge of Hydrocarbon Exploitation: the Case of Bovanenkovo, Yamal, West Siberia. Arctic 63(2):165–178.

IV Kumpula, T., Pajunen, A., Kaarlejärvi, E., Stammler, F., & B.C. Forbes, (2010). Land use and land cover change in Arctic Russia: ecological and social implications of industrial development. (submitted manuscript).

V Forbes, B.C., Stammler, F., Kumpula, T., Meschtyb, N., Pajunen, A. & E. Kaarlejärvi (2009). High Resilience in the Yamal-Nenets Social-Ecological System, West Siberian Arctic, Russia. Proceedings of National Academy of Sciences (PNAS), 106(52):22041-22048.

Article I Timo Kumpula is the responsible author and carried out GIS and remote sensing analysis. Alfred Colpaert took part in the research planning, in field data collection and in editing of the article. Botanist Wang Qian from Chengdu Institute of Biology, Chinese Academy of Sciences (China) was responsible for identification of plants. Angela Manderscheid as project leader organized the field excursion and participated in editing of the manuscript.

Article II Timo Kumpula is the responsible author.

Article III Timo Kumpula is the responsible author. Florian Stammler was responsible for the anthropological parts of this article. Bruce Forbes participated in field work and article writing.

Article IV Timo Kumpula is the responsible author. Anu Pajunen was responsible for the botanical work and she was the second main contributor in writing the manuscript. Florian Stammler was responsible for the anthropological field work and related of this article. Bruce Forbes participated in the field work and article writing. Elina Kaarlejärvi participated in the field work and in editing of the manuscript.

Article V Bruce Forbes designed the work. Bruce Forbes is the responsible author. Timo Kumpula did all remote sensing and GIS-analysis and participated in the writing of the article. Anu Pajunen was responsible for the botanical analyses and in editing of the manuscript. Elina Kaarlejärvi participated in the field work and in editing of the manuscript.

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List of acronyms

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATV	All Terrain Vehicle
BGF	Bovanenkovo gas field
CAVM	Circumpolar Arctic Vegetation Map
ETM+	Enhanced Thematic Mapper Plus
GIS	Geographical Information System
MSS	Multi Spectral Scanner
NAO	Nenets Autonomous Okrug
NDVI	Normalized Difference Vegetation Index
NIR	Near-infrared
ROS	Rain on Snow
SPOT	Satellite Pour l'Observation de la Terre
TEK	Traditional Ecological Knowledge
TIR	Thermal Infrared
TM	Thematic Mapper
VHR	Very High Resolution
VNIR	Visible and Near-infrared
YNAO	Yamal – Nenets Autonomous Okrug

1. Introduction

Rangelands cover a significant part of the Earth's land surface and animal husbandry is practiced on all continents except Antarctica (Tueller 1988; Johnson & Mayeux 1992). Rangelands have been estimated to cover 47 % of Earth's land surface. Animal husbandry practiced on rangelands is therefore one of the most significant form of land use (Williams *et al.* 1968; Friedel *et al.* 2000). Animal grazing is an important controlling factor of vegetation i.e. land cover of the world's uncultivated land (Miles 1979) and natural pastures i.e. rangelands are, according to Stoddart *et al.*'s (1975) definition, areas where rainfall is minimal or seasonal, elevation differences are significant or they are unsuitable to permanent agriculture due to the cold climatic conditions. Nevertheless, these areas are suitable as pastures for free ranging wild or domestic animals. However land use even on remote rangelands is a mixture of several activities like traditional hunting and fishing or modern exploitation of different natural resources like timber and minerals. Animal husbandry based on grazing of rangelands is considered a form of extensive agriculture where large areas are used and the productivity per hectare is comparatively low. Grazing enables the exploitation of areas where other forms agriculture would not be profitable because of climatic, soil or altitudinal factors (Cutter *et al.* 1985; Mannetje 2002).

Natural rangelands of the Eurasian continent for example consist of the tundra zone, the northern boreal zone and the Hindu Kush-Himalayan sub-alpine, alpine, and steppe-zones. According to Lent and Klein (1988) tundra vegetation as a rangeland resource covers about 10 – 15 % of the Earth's land surface of which 3 million km^2 are located within the Russian Arctic and 3.2 million km^2 within North America. The northern coniferous forests cover about 17 % of land surface, which is about 23.2 million km^2 (Walter 1979). The Tibetan steppe grazing ecosystem comprises about 1.65 million km^2 (Miller 1997; Miller 2005).

Domestication of animals has been one of the most important innovations of the human Holocene history (Diamond 2002). The most widespread domesticated grazing animals are cattle (*Bos taurus*), goat (*Capra aegagrus hircus*) and sheep (*Ovis aries*). The reindeer (*Rangifer t. tarandus* L.) is a ruminant of the family *Cervidae* with a circumpolar distribution (caribou in North America). The date and location of the first appearance of semi-domesticated reindeer is not clear, but Northern indigenous people have been hunting and using reindeer as draught animal for more than a thousand years. According to Røed *et al.* (2008) it seems that reindeer has been domesticated independently in Fennoscandia and northern Russia. As wild reindeer herds declined, a large-scale private ownership-based reindeer husbandry was formed a few hundred years ago (Ingold 1980; Krupnik 1993; Jernsletten & Klokov 2002; Forbes 2005). The pastoralism practiced by the indigenous peoples of the Eurasian tundra and Northern boreal vegetation zones differs from the pastoralism elsewhere as it relies on just one species, that is reindeer (Galaty & Johnson 1990; Stammler 2005). On the Tibetan plateau, wild yak (*Bos bos grunniens*) has been domesticated already 4 000 years ago (Barfield 1989) and new paleoecological research suggests that the pastoral environment began to evolve already 8 800 years ago (Miehe *et al.* 2010). In the Tibetan pastoralism also horse (*Equus caballus)* and sheep breeding are important types of animal husbandry (Wu 1997; Wiener 2003).

Rangeland managers are mainly concerned with the optimization of animal production (Beach 1997; Fox 1998; Kumpula 2001; Lundqvist 2007; Lundqvist *et al.* 2007). However, the importance of rangelands is far greater. Rangelands are the main forage resource for traditional livestock rearing systems in many parts of the world. Traditional animal production provides food (milk, meat and blood), wool, skin, draught power, transportation, added security and the way to accumulate wealth and status (Krupnik 1993; Mannetje 2002; Stammler 2005; Crate *et al.* 2010). Lambin *et al.* (2001) argues that some management specialists still hold to the misconception that rangelands are natural entities which, in the absence of human impact, would remain unchanging. Across most parts of Eurasia, semi-domestic and domestic grazers have modified the original vegetation communities for several thousand of years (Prins & Gordon 2008). Significant parts of rangelands are maintained in their current state by the interaction of human and biophysical drivers (Sneath 1998; Mysterud 2006; Forbes *et al.* 2006). As human activities are commonly a functional part of these 'semi-natural' rangeland ecosystems, reducing or eliminating anthropogenic impact will cause significant changes (Walker 1993).

Change in land use is one of the most extensive human impacts on the environment globally (Millennium Ecosystem Assessment 2005). Human activities are increasingly being recognized as a major force in environmental change (Lambin *et al.* 2001; McMichael *et al.* 2003; Prins & Gordon 2008). To understand how land cover and land use is changing, the drivers that usually consist of economic, technological, cultural and demographic factors need to be defined. Land cover is continually molded and transformed by land use changes like forests converted to crop lands. Change and especially intensification of land use also can lead to ecosystem degradation, e.g. rangeland degradation which is reducing the biological and economic productivity of ecosystems (Reynolds 2001).

For the purposes of the studies presented here, land cover refers to vegetation on rangelands. Land cover also includes the quality of pastures, i.e. available fodder sources for animals. Land use however refers to human activities on land cover like forestry, grazing, agriculture or nature protection (Turner & Meyer 1994). Land use can maintain or change the original land cover (Foley *et al.* 2005). Land use on rangelands also includes socio-economic factors, e.g. the division of rangelands between herders. In arctic, sub-arctic and alpine environments, free ranging animal husbandry is an important and traditional form of land use.

Since the late 19th century, new forms of land use form began to extend into northernmost Finland (Näkkäläjärvi 2003; Pennanen 2003). Sámi reindeer herding in northernmost Finland experienced significant changes when in the year 1852 border closure with Norway prevented traditional pasture migration between Ice Sea coastal summer pastures and winter pastures in lichen-rich pine forests on the Finnish side (Lähteenmäki 2004). Landscape modification after World War II has been drastic in northern Finland, especially in the state-owned coniferous forest areas (Müller-Wille *et al.* 2006; Laakso 2008). Much of the Finnish post-war economic growth was built upon wood from northern forests and rivers that were harnessed for hydropower. Heavy forest management (large clear cuts, tilling, drainage, fertilizers) methods were used from the 1960's to the 1990's (Helle & Jaakkola 2008). In Finnish Lapland, tourism has expanded as a competing land use form drastically since the 1960's. However, tourism pressure is concentrated in and around tourist centers (Helle & Särkelä 1993; Tolvanen *et al.* 2001; Törn *et al.* 2006; Törn 2007; Törn *et al.* 2007).

In the Russian Arctic, nomadic reindeer herders' culture remained relatively intact until the early 20th century. First major changes of the traditional land use system came in the 1930's by the first attempts of collectivization which reformulated animal and land ownership (Krupnik 1993; Stammler 2005). The Russian petroleum industry expanded from the northern forest into the tundra zone since the 1960's (AMAP 1998; Krupnik 2000; ACIA 2005; Stammler 2005). On the Tibetan plateau changes came later. Nevertheless, the Tibetan animal husbandry has gone through vast changes in the past 50 years, from seasonal pasture rotation herding to collectivization in the 1960's and again to privatization in the late 1980's and 1990's. The privatization of livestock and the re-organization of the pasture lands, including fencing, has limited the herders' and animals' mobility and reduced the possibilities for pasture rotation (Wu 1999; Miller 2005; Yan *et al.* 2005; Yan & Wu 2005; Harris 2010).

1.1 ASSESSMENT OF HERBIVORE IMPACTS ON RANGELANDS

Herbivore grazing is one of the most extensive forms of land use affecting the quality, quantity and productivity of rangelands (Watkinson & Ormerod 2001). Accurate and comprehensive knowledge about the quality of pastures supports a sustainable use of pastures (Price *et al.* 2001).

The ecological carrying capacity of rangelands is defined as the maximum number of ungulate herbivores per unit area that can be maintained without degradation of the rangeland (Kumpula 2001; van der Wal 2006; Mysterud 2006). The equilibrium line between ecologically sustainable and unsustainable grazing varies spatially and temporally. Carrying capacity can be studied using ecological and/or socio-economic approaches (Caughley 1976; McCullough 1979; Beach 1997; Kumpula 2001; van der Wal 2006; Mysterud 2006). In Fennoscandia and Russia, carrying capacity models are generally employed by the respective nations to manage semi-domestic animals in relation to state-sponsored scientific assessments of range conditions (Podkorytov 1995; Beach 1997; Fox 1998; Syroechkovski 1999; Baskin 2000; Kumpula 2001; Yuzhakov & Mukhachev 2001; Stammler 2005).

Overgrazing as a result of unsustainable pasture use is difficult to define and quantify (Helle & Kojola 2006; Mysterud 2006; van der Wal 2006; Lundqvist 2007). For example Wilson & Macleod (1991) question the idea in general and ask whether it is at all that common. For example, plant species composition changes as an indicator of overgrazing may not be unambiguous as species composition changes in succession and via various processes (van der Wal 2006). Animal numbers on natural rangelands are dependent on variations in natural conditions (weather, available fodder, snow conditions, predators, parasites, diseases etc.) and, accordingly, animal populations fluctuate regularly (Helle 1980; Helle *et al.* 1990; Kumpula 2001; Helle & Kojola 2006). In North America caribou population dynamics vary according to environmental conditions, predators and hunting by humans (Klein 1968; Messier *et al.* 1988; McCullough 1992; Ulvevadet & Klokov 2004). In Fennoscandia and Russia among semi-domesticated reindeer herds human intervention via parasite vaccinations and supplementary feeding helps buffer against potentially drastic natural population fluctuations.

Ecological research and assessments of herbivores' impacts on rangelands produce essential information on the quality and quantity of fodder sources (Oksanen 1978; Väre *et al.*1996; Olofsson *et al.* 2000; Bråthen & Oksanen 2001; Olofsson *et al.* 2002). Grazing affects species composition and habitat productivity (Suominen & Olofsson 2000; Virtanen *et al.* 2002; Bråthen *et al.* 2007; Kitti *et al.* 2009; Pajunen 2010).

Watkinson & Ormerod (2001) are critical of experimental pasture research. They argue that research results on grazing impacts are artifacts resulting from limited sampling, when small fenced and unfenced areas are compared. Fenced areas are often so small that grazing impacts on vegetation structure are not necessarily detectable. On the other hand comparing fenced and unfenced areas can provide detailed information of grazing impact on ecosystems. A good example can be found in Olofsson *et al.* (2004), who compared carbon (C) and nitrogen (N) concentrations in soils on fenced and unfenced reindeer lichen pastures in Northern Norway. Additionally, herbivore grazing can have effects on other animal species like birds, lemmings and other grazers (Virtanen 2000; Suominen & Olofsson 2000).

1.2 REMOTE SENSING OF RANGELANDS (REINDEER AND YAK)

The launch of the first Landsat (originally Earth Resources Technology Satellites ERTS) program in 1972 started the era of civilian use of optical satellite remote sensing and related land use and land cover applications (Lillesand *et al.* 2004). Satellite remote sensing broadened the spatial scale of investigations from small areas covered by aerial photography up to regional scales (thousands of square kilometers). The subsequent spectral enhancement ranging from the visible wavelength spectrum to near infrared (NIR) increased the capability of vegetation detection. Remote sensing opened the door for new rangeland assessment applications globally (Tucker *et al.* 1975; Tucker *et al.* 1983; Tucker & Sellers 1986; Tueller 1989; Haas 1992).

Remote sensing is now the primary method for the inventory, mapping and classification of vast rangelands in relative detail (Colpaert *et al.* 2003). Traditional pasture inventory methods like vegetation plots and experimental fences do not allow large scale assessments of pasture quality. By combining remote sensing and geographic information systems (GIS), large scale pasture inventories are possible and cost efficient (Colpaert 1998). The focus of the studies presented in the following paragraphs was remote sensing applications to rangelands of reindeer and yak.

Inventories of caribou, muskoxen and elk habitats have been performed in arctic and boreal Alaska and Canada since the 1970's (George *et al.* 1977; Thompson & Klassen 1980; Arsenault *et al.* 1997; Hansen *et al.* 2001; Théau *et al.* 2005). Käyhkö & Pellikka (1994) used SPOT imagery in reindeer grazing study in the border zone of Finland and Norway. Finnish and Norwegian reindeer herding areas have both been inventoried with Landsat TM imagery (Tømmervik & Lauknes 1987; Johansen *et al.* 1995; Colpaert *et al.* 1995; Kumpula *et al.* 1997; Johansen & Karlsen 2000). The Finnish Fish and Game Research Institute (FGRI) produced an inventory of Finland's reindeer pastures from Landsat TM image classification which has been applied for the estimation of pastures' carrying capacities (Kumpula *et al.* 1998a; Kumpula *et al.* 1998b). Colpaert *et al.* (2003) and Kumpula *et al.* (2006) have focused on developing more reliable field inventory and image classification methods. They calculated different indexes to evaluate for example available plant nutrients and species biomass as reindeer fodder from field data. The new generation of Very High Resolution (VHR, with less than five meter resolution) satellite (e.g. IKONOS-2, Quickbird-2) were launched in the early 2000's. IKONOS-2 imagery has been used in several applications in Fennoscandia and arctic areas for detailed mapping of pasture conditions and degradations (Nordberg & Allard 2002; Allard 2003; Stow *et al.* 2004).

The Qinhai-Tibetan Plateau, northern China, Inner Mongolia and Mongolia are important rangelands in the Chinese context. Animal husbandry based on grasslands is a major source of livelihood and there is a growing need for meat in domestic markets. Rangeland degradation, erosion, and desertification are severe problems in these large areas. Recent news reports that during the exceptionally harsh winter of 2009 – 2010 about 1.5 million goats, 921 000 sheep, 169 000 cows and yaks, 89 000 horses and 1 500 camels perished in Mongolia (Foster 2010). Remote sensing studies of Tibetan grasslands mainly focus on rangeland degradation, carrying capacity, and desertification (Lehmkuhl 1993; Peng *et al.* 1996; Ryavec & Veregin 1998; Rasmussen *et al.* 1999; Sujatha *et al.* 2000; Gao & Zha 2001; Zeng *et al.* 2003; Huang & Siegert 2006; Bai *et al.* 2007).

In the Russian Arctic, satellite remote sensing has not been used in rangelands inventory on a large scale so far. Reindeer husbandry lies within the domains of the respective agricultural ministries. It is subject to the use of carrying capacity models. The inventory method is based on intensive field surveys and mapping and focuses on lichen, green fodder and seasonal pastures (Jernsletten & Klokov 2002; Yuzhakov & Mukhachev 2001). Rees *et al.* (2003) studied visible changes in reindeer pastures associated with grazing and trampling in the Nenets Autonomous Okrug (NAO) using Landsat TM -data. When satellite remote sensing is used in studies of reindeer rangelands in the Russian Arctic, the focus has usually been on studying the industrial disturbances (Rees 1999; Toutoubalina & Rees 1999; Virtanen *et al.,* 2002; Tømmervik *et al.* 2003; Walker TR *et al.* 2009).

1.3 LOCAL KNOWLEDGE AND REMOTE SENSING OF RANGELANDS

Local knowledge on pasture quality, quantity and management has been discussed for decades, especially since Hardin published his *tragedy of the commons* -theory (Hardin 1968). The idea is that common resources are overused in order to fulfill everyone's personal interest to maximize their own profits. The effect on pastures is that they are overgrazed faster as every herdsman tries to optimize his own stock. Overgrazing is a term which is used in pointing out failed management or too high numbers of animals. Some authors have argued persuasively that the concept of overgrazing has become more of a political issue rather than a well-defined ecological concept (Dwyer & Istomin 2006; Mysterud 2006; van der Wal 2006; Lundqvist 2007). In contrast, Moxnes (1998) and Helle & Kojola (2006) argued that the increase of Fennoscandian reindeer numbers between the 1960's and 1990's is not an example of the tragedy of the commons. Paine (1992) stated that the intervention by the state on the basic rules of reindeer herding caused overgrazing in Norway. According to Stammler (2005) the lowering of the Yamal areas' carrying capacity and related animal numbers has no grounds from the herders' point of view. In the Tibetan plateau context Harris (2010) questions overgrazing claimed by Chinese authors.

Local knowledge, sometimes equated with *traditional ecological knowledge* (TEK), has been recognized as an important source of information to contribute to new aspects scientific research, i.e. for the conservation of biodiversity and sustainable resource use (Gadgil *et al.* 1993; Ferguson *et al* 1998; Berkes *et al.* 2000; Huntington 2000; Kitti *et al.* 2006). Animal husbandry as a land use form on rangelands is so complex that multidisciplinary research approaches are required in order to investigate social and ecological components holistically (Forbes *et al.* 2006). The drivers behind the use of rangelands, in addition to their quality and quantity as fodder resources, include further factors like pasture accessibility, snow conditions, snow depth and hardness. These additional factors may help to explain observed differences in vegetation biomass and species composition, which are often used as indicator of grazing intensity or sustainable pasture use (Ferguson *et al.* 1998; Stammler 2005; Kitti *et al.* 2006). Hence, remote sensing of rangelands, coupled with local knowledge from herders and other local people, can provide essential information on important factors driving grazing patterns. Mutual discussion with herders has become an important component of the research process already at the stage of research when scientists are defining research topics and questions (Rees 2003; Forbes *et al.* 2006; Walker TR *et al*. 2009; Forbes *et al*. 2009).

1.4 RUSSIAN ARCTIC OIL AND GAS DEVELOPMENT ON RANGELANDS

Russian oil and gas industry is investing and spreading fast towards northern reindeer herding areas in the *Nenets Autonomous Okrug* (NAO) and *Yamal – Nenets Autonomous Okrug* (YNAO) (AMAP 1998). Almost all known oil and gas reserves in European Russia derive from the Timan-Pechora hydrocarbon province, of which the northern half is located in NAO, the fastest growing Russian oil region (Stammler & Forbes 2006). The exploration phase of oil and gas resources in NAO and YNAO began already in the 1960's but just recently the construction is moving towards production. In 2001 the NAO Varandei oil terminal opened and extraction from the surrounding tundra accelerated (Forbes 2004). On the isolated Yamal Peninsula in YNAO, the enormous gas field of Bovanenkovo is currently preparing for production (Mäkinen 2010). Together these hydrocarbomn resources are located in the core areas of Nenets reindeer herding on either side of the Ural Mountains (Jernsletten & Klokov 2002; Tuisku 2002; Stammler 2005). Among all the Russian indigenous reindeer nomads, the Nenets reindeer herders fared best during and after the Soviet period. Especially on the Yamal Peninsula, nomadic reindeer herding was especially well preserved (Zen'ko 2004; Stammler 2005; Vitebsky 2005). However, the nomadic lifestyle is in change, modern equipments like skidoo and mobile phones are used nearby settlements, although in tundra there is no network of GSM-towers or places to supply gasoline (Tuisku 2002; Nuttall *et al.* 2005; Stammler 2005).

The hydrocarbon industry is presently the source of most ecological changes in West Siberian tundra and socio-economic changes to the Nenets people. The tundra zone has until recently been considered a desolate land with limited potential for extensive use of its natural resources beyond fish, fur and reindeer meat (Stammler 2005). YNAO and NAO like, all territories with hydrocarbon reserves in the circumpolar Arctic, are facing extensive land use and land cover changes (National Research Council 2001; ACIA 2005). As a consequence, Nenets reindeer herding is under pressure to decline or adapt. Increasing environmental awareness and oil and gas companies increased concern of their public image have improved the ability of indigenous people to negotiate on e.g. preferable pipeline routing and compensations (Stammler 2005; Stammler & Wilson 2006; Rees *et al*. 2008).

1.5 OBJECTIVES OF THE THESIS

This thesis focuses on the use of rangelands under arctic, sub-arctic, and alpine conditions in four different locations on the Eurasian continent. The study areas encompass the Eastern Tibetan plateau, China; the Jauristunturit area on Finnish–Norwegian border; and the Nenets and Yamal-Nenets Autonomous Okrugs, Russia.

The main objective of this study was analyzing rangelands in remote parts of Eurasia's high latitude and high altitude zones and to examine the capacities of different remote sensing platforms and procedures to detect variations in land cover and land use within and among various regions. In addition, the objective was to move from a purely biophysical approach, typically employed in pasture inventories at regional spatial scales, to a more socio-ecological analysis incorporating data from different disciplines, e.g. social anthropology, plant ecology and geography.

This research focuses on following main topics and questions:

1) How suitable are the different types of satellite imagery and which scales of optical remote sensing are appropriate for detecting land cover and land use characteristics in rangelands?
2) How does free ranging animal husbandry interact with other forms of land use and how does it affect rangeland conditions and management?
3) What are the combined environmental and social impacts of oil and gas activities on reindeer rangelands in Arctic Russia?
4) How can remote sensing be fruitfully combined with other forms of ecological, social, geographical and local knowledge data?

2. Study areas

The research areas are located in four different regions (see Figure 1):

1. Dzoge county on the Eastern Tibetan plateau, China (article I).
2. Jauristunturit mountain area in the Finnish – Norwegian border (article II).
3. Bovanenkovo gas field on the central Yamal Peninsula in the Yamal – Nenets Autonomous Okrug in Arctic Russia (articles III, IV and V) and
4. Toravei oil field in Varandei tundra in the Nenets Autonomous Okrug in Arctic Russia (article IV).

In all four regions the traditional land use form is pastoral animal husbandry on rangelands. These areas were chosen within three different research projects. Dzoge was research area in the Academy of Finland funded project *"Ecological carrying capacity of natural pastures: A case study on the Tibetan Plateau"*. Jauristunturit was studied under EU-funded research project *"REiNdeer MANagement"* (RENMAN). The Bovanenkovo and Toravei research areas were studied during the project *"Environmental and Social Impacts of Industrialization in Northern Russia"* (ENSINOR), which was funded by the Academy of Finland.

Table 1. Geographical locations and climatic conditions of the research areas.

Research area/article	Location	Altitude m.a.s.l	Annual mean temp.	Annual precipitation	Area km2
Dzoge, Eastern Tibetan Plateau/I	33°45´ N, 105°00' E	3400	0,6	635	6000
Jauristunturit, Lapland / II	68°45´ N, 24°00' E	450	-1,3	450	100
Bovanenkovo,Yamal YNAO /III, IV, V	70°45´ N, 68°00' E	30	-7,5	300	2052
Toravei, NAO /IV, V	68°45´ N, 58°00' E	30	-5,6	338	1500

The county of Dzoge (article I) is located in the north western part of the Sichuan province in the Peoples Republic of China on the eastern edge of the Tibetan Plateau at an altitude of 2800 – 4000 meters a.s.l. (Table 1). The Tibetan plateau is one of the largest grazing areas in the world. Two million nomads and three million agro-nomads live there with 12 million yaks and 30 million Tibetan sheep (Weiner *et al.* 2003; Miller 2005). In Dzoge nomadic animal husbandry is the main source of livelihood (Figs 2a & 2b). (Wu 1999). The livestock on the grasslands consists of 430 000 yaks (71 per km^2), 540 000 sheep (90 per km^2) and 30 000 horses (5 per km^2) (Dzoge local administration 2000).

The second research area (article II) Jauristunturit (*Jávrresduottar* in Sámi) is partly located in the Finnish Näkkälä reindeer herding district and partly in the Norwegian West Finnmark reindeer herding area (Table 1) (Figs 2c & 2d). The size of Jauristunturit study area was 100 km^2. Area was chosen in after discussions with local reindeer herders (in the beginning of RENMAN project) to study different pasture use regimes in Finland and Norway. In Näkkälä there were about 8 700 reindeer in 2002 (2.5 reindeer per km^2) (Paliskuntain yhdistys 2003). The Norwegian West Finnmark reindeer herding cooperative has an area of 24 000 km^2 and 60 000 reindeer (2.5 reindeer per km^2). The Jauristunturit area is situated in the hemiarctic zone where the main plant growth forms are dwarf shrubs, shrubs (*Betula nana*, dominant on mountains), mountain birch, lichens, sedges and mosses. Area is situated also in vegetation sector division into continental sector (C1), where precipitation is low (Ahti *et al*. 1968; Helminen 1988; Oksanen & Virtanen 1995). The research area is divided by a three metre high fence, which mainly follows the national border between Finland and Norway. The Norwegian part of the area is used only as winter pasture for a few months per year, whereas the Finnish part is used as early summer pasture and reserve winter pasture. Reindeer herding is the main form of land use on both sides of the fence.

The third area (articles III, IV and V) is located on the Yamal Peninsula which is about 700 km long and 150 km wide. The focus of the study is the Bovanenkovo gas field (BGF) which is located within Subzone D of the Circumpolar Arctic Vegetation Map (CAVM) (Walker *et al*. 2005) (Table 1), where dominant the plant growth forms are dwarf shrubs, sedges and mosses. The mean July temperature at the southern boundary of Subzone D is about 9°C. The gas field is located in the area to which the Yarsalinski reindeer sovkhoz holds the principal land title. Officially the gas field covers an area of 2 052 km^2 (VNIPIGazdovycha 2005) (Fig 2f). Bovanenkovo is on the migration path of two major (nr. 4 and 8) Yarsalinski sovkhoz reindeer brigades (collective management units). The territory of the 8th brigade covers an area of 7 330 km^2 and 4th brigade has an area of 7 500 km^2. These brigades migrate about 680 km from their late summer pastures on the Kara Sea coast to their winter pastures on the south side of the river Ob (Fig 2e). Today YNAO is the world's most productive reindeer herding region in terms of total number of animals with 631 000 domestic reindeer, herded by approximately 14 500 nomadic Nenets and to a lesser extent Komi and Khanty families. On the peninsula there are approximately 310 000 reindeer and 1 000 fully nomadic households, comprising more than 5 000 persons (Stammler 2005; UralPolit 2008).

The fourth research area (article IV) is the Toravei oil field, which is located within the Varandei tundra (68°66' N, 58°33E) in NAO. Toravei also lies within the CAVM Subzone D (Walker *et al*. 2005). The soils are richer and the number of plant species greater than on the Yamal Peninsula (Pajunen *et al*. 2009). The Toravei region belongs to the Erv reindeer herding enterprise which encompasses a territory of 15 590 km^2. Exploration of the oil field in the area began in the late 1970's. In 2001, an offshore oil terminal was opened in Varandei and soon after that oil pumping started from the Toravei field.

2.1 RANGELAND MANAGEMENT IN THE FOUR RESEARCH AREAS

Presently the use of natural rangelands in the study areas is regulated at: a) the state level by legal and administrative bodies and at b) the local level by written or verbal agreement and authorities. Also traditional practices and local customs are commonly used in regulating the usage of pastures. In Finland the highest allowed numbers of reindeer in the reindeer husbandry area are set by a working group including representatives from the Ministry of Agriculture, the herder's association, and from reindeer research. Then these numbers are distributed to the different herding cooperatives (*paliskunta* in Finnish).

In NAO and YNAO in Arctic Russia, the highest number of allowed animals is calculated based on carrying capacity evaluations made by special companies contracted for this purpose (Stammler 2005). Afterwards, agreements with municipality and regional administration have to be made (Stammler 2005). The pasture evaluation in YNAO was conducted in 2009 for the first time since the collapse of the Soviet Union while in NAO it has been done twice.

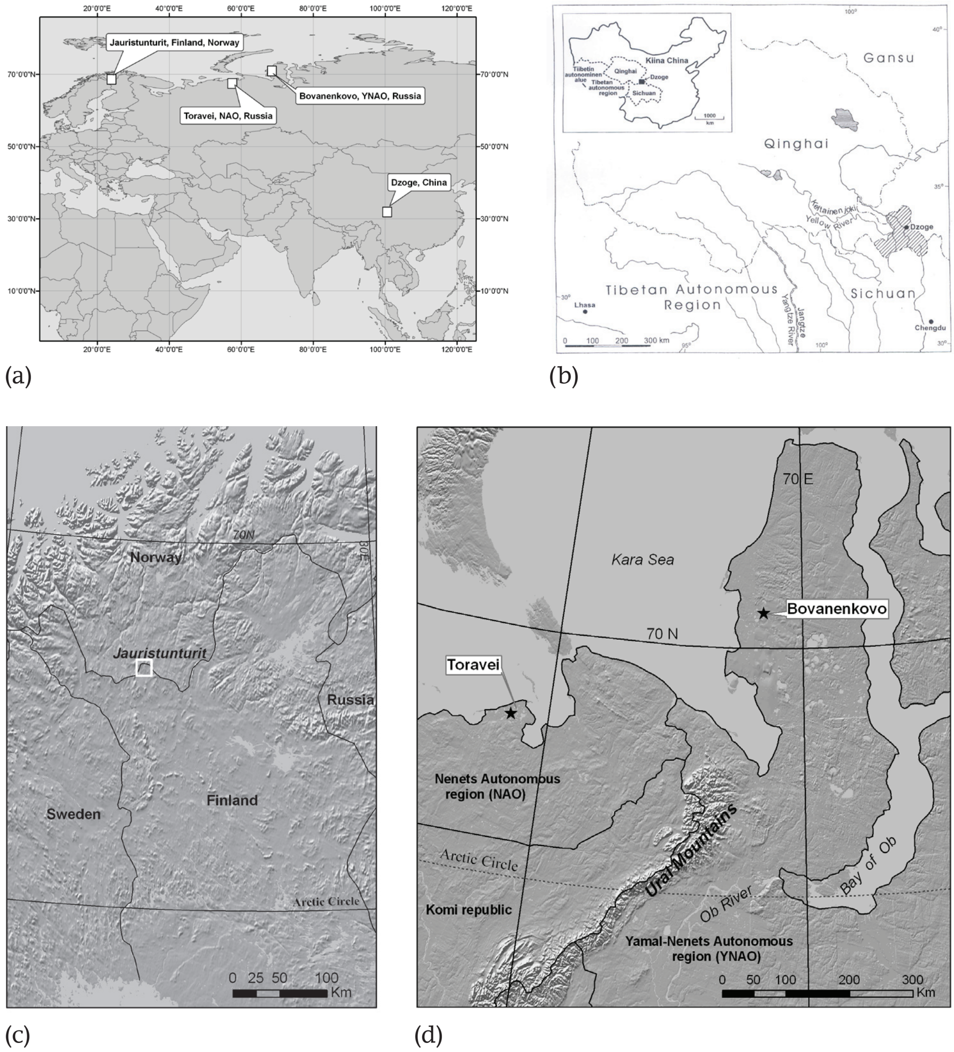

Figure 1 a-d. Figure 1a-d. The location of the research areas (a). Dzoge county (b) in Eastern Tibetan Plateau in China (Article I), Jauristunturit (c) in the border area of Finland and Norway (Article II), Toravei in Nenets Autonomous Okrug (NAO) and Bovanenkovo (d) in Yamal-Nenets Autonomous Okrug (YNAO) in Russia (Articles III-V).

In the Eastern Tibet Dzoge county the Bureau of Agriculture and Husbandry evaluates the carrying capacities of grasslands using sampling methods which were developed by the Sichuan Grassland Research Institute in the 1980's. On the Tibetan plateau and in Dzoge, the privatization and distribution of animals to the herders began in the 1990's, The former collective grasslands were distributed to individual persons or to herding families by the Chinese government by contracts which will expire after 50 years (Table 2).

Table 2. Characteristics of animal husbandry practices in the research areas. Pasture rotation is practiced within all research areas but to different degrees. In Dzoge, the practice of rotation is declining because of privatization and fencing. In Jauristunturit, on the Norwegian side of the border pastures are used only in winter, whereas on the Finnish side pasture rotation has been reintroduced recently. Herding practices also differ. In Fennoscandia, herding has been motorized with skidoo and all terrain vehicles (ATVs). At all other sites mobility is acheived primarily on foot or horse, or via reindeer-drawn sledges. In Dzoge, motorbikes and in Nenets sites skidoo are used for local transport of supplies.

	Dzoge	**Jauristunturit**	**Bovanenkovo,YNAO**	**Toravei, NAO**
Pasture rotation	yes/no	yes/no	yes	yes
Fencing	yes	yes	no	no
24 h herding	no	no	yes	yes
Herding practices	foot/horse	skidoo/ATV	reindeer	reindeer

a) b) c) d) e) f)

Figure 2a-f. The views from the research areas. a) Herders with motorbikes returning from buying supplies, Dzoge; at the rear is a boy riding a yak while herding. b) Yaks grazing, Dzoge. c) Cladina stellaris dominated lichen heath on the Norwegian side of the national border, Jauristunturit. d) The same habitat intensively grazed, now dominated by Cetraria nivalis on the Finnish side. e) Elder reindeer herder ready to migrate on Yamal Peninsula. f) One of the workers' stations in Bovanenkovo gas field.

3. Material and methods

The main datasets used in this research are derived from remote sensing imagery comprising different spatial, spectral and temporal scales (Table 3.). As the field research was conducted in areas of different size, the use of multiple sources of satellite imagery with different spatial resolution was appropriate.

3.1 REMOTE SENSING IMAGERY AND SCALES OF INVESTIGATION

In Dzoge Landsat TM imagery (acquired on 31st August 1999) was chosen because the research area covered the whole county (6000 km^2) and the scale of investigation was at the herding district level and sub-regional level (Fig 3). Landsat TM image's radiometric, temporal and spatial resolution had proven to be suitable in the Finnish reindeer husbandry regions' pasture evaluation projects both at the district and regional levels in previous studies (Colpaert, *et al.* 1995; Kumpula, *et al.* 1997; Kumpula, *et al.* 1998b). Obtaining cloud-free imagery from Eastern Tibetan plateau during the growing season (May – August) was difficult, as the area is in the region of summer monsoons. However, the image acquired had cloud coverage of 10 – 15 %.

In Jauristunturit case the idea was to use significantly more detailed spatial resolution satellite imagery, in contrast to reindeer pasture studies where Landsat images were used (eg. Colpaert, *et al.* 1995; Johansen & Karlsen 2000; Johansen & Karlsen 2005). What was gained in detail was lost in spatial coverage. Jauristunturit represents the local scale e.g. herding district' winter (NOR) or early summer (FIN) pastures (Fig 3). IKONOS-2 image (acquired on 28th June 2001) was the highest resolution satellite remote sensing data available at the time and has four metre resolution with multi-bands (blue, green, red and infra-red). Imagery was expensive (28 USD per km^2) and the project could afford to cover a study area of ≈100 km^2. The aim was to investigate the different grazing and trampling intensities from IKONOS-2 multispectral imagery.

Table 3. Characteristic of the satellite sensors used in research.

Sensor	Spatial resolution	Spectral region	Wavelenght (µm)	Swath witdh	Temporal resolution
Landsat MSS	68 m x 83 m	green	0.5–0.6	185 km	18 days
	69 m x 83 m	red	0.6–0.7		
	70 m x 83 m	NIR	0.7–0.8		
	71 m x 83 m	NIR	0.8–1.1		
Landsat TM	30 m	blue	0.45 - 0.52	185 km	16 days
	30 m	green	0.52 - 0.60		
	30 m	red	0.63 - 0.69		
	30 m	NIR	0.76 - 0.90		
	30 m	NIR	1.55 - 1.75		
	120 m	TIR	10.40 - 12.50		
	30 m	NIR	2.08 - 2.35		
Landsat ETM+	30 m	blue	0.45 - 0.52	183 km	16 days
	30 m	green	0.52 - 0.60		
	30 m	red	0.63 - 0.69		
	30 m	NIR	0.76 - 0.90		
	30 m	NIR	1.55 - 1.75		
	30 m	TIR	10.40 - 12.50		
	30 m	NIR	2.08 - 2.35		
	15 m	Panchromatic	0.52-0.9		
SPOT	20 m	green	0.50 - 0.59	60 km	26 days
	20 m	red	0.61 - 0.68		
	20 m	NIR	0.79 - 0.89		
	10 m	Panchromatic	0.51 - 0.73		
ASTER VNIR	15m	green	0.52 - 0.63	60 km	16 days
		red	0.63 - 0.69		
		NIR	0.76 - 0.86		
IKONOS-2	4 m	blue	0.44-05.1	11 km	3 days
		green	0.50-0.59		
		red	0.63-0.69		
		NIR	0.75-0.85		
	1 m	Panchromatic	0.52-0.92		
Quickbird-2	2.4 m	blue	0.45-0.52	16.5 km	1-3.5 days
		green	0.52-0.6		
		red	0.63-0.69		
		NIR	0.76-0.9		
	61 cm	Panchromatic	0.45-0.9		

In the Russian Arctic the main focus was the detailed investigation of land use and land cover changes in the vicinity of hydrocarbon extraction sites. The aim was to cover oil and gas fields with imagery of the highest available resolution, which, in this case, was Quickbird-2 panchromatic (63 cm spatial resolution) and multispectral (2.4 m spatial resolution) images (120 km^2 coverage in both areas). The main focus was to investigate fine and local scale impacts of oil and gas activities on reindeer pastures specifically and nomadic reindeer herding in general (Fig 3). Due to the high costs of Quickbird-2 imagery (24 USD per km^2), also lower resolution ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) VNIR (Visible Near Infrared), SPOT (Satellite Pour l'Observation de la Terre) and Landsat (MSS, TM, ETM+) imagery also had to be used. Landsat images were downloaded freely from the Global Land Cover Facility, University of Maryland. SPOT imagery was obtained from OASIS program (Optimising Access to Spot Infrastructure for Science http://medias.obs-mip.fr/oasis/).

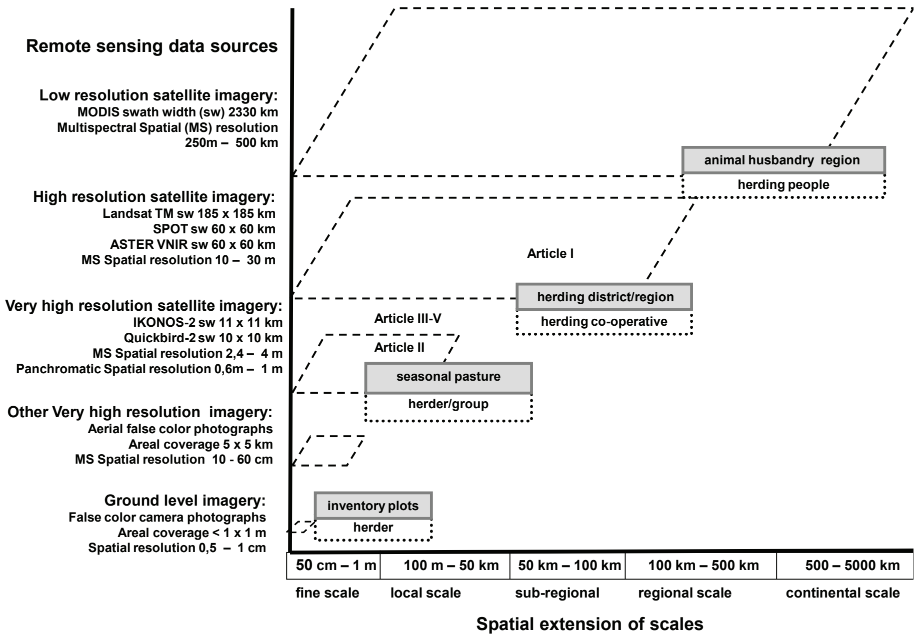

Figure 3. Spatial scales of investigations and remote sensing platforms. Research focused on local and sub-regional scale.

In the YNAO and NAO research sites covers relatively small portions of the reindeer herding brigades' total territories were under investigation. In YNAO the herders' migration route is ≈1 200 km per year. Therefore, the gas field covers just a fraction of the total rangeland that the reindeer herding brigades actively use. In NAO the migration route's distance is much shorter (200 km). Therefore, the annual pasture rotation brings herders into contact with oil fields and associated impacts more often.

3.2 FIELD SAMPLING

The field data for article I was collected in the years 2000 and 2001 in Dzoge county on the Eastern Tibetan plateau in China. The field data collection for article II was conducted between 2001 and 2004 in Jauristunturit, located in Finnish – Norwegian border area. The field data for articles III, IV and V were collected in the years 2004 – 2006 in and around the Bovanenkovo gas field on Yamal Peninsula area and in the Toravei oil field area of NAO in North Western Arctic Russia (Table 4).

Field data were collected for satellite image rectification, image interpretation and classification, vegetation classification, biomass estimation, and industrial disturbance evaluation (Table 3). Each of the selected field study plots was additionally inventoried in the field and represented a homogenous vegetation or land use type. The size of the field study plots used in article I (Landsat TM used as remote sensing data) was 200 x 200 m and in article II the size was 20 x 20 m (IKONOS-2 used as remote sensing data). In articles III-V field study plot size varied from 20 x 20 m to 200 x 200 m depending on the resolution of satellite imagery used. The field study plots were selected semi-randomly which means they were chosen from within the main vegetation types and land use patterns. The grazing intensities were estimated in articles I and II according to signs of grazing, using a relative scale ranging from light grazing to moderate and heavy grazing. In article II special emphasis was placed on reindeer lichens. They were carefully inventoried by estimating the percentages of cover and average height of each species. Then the biomass of reindeer lichens was estimated using the formula developed by Colpaert *et al.* (2003).

Vegetation quadrats of 50 cm x 50 cm size were used in vegetation type identification at all sites. Vegetation cover was estimated visually and plant species composition in percentages were determined to the lowest possible taxon. Furthermore, bare soil coverage and the average height of the plants were measured. The locations of the field study plots were marked with GPS with an accuracy of 3 – 8 meters.

Table 4. Data collected from the research areas. Number of field study plots in articles IV and V is including both data collected from Bovanenkovo (220) and Toravei (225).

	Article I	Article II	Article III	Article IV	Article V
GPS-points for image rectification	22	no	no	no	no
Number of field study plots	185	280	220	220 + 225	220 + 225
Field study plot size	200 x 200m	20 x 20 m	varying	varying	varying
Vegetation quadrat size	50 x 50cm	50 x 50 cm	50 x 50 cm	50 x 50 cm	50 x 50 cm
Biomass sampling	grasses	lichens	no	willows	willows
Interviews with herders	yes	yes	yes	yes	yes

3.3 REMOTE SENSING AND GIS-ANALYSIS

The satellite imagery for articles I and II was analyzed with ERMapper-versions 6.0 – 7.0 and with Arc/INFO and ArcGIS version 8.0 – 8.2. The image in article I was rectified into Universal Transverse Mercator (UTM) projection and World Geodetic System 1984 (WGS84) datum using GPS locations sampled in the field. In article II image was rectified into the Finnish national coordinate system using digital maps produced by the Finnish National Land Survey. In article II to prevent mixture of shrub-dominated peat land with other shrub-dominated biotopes, peat land was separated as its own layer using a peat land mask produced by Finnish National Land Survey. Then layers were classified separately (main layer without peat land classes and peat land layer only with peat land classes) and finally merged into one layer. Atmospheric corrections were not made because according to Song *et al.* (2001) they have little effect on the classification accuracy of single date images. Topographic corrections were not conducted because of relatively flat terrain. Images were classified using unsupervised and supervised methods. Accuracy assessments were made using collected field material.

For articles III, IV and V, satellite imagery was analyzed with ERDAS Imagine -versions 7.0 – 9.2 and with ArcGIS-versions 8.3 – 9.2. In article III, eight satellite images with different resolutions were compared to assess their applicability for detecting anthropogenic impacts in the Bovanenkovo gas field at three scales: small (< 0.09 ha), medium (>0.1 ha – < 1 ha) and large scales (> 1 ha). Quickbird-2, ASTER and Landsat images acquired and downloaded from www-servers were in a UTM projection and WGS84 datum. Then they were re-projected into UTM WGS84 zone 40N (in NAO); zone 42N (in YNAO) and then synchronized to match each other using ERDAS Imagine -software's AutoSync -module. Atmospheric corrections were not made because images were processed separately and topographic corrections were not necessary due to the flat terrain. Anthropogenic impacts were interpreted and digitized from Quickbird-2, ASTER VNIR, SPOT and Landsat TM/ETM+ images. In a next step, the spatial extents of the respective impacts were calculated using various sizes of buffers. To estimate the capacity of different satellite systems to detect disturbances' impacts at different scales and of different sizes, field data, ground photographs and photographs taken from helicopter were used. Reindeer herders' migration routes and brigadiers' notes on satellite image printouts in the field interviews were later digitized as shapefiles in GIS-format. A map depicting the total area of cumulative disturbances around the Bovanenkovo gas field (YNAO) and Toravei oil field (NAO) were produced.

4. Results

4.1 REMOTE SENSING IN INVENTORY OF HIGH ALTITUDE RANGELANDS DZOGE, CHINA (I)

The grasslands of Dzoge were classified into 12 classes using a Landsat TM image (article I). From the Landsat image, winter pastures were differentiated from the summer pastures with 84% classification accuracy. For accuracy assessment 134 field study plots were used as reference data to test classifications accuracy. Areas where winter and summer pastures were separated by a fence were also detectable from the satellite image based on different grazing intensities. Without fences, the boundary between particular pasture units is more indistinct and it is more difficult to distinguish from imagery and in the field. To correctly detect winter and summer pastures from the Landsat TM image requires basic information about the pasture rotation which emphasizes the importance of field work and interviews with local herders.

In Dzoge county, the biomass productivity of high altitude grassland is high (Wu 1999). Accordingly, the animal number is also very high which results in heavy grazing pressure. The fresh biomass of the above ground vegetation varied between 200 and 6000 kg per hectare in the different pasture types. In field sites where the biomass was very low, there were signs of heavy grazing and unpalatable plants (e.g. *Ligularia virgaurea*) occurred more frequently. A few heavily grazed locations with potential for erosion were found in sand dune areas close to the Yellow River (*Huang He*). Re-activated sand dunes were fenced off from grazing by the pasture administration.

The degradation of land cover and rangelands in China is claimed to be a serious problem and statistics state that 90% of grasslands are somewhat degraded (State council 2002; Wang *et al.* 2005; Harris 2010). In Dzoge county there were few signs of overgrazed or degraded rangelands. The condition of rangelands is of concern to local nomadic herders. Their most important management method has been pasture rotation in summer and winter. Local administrators in the Dzoge Grassland Bureau control the use of rangelands. The pastures of family farms still belong to the state and families pay according to a long-term grassland lease contract with the government (Yan & Wu 2005). The livestock belongs to the family. Another way to control the pastures' use is fencing supported by the administration, which is hindering the possibilities for the traditional pasture rotation system. The Grassland Bureau estimates the suitable number of animals for each family group.

There is growing pressure among the herders to increase the number of animals due to free trade and the opening of markets. Use of modern equipment like motorcycles for transport and radios, TV's and solar panels in traditional black tents (commonly used by nomads on the Tibetan plateau) is a trend which requires cash gained by selling meat and butter (Manderscheid 2001a; Manderscheid 2001b).

4.2 REMOTE SENSING OF JAURISTUNTURIT RANGELANDS IN NORTHERN FENNOSCANDIA (II)

In the Jauristunturit area VHR IKONOS-2 imagery was used to make a detailed classification of reindeer pastures (article II). The Jauristunturit area was divided by the national reindeer fence built in the late 1950's. The fence is separating naturally similar rangelands into winter pastures in Norway and early summer pastures in Finland. One main question was whether it is possible to detect the intensity of reindeer trampling and grazing from IKONOS-2 imagery. The area is naturally rich in reindeer lichens, the dominant winter forage resource for reindeer. Lichen biomass was evaluated on the basis of image classification coupled with field measurements.

The results of the IKONOS-2 image classifications showed that the lichen-dwarf shrub dominated pastures of Jauristunturit can be divided into five main classes: *Cladina stellaris* lichen heath (Norway side), *Cetraria nivalis* lichen heath (Norwegian side), *Cetraria nivalis* heath (Finnish side intermediately grazed), *Cetraria nivalis* (Finnish side intensively grazed) and *Empetrum*-dominated lichen heath. These types correlate to grazing and/or trampling intensities on the basis of lichen biomass. On the Norwegian side it was easier to distinguish the ungrazed and heavily grazed lichen-dominated vegetation types from each other. This is partly due to the local differences in thick accumulation of snow (≥ 1 m). Here, the thick snow cover protects lichen grounds from both intensive grazing and trampling. The grazing pressure is noticeably higher where snow cover is thinner. In contrast, trampling on the Finnish side during summer time destroys the lichens which become very brittle when dry. The classification accuracy achieved was as high as 88% and based on 203 field study plots which were used as reference data to test classifications accuracy.

Biomass calculations of reindeer lichens are based on field measurements of reindeer lichen cover and height. The biomass of reindeer lichens was estimated by using a formula developed by Colpaert *et al.* (2003).

> lbm [lichen biomass (kg ha-1 dry mass)] = (0,61434*lc*lh) + 0,000038075*lh2*lc2
> where lc = lichen cover in percent and lh = lichen height

Cladina stellaris lichen heath had the highest biomass value (3 436 kg/ha) where the snow cover had been thickest. Such locations were found only on the Norwegian side, which confirms the destructive impact of summer grazing and trampling on fragile reindeer lichens as found on the Finnish side of the fence. *Cetraria nivalis – Cladonia sp.* type lichen heath had the lowest value of lichen biomass (225 kg/ha). This type is mainly found on the Finnish side, but some patches were also present on the Norwegian side and occurred typically on the highest parts of hills and ridges. The main reason for these differences in lichen biomasses are the contrasting pasture management regimes. Norwegian herders are allowed to use their area only in late winter for a few months (no trampling of lichens during summer). Finnish herders have been using the area as early summer and reserve winter pasture (trampling of lichens during summer).

4.3 REMOTE SENSING AND LOCAL KNOWLEDGE OF GAS FIELD IMPACTS ON REINDEER HERDING YAMAL PENINSULA, NW SIBERIA (III)

Environmental impacts caused by gas industry activities were studied using multidisciplinary analyses combining remote sensing technologies with the Nenets reindeer herders' and gas field workers' indigenous and local perceptions of processes of change (article III). One objective was to investigate the capacity of multi-resolution satellite images to detect and to analyze different kinds of environmental impacts. Field surveys were conducted and combined with local and indigenous knowledge in order to enhance the interpretation of the various satellite images. Another objective was to characterize the effects of industrial development of oil and gas on traditional livelihoods and the supporting society in YNAO.

Changes in land cover caused by oil and gas exploitation and production activities occur at various scales ranging from local to wide-ranging. The impacts were divided into the three spatial scales: small (< 0.09 ha), medium (0.1 ha to 1 ha) and large (> 1 ha). Scales were adapted from research by Walker and Walker (1991) on cumulative impacts of oil fields in Alaska. Industrial impacts in oil and gas fields are usually less than a few hectares in size. They consist of fragmented patches and linear transportation networks connecting workers' settlements and production fields. In our multidisciplinary approach the resolution of satellite imagery, field surveys (anthropological and natural scientific), and reindeer herders' perceptions were compared referring to the various scales of industrial impacts. Bovanenkovo Gas Field's (BGF) active area, as interpreted from satellite imagery, was 40 x 13 km. One Quickbird-2 image (120 km^2) was acquired to cover the core area of the BGF. The surrounding areas were covered with ASTER VNIR, SPOT and Landsat TM/ETM+ images.

Industrial waste typically consisted of rather small objects, sparsely distributed over the area which, even with Quickbird-2 panchromatic images, are difficult to detect. Sparsely distributed waste material is often partly or completely covered by vegetation and can injure reindeer directly or indirectly, e.g. when damaged hooves are exposed to infections that may be fatal.

Signs of impacts at the medium scale were generally detectable with all types of satellite imagery used. On the other hand, areas with transformed vegetation require greater effort to be separated from the surrounding landscape. Essentially, what can be detected is a basic differentiation between disturbed and undisturbed terrain, but determining the cause of impact requires field observations. When the average size of impact is greater than one hectare the detection potential of ASTER VNIR, SPOT and Landsat TM/ETM+ images becomes more reliable.

The high potential of VHR images became obvious when the Yarsalinksi sovkhoz brigades campsites could be identified from both Quickbird-2 images of July 15th 2004. This brigade had four tents (*chums* in Russian) that were noticed from the panchromatic Quickbird-2 image as an unusual group of whitish spots, which at first were misinterpreted as patches of bare soil. Closer inspection revealed the four chums and 72 sledges in rows and 4 000 or more reindeer clustered together (see article III page 173 Figure 4).

Interviewing the reindeer herders and participating directly in their migration through the gas field at Bovanenkovo was essential to gain a more holistic understanding of oil and gas development's impacts on humans and animals. The predominant survey method used was participant observation, coupled with semi-structured interviews in situations where herders or oil/gas field personnel could not be followed for extended periods to verify their respective testimonies. Herders, through their perceptions of the migration route and the industrial area, added an important level of historical depth and detail to our collective understanding of recent changes in the area. Gas company workers also provided useful details about the area and its history from their point of view. Furthermore, they provided information concerning the future of oil and gas exploration in the area.

Therefore, field surveys are essential for reliable satellite image interpretation. The social scientific survey that relied on local herders' knowledge, provided information on both the exploration and early development phase of the gas field. This would not have been achievable with satellite imagery alone. To assess the overall impacts of oil and gas activities requires a combination of remote sensing and detailed ground-truthing, coupled with ecological and social scientific field surveys.

4.4 MULTIDISCIPLINARY APPROACH TO ASSESSING HYDROCARBON INDUSTRY IMPACTS IN NW RUSSIA (IV&V)

An integrated multidisciplinary approach was employed to gain understanding of the coupled social-ecological systems also in NAO and YNAO (articles IV & V). The two study regions differ considerably in so far as the Toravei field in NAO consists of several smaller oil deposits located in close proximity to each other, while the Bovanenkovo field in YNAO is a giant gas deposit situated in one area.

Remote sensing, coupled with ecological and anthropogenic field surveys, was conducted to study hydrocarbon industry impacts of oil and gas fields. As interpreted from satellite imagery data as of 2005, the affected terrain in the vicinity of BGF was about 450 km^2 (550 km^2 in 2009 unpublished data analysis). This differs significantly from official numbers 277 – 287 km^2 (VNIPI Gazdovycha 2005) for the same time period. Roads and infrastructure sites can be considered as permanently transformed areas. In 2005 the road network was 79 km and covered 143 ha. Although average roads are only approximately 18 m wide, the actual affected zone around them is demonstrated to be much broader due to the cumulative impacts of sand and dust blowing as well as altered hydrology (cf. Forbes 1995). Increasing poaching is another side-effect of a denser road network (Forbes 1998). The two most affected reindeer herding brigades of Yarsalinski sovkhoz by BGF had direct impacts on more than 20% of their late summer pastures (by 2005). In contrast, less than 1.0% of territory of the neighboring brigade (nr. 2), which passes just south of BGF, has been affected.

Since the Yamal brigades migrate through narrow corridors only a few kilometres wide, even a relatively small-scale industrial site covering 10 – 30 km^2 may partially or completely block a given brigade route. The result is that brigades and also the whole sovkhoz can be quite sensitive to minor changes in land use when the survival of units is dependent upon access to limited pastures (Zenko 2004; Stammler 2005). All territories in each region are already allocated to different brigades. Hence, for brigades that lose pastures, relocating onto neighbouring areas is not an option.

In the NAO study site about 67 km^2 have been affected by oil fields (article IV). In Toravei field oil pumping had begun in 2001 via the Varandei terminal. The reindeer herding brigades 2 and 7 in the Toravei area (NAO) are less mobile than their Yamal counterparts. They have most of their pastures in close proximity to industrial installations throughout the year. In Toravei petroleum activities are more spread out over the territory and along the coast. In addition, relatively intensive disturbances typically occur in oil and gas fields within an area considerably larger than the areas of direct impacts. Additional minor disturbances occur within an area which is about ten times larger. However, impacts can also have positive feedback, in both areas there was a lot of off-road vehicle traffic in the late 1980's and early 1990's. On off-road vehicle tracks, vegetation was disturbed and partly destroyed. Now 15 – 20 years later tracks have revegetated naturally and the percentage of graminoids has increased significantly as well as their quality as fodder for reindeer.

Articles IV and V demonstrate clearly the benefits of employing a multidisciplinary approach in assessing how industrial activities affect complex socio-ecological rangeland systems. As a result it is apparent that the combined biophysical, social and cultural impacts on Nenets reindeer herding are much greater than the sum of assessed impacts of individual impacts or infrastructural components (e.g. pipelines, roads, quarries). The broader regional effects become apparent only after a holistic strategic impact assessment (Spiridonov 2006), for which so far neither the companies nor the relevant administrations have made concrete efforts.

By involving local practitioners, the participatory approach ensures that focus is on the most relevant locations and issues. It is beneficial to link the remote sensing and GIS-methods to combined social and ecological investigations at scales relevant to locals, in this case reindeer herders. The end result is a suite of interpretations, rich in detail and context from both scientists and local stakeholders, which would not have been achievable without each other.

5. Discussion

The thesis is based on articles from studies in different geographic locations. Although rangelands along the gradient Northern Fennoscandia – Russian Arctic – Eastern Tibetan plateau exhibit significant bio-physical differences, the identified environmental and social drivers affecting rangelands are quite similar. In all these remote regions since agriculture is not feasible, animal husbandry (reindeer and yak) has been the primary form of land use. Rangeland quality and quantity are the key factors for local animal husbandry with reindeer and yak. In each of these respective study regions indigenous peoples are coping with modern pressures caused by the prevailing state institutions. At the same time, they face competition from other forms of land use leading to changes in both land cover and local socio-economic structures.

5.1 OPTICAL REMOTE SENSING SCALES AND PLATFORMS FOR RANGELAND ASSESSMENTS

The value of remote sensing for distinguishing vegetation types on rangelands is well established (Carneggie *et al.* 1983; Tueller 1989; Driscoll *et al.* 1997; Everitt *et al.* 2001; Hunt *et al.* 2003). The spatial scales of rangeland surveys are usually large: hundreds km^2 to hundreds of thousands km^2. Various research questions at multiple spatial and temporal scales can be addressed with different remote sensing imagery.

The research areas in the present study varied in size from 100 km^2 to 6000 km^2 depending on the focus of the study. In Dzoge, at the sub-regional spatial scale (article I), with Landsat TM accurate and detailed classification of rangelands was achieved, as it has been used in other studies in the Qinhai-Tibetan region (Xu *et al.* 2007; Bai *et al.* 2007; Qiu *et al.* 2009; Xiao *et al.* 2010). Landsat TM/ETM+ imagery's spatial coverage (185 x185 km) makes it possible to cover animal husbandry regions or larger areas. SPOT and ASTER images covers about 60 x 60 km and it takes 9.5 images to cover the surface area of a single Landsat TM/ETM+ image. In theory, the Finnish herding area 115 000^2 km could be covered with 3.5 Landsat TM/ETM+ images (Kumpula *et al.* 1997 used 22 images) or 31.5 SPOT images. This clearly limits the utility of SPOT and ASTER VNIR or similar satellite platforms for regional scale investigations. The benefits of SPOT's and ASTER VNIR's higher spatial resolution (20 and 15 m) allows more detailed study of land cover and land use than with Lansat's (30 m) (article III, IV). Landsat TM/ETM+ images have higher spectral resolution with seven bands, the most important bands N*ear*I*nfra*R*ed*-RED-GREEN are more or less equal in all sensors. The popularity of Landsat is also based on its extensive archive of global imagery since the early 1970's (USGS 2009). Even the long life span of Landsat (since 1972) does not guarantee that good quality imagery is available from each year, or even within each decade. A temporal resolution of 16 days combined with the short summer period limits the possibility to achieve good quality images from the peak of the growing season, which is usually the best time to obtain images for rangeland studies. Finally, its free access is cost efficient from the perspective of individual researchers and research projects (e.g. Global Land Cover Facility, University of Maryland). SPOT imagery can also be obtained free via scientific programs like OASIS. ASTER VNIR images can be purchased at relatively low prices.

Whereas Landsat, SPOT and ASTER represent imagery suitable for sub-regional and regional scale analyses, there is also a need for more detailed local scale research. VHR imagery, such as IKONOS-2 and Quickbird-2 with a multispectral spatial resolution of 2.4 – 4 metres, has the capacity for small-scale habitat or disturbance investigations in rangelands (Allard 2003; Stow *et al*. 2004). Advantages of VHR imagery were particularly evident in detecting anthropogenic impacts of industrial sites. In Alaskan oilfields aerial photographs have been used in assessments of cumulative disturbances (Walker *et al*. 1987; Walker & Walker 1991; Walker 1997). From VHR images an experienced analyst working in the laboratory can easily identify different objects in a gas field, especially if combined with personal field experience. But interpreting the cause of, for example, an exposed surface in a certain part of a gas field, may remain difficult. On the other hand, an exposed surface can be detected as a quarry, dump, natural landslide or an aeolian surface in Landsat TM scale imagery (article III). Here again, even VHR imagery does not reveal all and reliable ground truthing is required for more accurate data analysis.

What is gained in detail is lost in spatial coverage. VHR images are not suitable to work on large areas due to their limited spatial coverage and high costs. Also, the availability of archival imagery is limited. However, national archives of aerial photographs, if available, can expand the time series up to 40 – 60 years. From Russia CORONA spy satellite archives imagery from late 1950's to 1970's add valuable source for VHR coverage. New VHR-satellites (e.g. GeoEye- 1/2 Worldview-1/2) have been recently launched and amount of imagery will increase significantly in coming years. However, the VHR images chosen from special areas of interests within a herding district can improve the interpretation, classification and accuracy assessments of coarser resolution imagery (Landsat, SPOT, ASTER, MODIS etc.) from the same or surrounding areas.

5.2 ENVIRONMENTAL CHANGES IN RANGELANDS

Although it is not the main focus of this thesis, climate change may have concrete implications for grazing practices in remote Eurasian rangelands (IPCC 2007). In this research the nomadic herders involved in the field research possessed highly functional knowledge of rangeland quality. They changed grazing practices according to the needs of their herds regarding climatic conditions or rangeland fodder quantity and quality. Yet over large areas and among sizable numbers of families dependent on reindeer and yak, certain pressures exceed climate change as immediate threats to their livelihood. These include steadily intensifying land use, property ownership regimes and institutional matters concerning governance as it pertains to reindeer management (Forbes *et al.* 2006; Laakso 2008; Forbes & Stammler 2009; Konstantinov & Vladimirova 2006; Nuttall *et al.* 2005).

Rain on snow (ROS) -events under a standard climate change scenario, a global climate model by Putkonen & Roe (2003) predicted a 40% increase by 2080's, with serious implications for both semi-domestic and wild reindeer herds. In case of a ROS event during wintertime there is rainfall on snow and when refreezing again a hard ice layer forms, which impedes foraging. Such events are usually related to larger scale weather patterns and therefore potentially affect entire regions. When this occurs, reindeer herders are forced to change their migration patterns (Bartsch *et al.* 2010). ROS has circumpolar implications for *Rangifer* -pasture quality and animal population dynamics e.g. severe ROS-events prevent reindeer digging for forage and cause starvation and death (Putkonen & Roe 2003; Gunn *et al.* 2006; Tyler *et al.* 2007; Helle & Kojola 2008; Bartsch *et al.* 2010).

ROS-effects on reindeer herding are usually more drastic in NAO and YNAO than in Fennosscandia because supplementary feeding is not practiced. Radar remote sensing is not dependent on weather conditions and provides data in all weather conditions for the investigation of ROS-events (Ulaby & Stiles 1980; Putkonen & Roe 2003). Tyler (2010) argues that the evidence is limited for ice crusts as a "ubiquitous and potent agent in the dynamics of *Rangifer*". However, Bartsch *et al.* (2010) successfully used Quikscat radar data to detect ROS extent and frequency on the Yamal Peninsula and documented a loss of ≈25% in the affected herds. Herders could provide information on ROS-events extension and implications to grazing and herding. ROS events also occur on the Qin-Hai Tibetan plateau where supplementary feeding is also uncommon and may lead to mass starvation of animals (Wu & Yan 2002).

From Mongolia and the QinHai-Tibetan plateau there have been reports of increasing droughts and also severe winter conditions, which can cause mass starvation of animals. Such events may result from a combination of both degradation of pastures and ROS events (Wu & Yan 2002). In Dzoge there have been few reports of hard winter periods, e.g. 2000 and 2006, but no massive starvation of animals has occurred (personal information from Dr. Wang Qian 2010). Several recent studies on wetlands, peatlands and desertification in Dzoge with different remote sensing imagery (Landsat MSS/TM/ETM+ and MODIS) indicate that there is clear reduction of peatlands and increase of desertification (Bai *et al* 2007; Xu, *et al.* 2007; Qiu *et al.* 2009; Xiao *et al.* 2010).

It has been investigated with long term Normalized Difference Vegetation Index (NDVI) datasets whether climate warming in the arctic increase vegetation biomass and contributes to the "greening" of arctic (Myneni *et al.* 1997; Jia *et al.* 2003; Stow *et al.* 2004; Jia *et al.* 2006; Verbyla 2008; Goetz *et al.* 2011). NDVI is a ratio calculated from red and near infrared channels (Tucker 1979). Vegetation indices (mainly NDVI) derived from satellite imagery are a primary source of data in greening of arctic research (see, also Forbes *et al.* 2009). For example, in northern Alaska, time-integrated NDVI has increased 20% during the period 1982 – 2007 of satellite observations (Walker DA *et al.* 2009). In the Yamal region, Walker DA *et al.* (2009) did not find a significant increase in NDVI between 1980 and 2008. Another question here is the potential impact of grazing on NDVI and "greening". Is the minimal increase in Yamal's NDVI the result of intensified reindeer grazing? At least the number of animals in Yamal has been increasing steadily for several decades (Stammler 2005). This may have counteracted the "greening" effect in Yamal, as has been proposed for Fennoscandian tundra (Olofsson *et al.* 2009). Another factor may be the general poor quality of soils on Yamal relative to neighboring regions, such as NAO, with more significant increases in NDVI (Raynolds *et al.* 2008). It is challenging to determine the effects of reindeer on greening patterns because of the lack of control areas where reindeer grazing is excluded. A warming climate and enhanced winter snow will likely exacerbate positive feedbacks between climate and permafrost thawing (Walker DA *et al.* 2009).

Thawing of permafrost is likely to increase thermokarst on rangelands causing e.g. drainage of lakes (Smith *et al.* 2005). In the Bovanenkovo area over 400 new landslides occurred in 1989 within an area of 10 km^2. This was in response to an abnormally wet year when the additional water apparently lubricated the slide surfaces (Leibman 1995). The spatial scale of thermokarst and landslides varies from a few meters to hundreds of meters. VHR-remote sensing is an essential tool to interpret the spatial extent and the development of such events.

5.3 FREE RANGING ANIMAL HUSBANDRY AS THE MAIN LAND USE FORM IN DZOGE AND JAURISTUNTURIT

In Dzoge and Jauristunturit (articles I and II), animal husbandry based on rangelands is the traditional and dominant form of land use. In Dzoge the increase in livestock which took place in the 1980's has kept intense grazing pressure on grassland for more than 20 years. With the expansion of herds and the privatization of the Tibetan rangelands since the late 1980's, the herds were restricted to limited areas and fencing became more prevalent (Manderscheid 2001; Wu & Yan 2002; Yan & Wu 2005; Harris 2010). Fencing reduces the possibility for pasture rotation and consequently pastures are grazed and trampled more heavily. The resilience of vegetation is reduced due to high pressure from long term trampling and grazing, which eventually reduces also the height of the vegetation (Wu *et al.* 2004; Kitti *et al.* 2009). Grazing can also contribute to the homogenization of the vegetation in the pastures by spreading seeds and by selective animal grazing (Harris 2010).

There are increasing reports and signs of rangeland degradation in various locations on the Qinhai-Tibetan plateau such as increasing cover of bare soil in the sub-alpine meadow zone, which makes the land more vulnerable to erosion (Wu & Yan 2002; Liu *et al.* 2004; Harris 2010). Changes in temperature and precipitation may trigger severe problems. Although Harris (2010) showed that there is no trend of declining precipitation on the Qinhai-Tibetan plateau, the rise of summer temperatures may reduce rangeland productivity (Klein *et al.* 2007; Harris 2010). In 2000, high mortality of livestock occurred during a harsh winter following directly a severe drought in 1998 – 1999 (Wu & Yan 2002). Large Dzoge peatlands have been reported to shrink significantly causing diminished water supplies for grazing animals over large areas (Bai *et al*. 2007).

Since the market economy prevails all across the Qinhai-Tibetan rangelands, socio-economic drivers tend to determine the total numbers of animals (Article I). The rangelands of Dzoge are likely to continue to experience intensive grazing in the foreseeable future (Harris 2010).

The case of Jauristunturit is quite similar to Dzoge. The area is located above the treeline and reindeer herding is the main form of land use. Tourism, in the form of individual hiking, skiing and fishing, is the second most important form of land use. Both the Finnish Näkkälä herding district and the Norwegian West Finnmark herding district are affected by other forms of land use. Forestry, agriculture and road networks fragment pasture lands. Näkkälä is located in the transition zone between the pine forest, the mountain birch forest, and the treeless tundra biome and has been affected by forestry more than the neighboring Norwegian district in Finnmark where forestry is of limited importance. In the Finnish reindeer husbandry context, Näkkälä has been affected by intensive forestry methods much less than, for example, the Lappi district where 20% of pasture land has been permanently lost or significantly transformed (Kumpula *et al.* 2005). Jauristunturit is important rangeland for both Finnish and Norwegian reindeer herders (article II). Area is naturally rich in reindeer lichen and most important factor contributing to the quality of the rangeland is the pressure of the grazing i.e. number of animals and herding practices.

5.4 THE COMBINED ENVIRONMENTAL AND SOCIAL IMPACTS OF PETROLEUM INDUSTRY ACTIVITIES ON REINDEER RANGELANDS IN ARCTIC RUSSIA

Reindeer rangelands in Arctic Russia are undergoing extensive changes caused by the recent expansion of industrial hydrocarbon extraction, which has potentially severe ecological and social impacts (Sulyandziga & Bocharnikov 2005). In YNAO and NAO, which are the core areas of reindeer herding in the Russian Arctic, Nenets have been able to cope relatively well with oil and gas development so far (Stammler 2005; Forbes 2008; Forbes & Kumpula 2009). South of YNAO and NAO, in the taiga forest zone of the Komi Republic and the Khanti Mansisk

Autonomous Okrug, the oil and gas extraction began 20 years earlier and the implications for reindeer herding have been severe (Habeck, 2005; Stammler & Forbes 2006). One of the largest petroleum disasters in Russia occurred in the Komi Republic's Usinsk area, where 110 000 tons of oil seeped out into the Kolva river and down into the Pechora River in October 1994 (Vilchek 1997). Articles III – V demonstrates recent progress in NAO and YNAO, and indicates that these regions are at the brink of exceptional large environmental and social changes. Now the petroleum industry is expanding even to the most remote settlements and herding territories in NAO and YNAO.

In the Bovanenkovo Gas Field (BGF) in YNAO the development of the petroleum industry is still in the early stages but it already includes intensive terrestrial and aquatic impacts (articles III – V). By 2005 BGF encompassed more than 200 km^2, of which half was severely disturbed. Officially, about 14% of the territory (277 – 287 km^2) around BGF was severely disturbed as of 2005 (VNIPI Gazdovycha 2005). The former figure is already 30 times greater than the total of severely disturbed terrain for Prudhoe Bay Oil Field in Alaska (National Research Council 2003). In the very near future 743 new wells will be drilled for gas extraction in the vicinity of BGF and Kharasavey and the directly disturbed area will increase significantly in coming years. Also, the railroad to BGF from Obskaya has been completed between 2007 – 2010 (250 km was build). A similar expansion of activities and infrastructure is underway in NAO's Varandei oil field, pipelines are under construction to gather oil from hundreds of kilometers distance to Varandei oil terminal. This will disrupt the migration patterns of reindeer herding brigades.

The ecological consequences of the oil and gas extraction on reindeer herding include the degradation of reindeer pastures via pollution and mechanical disturbance of the vegetation and top layers of the soil (Khitun 1997; Vilchek 1997; Forbes *et al.* 2001). Therefore, an increasing amount of pastures has become unsuitable for reindeer herding. In the near future, the grazing pressure on YNAO and NAO reindeer rangelands may increase even if the reindeer populations of these respective regions remain at the present levels. The construction of oil pipelines, railroad and roads constitute linear obstacles which complicates the migration of reindeer (Stammler 2005). Areas with limited or restricted accessibility are growing as the transport network is expanding and important pasture lands can be simply blocked off from use.

Direct impacts of drilling are quite local, but can strongly affect certain herding brigades. This in turn may increase the grazing pressure on neighboring brigades' or sovhozes' pasture lands. Old drilling sites and off-road vehicle tracks potentially have increased value, in terms reindeer fodder, due to the relative increase in the amount of graminoids (articles IV and V). However these areas are generally avoided because herders consider them as devalued pasture land because of the higher risk of reindeer hoof injuries and infections caused by waste metal and broken glass (article III). The cleaning up of such industrial and other trash would enhance the possibilities for herders to use abandoned sites and their surroundings significantly. Unfortunately in many cases, the responsibility for the cleanup of drilling sites and exploration sites is unclear or the current owner considers not being responsible of previous owner's malpractices (Forbes 2008). However, the effects of petroleum industry are not merely negative: Nenets people benefit from improved transportation in tundra, as well as medical services and increased possibilities to trade.

5.5 MULTIDISCIPLINARY APPROACH COMBINED WITH REMOTE SENSING OF RANGELANDS

Rangeland research and inventories based on remote sensing to date have mostly addressed pasture extent and forage quantity. In the 1990's, pasture inventories in Fennoscandia focused on regional husbandry. More recently it has become apparent that future assessments of environmental and social impacts in the rangelands would benefit by deploying multidisciplinary teams and exercising tighter integration across traditional disciplinary borders beginning already at the planning stages. Research projects employing a multidisciplinary approach have been the key towards incorporating traditional and local knowledge into rangeland research (e.g. HIBECO Wielgolaski *et al.* 2005; RENMAN Forbes *et al.* 2006; BALANCE Lange *et al.* 2008, ENSINOR Forbes *et al.* 2009). By involving local practitioners early in the planning process projects it is possible to focus on the most relevant locations and topics within targeted rangelands.

Herders' traditional or local knowledge has been taken into account in several remote sensing and GIS-applications (Rees *et al.* 2003; Sandström *et al.* 2003; Chapin *et al.* 2005; Walker *et al.* 2006). It is essential to link the latest remote sensing and GIS-methods to ecological investigations at scales relevant to local actors, in this case herders (articles III – V). The end result is a suite of quantitative and qualitative interpretations, extremely rich in detail and context from both scientists and local stakeholders, which would not have been achievable without each other.

What researchers using remote sensing are usually lacking is information on the contemporary and historical use of pastures. Stammler (2005) states that the carrying capacity calculations in Yamal neither explain reindeer numbers nor the manner in which Nenets herders utilize tundra pastures. For Russian geobotanists classifying rangelands, the height and extent of reindeer lichens is typically the most important value in defining the quality of pastures. For herders, however, lichen coverage may in some cases be ranked second or third in terms of its importance (Stammler 2005). Still other factors may be more important. For example, if an area is known for high predator risk or deep snow it might be avoided even if it has good lichen forage resources. In addition, social drivers may affect rangeland use, like if there is no hut or suitable shelter from bad weather within an area or if it is too close to the neighboring brigade. At the same time, detailed information on herding patterns, such as summer – winter pasture rotations and reserve areas are important in pasture evaluations.

Perhaps the most challenging task for future rangeland research is to develop a common language and ways to cooperate between herders and researchers. It requires a common will to begin discussions of research aims. This step may be difficult because of prevailing negative prejudices. Especially in remote regions, herders may perceive researchers as representatives of the administration who are seeking information to be used against them on issues like overgrazing, pasture misuses and other negative practices. Researchers may on the other hand underestimate the herders' knowledge of pastures by arguing that they do not understand large-scale pasture management. Integration of natural and social sciences, including local knowledge as well as recognition of the increasing role of global factors, is required to meet the challenges of managing rapidly changing rangelands (Lambin 2001; Chapin et al. 2006; Kitti et al. 2006).

6. Conclusions

This thesis has compared land use on remote rangelands of Eurasia at four contrasting geographical locations. Although the research areas present only a small fraction of Eurasian rangelands, they represent typical environmental conditions. In all research areas animal husbandry is the main form of land use. Animal husbandry in the Dzoge region of the Eastern Tibetan Plateau is based on yak, sheep and horse breeding on alpine rangelands and is practiced by Tibetan nomads. These nomads in Dzoge have experienced drastic changes from the Cultural Revolution to privatization within a period of 50 years. Reindeer herding in Jauristunturit (Fennoscandia) has been transformed from traditional nomadic herding to a modern form of animal husbandry emphasizing meat production within the past 60 years. Reindeer herding practiced by Nenets nomads in NAO and, especially in YNAO, has survived relatively intact from among all Russian Arctic indigenous reindeer herders from the Soviet period. Since the late 1960's the hydrocarbon extraction industry has expanded its activities into the core areas of Nenets reindeer herding in both regions.

In this thesis remote sensing and GIS coupled with field inventories were the main methods employed to investigate land use and land cover on rangelands. Various optical remote sensing images ranging from very high-resolution (Quickbird-2, IKONOS-2) to high resolution (ASTER VNIR, SPOT, Landsat) were analyzed to obtain information on rangeland conditions (I and II) and hydrocarbon industry impacts (II, IV and V). VHR imagery enables detailed landscape level mapping of rangeland quality (i.e. lichen coverage and biomass) (II) and detailed industrial impact assessment (III; IV and V). Key limiting factors for the utility of such VHR imagery include its high cost and, secondly, the minimal surface area coverage and relative lack of archival imagery. For management purposes of rangelands larger than 500 km^2, coarser resolution imagery remain the best choice, e.g. ASTER VNIR, SPOT and Landsat. Landsat has the longest temporal coverage (early – mid 1970's to present) if the research focus is on changes in land use and land cover.

The evaluation of land use on vast rangelands requires the use of remote sensing and GIS due to the large spatial context. Secondly, remote sensing requires ground-based evaluation of different biophysical variables (ecological ground surveys). Thirdly, to comprehensively assess issues of land use, e.g. herding practices, changes in land cover, or socio-economical aspects, a strongly multidisciplinary approach is required. Geography itself is multidisciplinary in nature and geographers have certain abilities to function as a bridge between the sciences in multidisciplinary research projects.

Today, Nenets reindeer herding is experiencing the most intensive outside pressures, in the form of oil and gas development, since the introduction of collectivization in the 1930's. In contrast to collectivization, oil and gas activities have severe impacts on land cover. The industry's impact in the northern tundra zone is still in the early stages but it already includes intensive terrestrial and aquatic impacts in the Toravei and BGF areas. Cumulative impacts will expand in the near future and it remains to be seen how reindeer herding can cope and whether or not coexistence with petroleum development is feasible in practice (Stammler *et al*. 2009). However, if the reindeer herders' views and needs are heard and taken into account during the planning and construction phases, the negative impacts towards herding can be minimized. Anthropogenic impacts have recently expanded to inflict large-scale land cover change in the Arctic. In YNAO and NAO, herders and their reindeer have influenced vegetation patterns for centuries. On the other hand, expanding hydrocarbon development has great potential to affect vast areas of YNAO and NAO dramatically in the near future.

Local and indigenous peoples' assessments add a new level of interpretation of changes in the tundra. Such an interdisciplinary approach leads to better integration of research results and more comprehensive understanding of combined social and environmental impacts.

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