A toolbox for Co-production of Knowledge and Improved Land Use Dialogues

The Perspective of Reindeer Husbandry

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A toolbox for Co-production of Knowledge and Improved Land Use Dialogues – The Perspective of Reindeer Husbandry

Abstract

In northern Sweden, forestry, wind and hydropower, mining, infrastructure development and associated influence zones together constitute a complicated, land use situation that strongly impacts reindeer husbandry, a unique and extensive land use system. This situation has led to challenges for land managers and decision makers. Because of limited use of existing knowledge and lack of specific data on key resources, the land use dialogue among the reindeer herding communities, other land users and agencies has been inadequate. To overcome this problem, reindeer herding communities initiated a process to improve this situation together with researchers and with state and regional agencies.

Key findings from the collaborative, process-focused papers in this thesis showed that the diverse groups that worked together could co-produce methods and tools that increased the engagement and the ability to negotiate and find solutions. Furthermore, the co-production of knowledge served as a heuristic, increasing the use and understanding of compiled information. The co-production further created an exigency for conventional research that then informed the tools, thereby increasing the potential contribution towards improved dialogue.

Findings also indicated that significant declines have occurred in the amount and distribution of forest floor lichen, – a key reindeer winter grazing resource – since the introduction of modern forestry practices in the mid-20th century. Furthermore, forecasting alternative forest practices indicated that current forest practices would further diminish the forest floor lichen resource. Promising results demonstrated that satellite-based mapping of forest floor lichen can be carried out successfully and can identify crucial areas for directed forest management, which can improve conditions for forest floor lichen. In combination, the co-produced toolbox and the findings about the status, trend and distribution of the lichen resource can potentially improve future dialogue.

The work represented in this thesis can potentially serve as a stronger foundation to safeguard the continuation of the complex land use system of reindeer husbandry, which constitutes both a fundamental component in the indigenous Sami culture, as well as a key to successful sustainable landscape management.

Keywords: Co-production of knowledge, cumulative impacts, dialogue, indigenous people, land use, pGIS, reindeer husbandry planning, sustainable landscapes

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Dedication

To working together

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Sandström, P., Pahlen, T.G., Edenius, L., Tommervik, H., Hagner, O., Hemberg, L., Olsson, H., Baer, K., Stenlund, T., Brandt, L.G. & Egberth, M. (2003). Conflict resolution by participatory management: Remote sensing and GIS as tools for communicating land-use needs for reindeer herding in northern Sweden. *Ambio,* 32(8), pp. 557-567.

II Sandström, P., Sandström, C., Svensson, J., Jougda, L. & Baer, K. (2012). Participatory GIS to mitigate conflicts between reindeer husbandry and forestry in Vilhelmina Model Forest, Sweden. *The Forestry Chronicle,* 88(3), pp. 254-260.

III Herrmann, T.M., Sandström, P., Granqvist, K., D'Astous, N., Vannar, J., Asselin, H., Saganash, N., Mameamskum, J., Guanish, G., Loon, J.-B. & Cuciurean, R. (2014). Effects of mining on reindeer/caribou populations and indigenous livelihoods: community-based monitoring by Sami reindeer herders in Sweden and First Nations in Canada. *The Polar Journal,* 4(1), pp. 28-51.

IV Poudyal, M., Lidestav, G., Sandström, S. & Sandström, P. (2015). Supporting community governance in boreal forests by introducing participatory-GIS through action research (Submitted to Journal of International Action Research 14-11-28).

V Sandström, P., Cory, N., Svensson, J., Hedenås, H, Jougda, L., & Brochert, N. (2014). On the Decline of Ground Lichen Forests in the Swedish Boreal

Landscape – Implications for Reindeer Husbandry and Sustainable Forest Management (Submitted to AMBIO 14-10-21).

VI Korosuo, A., Sandström, P., Öhman, K. & Eriksson, L.O. (2014). Impacts of different forest management scenarios on forestry and reindeer husbandry. *Scandinavian Journal of Forest Research,* 29, pp. 234-251.

VII Gilichinsky, M., Sandström, P., Reese, H., Kivinen, S., Moen, J. & Nilsson, M. (2011). Mapping ground lichens using forest inventory and optical satellite data. *International Journal of Remote Sensing,* 32(2), pp. 455-472.

Papers I-III and VI-VII are reproduced with the permission of the publishers.

The contribution of the authors of the papers included in this thesis was as follows:

I LJ initiated the process and PS and LJ conceived the study. PS, LJ organized workshops, meetings and trainings. KB, TS and LB participated in meetings and trainings. KB and TS contributed with knowledge about reindeer husbandry. HT designed field work and field trainings. All participants co-produced knowledge and methods. PS wrote the paper and others commented.

II PS and CS conceived the study. CS analyzed the interview material. PS wrote the majority of the paper with CS and JS contributing with texts and comments. LJ and KB contributed with expertise and advice.

III TH conceived the study. PS and KG contributed with the Swedish case. PS cooperated with the reindeer herding communities and supported reindeer herding communities work in RenGIS. JV contributed with knowledge about reindeer husbandry and invented new modules for RenGIS and described of the ongoing process TH wrote the majority of the paper, PS and KG contributed with texts and comments for the Swedish case.

IV MP, GL and PS conceived the study. SS, GL and MP held workshops. MP wrote the majority of the paper and PS, GL and SS contributed with texts and comments.

V PS conceived the study. NC did all the work with the Swedish National Forest Inventory database. PS, JS and HH analysed results. PS wrote the majority of the paper with great support from JS, HH and NC.

VI PS and AK conceived the study, AK, OE and KÖ planned the problem formulation. AK simulated scenarios, analysed the results and wrote the major part of the paper. PS contributed with reindeer and lichen expertise and texts and comments.

VII PS, HR and MN conceived the study. MG did most of the image classification work. PS and JM designed field study. PS and MG did field work. MG was lead author with PS and HR contributing with texts and comments.

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Abbreviations

FSC	Forest Stewardship Council
IPCC	Intergovernmental Panel on Climate Change
MEA	Millennium Ecosystem Assessment
NFI	National Forest Inventory
SEPA	Swedish Environmental Protection Agency
SFA	Swedish Forest Agency
SGU	Geological Survey of Sweden
SOU	The Swedish State's Public Assessment
SSR	The Swedish Sami Organization
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

1 Introduction and background

1.1 Context

Northern regions are undergoing rapid changes due to human expansion in connection with industrial exploration and exploitation of natural resources (UNEP, 2013). This is especially true in northern Fennoscandia where forestry and other extensive and intensive land use systems play important economical roles (Forbes *et al.*, 2006; Forbes *et al.*, 2004). Areas that historically were lightly impacted by industrial development, currently experience developments at unprecedented rates. There is growth in industries that extract and use oil, gas, minerals, energy sources and forests, accompanied by expanding transportation and other infrastructure that are associated with these land use forms (Svensson *et al.*, 2012). The cumulative impacts of the land use activities increase the risk for land use conflicts and impose pressures and threats to ecosystems and local, rural communities (MEA, 2005). These risks necessitate evaluations that explore the consequences of new developments in relation to the present day land use situation.

General strategies for sound ecosystem management (Folke *et al.*, 2004; Christensen *et al.*, 1996; Grumbine, 1994) ecosystem stewardship (Chapin Iii *et al.*, 2010) and sustainable forest management (Duinker, 2011; Lindenmayer *et al.*, 2000) are well established and discussed in research communities. Advances in ecological sciences have the potential to provide the scientific basis for policy choices regarding ecosystem management (Angelstam *et al.*, 2004), adaptive monitoring (Lindenmayer & Likens, 2009), and holistic landscape approaches (Svensson *et al.*, 2012) that include the people and communities using the landscape (Garedew *et al.*, 2009; Sandewall *et al.*, 2001) and multiple land users operating in the same areas at the same time (Lindenmayer *et al.*, 2008). Despite the existence of these strategies, practices, advances and tools, the benefits have not often been realized. Instead land use planning for large geographical areas are often carried out by land owners or regional governments who use strategies that reflect policies of single resource utilization (Svensk Energi,2014; Government Proposition, 2013; SGU, 2013). Such strategies seldom include socio-ecological components (Plummer & Armitage, 2007; Foley *et al.*, 2005) or address the cumulative and conflicting land use systems (Theobald *et al.*, 1997; Smit & Spaling, 1995).

In the ecosystem management approach, management decisions should be based on strategies that use cumulative land use assessments to address sustainability, landscape connectivity and acknowledge the importance of human needs (Christensen *et al.*, 1996; Grumbine, 1994). The key to such management is a clearer, more comprehensive understanding of the spatial and temporal relationships in ongoing land use processes (Bringezu *et al.*, 2014). Such an understanding benefits from merging the best available local stakeholder knowledge with the best scientific expertise (Huntington, 2011; Foley *et al.*, 2005). Indigenous and local ecological knowledge is increasingly recognized as "an invaluable basis for developing adaptation and natural resource management strategies in response to environmental and other forms of change" (IPCC, 2007), a recognition that is reaffirmed in IPCC (2010). Considerations of indigenous knowledge were included, for example, as a guiding principle for the Cancun Adaptation Framework (UNFCCC, 2010).

Involving local stakeholders is recognized to benefit management decision-making processes in multiple ways, for example by contributing to knowledge production, defining land use problems, and exploring solutions to land use problems (Huntington, 2011). Compiling the local and specific knowledge can potentially illuminate the complex yet specific nature of a given land use problem on both the local and on broader scales. Local stakeholders often have a vested interest in the land use dialogue, and a reason to be concerned that accurate land use data is applied in the negotiations of potential land use solutions. We need strategies to work with the local stakeholders, strategies to collect and make best use of stakeholders' knowledge and needs, and strategies to incorporate this into a platform for sound, holistic land use solutions.

This thesis builds on 14 years of experiences of developing such strategies. The land use system of reindeer *(Rangifer tarandus)* husbandry provides the basis for this work as it represents a unique land use system that, ultimately depends on how other land use systems are carried out. Thus, the focus on reindeer husbandry has made it possible to approach the circumstances that impact the sustainability of this particular land use system in the context of other land use systems, in order to highlight obstacles and possibilities for holistic landscape and land use in northern Sweden. This thesis describes the process of development, implementation and evaluation of a toolbox in which co-production of knowledge provides key information for improved dialogue among land users. Additionally, this thesis provides new knowledge about key landscape and land use resources to support strategic and operational planning and to further improve the land use dialogue.

1.2 Land use in northern Sweden from a reindeer husbandry perspective

The reindeer husbandry system constitutes an extensive, complex and unique land use form carried out by the indigenous Sami people across *Sapmi,* an area covering much of northern Sweden, Norway, Finland and Northwestern Russia (Figure 1a). Reindeer husbandry is also carried out by more than 20 other indigenous groups across the Russian north and Mongolia (Oskal *et al.*, 2009). The reindeer husbandry land use system can be considered the only remaining grazing system of domesticated animals which uses the native range and seasonal movements to access and use grazing resources in the same or similar way as its native ancestor species. With continuous lands connected by migration routes, those annual long-range migrations of reindeer (Figure 1b) are the last remaining large-ungulate migrations in the northern hemisphere (Vors & Boyce, 2009). Maintaining such land use system today offers both challenges and opportunities for managers as well as policy makers.

In Sweden, reindeer husbandry can be carried out in an 22.6 million ha area, equal to 55% of the Swedish land base (Swedish Reindeer Husbandry Act, 1971:437; Sametinget, 2014; Paper V). This area includes more than 50% of the productive forest land, and the majority of the boreal and alpine biomes in Sweden. No part of the reindeer husbandry area is set aside exclusively for reindeer husbandry. Instead reindeer husbandry is always carried out in conjunction with other land uses (Paper I, II and V).

The reindeer husbandry area constitutes the sum of all land presently used by the 51 reindeer herding communities in Sweden during all grazing seasons, including both seasonal grazing areas and migration routes (The Reindeer Grazing Law 1928; The Reindeer Husbandry Act 1971:437; Sametinget, 2014; Figure 1b). A reindeer herding community is both a large geographic area – usually stretching from the Norwegian mountain border in the west to the Bay of Bothnia in the east – and an administrative and financial organizing association for the Sami reindeer herder's companies. Many reindeer herding communities are further divided into *siidas* (winter groups), each containing one or several reindeer herding companies. Currently there are about 247 000 reindeer in Sweden, a number that has remained relatively constant the last decades (Moen & Danell, 2003), distributed among 4700 reindeer owners of with the majority being part time herders (Sametinget, 2014).

Understanding the situation for reindeer husbandry today requires a historical perspective of reindeer husbandry concerning actual land use, legal rights, and the way in which interpretations of legal rights have changed (Brännlund & Axelsson, 2011; Mörkenstam, 1999). Various forms of reindeer husbandry has existed for millennia (Aronsson, 1991), and until the 19th century, reindeer husbandry in combination with hunting and fishing was encouraged and privileged by the government of Sweden as the best suited land use form in the north (Cramér & Ryd, 2012; Lantto, 2012; SOU, 2006). The gradual move towards reindeer husbandry as a land use form derives from the taming of a few reindeer for milking, as pulling animals or as decoy to attract wild reindeer during hunting (Bjørklund, 2013; Bately & Englert, 2007). The migratory system of reindeer husbandry became more widespread in the 16th century and by 1650 most reindeer in Sweden had become domesticated (Lundmark, 2008). For the Sami, the forming of a more organized land use system was necessary to increase their production capacity, an increase that was necessitated by the increased government tax burden (Cramér & Ryd, 2012).

The first Lapland treaty in 1673 opened northern Sweden for more permanent settlements based on animal breeding, hunting and fishing and thereby introduced parallel land use by the Sami who were already established, and the immigrating farming settlers (Allard, 2006; Sandström *et al.*, 2006; Hahn, 2000). The treaty essentially tested the possibility of co-existence and co-management of land resources. Although less than 1% of the land was transformed to arable land (Östlund *et al.*, 1997), conflicts between reindeer husbandry and other land users begun to occur (Brännlund & Axelsson, 2011). Around the 1850's, forestry began its progress northwards in Sweden (Fredén, 2002; Arpi, 1959) and more and more of Sweden's prosperity and economic expansion were derived from natural resources, from the northern parts of the country.

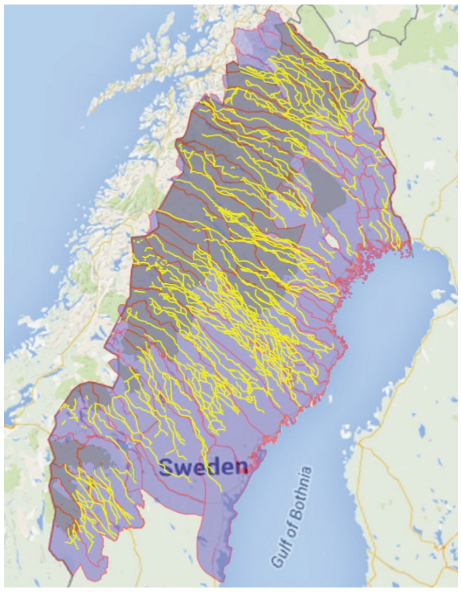
From 1695 through 1928, the Sami taxation lands became well established and recognized by the State due to the revenues they produced (Lundmark, 2006). In fact, it is the outer boundaries of the Sami taxation lands that defined the current national boundaries to the north and west (Cramér & Ryd, 2012; Lundmark, 2006). Hence, hunting, trapping, fishing and lately reindeer husbandry was privileged and preferred land use activities up until about 1850 when Sami rights were the strongest (Lundmark, 2008).

In 1886, the Reindeer Grazing Act permanently acknowledged the rights for the Sami to graze their reindeer on all private and public lands. According to most legal scholars, this right is considered equal to an easement and as strong as the land owner's user rights (Allard, 2006; Hahn, 2000). Accordingly, each land owner does not have the right to negatively affect the conditions of the land for the easement holder, i.e. the reindeer herding community (Allard, 2006; Hahn, 2001; Hahn, 2000). In terms of legal protection, the Reindeer Grazing Act makes the grazing right as strong as the right to carry out forestry and equal to land ownership rights, thus much stronger than the public right to access (Hahn, 2000). In addition, according to the Reindeer Grazing Act, it is not possible for the land owner or land user to buy out the grazing right (Hahn, 2000). Consequently, the only solution should be to find ways for mutually beneficial coexistence and commonly accepted land use practices of all land in the reindeer husbandry area.

For many decades the property rights of the early farmers and Sami co-evolved, with the State appearing to support the land use form that generated the most taxes (Cramér & Ryd, 2012). As farming moved north and west, the of rights began to shift, and when forestry was established, the interpretations rights of reindeer husbandry markedly weakened (Hahn, 2000). During the hydropower building epoch from the 1920's to 1980 (Össbo, 2014) and during the now ongoing forestry, mining and wind power epochs, the interpretations of land use rights continue to shift (Allard, 2006; Hahn, 2000). Land use issues have become more complex as the number of land users has increased.

From a legal perspective, equal, mutual, consideration between the land owner or the land user and the reindeer herding community is required on all lands in the reindeer husbandry area (Hahn, 2000). However, though legal rights have not changed since the Reindeer Grazing Act of 1886, the State's interpretation of the rights appear to have changed based on how the economic importance of the different land use forms has shifted (Cramér & Ryd, 2012). To summarize, reindeer husbandry system has gone through many changes over time, but has persevered despite the rapid landscape changes over time and the increased difficulties to claim their rights (Johansson, 2013; Lantto & Mörkenstam, 2008; Sandström & Widmark, 2007).

a



b

Figure 1. a. *Sapmi*, the home of the Sami people spans northern Sweden, Norway, Finland and North Wetern Russia (gray). b. The reindeer husbandry area in Sweden (purple), boundaries of 51 reindeer herding communities (red), reindeer migration paths (yellow), and year-round grazing lands (gray). Data and mapping from RenGIS.

1.3 Other Land Use Systems in Northern Sweden

From the 1950s, human impact on the northern landscapes has accelerated, resulted in profound direct and indirect impacts on reindeer husbandry, and also resulting in changes in policy and interpretations of rights. Understanding, measuring and solving cumulative impacts on reindeer husbandry requires considerations of how other land use forms have developed and continue to develop. As a consequence of these landscape changes as well as technical changes, the reindeer husbandry system has also gone through many changes during this time period.

In this section some of the other major land use systems in northern Sweden are described: energy production from hydro and wind power, mining, forestry and infrastructure developments and associated impact zones.

1.3.1 Hydropower

The first major hydropower developments were established in the 1910's and 1920's. By the 1950's and onward, the period when modern forestry was also introduced, hydropower developments spread north and westward, affecting practically all river valleys in Sweden (Össbo & Lantto, 2011; Figure 2). By the 1970's most of the expansion was already in place and since 1980 few new hydropower stations have been developed in Sweden (Össbo, 2014). Hydropower is the base of Sweden's renewable energy production, producing 41% of Sweden's electricity and is, also the largest renewable energy resource in EU (Svensk Energi, 2014). About 80% of Sweden's hydro power is produced in northern Sweden (Svensk Energi, 2014).

Where hydropower is established, significant impacts on other land uses are apparent. Major impacts include loss of shoreline habitats to flooding, drained riverbeds where the water goes underground through power producing turbines, complete barriers to migrating fish, artificial shoreline constructions, and dangerous ice conditions because of shifting currents and water levels (Mahoney & Schaefer, 2002). Originally, the river valleys constituted the core of the migration routes for reindeer husbandry and the consequent loss of this infrastructure created a major obstacle to migration.

Figure 2. Hydropower reservoirs are established in all but four major river valleys (dark blue) and their associated high voltage power line network (yellow lines) in the reindeer husbandry area (purple) in northern Sweden. Undammed lakes (light blue). Data and mapping from RenGIS.

1.3.2 Windpower

Windpower development is a quickly expanding land use form in Sweden. Between 2006 and 2013, windpower production increased tenfold from relatively few and small windpower parks producing 1.0 TWh, to a large number small and large parks producing 9.9 TWh in 2014 (Svensk Energi, 2014; Figure 3). Currently in northern Sweden there are about 500 constructed turbines and an additional about 4000 in the application process (Energimyndigheten, 2014; in RenGIS database). The national political goal, as declared by the Parliament, is to triple the production to 30 TWh by 2020 (Government Proposition, 2009).

Early windpower development was mostly located in southern and coastal Sweden, but more recently a frontier movement of windpower development is spreading north, taking advantage of the existing high voltage power lines established as part of the hydropower expansion (Figure 3). Windpower offers prospects for employment opportunities in rural areas by some recognized as of critical importance to rural northern Swedish municipalities. However, the impacts on ecosystems from large area wind power developments are not yet known. Such rapid expansion necessitates a yet undeveloped strategic planning process that takes environmental impacts into consideration in a holistic perspective (Skarin *et al.*, 2014; Skarin *et al.*, 2013). Known impacts from wind power developments include complete removal of vegetation cover at each turbine site and along road networks, sound and sight effects on surrounding landscapes, and construction of extensive networks of power lines and roads (Skarin *et al.*, 2014; Vistnes & Nellemann, 2008).

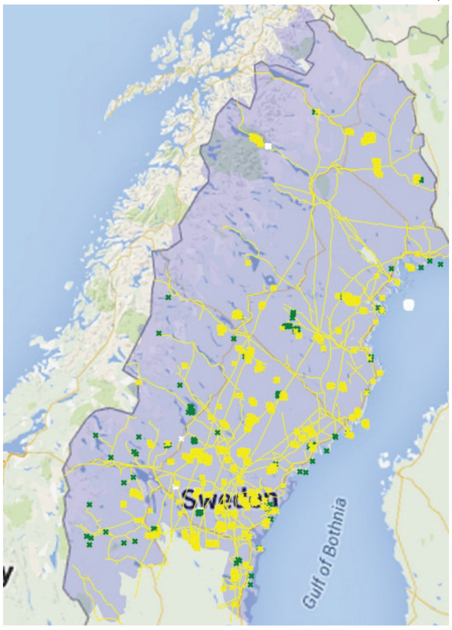


Figure 3. Constructed wind power parks with about 500 installed turbines (green), about 1500 granted and about 1500 official applied for wind turbines (yellow) and high voltage power lines (yellow) in the reindeer husbandry area (purple). Mapping from RenGIS and data about wind power parks from Energimyndigheten (2014).

1.3.3 Mining

Mining has a long and diverse history in Sweden. Between 1900 and 1920 there were about 300 small, active mines in Sweden producing around 8 million tons of ore per year (SGU, 2013). Most of these mines were located in south-central Sweden and had a significant local impact both on communities and the environment, while in northern Sweden, mining was only an occasional part of the landscape at that time (SGU, 2013). Since the 1940's there has been a steady decline in the numbers of mines, yet a substantial increase in the amount of ore produced (SGU, 2013). Today, northern Sweden has only 12 active mines, but they produce about 75 million tons of ore making Sweden EU's largest producer of minerals and providing 90% of EU's iron ore (SGU, 2013). The Swedish mining industry's hopes for future expansion are expressed in the 959 valid exploration permits in Sweden, the 130 new applications for exploration and the 57 granted land concessions mostly located in northern Sweden (Figure 4a). But because the mining industry is sensitive to global market interests and political incentives, Sweden's mining future seems hard to predict. This uncertainty is reflected in the massive buildup of a major iron mine around Pajala in northernmost Sweden from 2012, and the bankruptcy of the mining company in 2014 (Northland, 2014).

General impacts on the landscape in and around the 12 active major mining sites in northern Sweden include sound pollution, dusting and visual effects on the surrounding areas, complete removal of all vegetation cover at the mining sites' tailing ponds and industrial zones, and risks for polluted ground and surface water. High nature conservation values may be completely lost if mines are developed in areas with Nature 2000 and other focal areas and habitats (SEPA, 2013b). Additionally all mining sites impact the landscape significantly due to continuous transportation of ore and heavy equipment between the mine and the shipping point creating obstacles to animal movements. An overview of direct impacts of the Aitik copper mine and Malmberget iron mine outside Gällivare in northern Sweden on a 900 km^2 landscape as detected in a SPOT satellite image from 2013 is provided in Figure 4b.

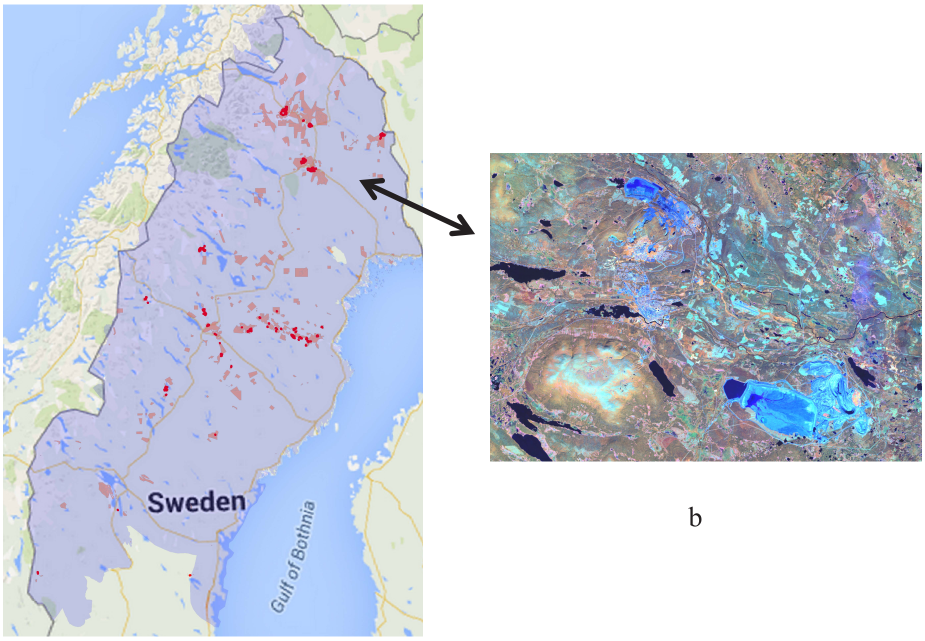


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Figure 4. a. Existing mines and granted land concessions (red) and areas with granted license to explore (pink) in the reindeer husbandry area (purple) in northern Sweden. b. A satellite image view over the 900 km^2 local area around the Aitik and Malmberget mines. The mining and tailing areas are clearly visible as blue areas in a SPOT satellite image from 2013. Mapping from RenGIS with data about the mines from SGU (2013).

1.3.4 Forestry

Second to reindeer husbandry, forestry is the most spatially extensive land use system in northern Sweden. Viewed from the scale of northern Sweden, forestry activities occur everywhere on productive forest sites (Figure 5), which in various ways have impact on all other types of land uses.

The use of forests and forest products has a long history in northern Sweden. Historic forest use was largely restricted to areas close to farmlands and settlements, where the forest landscape was less impacted in some areas, and more in others (Östlund *et al.*, 1997). Subsequent to the establishments of farming settlements, the sawmill industry began its expansion north- and westwards around 1850, mostly using selective harvesting of large trees (Östlund, 1993; Arpi, 1959). The expansion came about quickly, and by 1870 Sweden was the world's largest exporter of sawed logs with much of the timber coming from northern Sweden (Björklund, 1984). The impacts of forestry on reindeer grazing lands at this time were partly positive, as selective harvesting of the largest trees opened the forests, oftentimes benefitting grazing conditions for reindeer (Berg *et al.*, 2008; Paper V). In the 1950s, the forestry practices changed from primarily selective to stand-oriented, even-aged and monoculture forestry, now introducing methods of soil scarification, planting, pre-commercial thinning, thinning, the introduction of *Pinus contorta* and clear cutting (Berg *et al.*, 2008). Such practices had a profound effect on forests and the landscape (Esseen *et al.*, 1997; Östlund *et al.*, 1997). The landscape of northern Sweden was re-formed, not only by the actual harvesting levels and uniform harvesting of large patches, but also the construction of an extensive network of forest roads (Östlund *et al.*, 1997).

Figure 5. The reindeer husbandry area (purple) of northern Sweden with alpine areas above the tree line (pink), protected alpine areas (grey), protected forested areas (green) and productive and managed forest areas including mires and lakes (purple). Data and mapping from RenGIS.

1.3.5 Infrastructure and other impacting factors

All of these described land use forms; forestry, hydropower, mining, wind power and related infrastructure developments such as roads, railroads, power lines and towns around industrial sites (Figure 6) also have surrounding zones of influence associated (Skarin & Åhman, 2014; Nellemann *et al.*, 2010; Johnson *et al.*, 2005; Cameron *et al.*, 1992). In combination, these impacts require considerably more space than the actual land use activity itself, and they can create barriers that fragment the landscape (Vistnes, 2004; Nellemann *et al.*, 2003; Nellemann, 2001). Consequently, although land use activities such as mining (Figure 4) and wind power (Figure 3) require relatively small areas of land when viewed on the scale of northern Sweden (Danell, 2005; Nellemann *et al.*, 2003), the associated infrastructure and consequent zones of influences that are linked to these activities are significant (Skarin & Åhman, 2014; Figure 7).

There are other factors and land use forms, than those mentioned above that also have considerable impact on reindeer husbandry, such as tourism, climate change and predation. These factors are important for a more comprehensive view of the land use and management premises in northern Sweden. Because of the lack of updated mapped and spatially explicit information about these factors, they will not be explored in the context of this thesis. Clearly, these aspects need further scientific attention.

Figure 6. Infrastructure developments in the reindeer husbandry area (purple) of Sweden with major roads (grey), railroads (black), towns (red) and power lines (yellow). Data and mapping from RenGIS.

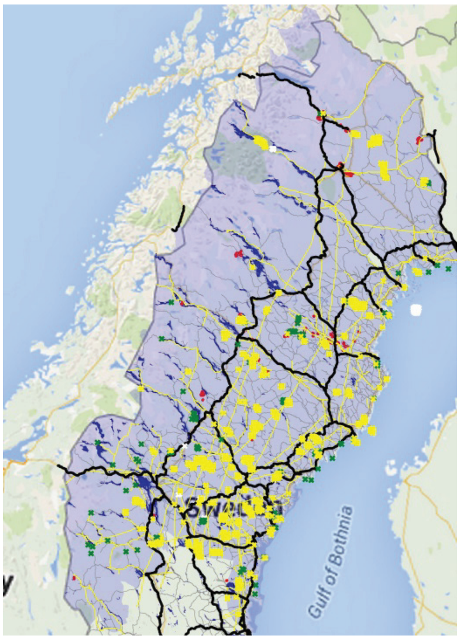

Figure 7. Map over the reindeer husbandry area (purple) of Sweden with constructed (green) and proposed windpower developments (yellow), hydropower reservoirs (dark blue) and major roads (light grey), railroads (black), mining sites (red) and power lines (yellow lines) illustrating the cumulative impacts. Data and mapping from RenGIS.

1.4 Forestry and reindeer husbandry land use conflicts

Forestry has been a prioritized land use form in northern Sweden because of its economic importance in terms of employment numbers and export value. As the demand for forest products has increased, so have the impacts on the reindeer husbandry system. Forestry impacts reindeer husbandry in numerous ways. First and most importantly, modern forestry has a profound impact on mat-forming *(Cladina* or *Cladonia*) and arboreal lichens (such as *Bryoria fuscescens* and *B. fremontii*) which are pivotal key winter grazing resources (Paper V). Much of the conflict and dialogue between reindeer husbandry and forestry revolves around management of lichen forests.

Other negative impacts of forestry on reindeer husbandry include densification of forests which inhibits ground lichen growth and aggravates reindeer and herder’s movements through forest stands. Intensive soil scarification methods remove vegetation cover, inhibit movements, and cause changes in the forest structure that can lead to negative effects on snow conditions (Roturier & Bergsten, 2009; Roturier & Roué, 2009; Roturier & Bergsten, 2006). Despite these negative impacts, it has been argued that it is technically possible to adapt forest management practices to the needs of reindeer husbandry (Roturier, 2009). However, such solutions as gentle soil scarification methods have not yet been realized. Lack of such solutions is connected to the forest sector poor understanding of reindeer's use of pastures and the movement patterns of the reindeer. Solutions are also held up because of a halting consultation procedure (Roturier, 2009; Sandström *et al.*, 2006; Paper I).

Initiatives to mitigate the conflictual situations between reindeer husbandry and forestry were taken quite early. A governmental group was assembled in 1971 with representatives from both reindeer husbandry and forestry called the Central Advisory Group for Reindeer Husbandry and Forestry (Jougda *et al.*, 2011a; Sandström & Widmark, 2007; Hemberg, 2001). In a further attempt to find solutions and balance, the Swedish Parliament in 1979 made consultation procedures between the two sectors compulsory on all lands above the "year-round boundary" (Sandström & Widmark, 2007; The Swedish forest act, 1979:429; Figure 1b). About 20 years later, under the Forest Stewardship Council (FSC), the consultation procedures were elevated to also include winter grazing lands all the way to the coast (FSC, 2013; Johansson, 2013). General recommendations about forestry considerations towards reindeer husbandry were included in the Swedish Forest act in 1982 (Jougda *et al.*, 2011a). In 1993 the Swedish Parliament passed its new forest policy which put production and environmental concerns on equal ground. It also stated that forestry had to be conducted without causing harm for reindeer husbandry (Hemberg, 2001).

Throughout these processes the goal has been to find forms for an impartial and effective consultation procedure. The forestry act of 1979 states that the reindeer herding community should be consulted about forestry activities, but the reindeer herders opinions were seldom noticed or adhered to (Sandström & Widmark, 2007; Sandström *et al.*, 2006; SFA, 2001). Ongoing conflicts indicate that the consultation procedures have not been satisfactory (Sandström & Widmark, 2007; Paper I). Earlier attempts for improvements included efforts to document land uses in reindeer husbandry and to map and inventory the grazing resource as seen in a process termed the Jokkmokk model (Heikka, 1981). But evaluations showed that the communication during consultations was not productive. The Sami reindeer herders felt that the consultations were mostly limited to notifications about management decisions that were already made (SFA, 2001). The Sami reindeer herders appeared to have no effective way to express their concerns, partly because of a communication venue that seemed to be unidirectional with the forest sector holding and presenting all information. The Sami reindeer herders felt they had no access to tools for sharing their knowledge about their land use needs (Sandström *et al.*, 2006; Paper I and II).

2 Problem Statement - Towards improved dialogue equipped with appropriate tools

The landscapes and natural resources in boreal northern Sweden have experienced land use impacts at low or moderate rates throughout history. Since the 1950's, however, there has been an unprecedented increase in land use impacts, with respect to the intensity of land use and to the diversity of land users. The cumulative consequences of all land uses, combined in space and time, have profound effects on the capacity of ecosystems and ecological processes to respond to factors such as climate change (Moen *et al.*, 2014), but also challenge the premises for any single land use stakeholder or land use form. Land use conflicts occur that affect land users differently depending on their intrinsic capacity and economic importance. Reindeer husbandry is a land use form that is carried out simultaneously with other land use forms and is affected by the activities of other land users. A functioning and sustainable reindeer husbandry system benefits from a range of tools that can enhance the reindeer herding community's capacity to define and explain their land use needs. Better definition and explanation of reindeer herding needs require strategies that rely on good local stakeholder knowledge, appropriate landscape data, and better means to communicate with policy and decision making bodies.

We see in the example of simultaneous land use by forestry and reindeer husbandry that the situation is complicated, and that solving the problem of mutual land use impacts requires an integrated approach. The approach must include both local and broad scale landscape analyses. Such integrated approaches can address the challenges that have evolved from intensified resource use among competing interests (Pape & Löffler, 2012; Meinke *et al.*, 2006). These approaches can be combined with conventional, sectorial approaches that investigate different aspects of specific land use forms or types of natural resources in depth. Topical and sectorial studies can provide critical data that lay the foundation for integrated approaches but such studies are insufficient to generate a cumulative impact assessment. Such an integrated perspective requires an approach that integrates economic, social and environmental aspects (Opdam *et al.*, 2009) and that includes all land cover types (Svensson *et al.*, 2012).

To attend to the complicated situation of multiple land use forms and to understand how activities overlap in space and time, we need detailed documentation and clear presentation using best available knowledge. The knowledge required includes information about the amounts, the distribution and the limitations of specific key natural resources. The knowledge should also include best available information about other land use systems for analysis of the cumulative impacts both for local and landscape overviews. As a starting point, we need to develop a system for compilation of stakeholders' available knowledge and other available landscape and land use data. The system should function as a platform for storage, visualization and analysis of land use scenarios and consequence assessments.

Forestry in Sweden with its a long history of advanced, operative and strategic planning has been equipped with such a system (Wikström *et al.*, 2011). A forest plan is a tool for strategic and operational planning of forestry activity with short and long term management guidelines and economic consequences of planning future scenarios. It contains data on the actual and potential forest conditions as well as management recommendations for each forest stand with corresponding maps. With such plans, the forest owner can make informed decisions about the management of the forest resource, while also communicating with authorities, timber buyers, contractors and with other land users (Brukas & Sallnäs, 2012). In contrast, reindeer husbandry previously relied on a tradition of oral communication of knowledge for their strategic and operational planning. Compared with forestry, reindeer husbandry's limited planning tools reflected its status as a small-scale "industry" where most of the work is carried out separately among reindeer herders.

Inspired by the concept of forest plans, some Sami reindeer herders began to develop corresponding reindeer husbandry plans (Paper I). Ideas and attempts came from several places and persons. Baste reindeer herding community started to map grazing lands, Gabna reindeer herding community had plans to map their grazing lands, and Malå reindeer herding community initiated similar efforts (Vestman, 2014; Jougda *et al.*, 2011a; Hemberg, 2001). These attempts lay the foundation for the first project meeting that aimed to address the problem of ongoing but poor dialogue between the reindeer herders and the forest sector. The first meeting focused on how to document the reindeer herders' detailed knowledge of the land and of how the reindeer use the land.

The issues at stake were complex and involved many different stakeholders with varied plans and goals. Much knowledge was in place, but was not compiled and not always available for consultations and management decisions. We needed tools for compiling old and new knowledge and information. We also needed tools to visualize, analyse and propose better land use solutions. The process of developing reindeer husbandry plans, ongoing since 2000, forms the backbone for the work described in this thesis. The development and use of a toolbox, a participatory GIS (pGIS), played a major role in this process. The toolbox represents the hub for co-production of knowledge, data assembly, data visualization, and data analysis towards improved land use dialogue.

3 Objectives

In an effort to mitigate land use conflicts, this thesis describes the process of development, implementation and evaluation of a toolbox in which co-production of knowledge provides key information for improved dialogue among land users. Additionally, this thesis provides new knowledge on key landscape and land use resources that support strategic and operational planning and that further improve the land use dialogue. The point of departure is reindeer husbandry, as it represents an extensive and complex land use system that is ultimately dependent on other land users and their land use decisions. Although this thesis takes the perspective of reindeer husbandry in relation to other land use systems, the toolbox and the process could also be applied in other land use situations.

This thesis is based on seven papers with the overall objectives to:

- Describe the process of developing a toolbox that will support co-production knowledge and improve land use dialogue (Paper I, also includes the continued work until December, 2014)
- Use and evaluate the toolbox that is intended to support co-production of knowledge and improve land use dialogue (Paper II, Paper III and Paper IV)
- Document past and present status, develop future scenarios and map the distribution of key resources (Paper V, Paper VI and Paper VII)

In consideration of reindeer husbandry as a land use system, the seven papers highlight some of the most critical problems that need to be addressed in an attempt to maintain a functioning and sustainable reindeer husbandry system as a fundamental component in the indigenous Sami culture as well as a key to successful sustainable landscape management.

4 Methods and Materials

4.1 Methodological approaches and principles

A platform for this thesis is provided by a process initiated by the Swedish Forest Agency, the County Board of Västerbotten and SLU at the behest of reindeer herding communities to develop reindeer husbandry plans. The two overall goals of the process to develop reindeer husbandry plans were to provide reindeer herding communities with support in their day to day operational work and to provide the basis for better communication that could lead to better land use dialogue and better land use decisions. The reindeer husbandry plans are informed by multiple knowledge sources, which include local stakeholders' knowledge, historical knowledge based on historical data (Manker, 1953b; Bergström *et al.*, 1918), data about other land use systems and scientific and technical knowledge that includes work by researchers from SLU and agency experts. The knowledge sources of the Sami reindeer herders was initially provided by a number of herders interested in working with the research project as active participants. Participation included sharing of local knowledge, contributing to the development of and learning about new tools and committing to the ongoing activities connected to knowledge co-production and use (Armitage *et al.*, 2011). The ongoing process was continually supported by researchers and managers.

A number of methodological principles were adhered to the work. The approach to the project was bottom-up to effectively address the needs of the reindeer herders. This approach is also considered important to not marginalize local expertise (Rammelt, 2014). The reindeer herders participated not simply as informants, but also in setting priorities, defining the problems, formulating question and assessing the solutions. We therefor altered aspects of the project as the reindeer herders' needs became known to us. This was a process of stakeholder-driven development of the progress and the tools. In the development of reindeer husbandry plans, we as researchers and agency personnel did not decide in advance which procedures and tools to develop and use. At each decision point, a collaborative, iterative process took place that included planning, acting, observing, and reflecting. These principles reflect what is described as participatory action research (McKay & Marshall, 2001; Hall, 1975).

An important aspect of combining the stakeholder participation with the land use mapping was the development and use of a custom made pGIS (Dunn, 2007; Abbot *et al.*, 1998). Important advantages include the power of pGIS to store and display knowledge and data, the ease of updating the data over time, the provision of baseline data so that future developments can be compared, and the facility of accessing data (McConchi & McKinnon, 2002).

Throughout the working process it was necessary to bridge the specific needs, expressed by the reindeer herders, and the general societal needs, expressed by the Swedish Forest Agency as the national forest authority. In the capacity of a researcher, planner, instructor, data collector, learner, observer and reporter, I was cautious to not breach the trust given by the participants. There were a number of principles that guided the work which are established in the framework of such a research methodology (Charles & Neil, 2007). These principles include the following:

- Those reindeer herding communities that participated needed to initiate their process of participation. Reindeer herding communities were never pressured to participate.
- We co-produced methods and definitions that the reindeer herding communities used in the process.
- We co-produced the toolbox that was offered to the reindeer herding communities.
- We co-produced the questions and issues addressed in the research papers (Paper V, VI and VII).
- The materials, maps and data were and continue to be owned by each participating reindeer herding community, and are therefore not reproduced or distributed without their permission.
- The reindeer herding communities chose and continue to choose with whom they want to share their data, and they are themselves responsible for transferring the information they choose to share.
- The identities of the participants were anonymized in documents unless people gave permission.
- Specific information from field inventories and specific and detailed area descriptions as part of the delineation of important grazing lands is not shared with other land users.

- Co-authorship was initiated whenever possible with active participants of the research elements of the project (Sami reindeer herders as co-authors in Paper I, II and III as well as in Löf *et al.* (2012) and State agency personnel in Paper I, II, III, and V).
- Decisions regarding the project were made collaboratively in all instances that seemed significant to the participants.
- The progress of the project was transparent so that participants could make suggestions for changes.
- It is clearly stated that a reindeer husbandry plan is always a work in progress that needs updates as conditions and knowledge change.

For the purposes of this thesis, the activities and the outcomes in the studies that comprise the actual development of working methods and individual tools are therefore included in the section of Results and Discussion.

4.2 Summary of Methods and Material used in Paper I-VII

The objectives of Paper I was to collaboratively develop tools that can both support co-production of knowledge and land use dialogue. The collaboration was initiated by the Sami reindeer herders who needed support on how to describe and document land uses in reindeer husbandry. At the time of the first meetings, no procedure existed that allowed for description of land use needs and strategies in reindeer husbandry. Development of reindeer husbandry plans matured stepwise during numerous meetings and discussions with the initial actors consisting of Sami reindeer herders from Malå and Vilhelmina Norra reindeer herding communities, the Swedish Forest Agency, the County Board of Västerbotten and researchers from SLU. Further into the process additional reindeer herding communities contributed to the process. Consequently, the initial study area for Paper I were the two reindeer herding communities of Malå and Vilhelmina Norra (Figure 8) but the developed methods are presently at work within the entire reindeer husbandry area. Because of administrative changes the role of the County Administrative Boards was phased out and replaced by the Sami Parliament.

Through group consultation and based on earlier experiences, it was decided that detailed documentation of reindeer habitat was needed which would include information on the herds' habitat use and movements, environmental conditions and Sami reindeer herders strategies. Temporal information was also needed in the documentation, as was visualization of the data to better communicate the land use needs of reindeer husbandry. The collecting and visualization of data required adoption of innovative tools. GIS, GPS and remote sensing techniques were used to collect and incorporate local indigenous ecological knowledge and to effectively visualize data. We co-produced a pGIS with custom-made modules for screen digitizing, field data entry, data storage, analysis and visualization. Reiterative steps were taken throughout the ensuing years to strengthen the process of collecting and communicating this ecological knowledge. The process of developing methods which are part of the reindeer husbandry planning process are still continually being improved upon in close collaboration with a growing number of Sami reindeer herders.

The main objective of Paper II was to evaluate the potential and limitations of pGIS as a toolbox to support co-production of knowledge and to improve dialogue between reindeer herding communities and the forest sector. In this study we conducted qualitative, semi-structured interviews with reindeer herders, forest company and forest agency personnel. Participating interviewees were represented both from within the specific study area, the municipality of Vilhelmina (Figure 8), as well as from 12 other reindeer herding communities throughout the reindeer husbandry area. The responses from the interviews were categorized into the following themes: 1). the experience with the toolbox, 2). the use of the toolbox, 3). the effect of the toolbox upon the outcome of the consultation process. For each theme we summarized and discussed the answers and the consequences with regards to improvements of the ongoing process and to the impacts of the toolbox on the dialogue.

In Paper III we selected two Canadian and one Swedish example of community-based environmental monitoring systems used by different indigenous groups. The Swedish case involved the ongoing process regarding a proposed mining development in the municipality of Jokkmokk (Figure 8) and how the affected reindeer herding communities used our co-produced pGIS toolbox. We documented, described and analyzed the use and effectiveness of the provided toolbox partly as observers and partly as participants in the process. Through the evaluation and analysis of the utilization of the toolbox we identified needed improvements and rectified key components of the toolbox.

In Paper IV we took a participatory action research approach to investigate and remedy the low participation and apparent passiveness among members and shareholders of the Vilhelmina Upper Forest Common (Figure 8). We discussed possible methods to re-engage shareholders with the board members of the Common and decided to introduce a pGIS as a suitable approach. We organized workshops for shareholders of the Common and introduced and installed our already developed pGIS on their laptop computers. In the roles of researchers, participants and observers we evaluated the progress of participants' pGIS use and engagement. The objectives were to better understand the problems related to shareholder engagement and to study the role of the pGIS for revitalization and increased engagement of the shareholders.

In Paper V, VI and VII we take a different research approach. During numerous meetings with reindeer herding communities we identified the need for accurate information about the status, trend and present distribution of ground lichen. In Paper V we addressed this issue by compiling and analysing specific data from the Swedish National Forest Inventory (NFI) from 1953 to 2013 (Fridman *et al.*, 2014). The analysis was based on the defined variable definitions from Swedish NFI protocol and covered the entire reindeer husbandry area (Figure 8). We produced figures and maps presenting the changes in distribution of ground lichen over a 60 year time sequence. Furthermore, we produced information about relationships between forest stand conditions and ground lichen cover.

In Paper VI, another form of support information was needed for reindeer herding communities' dialogue with the forest sector, which was the future outlook for ground lichen. In order to investigate implications of various forestry management practices on ground lichen conditions we used the forest decision support system Heureka's PlanWise application (Wikström *et al.*, 2011) to simulate three different scenarios: Business As Usual (BAU), forestry adjusted for reindeer husbandry (ADJ) and net present value. We analysed the resulting 100-year scenarios with respect to their estimated suitability for providing reindeer pasture areas. We produced figures and maps illustrating the consequences of the scenarios on ground lichen conditions in the local study areas on the forest company Holmen Skog AB's land within Vilhelmina Norra reindeer herding community's winter grazing lands (Figure 8).

Mapping of the distribution of ground lichen was repeatedly indicated as important by reindeer herding communities. In Paper VII we used lichen information collected in the Swedish NFI (Fridman *et al.*, 2014) as training data to classify optical satellite images into ground lichen cover classes and ground lichen distribution maps. The study site consisted of the common area covered by two contiguous Satellite Pour l'Observation de la Terre (SPOT)-5 scenes and one Landsat-7 Enhanced ThematicMapper Plus (ETMþ) scene within Vilelmina Norra reindeer herding communities winter grazing lands (Figure 8). We tested three classification methods: Mahalanobis distance (Mahalanobis, 1936), maximum likelihood (Strahler, 1980; Goodenough & Shlien, 1974) and spectral mixture analysis (Radeloff *et al.*, 1999).

Furthermore, we applied a post-classification calibration method using a membership probability threshold in order to match the NFI-measured proportions of lichen coverage classes (Hagner & Reese, 2007). Finally we carried out an accuracy assessment using our independently collected field dataset to produce a confusion matrix.

Figure 8. The comprehensive study area encompassing the entire Sami reindeer husbandry area in Sweden and the locations of the study areas of the seven papers. Paper I, the reindeer herding communities of Malå and Vilhelmina Norra (black); Paper II, Vilhelmina municipality and Model Forest (pink); Paper III, the proposed mining area, Kallak near Jokkmokk (red); Paper IV, the Vilhelmina Upper Forest Common (red); Paper V, the entire reindeer husbandry area (purple); Paper VI, the Holmen Skog AB inholdings (green) and Paper VII, part of the extent of two contiguous SPOT images (yellow). Data and mapping from RenGIS.

5 Results and Discussion

This section is organized according to the three overall objectives addressed in this thesis. Under the first objective – describe the process of developing a toolbox – the procedures and outcomes of the overall process of co-producing methods and tools are presented under sub-sections. Objective two – use and evaluate the toolbox – is first addressed through separate summaries of Paper II, III and IV, and then followed by a section discussing the combined lessons learned from those papers. Under objective three – documenting past and present status, developing future scenarios and mapping of the distribution key resources – result and discussion are integrated and combined for Paper V, VI and VII.

5.1 Objective I: Describe the process of developing a toolbox that will support co-production of knowledge and improve land use dialogue

In this section I present and discuss the methods applied as part of process to develop reindeer husbandry plans and the role of pGIS. Because the process of developing reindeer husbandry plans has continued to be updated since the publication of Paper I, activities through December, 2014 are included in this section. This includes descriptions of activities that were important to the evaluations and tests of the tools later described under Objective II, such as using of GPS on reindeer (Paper II and III), compiling data on other land use activities (Paper III), and introducing a 2013 version of the pGIS toolbox (Paper IV).

The work summarized under Objective I are the results of an extensive cooperative effort initiated in 2000 involving reindeer herders from all 51 reindeer herding communities, personnel from Swedish Forest Agency, our pGIS programmer, personnel from the Sami Parliament and the County Administrative Board of Västerbotten, as well as representatives from the forest companies Sveaskog, Swedish Property Board, Holmen Skog AB and SCA Skog AB.

5.1.1 Defining common terminologies for grazing lands

Because of the reindeer's extensive yearly movements, a system had to be developed to divide and delineate the grazing lands both spatially and temporally (Paper I). Partly based on earlier experience and work in the reindeer herding communities of Vilhelmina North in 1983 (Sikku & Nilsson, 1995) and Baste in 1990 (Hemberg, 2001) as well as land use accounting in reindeer husbandry (Sametinget, 2014), we defined five categories of grazing lands (Näsholm *et al.*, 2012a; Table 1). In the Sami tradition, the reindeer grazing year is divided into eight seasons (Manker, 1953a; Paper I), so we used this system of seasonal categorization in our work (Näsholm *et al.*, 2012a; Table 2; Paper I). These categories and definitions for grazing lands have been consistently used since 2000.

Table 1. Defined categories for the delineation of grazing land (Näsholm et al., 2012a; Paper I).

Type of grazing land	**Definition**
General seasonal grazing area (in Swedish betestrakt)	The overall area used by a winter group during one season.
Core area (in Swedish kärnområde)	Core areas represent regularly used areas which provide pastures for reindeer grazing and rest within the general seasonal grazing area. Core areas include calving and rutting areas and areas sensitive to encroachment from other land uses. Consultation with other land users is needed in land management.
Key area (in Swedish nyckelområde)	Key areas are necessities to maintain reindeer husbandry. Key areas are islands within core areas to which the reindeer naturally move. Key areas are extremely sensitive to disturbances. Consultation with other land users is critical.
Low use area (in Swedish lågutnyttjat område)	Areas that could have good grazing status but for some reason is used less frequently because of other ongoing land use activities.
Area needing specific actions (in Swedish åtgärdsområde)	Other land uses have affected the grazing potential negatively to a substantial extent. The area description usually proposes action for restauration.

Table 2. The eight seasons of the reindeer year (Näsholm et al., 2012a; Paper I).

Season	Activity (general description)	Approximate months
Spring-winter	End of winter gatherings until movement to calving lands	March-May
Spring	Arrival at calving lands until calving	April-May
Pre-summer	Calving until the first marking of the calves	May-June
Summer	First to last marking of the calves	June-July
Late summer	Last marking of the calves until fall slaughter	July-September
Fall	Butchering of young males until fall separation of herds	September-November
Pre-winter	The end of the rutting until lichen grazing season begins	October-January
Winter	Lichen grazing season until end of winter gatherings	November-April

5.1.2 Satellite image interpretation

Categorization, identification and delineation of reindeer's seasonal and spatial habitat use and the associated reindeer herding strategies were a central part of the documentation process (Jougda et al., 2011b; Paper I). The purpose of the mapping based on categorization, identification and delineation was to attain both overview and detailed information about existing grazing resources. Emphasis was placed on key grazing areas. Mapping was conducted by the reindeer herder with the most local knowledge for each particular area and for each particular season.

As background for the mappings, we needed a source of information where variations in vegetation were detectable. Because no appropriate, accurate and updated vegetation maps existed for the reindeer husbandry area in Sweden, the best option was to use unprocessed satellite data. Interpretation of satellite images for the purposes of mapping has been used previously with mixed results (Maynard *et al.*, 2011; Maynard *et al.*, 2005). For our first meetings with the reindeer herding communities in 2000, we brought printouts of two unclassified SPOT images. The images were color enhanced using the band combination near infrared/mid infrared/red (SPOT bands 3, 4, 2). Satellite image interpretation proved highly successful due to reindeer herder's detailed knowledge about the grazing lands. The reindeer herders could easily interpret the colors in the satellite image and link them to cover types and grazing value (Figure 9). Using colored pens, the reindeer herders delineated pine forests with ground lichen based on the distinct colors in the raw satellite image.

Because recognition and consistency is important in satellite image interpretation, we subsequently always used either the described band combination in SPOT or the 4, 5, 3 band combination when using Landsat data (Maynard *et al.*, 2005).

As part of the satellite database and cooperative agreement termed Swedish SACCESS (Lantmäteriet, 2014) we have added full coverage satellite image mosaics that cover the entire reindeer husbandry area into our pGIS each year since 2007. The use of the latest satellite data for updated landscape information has become standard for the reindeer herding communities.

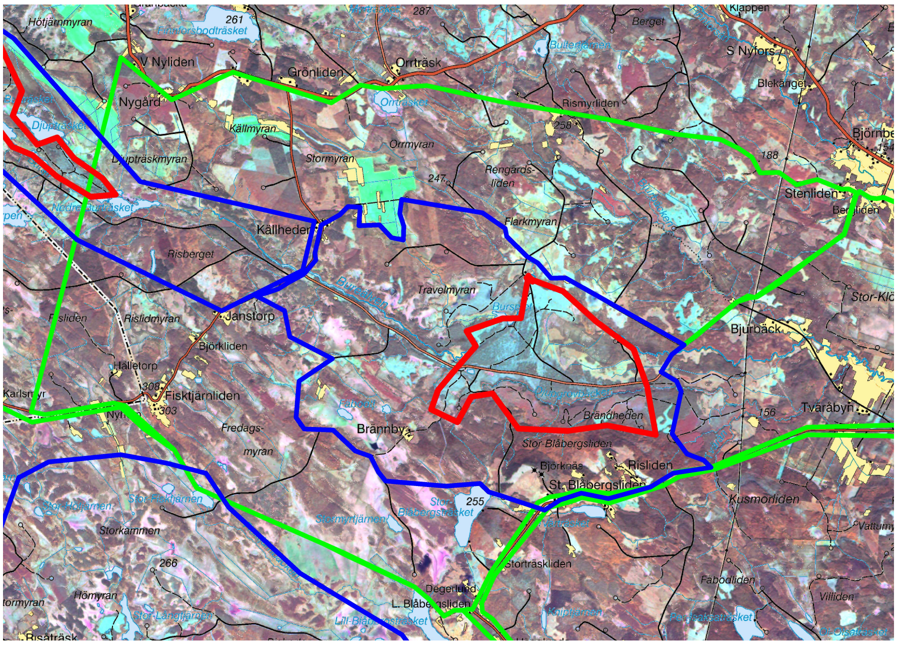

Figure 9. The Sami reindeer herders identified and digitized different categories of grazing lands using satellite images as background as illustrated with key areas (red) and core areas (blue). Forests with mat-forming ground lichen *(Cladina* or *Cladonia sp.*) are clearly visible in the satellite image as bluish areas while recent clearcuts are light blue. Other land uses then forestry visible in the image include agricultural lands (yellow), peat cuttings (green) and paved roads (orange). Data and mapping from RenGIS.

5.1.3 Development of a custom-made GIS – RenGIS

At the beginning of the process, the Sami reindeer herders used color pens to delineate grazing lands, and personnel at the County Administrative Board of Västerbotten interpreted and digitized their drawings. This work method was soon rejected due to difficulties for an outsider to interpret and digitize the reindeer herder's drawings. Instead, we realized that the Sami reindeer herders needed to digitize and describe their grazing lands themselves. This led us to develop the first version of our custom made GIS which we named RenGIS (in English; ReindeerGIS). RenGIS version 1.0 was originally developed in the standard commercial ArcView 3.0 GIS environment (ESRI, 2001). As the number of reindeer herding communities began their work to develop reindeer husbandry plans, the need for more specific custom made tools increased. Also, the license cost for using a commercial GIS platform increases as the number of users increase. As a consequence, the more successful we are at engaging users to use the toolbox, the higher to costs for licences. To remedy this, in 2008 we converted the pGIS system to the programming environment of TatukGIS, resulting in the development of RenGIS version 2.0 which is currently in use (TatikGIS, 2014). Now we could produce a system with no license cost per user. This is the platform of pGIS that has been tested and evaluated in Paper II, III, and IV.

At the end of 2014, the toolbox RenGIS has numerous functions, purposes and roles (Sandström *et al.*, 2012e; Sandström *et al.*, 2012d; Sandström *et al.*, 2012c; Näsholm *et al.*, 2012b; Sandström *et al.*, 2012b; Sandström *et al.*, 2012a; Sjöström *et al.*, 2012; Näsholm *et al.*, 2011b; Sandström *et al.*, 2011). RenGIS is the digitizing tool where delineation of important grazing lands is carried out through on-screen digitizing with a satellite image as background. RenGIS has also developed into a large data storage and display tool that contains a series of satellite image mosaics and topographic maps that cover the entire reindeer husbandry area. Additionally, RenGIS contain the most thorough and complete compilation of other land user's foot prints, including hydropower dams, present and prospected mines, wind power parks, forestry and other infrastructure (see section 5.1.6.). Also incorporated is available information about nature protection areas, cultural sites and legal boundaries. Finally, RenGIS comprises all publicly available data about reindeer husbandry (Sametinget, 2014) as well as numerous sources of historical data about reindeer husbandry (SOU, 2006; Manker, 1953a; Bergström *et al.*, 1918). Because internet is not readily available where the Sami reindeer herders work with RenGIS, we chose to install all programs and data on each personal laptop computer so that all GIS work could be carried out independent of internet access. Consequently, we developed specific modules for back-ups and replications of data between computers (Näsholm *et al.*, 2012b).

Furthermore, RenGIS includes numerous tools for analysis and visualization (Sandström *et al.*, 2012d; Näsholm *et al.*, 2012b; Sandström *et al.*, 2012b). Each component was built in response to identified needs during the continuous cooperation and communication between the research team and the reindeer herding communities (Löf *et al.*, 2012; Sandström & Wedin, 2010;

Paper II and III). These communication events occurred either as part of the different consultation procedures or as part of trainings and everyday use of RenGIS. The short distance between the end user of the product, the reindeer herder and the researchers and programmer has been essential for developing relevant and user-friendly products. The researcher and the programmer's presence during consultations and trainings has been important for the development of user-friendly, customized and understandable solutions.

Financed through grants from the development of hydropower, the reindeer herding communities now own and operate more than 150 computers with RenGIS and the accompanying installed data. The RenGIS system is continually updated with new information about important grazing lands and new field inventories produced by the reindeer herders. Additionally RenGIS is continually updated with new databases information about other land uses, the latest satellite image mosaics and new modules developed by the researchers and programmer as proposed by reindeer herders.

5.1.4 Delineation of important seasonal grazing lands

The delineation and description of important seasonal grazing lands was carried out by the Sami reindeer herder with most knowledge of the local area. With a satellite image as background, general areas were identified and a preliminary map produced (Paper I). The specific delineation was then discussed and readjusted in consultations with the local expert for each local siida (winter group). The specific working strategy varied by reindeer herding community, but most commonly, one or two reindeer herders hold the GIS skills and they gather the local experts from each siida and digitize the local knowledge. By using this system, each local area was mapped for each season by each local expert. Mappings for each local area were subsequently merged to cover the grazing lands for each season and seasonal lands were merged to cover the entire reindeer herding community (Figure 10). Data from the field inventories, which are described in section 5.1.5., were also entered into RenGIS.

The delineation of important grazing lands with associated field inventories has grown from a modest pilot project in two reindeer herding communities (Paper I; Figure 8) to cover the entire lands of 50 out of 51 reindeer herding communities representing an area of 225 000 km^2 and spanning more than half of Sweden's land area (Figure 11). A total of 5068 key areas have been delineated and the described, with the large majority in forests (Figure 11).

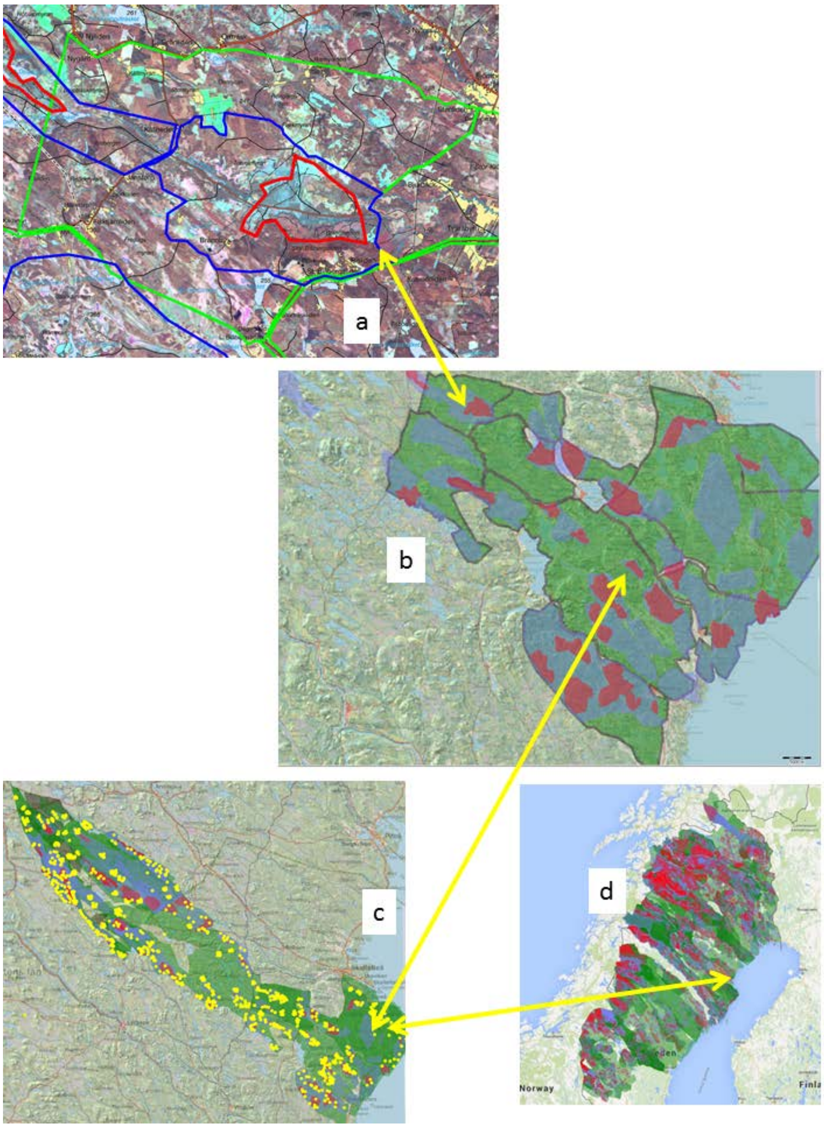

Figure 10. General description of the process of delineating grazing lands. a. First the general grazing area is digitized (green boundary) usually including the lands used by one winter group. Than the core areas (blue) and the key areas (red) are digitized by the Sami reindeer herder with the most knowledge of each local area. b. The digitized areas for all winter groups (gray boundaries) for the entire seasonal land are merged, in this example the winter lands. c. The digitized seasonal lands are merged to cover the entire reindeer herding community. Key and core areas are field inventoried (yellow dots) and field data is entered into RenGIS. d. Finally, all reindeer herding communities are merged to cover the entire reindeer husbandry area. Data and mapping from RenGIS.

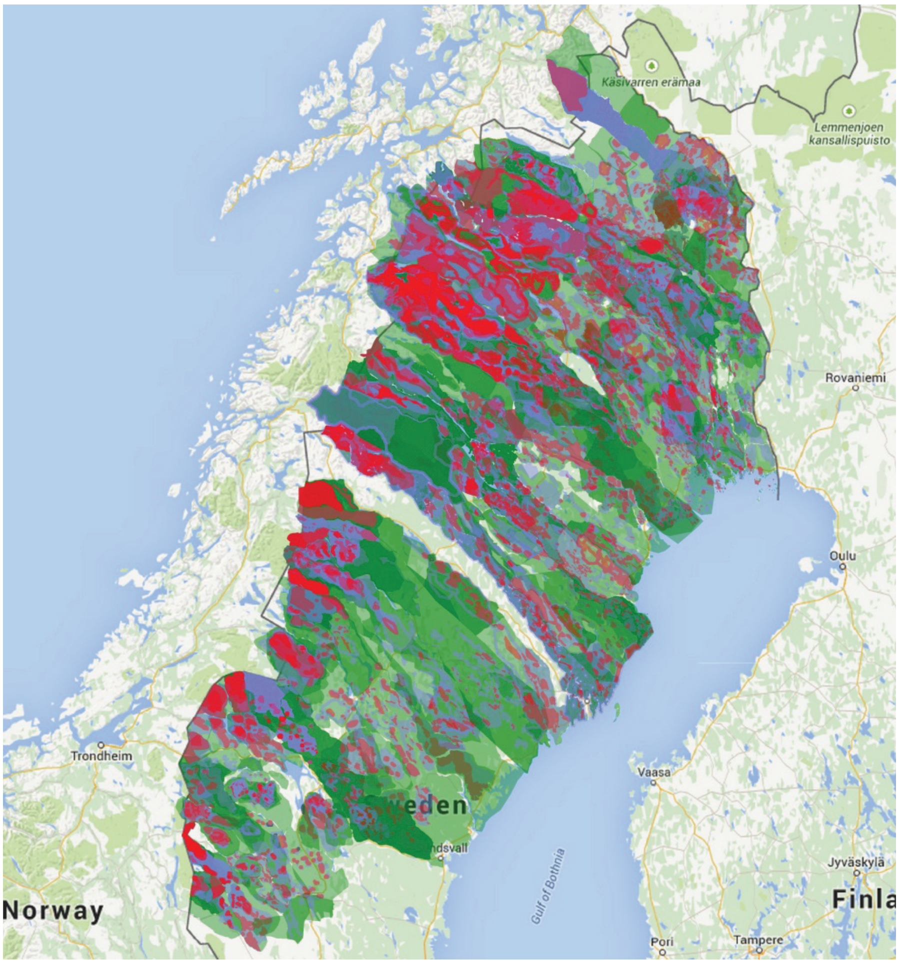

Figure 11. The division of grazing lands for 50 out of the 51 reindeer herding communities in Sweden as reported in December, 2014. In total there are 5 068 key areas (red), 2 551 core areas (blue) and 745 general grazing areas (green). Categories of grazing land are defined in Table 1. Data and mapping from RenGIS.

5.1.5 Develop and carry out field inventories

We developed a vegetation classification system for reindeer grazing types, adjusted according to reindeer herders' recommendations and to the protocol of the Swedish National Forest Inventory (NFI; Fridman *et al.*, 2014) with respect to variables and inventory methods. As part of the field protocol, we assessed reindeer grazing type, estimated ground and arboreal lichen cover, documented past and present forestry activities, and evaluated grazing pressure (Sandström *et al.*, 2011; Paper I). Each field plot was positioned with GPS, permanently marked, and photographed. The aim of the field inventories was to visit all identified key areas on the pre-winter and winter grazing lands in forest habitats (Sandström *et al.*, 2011). In a later stage we also developed field methods and protocols for mires and areas above the tree line (Hedenås, 2014). Using printouts of satellite images as field maps during the inventory, the reindeer herders gained experience in field-validated satellite interpretation and also more in-depth, site-specific knowledge.

In total, 8 797 field plots were inventoried, producing 18 026 field photographs with the majority located in identified and digitized pre-winter and winter key areas. To develop and validate a field inventory method which combine the scientifically established field inventory scheme used in the Swedish NFI (Fridman *et al.*, 2014) with local stakeholder land and land use knowledge, is an example of practical implementation and testing of the concept of adaptive monitoring (cf. Lindenmayer & Likens, 2009).

5.1.6 Compilation of other land use activities

In 2001 we identified the need to include data about other land uses in RenGIS. Together with reindeer herders we identified and categorized other land use systems (Figure 11) and the County Administration Board of Västerbotten was given the task to compile the data (Paper I). However, this task could not be prioritized by the County Administration Board. In 2010 we received funds from the Sami Parliament to complete the compilation.

The land use compilation in RenGIS now represents the most complete database available of land use activities, compiled from data provided by state agencies for their respective geographic areas of responsibility (Figure 11). Contributors of data include the Swedish Forest Agency, all large forest companies, the Swedish Mining Inspectorate, the Swedish Energy Agency, the Swedish Meteorological and Hydrological Institute, the Swedish Board of Agriculture, the County Boards of Administration, the Swedish Land Survey, the Swedish National Heritage Board and the Sami Parliament. Having this data available in RenGIS allows analyses of land use issues and activities considering cumulative impacts and has played a major role in numerous land use dialogues such as described in Paper III.

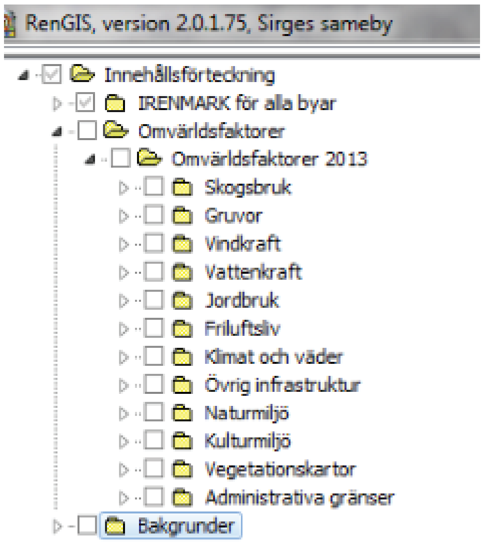

Figure 12. Data of other land use activities are included in RenGIS. The land use categories include forestry, mining, wind power, hydropower, agriculture, recreation, other infrastructure, protected areas, cultural areas, vegetation maps, administrative boundaries as well as background maps and satellite images and the general reindeer husbandry database. Such information is necessary to provide the user with the complete and cumulative information for each particular area and situation.

5.1.7 Realtime GPS on reindeer

The work using realtime GPS technique originates from a project working with Vilhelmina Norra reindeer herding community and commercial hardware developers with a goal to provide operational support for reindeer herders in tracking the movements of their reindeer in realtime (Sandström & Wedin, 2010). Initially using Vectronics GPS collars (Vectronics, 2014), we then developed the first generation of custom made and less expensive realtime reindeer GPS collars (Followit, 2014). This effort resulted in Vilhelmina Norra being the first reindeer herding community to use and manage their own GPS collars. The general technical solutions for realtime GPS existed and had been in use for moose research in Sweden (Dettki *et al.*, 2004). But, the introduction of this technique into reindeer husbandry was the first example of a fully participating end user taking advantage of the realtime GPS positions in their day to day work. Work with GPS collars on reindeer had previously followed the more traditional way of working where researchers equipped reindeer with collars and the reindeer's positions were delivered to the researcher for analysis when collars were retrieved (Skarin *et al.*, 2008; Skarin, 2006).

The realtime GPS collar consists of a GPS unit that positions the animal according to a user defined schedule. The collar has a communication unit like a cell phone that transfers the positions via the cellular network. Positions are transferred to a web server which displays the reindeer's location in web-based maps (Figure 12).

Throughout our work to compile different sources of data, equipping reindeer with realtime GPS-collars has provided us with valuable and important information to support the process of reindeer husbandry planning. The introduction and use of realtime GPS collars on reindeer has supported the overall goals with the development of reindeer husbandry plans (Paper II). The first overall goal – the development of tools that support operational reindeer husbandry (Paper I) – was strengthened through the hourly realtime updates of GPS positions (Paper II). Obtaining updated information with individual reindeer's positions and with overviews of the location of the herds on the reindeer herder's cellphone or laptop computer helps the herders' plan their everyday work. For example, in times of reindeer gatherings for calf-markings, for slaughter and for upcoming seasonal movements, hourly updates from GPS equipped reindeer have contributed important support and allowed herders to cut back on the use of snow mobiles, ATVs and helicopters time. Adoption of the technology has also resulted in reduced stress on the reindeer and improved working conditions for the reindeer herders. The second overall goal of the reindeer husbandry plans – the development of tools that support and improve the dialogue with other land users (Paper I) – has also benefitted from the GPS technique by providing compelling and understandable information about reindeer's habitat use and movements (Paper II). The visual demonstration of reindeer's movement and habitat use for different seasons and during varied environmental conditions is an example of important pedagogic support to the land use dialogue (Löf, 2013; Sandström *et al.*, 2012b; Löf *et al.*, 2012; Paper II).

GPS positions from collared reindeer have been instrumental in the refinement and strengthening of the delineation of important grazing lands. Figure 13 illustrates similarities from overlaying GPS equipped reindeer's individual winter home ranges from eight winter grazing seasons with reindeer herder's delineated winter key areas. Individual home ranges were calculated using the Browninan bridge method (Skarin *et al.*, 2013; Horne & Garton, 2006) an advanced statistical module which is incorporated into RenGIS and is in use by Sami reindeer herders (Sandström *et al.*, 2012b). This is an example of the kinds of specialized analysis and visualization tools that are continually developed and added into RenGIS.

As of December, 2014, there are a minimum of 25 reindeer herding communities that use and manage their realtime GPS-collars. Over time the collars have been in use by thousands of reindeer. Originally the reindeer herders saw the new GPS technique primarily as important support in everyday operation and planning. However, GPS data has also provided a historical archive of reindeer's habitat use and movements which can be used to show relationships with other land use activities and environmental and climate variations, and consequent varied grazing conditions (Löf *et al.*, 2012). Figure 14 illustrates major variation in reindeer habitat use during two winter seasons with varied snow conditions.

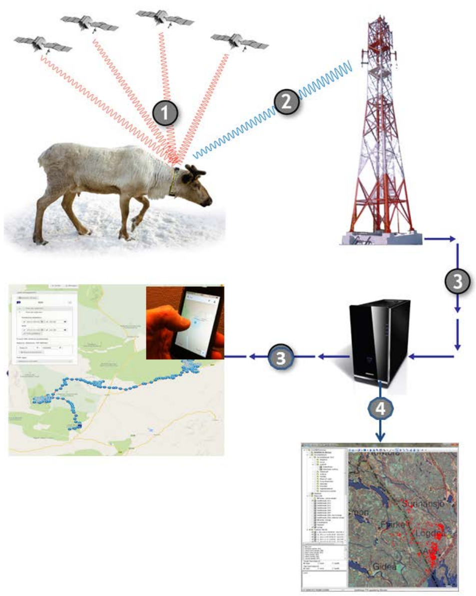

Figure 12 Reindeer are equipped with GPS collars that can provide hourly updates of movement in realtime. The system is supported through four inter-linked processes: 1. Reindeer are positioned with GPS and positions are stored in the collar. 2. Positions are sent as a text message via the cellular network. 3. Positions are displayed in real-time on web-based maps. 4. Positions are imported into RenGIS for analysis and visualization. Adopted from Sandström and Wedin (2010; Paper II).

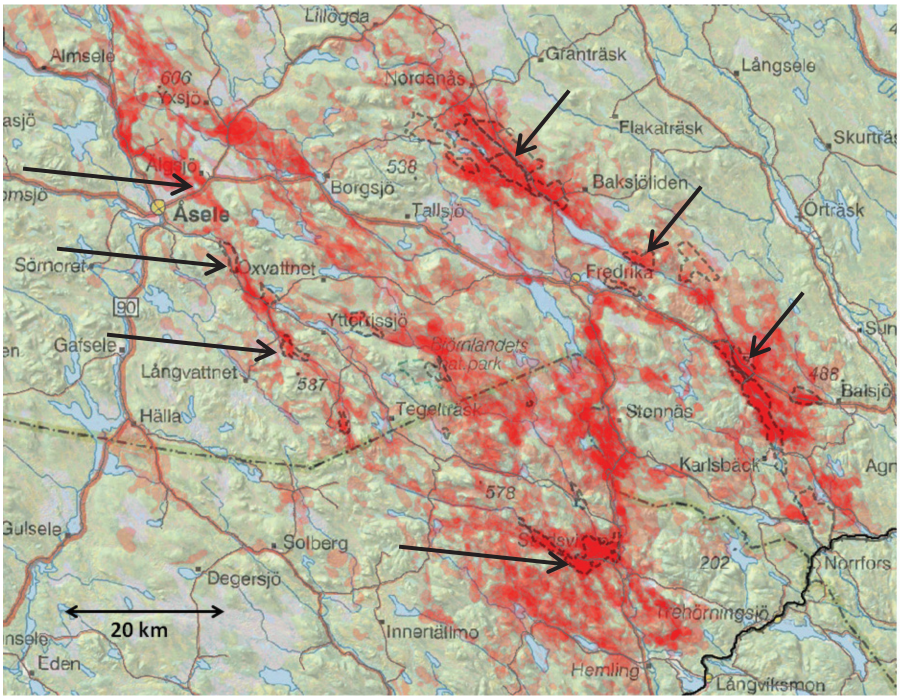

Figure 13. GPS data from eight winters representing actual reindeer use based on Brownian Bridge home range calculations (red; Horne & Garton, 2006). The more intense red colour indicates more overlapping home ranges as a result of higher reindeer use. Light red areas indicate the movement areas between the grazing patches that the reindeer use. Arrows point at black dashed lines showing Sami reindeer herders identified and digitized key areas. Prepared by Marita Stinnerbom using tools in RenGIS (Sandström *et al.*, 2012b; Löf *et al.*, 2012).

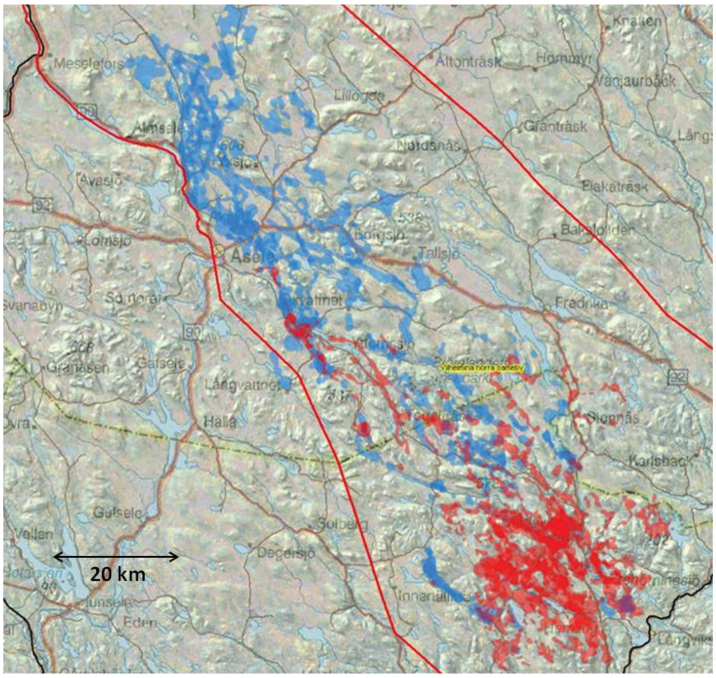

Figure 14. Individual reindeer's home ranges calculated using the Brownian bridge methods (Horne & Garton, 2006) for two winter seasons with varied snow conditions and consequent varied habitat use. Blue home ranges represents a winter season with good snow conditions and red home ranges represent a winter season with poor snow conditions as identified by Sami reindeer herders in Vilhelmina North reindeer herding community from Löf *et al.* (2012).

5.1.8 Co-production of knowledge and skills

As of December, 2014, more than 350 Sami reindeer herders from all 51 reindeer herding communities in Sweden have participated in trainings in GIS, field inventory techniques, GPS, and satellite image interpretation.

Trainings for involved reindeer herding communities were necessary for each operational component of the project. These trainings focused less on experts teaching of each operation and more on peers teaching peers. For example, the trainers did not deliver and instruct using tested and completed components, but instead trainings consisted of continually testing and developing prototypes. All involved participants evaluated and improved the processes together over time. Mutual learning and mutual development of the process has guided the project's efforts concerning improvements of pGIS, satellite image interpretation, database management and elements of field inventories. In fact, most of the ideas regarding improvements of existing modules and the invention of new modules originate from these learning opportunities. The presence of Sami reindeer herders, researchers and the pGIS programmer during all of the trainings have ensured the tight connection between identified needs and production of new modules into pGIS.

5.2 Objective II: Use and evaluate the toolbox that is intended to support co-production of knowledge and improve land use dialogue

Above was a description of how we developed the tools to support co-production of knowledge and enhanced dialogue among stakeholders. In the coming section I will summarize Paper II, III and IV which evaluate the applications and role of the pGIS in three different settings.

5.2.1 Summary of Paper II – the role of pGIS to support dialogue between reindeer husbandry and the forest sector

Paper II is a study of the reindeer husbandry planning process and its role in consultations with the forest sector. The study uses qualitative, semi-structured interviews with members of reindeer herding communities, personnel from forest companies and from the Swedish Forest Agency to evaluate the role of pGIS. The focus of the interviews was on the participants' experiences with the plans, the ways the plans had been used, and the ways the plans had affected the outcome of consultations with the forest sector required in the Swedish Forest Act and Swedish FSC (Johansson, 2013).

The overall results show that use of advanced techniques and tools such as pGIS, realtime GPS on reindeer and satellite imagery by non-experts have worked well. The keys to these promising results were twofold: that the training sessions were repeated and continuous, and that the tools were custom designed for its specific purpose and the specific user. Results from the interviews indicated that the tools provided a suitable platform for sharing and co-production of knowledge as well as collaborative learning among reindeer herders, researchers and state agency personnel. The integration of indigenous knowledge in forms of mapping of important grazing lands was identified as the most important contributor to the planning process.

The results from the analysis of the interviews indicated that pGIS supported planning and mitigated conflicts by providing the users with a clear, long-term perspective. The system was suited for land use planning to focus on local key areas, but also encouraged and indicated solutions for a larger landscape. The process of spatial communication, using maps between the two sectors contributed to a more open and transparent planning process. Within the reindeer herding community, participants perceived that the process led to more inclusive planning as it spread the knowledge wider to better include women and youth. Furthermore, those reindeer herders who were considered to hold most of the knowledge at the initiation of the process claimed to have increased that knowledge due to cooperating with the others.

Results concerning the consultation process showed that the reindeer husbandry plans improved the reindeer herding communities' preparations for consultations. The plans also contributed to a more knowledge-based dialogue between forestry and reindeer husbandry. The use of pGIS improved the understanding of how the two sectors affect each other, and provided the prerequisites to integrate new knowledge and tools for communication. Despite the improved communication and knowledge production, a majority of the respondents from all three groups – reindeer herders, state agency and forest sector personnel – claim that the outcome of the consultation has not yet led to any modifications in power relations. One reason for this is that much of the focus so far has been on collecting and compiling knowledge and much less on the use of pGIS for improved communication. We recognize this problem and intend to improve use and communication of the different data sources during upcoming training sessions.

Another conclusion we drew from this study is that many components of the toolbox and the process would likely work well in other settings. Knowledge-sharing, capacity-building and networking can be achieved under the common umbrella of a pGIS among partners and applied in other sessions. This conclusion was continually supported by the success in introducing and developing reindeer husbandry plans throughout extensive areas of northern Sweden.

5.2.2 Summary of Paper III – the role of pGIS during the application for mining development

Paper III describes three specific examples and evaluations of how indigenous groups use community-based environmental monitoring systems to address proposed industrial developments imposing on their traditional land uses. In the Swedish example we described, evaluated and analysed how our co-produced pGIS were used by reindeer herding communities in their replies to address proposed mining developments. This represents an example of how reindeer husbandry plans and pGIS are used by the reindeer herding communities outside its originally intended arena of consultations between reindeer husbandry and forestry.

The study describes, evaluates and analyses how the reindeer herding communities used pGIS as the platform to describe the specific impacts of the mine, including an analysis of the effects of the developments' associated infrastructure on reindeer husbandry in the area. For example, the reindeer herding communities used pGIS to address and illustrate the effects of the different alternatives for transportation of the ore away from the mining site. They also used the database describing other land use activities (Paper I; section 5.1.6.; Sandström *et al.*, 2012a) in pGIS to illustrate the compounding effects from historical hydropower developments directly adjacent to the proposed mining site. Earlier hydropower developments had made historic reindeer migration routes on lakes and along riverbeds unusable because of unstable ice conditions. Such information was possible to describe and communicate using pGIS and demonstrated the increased importance of reindeer migration routes across the proposed mining area. Using pGIS, the reindeer herding communities illustrated that a developed mine with its associated infrastructure, combined with the cumulative impacts from earlier developments would make it impossible to carry out reindeer husbandry the way it is done today. According to the pGIS analysis, the proposed development with associated transportation networks would directly affect an area > 2000 km^2 covering the five reindeer herding communities of Jåhkågaska Tjiellde., Sirges, Slakka Skogsameby, and Unna Tjerusj.

5.2.3 Summary of Paper IV – the role of pGIS to revitalize engagement in a forest common

In Paper IV we introduced pGIS and organized workshops for shareholders in the Vilhelmina Upper Forest Common in an attempt to revitalize the common and increase shareholder's engagement. Paper IV represents yet another evaluation of pGIS as a tool for increased participation and dissemination of knowledge. In Paper IV, however, pGIS is applied in a fundamentally different way than in Paper II and Paper III where we evaluated the use of pGIS among the users who were part of the co-production of the tool. The shareholders in Paper IV represent new and different users of an already produced and not custom-made pGIS. Another way that the effort in paper IV differed was how the need for pGIS was identified. Where the use of pGIS as the solution was driven by Sami reindeer herder's needs in Paper II and III, the shareholders had not identified pGIS as the toolbox for improving the internal communication and dialogue between the board and the members/shareholders in Paper IV. Rather, it was through surveys and interviews our research group identified the low levels of participation and engagement in Vilhelmina Upper Forest Common (Poudyal et al., 2013) and because other research has shown that active and dynamic participation of members is necessary for successful forest commons (Agrawal & Chhatre, 2006), we tried to engage shareholders by making knowledge and data more available by introducing the toolbox pGIS.

We compiled data specific to the area in and around the forest common into pGIS and installed pGIS on the computers of participants that wanted to be part of the process. We then arranged workshops in how to use pGIS, but few participated. At the beginning some members resisted using pGIS, claiming that use of GIS was too difficult for "non-experts". They further claimed to not need a GIS on their own computers because "they already had a GIS," with reference to the professional forester who managed the common's own GIS. Their trust in their own expert was so great that they did not feel they needed their own GIS. As the project progressed, participants became more willing to try the tool, to share their data, to learn from the data, and learn from each other. Although not explicitly measured in the study, the activity level and interest the board appeared to increase as a result of the process, as did the involvement of the shareholders. But the level of engagement and participation was low compared with that of reindeer herding communities who spent comparable amounts of time to learn and use pGIS. We attributed much of this to the importance of co-producing and custom making the toolbox and the importance of having a clearly identified need and use for the toolbox.

5.2.4 Lessons Learned and Activities Developed as a result of Paper II, III, and IV

The process is more than the tool

Paper II and paper III represent the evaluations of the roles the toolbox, pGIS played in different situations and its effect on land use dialogues. Paper II evaluates the overall experiences with using reindeer husbandry plans and pGIS in the case of reindeer husbandry and forestry, while paper III describes the role of pGIS in a specific case comprising reindeer husbandry and a proposed mining development. Both these studies reflect scenarios where the groups using pGIS and reindeer husbandry plans were involved in the development of the toolbox. In contrast, the introduction of pGIS in Vilhelmina Upper Forest Common (Paper IV) represents efforts where we introduced a tool that was not specifically developed in cooperation with the end user. The understanding of the tool, the trust in the process and the understanding of the data is different when a tool is delivered as a ready-made product rather than a tool that has been co-produced. Using an already developed tool has the advantage of saving time, however. Our experiences as described in these three Papers elevate the differences between a process of tool application in Paper IV, and the process of tool co-production as in Paper II and III. Our studies indicated that the processes of engagement were markedly different when the community of users did initiate the process, did identify the specific problems, and did request help. A conclusion that can be drawn from this is to not assume that the tool by itself will produce the effects of co-production of knowledge and improved dialogue. The process is more than the tool.

A co-produced toolbox will be used and understood

Our pGIS – RenGIS – was initially created for the purpose of providing better information and communication possibilities for the Sami reindeer herders in their consultations with forestry. Paper III describes and evaluates a different use of the toolbox, where the reindeer herders use the tool in relation to a different land use type than forestry. RenGIS improved the understanding of how mining and reindeer husbandry affect each other, it provided a platform for effective communication of how reindeer husbandry operates, it improved communication and understandings of the cumulative effects on the landscape, and it effectively integrated indigenous ecological knowledge with science.

This action could be taken because of the initial co-production of the tool that allowed the Sami reindeer herders to be familiar with the affordances of the tool. This case is not unique. The list is long of uses of RenGIS and reindeer husbandry plans in other dialogues and processes. Not only has RenGIS been used in relation to other land use activities, the development of new modules in RenGIS has also expanded, partly inspired by the work of reindeer herding communities work in Paper III. The reindeer herding communities' work serves as a good example of the combined use of the database of other land use activities and added, new modules to the RenGIS toolbox (Sandström *et al.*, 2012e; Sandström *et al.*, 2012d; Sandström *et al.*, 2012c). Such tools were needed to further incorporate indigenous ecological knowledge into decision making documents.

A specific example of the toolbox being used and understood in real life land use dialogue is that on October 1, 2014, the County Board of Administration of Norrbotten issued a statement addressed to the Swedish mining inspectorate suggesting that the mining application for Kallak should not be approved. The statement specified that the proposed plan would cause "irrevocable changes" to other land users (Länsstyrelsen, 2014). Information from RenGIS, statements from scientists and Paper III are factors considered to have played a major role in the legal process leading to the statements made.

5.3 Objective III: Document past and present status, develop future scenarios and map the distribution of key resources

During the meetings and trainings which are part of the overall process to develop and use data collection and planning tools, the project group identified knowledge gaps which needed to be filled to further improve the dialogue during consultations with the forest sector. This part of the thesis describes specific studies designed to collect and update knowledge to further support and to complement future consultations between reindeer husbandry and forestry. While much of the work with reindeer husbandry plans is built around knowledge that comes from within the project group of Sami reindeer herders, this knowledge can be verified and supplemented by more conventional research methods, data collection and analysis. One such example of "everyday knowledge" that we found needed further studies concerned the abundance of ground lichen for winter grazing reindeer. According to numerous reindeer herders, this key resource in reindeer husbandry has declined. The observation is generally reported as a 50% decline (Sandström et al., 2006; SOU, 2006) but had not been thoroughly investigated.

Based on numerous meetings and learnings sessions with reindeer herding communities, we identified the following key questions related to ground lichen as a key resource:

1. What is the current status and trend regarding the ground lichen resource and what specific forest conditions are related to occurrence of ground lichen (Paper V)?

2. Considering the forest conditions today, what is the long term prognosis for ground lichen abundance on a landscape scale considering current and alternative forestry practices (Paper VI)?

3. Is it possible to generate large area maps of ground lichen distribution with high accuracy (Paper VII)?

The answers to these questions can lay the foundation for an improved future consultation process based on best available scientific knowledge. The application of these answers will be most beneficial in combination with best available knowledge about reindeer husbandry and best available knowledge of forest management. The process of co-production of knowledge and skills (Paper I) is an example of how stakeholders can work with researchers in order to identify questions of importance. It was not only a form of co-produced questions and issues, but a way for research to find answers to these questions by taking advantage of indigenous ecological knowledge combined with conventional scientific methods. To provide the needed information, Paper V and VII use scientific methods for analysis and classification using field measurement data made available in the Swedish NFI (Fridman *et al.*, 2014). In Paper V NFI data is used to assess status of ground lichen and in Paper VII NFI data is used as ground truth data for satellite image classification. Paper VI uses the advanced forest decision support system Heureka (Wikström *et al.*, 2011) to forecast the outlook for ground lichen using alternative forestry practices. As information from Paper V, VI and VII become available and utilized, future consultations between reindeer husbandry and forestry can be further improved.

Debate, conflicts and delays concerning land use management are often a result of too limited solid information. For example, forest management has focused little on maintaining and improving lichen conditions because ground lichen has not been clearly identified as a declining and limiting resource. The broad scale consequence of intensive soil scarification on ground lichen has not been fully realized because the present status and trend of ground lichen has not been entirely known. Correct information is needed that can clarify the status of forest conditions and promote wise forest management decisions. Such information can also help direct the forest management focus to where the most can be gained. For example, knowing that a high proportion, 47%, of the remaining lichen abundant forest habitat is found on the 26% of state owned forests can influence future forest management policies (Paper V). Knowing that as much as 96% of the lichen abundant areas are found in forests dominated by Scots pine (>65% pine) gives an even more precise direction to policy development (Paper V). A final example comes from paper VI where we found that continuing today's forest practices – Business As Usual (BAU) – will further diminish the lichen resource, while with relatively inexpensive adjustments in forestry (ADJ), the declining trend could be reversed. Active forestry plays an intricate role in maintaining and improving lichen conditions (Paper V and VI). These are just a few examples of how a science-informed consultation process is a necessary component of improved dialogue between land users.

Forestry and vegetation data, continuously collected by Swedish NFI (Fridman *et al.*, 2014), can help to answer, verify and analyze key questions about ground lichen. The final three studies in the thesis address the current status of ground lichen (Paper V), the future outlook for the lichen resource (Paper VI) and the possibilities of mapping this key resource (Paper VII).

Key findings from Paper V, VI and VII include the following:

- Through the Swedish NFI we have reliable data to analyze the status and the trend of lichen (paper V), and also field data for satellite image based lichen mapping (paper VII).
- From the introduction of modern forestry in 1950 until today, the lichen abundant (>50% lichen cover) forest area has declined with 71% (Paper V).
- Today 0.41 million ha of lichen abundant forests and 0.54 million ha of lichen moderate (25-50% lichen cover) forests remain in the reindeer husbandry area (Paper V).

- Of the remaining lichen-abundant areas, 96% are in Scots pine (*Pinus sylvestris)* dominated forests (Paper V).
- State forests include 26 % of the forests in the reindeer husbandry area and 47% of the remaining lichen-abundant forest areas (Paper V).
- Focused ground lichen management policies on state owned pine forests present are critical for the maintenance and improvement of the lichen resource and can serve as a model for other forest lands (Paper V).
- Lichen abundant forests were equally distributed in forests in all forest age classes in the 1950's, while in 2013 lichen abundant forest are most common in young and middle age (3-60 year old) forests (Paper V).
- In the 1950's bare forest land had a similar proportion of ground lichen as older aged forests while in 2013 only a small proportion of ground lichen occur in recently clearcut areas (Paper V).
- The forestry scenarios that reflect the continuation of current forest practices (BAU) show that the ground lichen resources will diminish further (Paper VI).
- The forest scenario that reflect the continuation of applying forestry practices adjusted for reindeer husbandry (ADJ) would increase the amount of ground lichen, while increasing the overall costs for forest management with 5% (Paper VI).
- Satellite image based classification of ground lichen resources can produce accurate results and would provide much needed support to focused, future lichen management (Paper VII).
- Mapping of the ground lichen resource together with increased knowledge of the relationship between forest conditions and the occurrence of ground lichen can provide key information in improving forest management with specific attention to the lichen resources (Paper V and VII).

6 Final remarks

6.1 The choice of approach

The true nature of our initial approach was to realize a vision of improved dialogue between the extensive land use system of reindeer husbandry and forestry. The problem was clear from the start, namely to enhance the communicative and consultative capacity of reindeer herders in land use planning. However, there was no clear way towards solutions. The Sami reindeer husbandry is the focus of this work because the reindeer herding communities itself had defined this problem and identified a need for new tools and knowledge.

From a knowledge co-production standpoint, much information was available, but had not been used or confirmed by scientific or policy methods that would be respected by those outside of their community. Our work model developed as the relationships among the participants in the process developed, and as the knowledge and interest of the key participants developed. Our group of engaged Sami reindeer herders, researchers, knowledgeable and engaged managers from the Swedish Forest Agency, and a committed pGIS programmer worked throughout many years, meeting for the purpose of trainings. These meetings resulted in new directions for our work and learning for all involved. Such developments reflect the principles of participatory action research (Reason & Bradbury, 2001; Hiebert & Swan, 1999; Hall, 1975). The work continued and improved over 14 years. There were and continue to be recurrent real life problems and real life needs from which a researcher can constantly learn from and contribute to.

6.2 The power and value of mapping in a pGIS

Key findings in this thesis demonstrate that a functional first step towards creating a strategic and operational base for land use planning is to compile, map and communicate available land use data in cooperation with both scientific and local experts. The effort of mapping is important for several reasons. It has been argued that presenting spatially mapped land use information increases communities' and stakeholders' rights and power (Fox et al., 2006; Rambaldi et al., 2006). In the current work, mapping supported by the toolbox, pGIS benefitted ongoing land use dialogues between reindeer herders and other land users. Future prospects are promising (Paper I, II and III).

The toolbox was created in cooperation among agency personnel, researchers and reindeer herders working practically together and learning from each other over time. We found that this co-production process was effective. We also found that our ongoing re-buildings and improvements of the pGIS into a custom made toolbox led to good solutions that may not have been achieved if an already developed, commercial GIS was used. The lower engagement of participants in Paper IV where an externally produced toolbox was introduced further supports the conclusion that co-production of tools is advantageous.

The toolbox we developed can support processes for adaptive co-management as described by Olsson *et al.* (2004). Successful co-management in land use conflicts is facilitated because the stakeholders – in our case the reindeer herders – understand the assembled data and tools that can contribute to management decisions. Not only is the data familiar to them, but the co-production of the tools also ensures that the stakeholders have intimate knowledge of the tools. From a research perspective, co-produced knowledge allows for the collection of more comprehensive knowledge, and also paves the way for educated use of the knowledge. These processes fit the definition of adaptive co-management as used by Folke *et al.* (2005; 2002), namely, a process by which institutional arrangements and ecological knowledge are tested and revised in a dynamic, ongoing self-organized process of learning by doing.

6.3 Wider implication of this process

Reindeer herding communities' use of their reindeer husbandry plan and their RenGIS is currently a well-established component in land use dialogue and consultation. There are also numerous examples of the implementation of the process of developing reindeer husbandry plans and the toolbox pGIS in other settings and applications. For example, the role of reindeer husbandry planning process and associated results is realized in numerous governmental and non-governmental reports and strategies, including the following: the Swedish Environmental Objectives for the Magnificent Mountain Landscapes (SEPA, 2014) and Sustainable Forests (SEPA, 2013a), the Government commission "Consideration to reindeer husbandry" (SFA, 2011), "Dialogue Forestry Reindeer husbandry" (SFA, 2013), the Sami Parliament Environmental Program "Eallinbiras" (Sametinget, 2009), the Swedish FSC (FSC, 2013) and the Swedish Sami Organization Forest Policy (SSR, 2008).

The work with pGIS as reflected in studies II, III, and IV also led to further testing and development of pGIS in other settings. For example, in one project, we developed a separate, simplified and generalized version of RenGIS which we call MFGIS (Model Forest GIS) and produced an English version of the program. Vilhelmina Model Forest was the first arena for this test (VMF, 2014; Jougda *et al.*, 2008) where the main users of the pGIS were the board members, researchers with projects in Vilhelmina Model Forest and personnel from Vilhelmina Municipality. In another project, we developed a separate MFGIS dataset for Helgeå Model Forest in southern Sweden, where the main users were researchers working in Helge å Model Forest and agency personnel from Swedish Forest Agency (Hedblom *et al.*, 2014). MFGIS expanded also to the Prince Albert Model Forest in Canada (Carlsson, 2012) where the main users are aboriginal Cree people from five different bands and five different areas. Furthermore, we are currently using MFGIS in cooperation with international research groups in Kenya, Sudan and Sweden as part of an effort to develop an early warning system to predict upcoming outbreaks of the mosquito borne decease Rift Valley Fever (Hassan *et al.*, 2014). A critical aspect of this project involves real time GPS tracking of nomadic herds of cattle and camels, which was inspired by processes presented in Paper I and evaluated in Paper II, III and IV. Finally, the UNESCO world heritage site Laponia in northern Sweden (Laponia, 2014) has adopted RenGIS as their data and communication platform. Here the circle of RenGIS to MFGIS is closing, as some of the main users of the LaponiaGIS are the reindeer herding communities who have extensive experience with RenGIS and are now working with the management of Laponia. The outcome and effects of the studies described above have not yet been evaluated, but nevertheless, the conclusions of the studies have influenced praxis regarding engagement of other user groups. Future research will evaluate the processes of using these tools among the various groups.

Though development of RenGiS as a toolbox to collect, create and visualize information is well in place, its use for communication in land use dialogues can still be much improved. Currently there are more modules developed in RenGIS than are in practical use. Additional work and trainings for reindeer herders are needed to further improve the communication process and taking full advantage of RenGIS. Furthermore, ongoing discussions about how to incorporate information about predator as well as climate studies can mature into an even broader future dialogue.

Successful maintenance and incorporation of the complex and geographically extensive reindeer husbandry land use system in the context of other land use systems is a challenging real life test case for advanced, sustainable landscape management. The challenges span geographic scales that range from single grazing patch to half of the land area in Sweden. The work represented in this thesis can hopefully serve as stronger grounds for both sustainable landscapes and the continuation of an indigenous land use system.

The indigenous Sami people have been recognized as a marginalized indigenous group whose culture and land use are promoted in international policies such as the UN Convention of Biological Diversity (UNEP, 1993), and the European Landscape Convention (CBD, 2008). From an international perspective, a maintained and functioning Sami reindeer husbandry system is instrumental for Sweden to meet the commitments towards the United Nations Declaration on the Rights of Indigenous People adopted by Sweden in 2007. The importance of addressing land use issues connected to the Sami has also been confirmed by the Swedish parliament in a declaration in 1977 stating that the Sami are an indigenous people who, due to their cultural status, have the right to special treatment in Sweden (prop 1976/77:80, bet 1976/77:KrU43). It has been argued that if the land use pressures from other sectors continue to increase, that reindeer husbandry, and with it also the Sami culture, may collapse (Danell, 2005).

Not only does reindeer husbandry provide a challenging case, but it provides a meaningful case, as the cultural importance of reindeer husbandry to the Sami people cannot be overstated. There is a strong political and judicial value for Sweden to maintain the functioning balance between reindeer husbandry and all other land-use systems. Such a balance also has a practical, real life value for a large group of active Sami reindeer herders.

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