Intensification of Wood Production in NW Russia's Komi Republic:

Forest Landscape History and Biophysical Conditions for Tree Growth

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Abstract

Globally, countries with forests and woodlands make attempts to manage their resources in sustainable way. In the boreal biome this has resulted in several policy documents regulating forest planning and operations at multiple levels of governance. For example, due to shortage of accessible forest intensified wood production is a priority in the Russian Federation. Intensification requires knowledge of the past use of boreal forest landscapes, as well as about effective silvicultural practices. I employed a case-study approach to understand the forest landscape history of local timber frontier in NW Russia's Komi Republic (Paper 1), and made a comparative study of growth rates of young coniferous trees in NW Russia and Sweden (Paper 2). Three aspects of environmental history were examined in Paper 1: (1) changes in the natural environments of the past, (2) the technology or progress behind landscape development, (3) values, perception and ideology that supported changes. The results show that industrial utilization of boreal forest in NW Russia began in the end of 19th century, and attempts to intensify sustained-yield wood production were taken several times during the 20th century. In Komi the major industrial use of boreal forest started in 1927. Productive pine-dominated forests along rivers were harvested first. When transport infrastructures were developed spruce forests became accessible for harvest, and were logged and replaced by deciduous successions. However, pristine spruce forests along streams and those with a remote location remained. Forest landscape history thus provides knowledge about where forestry intensification could take place, as part of spatial planning that also considers the maintenance of green infrastructures for both human well-being and biodiversity. In paper 2 I tested the hypothesis that growth rates of young coniferous trees across latitudes in NW Russia and Sweden are the same. I therefore measured 5 long shoots of 30 young Scots pines and Norway spruces in 10 randomly selected stands in poor, mesic and rich site types at three latitudes in both countries. I did not find any significant difference in tree growth for Scots pine between the two countries. To conclude, introducing pre-commercial thinning widely is a prerequisite for sustained yield wood production. To satisfy increased needs for wood, as well as social and ecological dimensions of sustainable forest management, Russian and Soviet legacies of landscapes zoning approach should be maintained.

Keywords: forest management intensification, wood production, tree growth, forest use history, landscape history, Komi, NW Russia, Sweden

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Dedication

To my parents.

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 Naumov, V., Angelstam P., Elbakidze M. Intensification of wood production in the Russian boreal forest: environmental history of a regional logging frontier in Komi. (manuscript)

II Angelstam, P., Naumov, V., Elbakidze, M. Intensifying boreal forestry after Soviet wood mining: Are growth rates of trees different in NW Russia and Sweden? (manuscript)

The contribution of Vladimir Naumov to the papers included in this thesis was as follows:

I 80%

II 40%

1 Introduction

Efforts to change the way forests are managed to be used sustainably are made in many places globally (Puettmann et al., 2008). This is manifested in policies at multiple levels that stress the need to secure both raw material for forest industries, resilient forest ecosystems, and viable local communities in the long term. Thus, sustainable Forest Management (SFM) requires satisfying economic, environmental and socio-cultural objectives (Saastamoinen, 2005; Шматков, 2013a). Implementation of SFM policy on the ground requires knowledge about the states and trends of all sustainability objectives (Angelstam et al., 2004c; Axelsson et al., 2013), and may be approached with a multi-level collaborative landscape approach that includes actors and stakeholders at multiple levels of governance (Axelsson et al., 2011). The importance of innovative research supporting an integrated landscape approach to implement new forest management and governance strategies was recognized at the highest level at XIII World Forestry Congress in Buenos Aires, Argentina (Куликова, 2010). This is enhanced by comparative studies of landscapes in different contexts, such as landscape history (Marcucci, 2000; Antrop, 2005; Angelstam et al., 2011; Elbakidze et al., 2011) and governance legacies (Elbakidze et al., 2013; Greve and Rao, 2014).

The challenges of implementing the SFM concept are particularly relevant for resource-dependent communities and regions situated in Europe's boreal biome. Boreal forests provide important ecosystem services, including wood and non-wood forest resources and landscape values that are important for economy and human well-being (Vihervaara et al., 2010). This biome is also crucial for mitigation and adaptation to climate change (Carlson et al., 2009; Dise, 2009), provides habitat for species (Lopina et al., 2003), and cultural values for people (Bocharnikov et al., 2012). Being relatively remote from centres of economic development, the boreal forest is the least affected by exploitation and use among the European forest biomes (Aksenov et al., 2002; Hannah et al., 1995). Thus, there is thus both potential for intensified wood production, and there is still an opportunity to conserve biodiversity with higher levels of ambition, including ecological integrity and resilience (Angelstam et al., 2004a). There are two major trends in forest management that have emerged in boreal Europe over the past 2 decades. The first trend is the interest in intensification of wood, fibre and biomass production in NW Russia (Knize and Romanyuk, 2006; Nordberg et al., 2013). The second trend is the interest in the conservation of forest biodiversity in the Nordic countries such as Sweden (Anonymous, 2014), Finland and Norway which became one of 8 priority areas in EU Forest Strategy (Commission, 2013). However, in Sweden even the current Forest Stewardship Council (FSC) certification does not improve nature conservation as expected (Johansson and Lidestav, 2011).

NW Russia's forest resources have decreased drastically during the 20th century due to harvesting approaches that can be characterized as wood mining (Angelstam et al., 2009; Nordberg et al., 2013). Coniferous species in late successional stages are thus replaced by natural succession of young and middle-aged forests with a high proportion of deciduous species and thus limited values for the forest industry. In NW Russia this form of wood harvesting has been practised for several decades, and the share of mature and over-mature forests now cover more than half of coniferous forests area in NW Russia (Карьялайнен, 2009). However, these forests have limited accessibility due to high transportation costs. To restore and improve wood resources as desired by the forest industry (Романюк, 2013) and the state (Anonymous, 2013c), there is an urgent need to intensify forest management (Knize and Romanyuk, 2006). This may also decrease the total area of forests being used for timber production, and as a consequence reduce pressure of logging on high conservation value forests that are important for biodiversity and local communities (Fredericksen and Putz, 2003). Additionally, the European markets have became "greener" and it is harder to sell forest goods that are not certified (Gulbrandsen, 2005a; Gulbrandsen, 2005b). Thus, many large forest enterprises in Russia have certified their forest management and forest products (Anonymous, 2013b). According to the FSC standard forest companies should protect high conservation value forests, which were once the basis for logging activities. Today, export-oriented forest enterprises in Russia are therefore seek to intensify wood production and at the same time to conserve forest biodiversity (Elbakidze et al., 2011). For instance, forest companies from Siberia together with regional forest authorities and NGOs proposed to provide local research institutes with the task to develop regional norms for intensive silviculture (Брюханов et al., 2014). In Russia forest land is very often left for natural regeneration. To intensify wood production the forest company Mondi, who owns the forest industry in Komi and is also a major forest leaser, started to identify areas suitable for regenerating harvested stands by planting (Anonymous, 2012c). Finally, according to the survey which involved 161 forest companies from 18 regions of Russia (Шматков, 2012), more than half of respondents argued that the current forest policy does not facilitate intensification of forest management.

Intensification of wood production, or forestry intensification, has many definitions. Intensity of forestry is often described along economical or ecological gradients. From an economical point of view intensification is seen as a consolidation of all production factors such as soils, machinery, energy and manpower with the aim to get the highest financial net return from forest ecosystems. On the other hand, the ecological dimension of intensification describes degree of anthropogenic disturbance caused by forest management operations. Intensive forest management includes silvicultural operations aimed at increasing sustained yield wood production per area unit. These operations may include scarification, planting or seeding, pre-commercial cleaning, fertilization and commercial thinning. The degree of management intensity defines forest management approach (Duncker et al., 2012). In my study I understand intensive forest management as a set of silvicultural activities where economical, ecological and societal dimensions are balanced and aimed for long-term sustained yield wood production.

Increased sustained-yield wood production increases employment and provides more timber for buildings and furniture, cellulose for paper and chemical products like plastic and varnishes. On the other hand, it limits the aesthetic and cultural values of forest. From the ecological perspective intensification only diminishes the portfolio of regulating and supporting ecosystem services. For instance, fertilization of soils would transfer higher levels of nitrogen into lakes and rivers. However, to cope with complex socio-ecological issues collaborative spatial planning may facilitate the accommodation of multiple demands on forest landscapes (Andersson et al., 2013). The planning consists of spatial analysis of land cover data including also perceived values of a landscape. Ultimately, it is done on multiple levels and across different sectors. Stakeholder feedback and discussions are important parts of such planning.

In contrast, Sweden represents a country which succeeded in creating a successful production forest management system. Sweden has a long experience of developing intensive forest management (Nordström, 1959; Brynte, 2002; Östlund et al., 1997; Lagerqvist et al., 1999). This includes restoration of stand volumes and increased growth rates after wood mining during the latter part of the 19th century (Angelstam et al., 2011). However, from an ecological perspective, the long history of logging and later of intensive forest management in Sweden have transformed once naturally dynamic forests to an efficient wood production system along the lines of sustained yield forestry (Elbakidze et al., 2013). This has resulted in a loss of compositional, structural and functional elements of biodiversity found in naturally dynamic landscapes (Bütler et al., 2004), and there are no large intact forest landscapes left (Elbakidze et al., 2011). Consequently, in Sweden there are concerns among stakeholders outside the forest sector about the negative impact of intensive forest management on forest landscapes linked to a long history of maximum sustained yield forestry. This applies to forest ecosystem integrity and biodiversity conservation (Angelstam et al., 2004a; Elbakidze et al., 2011) as well as rural development and to cultural forest values. For example, the national Swedish rural research strategy (Anonymous, 2006a) and the Swedish Governmental Rural Development Committee (Waldenström, Westholm, et al., 2009) have identified a potential increase in the demand for biological resources (Larsson et al., 2008) as a factor that will further affect rural Sweden's ecological and social systems. To communicate the need for improved delivery of ecosystem services (i.e., provisioning, regulating, provisioning, and cultural) the concept green infrastructure has emerged at EU and Swedish policy levels (Andersson et al., 2013; Anonymous, 2013a).

Overall, NW Russia and Sweden represent a West-East gradient in Europe's boreal biome regarding the intensified economic use of forest landscapes on the one hand, and maintenance of functional green infrastructures for ecological sustainability on the other. NW Russia and Sweden can therefore benefit from each other by mutual learning about how to implement sustainable forest management policy on the ground (Nordberg et al., 2013). There are numerous studies debating technical possibilities to intensify wood production, often with a biodiversity focus (Eriksson and Hammer, 2006; Шматков, 2013b). However, other dimensions such as societal and environmental are considered independently of each other. This thesis attempts to look at the implementation of intensive forestry both from the point of view of environmentalist and historian, and uses case study approach to understand the problem holistically.

The objective of the thesis is to contribute to a landscape-based approach to spatial planning aimed at intensified wood production that also maintains ecological and socio-cultural sustainability. This thesis provides knowledge towards functional green infrastructure, the importance of which has been stated at the EU level (Anonymous, 2013a). Multifunctional resilient forestry is one of the benefits that functional green infrastructures deliver. Russia's forest policy (Anonymous, 2013c) strive also for forestry that supply multiple benefits. There is thus need to include into the study mixed research methods in order to diagnose the problem in complex socio-ecological systems such as boreal forest (Angelstam et al., 2013a). Consequently, I diagnosed the social system and the ecological system.

To learn about the societal system, I studied forest landscape history of local timber frontier in NW Russia (Paper I), and to review the state of ecological system I did comparative analysis about tree growth rates of young coniferous species (Paper II) in NW Russia and in Sweden. The goal of Paper I was to contribute to the understanding of barriers and bridges for intensification of timber production in Russia. Further, in order to test the hypothesis that biophysical conditions for growth rates of young coniferous trees in NW Russia and in Sweden are the same, and thus there might be other factors that hinder intensification of forestry in Russia, in I did comparative analysis of tree growth rates across latitudes and site types (Paper II).

2 Methodology

2.1 Study areas

In my study I focus on boreal forest landscapes located in Sweden and in NW Russia (Figure 1). The boreal forest in Sweden is a continuous area which

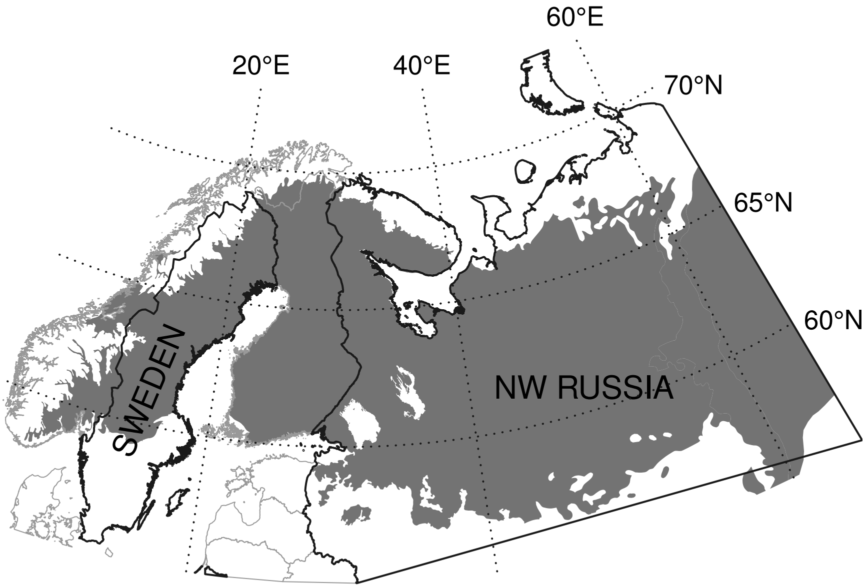

Figure 1: Study areas are located in NW Russia and Sweden. Boreal forest is shown in grey colour.

stretches from the coast to mountains up about 600 m above the sea level and located at approximately 59°-67°N. Moraine and glacio-fluvial sediment forms the soil across the whole country (Sjörs, 1956). In the European NW Russia the boreal biome stretches from 53° to 66°N (Anonymous, 1939; Грибова et al., 1980). The main tree species are the same in both countries and include Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (H.) Karst.), birches (Betula spp.) and aspen (*Populus tremula* L.). The NW part of the Russian Federation has the longest history of timber frontier development in Russia's boreal biome. Already in the late 17^{th} century most of NW Russia's forest near large rivers became the territory of logging for shipbuilding (Г. И. Редько and Н. Г. Редько, 2002). Since shipyards were located in the estuaries of big rivers such as Vychegda, Pechora and Northern Dvina, the expansion of logging took place gradually as a moving frontier in the upstream direction. A good example of this is Vychegda river in Komi Republic where industrial logging is estimated to have commenced in the 18^{th} century (Галасьев, 1961). Fellings of mature, old and old-growth forests in landscapes dominated by natural disturbances were intensified during Soviet period (Г. И. Редько and Н. Г. Редько, 2002). As an example of this development, I use the Kortkeros rayon (an administrative unit of the second level in Russia) in the Komi Republic (Figure 2) as a case study.

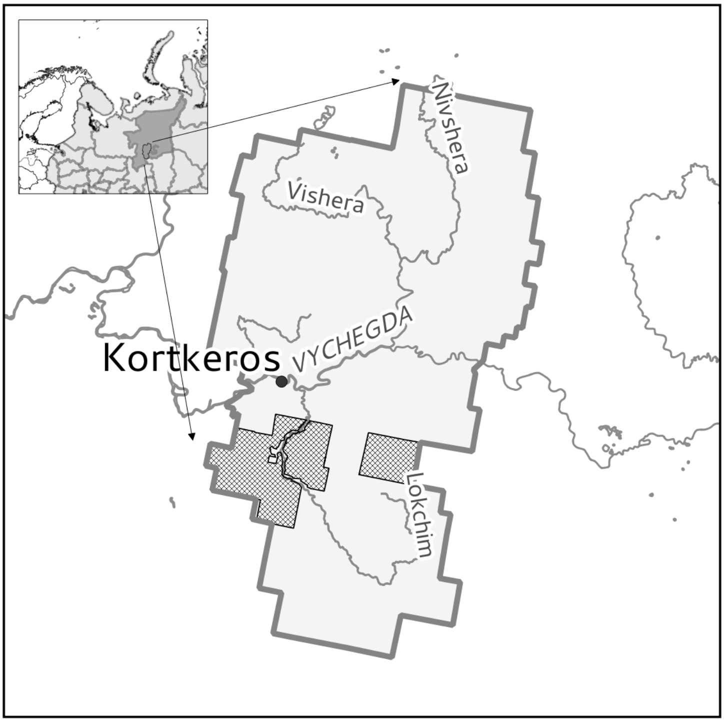

Figure 2: Map of the Kortkeros rayon study area in the Komi Republic with the area (hashed polygons) where spatial analyses were made. Inset map shows the location of Kortkeros rayon in NW Russia.

2.2 Methods

2.2.1 Paper I - forest landscape history analysis

I employed Worster (1994) framework to conduct the study of the environmental history of a place. Since the socio-ecological systems such as forest landscape are complex, this framework helps to understand it holistically. Employing the framework I examined three aspects of a landscape: (1) natural environments of the past, (2) technology or progress that make the changes in the landscape, (3) values, perception and ideology that support the processes of landscape change. This approach is very similar to using the landscape concept, which has biological, anthropogenic and perceived dimensions (Angelstam et al., 2013b; Angelstam et al., 2013c). Thus, I split up the study into three parts: (i) what happened with landscape during the time, (ii) who did the changes and (iii) what values and ideas were behind the changes.

2.2.2 Paper II - tree growth comparative study

To understand if biophysical conditions may hamper tree growth in NW Russia, I compared growth rates of young Scots pine and Norway spruce with respect to country (Russia and Sweden), latitude in the boreal biome (60°, 62° and 64° northern latitude; see Paper II, Figure 1), and coarse site type (poor and mesic for Scots pine, and mesic and rich for Norway spruce). Selection of stands of three coarse site types inside each study area was based on vascular plants as indicator species (Hägglund and Lundmark, 1999). Poor site conditions were on dry sandy soils with lingonberry (*Vaccinium vitis-idaea* L.), heather (*Calluna vulgaris* Hull) and lichens (Cladonia spp.). Mesic sites were on glacial till, and with grasses and blueberry (*Vaccinium myrtillus* L.) in the field layer. The rich coarse site type included sites on clay and silty soils, or rich in calcium, with tall and low herbs in the field layer. For each coarse site type 10 stands with 30 randomly selected specimens of Scots pine and Norway spruce were measured. The trees sampled were chosen to ensure that they were not suppressed by neighbouring individuals. My statistical null hypothesis is that there is no significant difference between sampling sites in Sweden and in Russia. To test this I employed three-factor nested ANOVA tests with stand ID as random factor.

2.3 Data

2.3.1 Paper I - reviews, plans and remote sensing

To locate stands with different site conditions in each landscape I used forest management plans from several state sources such as archives, libraries and forest management units. Forest stands younger than 10 years were mapped with remote sensing data such as Landsat.

I employed a two-step approach to describe the history of forest landscape. First, I reviewed the forest use history at state (Russia), regional (Komi Republic) and local (Kortkeros) levels. A literature review was conducted with focus on effects of logging, silviculture and other forest activities in the Kortkeros case study area. In the analysis I also used historical sources such as forest surveys and forest management maps from the local archive in Kortkeros (Paper I, Table 2). To understand the more recent history a local history expert was interviewed, and three focus groups were arranged. Second, on the secondary study area I did a detailed change detection analysis for period from 1965, when the first forest management unit was established in Kortkeros, to 2014.

The latest comprehensive forest inventory dates back to 1992. Scanned forest management maps for 1965 and 1992 were scanned and geo-rectified using 2nd order polynomial transformation matrix with mean error less than 10 m. Then, the maps were digitized including dominant species and stand age. The map of forest stands in 1965 provides the base for describing the initial age distribution. The forest was divided into 5 categories depending on phase of succession: (1) initial stage (0-10 yrs after clear-felling), (2) young (11-30 yrs), (3) middle-aged (31-70 yrs),(4) final felling and old-growth forests (>71 yrs) (Angelstam and Kuuluvainen, 2004). To digitize clear-cuts I used Landsat images (USGS Products). Clear-cuts were visually digitized using forest management map (1965) and Landsat images (1975, 1986, 1993, 2006, 2014). Finally, age of initial land cover base map (1965) was re-projected to new map of 1975. At the same time the final stand age distribution of 1975 was adjusted to digitized clear-cuts. This approach was applied sequentially for 1986, 1993, 2006 and 2014. In total I created 6 age distribution maps on the area 160,000 ha.

The forestry inventory data for 1992 was used to map the spatial distribution of forest site types along a soil fertility gradient. Selection of stands of three coarse site types representing poor, mesic and rich conditions for tree growth inside each study area was based on vascular plants as indicator species (Paper I, Table 4). Poor conditions were on dry sandy soils with lingonberry, heather and lichens. Mesic sites were on glacial till, and with narrow-leaved grasses (*Deschampsia flexuosa* Trin.) and blueberry in the field layer. Rich site type included sites on clay and silty soils, or rich in calcium, with tall and low herbs in the field layer. Later, in order to see development of different forest stages and structures at smaller scale, the information from age distribution maps were aggregated by site type. This was later discussed with regard to biophysical opportunities to intensification of wood production at local level.

To identify and describe main actors involved in forest landscape history of Kortkeros rayon I reviewed regional and local literature about forest history in Komi as well as state statistical reports, forest management plans and archive documents. Additionally, I used information from three focus groups with forest researchers, forest managers and local historians. In order to collect information about local stakeholders I employed focus group interviews as qualitative method to understand opinions and extract new knowledge about societal barriers (McLafferty, 2004). These groups were selected because they represented the most active stakeholders of Kortkeros forest landscape at local level. Each group included 4-5 persons. The method of focus group interviews implied that the organizer describes the topic and asks first question, then the role of the organizer is to facilitate the discussion among the participants, though not interfering in any way (Barbour, 2008). Finally, I evaluated values, perception and ideology behind the forest landscape history with help of literature review and interviews. Additionally, I used information from three focus groups with forest researchers, forest managers and local historians.

2.3.2 Paper II - field data

I measured growth rates of young Scots pine and Norway spruce in study areas located at different latitudes (60°, 62° and 64° northern latitude) and coarse site type (poor and mesic for Scots pine, and mesic and rich for Norway spruce) in the boreal biome in both Russia and Sweden. For each coarse site type 10 stands with 30 randomly selected specimens of Scots pine and Norway spruce were measured. I used soil maps from Swedish Geological Survey (Anonymous, 2012b) to locate different site conditions in the study areas. Young stands were mapped by using forest management plans.

3 Results

Analysis of forest use history in NW Russia (Paper I) demonstrated depletion of accessible coniferous forests especially Scots pine and rapid change of natural spruce and pine forests into deciduous successions dominated by aspen and birch. At the beginning, in 18th century the harvest level was very low due to primitive tools. For instance, trees were cut down with axes and transported by horses or rafted by rivers. Later, in the beginning of the Soviet period forestry policy was wood-logging oriented e.g. wood mining emerged. With creation and development of new tools (such as heavy machinery) the wood logging highly increased peaking in 1988. Forest older than 71 was harvested the most. Amount of younger forest especially with age between 31-70 yrs has greatly increased (Paper II). Additionally, rich sites has demonstrated increase of forest of all ages but not clear-cuts.

3.1 Paper I - forest landscape history

3.1.1 Changes on the ground

Before the 17^{th} century the study area was sparsely populated with only 0.1 persons per km^2 (Жеребцов et al., 1996). Rivers, which are without rapids in Kortkeros rayon, were the main means of transportation. People lived along the big river Vychegda, and its tributaries Lokchim and Vishera. Wood was used mainly for construction of buildings in villages and as firewood. Important non-wood forest goods of Kortkeros were furs of sable (*Martes zibellina*) and red squirrel (*Sciurus vulgaris*), which were sold to Novgorod. Some territories were cleaned of forest to allow agriculture.

In the 18^{th} century large Scots pine trees along the rivers were harvested by single-tree selection for the purposes of ship-building. For this work peasants from the closest villages were employed. Wood harvesting levels depended to a great extent on the availability of horses to transport logs to the river. The average transportation distance was approximately 10 km from the river (Орлов, 1927), but varied largely between breeds of horses, with the age of the horse, experience of the driver, weather and local site conditions. Season also has influenced logging. Once harvested and transported to the bank of the river, timber logs were then rafted, first on the main river Vychegda, then the North Dvina river to the sea port in Arkhangelsk. Export of Russian timber began in late 17th century, when England began buying timber. Since that time companies from Great Britain, Sweden, Holland and Germany invested money into wood harvesting in Komi (Галасьев, 1961). In the second half of the 19th century direct foreign investments in forest harvesting started to take place in NW Russia (Юшкова, 2001), and thus the pressure on naturally dynamic forests by wood logging increased.

The Russian revolution in 1917 brought instability in the whole country, also in forestry. After 1918 all the land and forest on it was nationalized. Forest was harvested mainly for fuel-wood during civil war 1918-1921, after which the USSR was established. A great increase in wood harvesting happened in the period 1937-1940 when a prisoner camp system was established in the Kortkeros rayon which is called LokchimLag. Such camps were created everywhere in Russia, but camps specializing in forest harvesting were mainly in Arkhangelsk region and Komi Republic. In Kortkeros camps were build first near the Vychegda river, and then along the Nivshera and Lokchim rivers. Gradually during the late 1930s narrow-gauge railways were constructed further away from rivers, and several temporary camps increased wood harvesting including LokchimLag. The wood was exported outside of Kortkeros as well as outside Komi Republic. Starting from the 1930s the government introduced clear-fellings concentrated near transport infrastructures, which resulted in a moving logging frontier into wilderness areas. In Kortkeros primary study area wood was logged in Lokchim and Nivshera catchments. As a consequence old Norway spruce forests were replaced with birch and aspen on mesic and rich sites. Scots pine recruited well after large clear-cuts on sandy soils.

Russia was involved into World War II in June 1941. This slowed down logging and concentrated it to close to villages and rivers. During the war prisoners made skis for military use. After World War II the economy of the country had to be restored. Hence, in 1960s pulp-mills were constructed all over the country. In 1969 a pulp-mill was build in Kotlas (350 km downstream from the study area), and in Syktyvkar (50 km downstream from the study area). By the end of the 1980s, just before the collapse of the USSR, the total harvest of wood in Komi peaked at 26 million m^3/year.

From 1988 to 1998 the harvest decreased with more than 2 million m^3/year, and reached a low of only 5 million m^3/year. This coincided with the Russian financial crisis in 1998, also called the Russian Flu. Afterwards, wood harvesting recovered slightly to about 9 million m^3/year. Wood harvesting in the Kortkeros rayon followed the same pattern as in Komi (Figure 3). From 1988 to 1998 wood harvests in the Kortkeros study area declined from 1.3 million to 0.3 million m^3. After the stagnation period 1999-2006 wood production increased to about 1 million m^3/year in 2007, thus approaching the same level as before the collapse of Soviet Union. Nevertheless, starting from 2008 it continues to decline today.

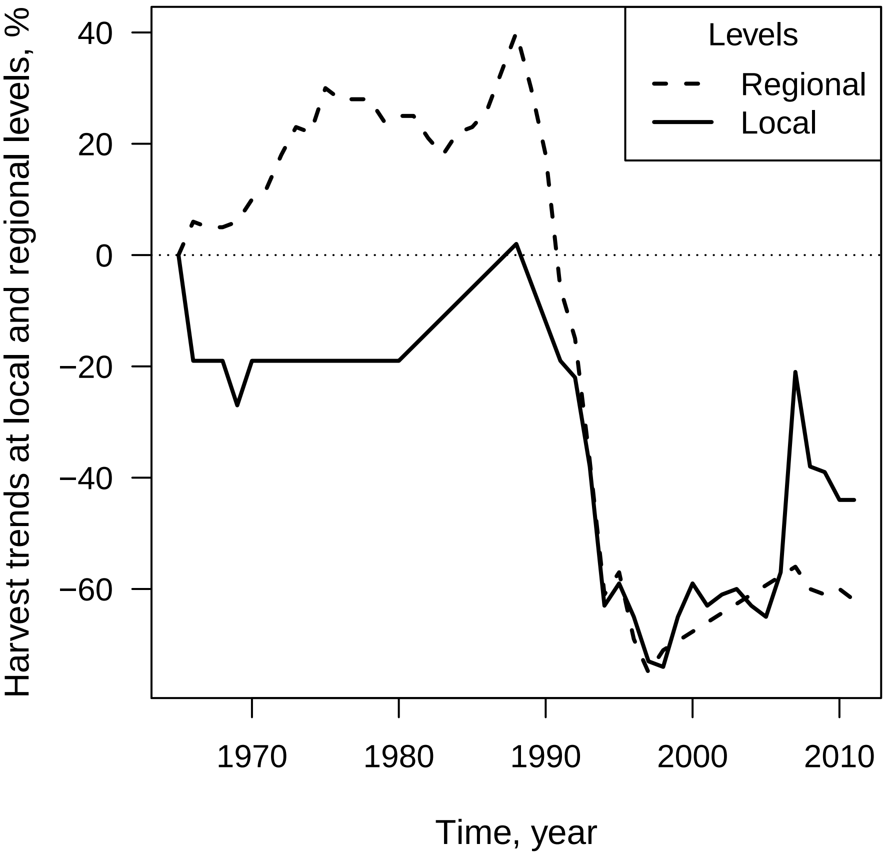

Figure 3: Harvest trends relative to 1965 at regional (Komi) and local (Kortkeros) levels.

What were the consequences for forest age distribution among coarse site types (see also Paper II) at the local level? My analyses demonstrate that the amount of middle-aged forest available for commercial thinning increased continuously since 1965 (Paper I, Figure 4). The age distributions on different site types were similar, but forests on mesic sites demonstrated smaller magnitude of changes due to their remoteness and difficulty to reach them for harvesting. Site types in the secondary study area ranged from poor (62 % of total area) and mesic (36 %) to rich (2 %). The proportion of clear-cuts had the same temporal pattern across all site types with a maximum in the mid 1970s and a minimum around 2005. The area of young forest increased gradually over the study period and peaked around 2005. The amount of middle-aged forest has been increasing on all site types during the entire study period. Final-felling forest on poor and mesic site types was relatively the same during 1965-2014, whereas on rich site types it doubled until the mid 1970s and holds now the same area. Mesic site types did not demonstrate the same variance as poor and rich site types. An illustration of the site type and age class distribution is shown in Figure 4.

3.1.2 Different actors

The wood logging began with simple tools like axe. Noble persons and tsar servants employed peasants from nearby villages to cut down forest. Later in 1719, after creation of state forest service, the forest was managed and cut under supervision of officials. The forest land was also sold to private companies who managed it themselves, usually including logging as the only forest management operation. Metallurgical factories in Kazhim (about 300 km from Korteros rayon) and Njuvchim (about 90 km away) employed peasants, also from Kortkeros, to harvest forest in order to convert ore into metal (Галасьев, 1961).

During the Civil War (1918-1921) that followed after the revolution forests in NW Russia was a very valuable resource of wood for Bolsheviks because their foes – the pro-tsarist forces – controlled Donbass, which was the main coal reserve area in former Imperial Russia and located in today's Ukraine. Therefore, pressure on forests in NW Russia, and thus in Komi and Kortkeros, increased to satisfy needs of industry. Political repression in Soviet Union in the 1930s facilitated further deployment of forest industry in NW Russia. Kortkeros in Komi was one of the centres in the GULag system, and was used as a role model (Similingis pers. comm., 2013). People who were farmers of South and Central Russia were forced to move to the north where climate conditions are severe. They built temporary logging camps for forest workers and transport infrastructure. The GULag system existed until the death of Stalin (in 1953) when political leadership was changed.

Starting from the end of 1930s the forest industry in Komi and Kortkeros began to upgrade logging technology and improve organization. For example, the first tractors in Komi were introduced in the 1930s. However, forestry in Kortkeros was fully mechanized only by 1965. Mechanization greatly increased wood harvest and facilitated work in forest. The logging camp organization contributed to a strong system of forest industry. Later some of logging camps formed the base for forest villages where the local population were occupied by logging.

Today private companies harvest wood on forest areas which can be leased for 10-49 years (Anonymous, 2006b). There are large international forest companies operating in Komi such as Mondi international packaging and paper group as well as small-scale businesses. These logging companies introduced modern technologies in forestry like harvester-forwarder logging groups. International and especially European markets strongly influence forestry in Russia. For example, forest certification was made in Komi by these private forest industries. However, the opportunity for introducing active forest man-

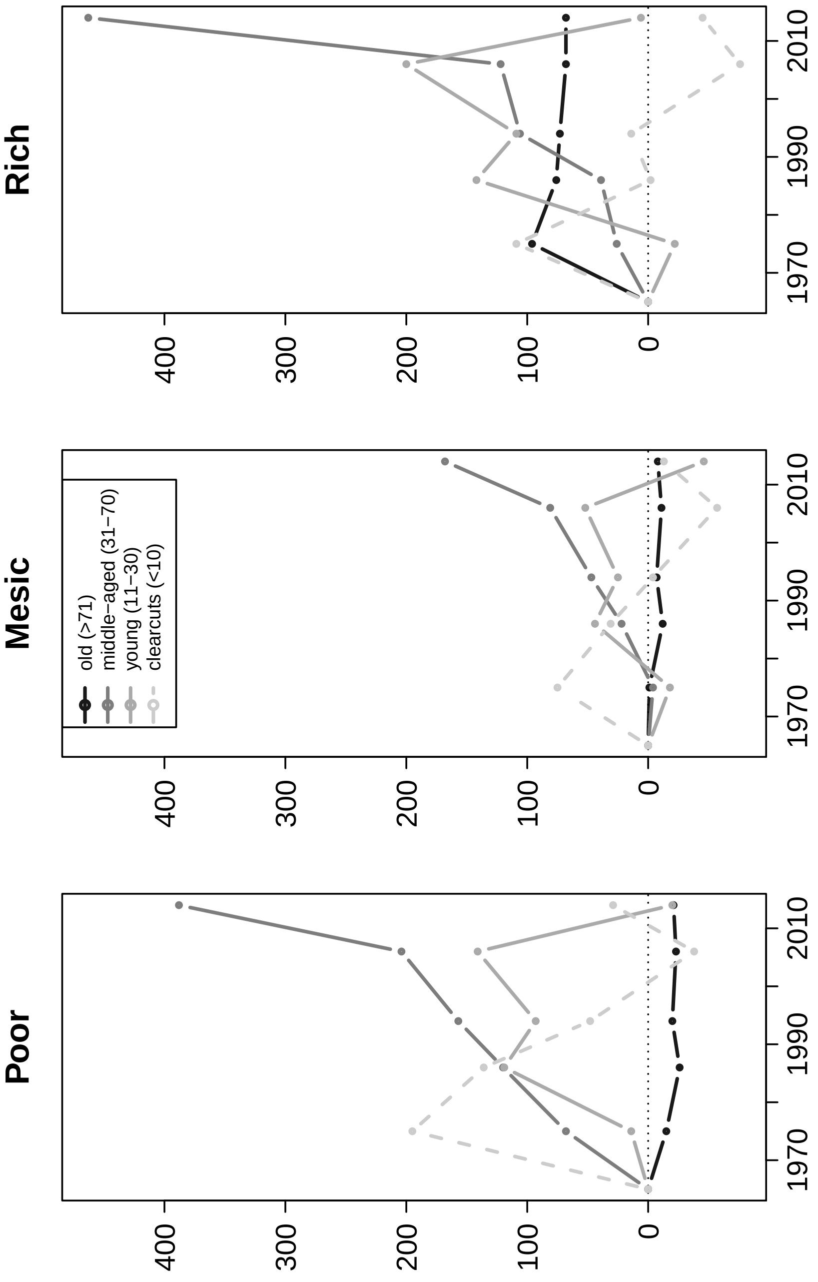

Figure 4: Age classes trends on different site types in Kortkeros case study (paper I).Trends in the area of different age classes on poor (62 % of the study area), mesic (36 %) and rich (2 %) site types from 1965 to 2014. The y-axis shows the area change relative to the initial cover in 1965. The analysis was performed on a total area of 160,000 ha (Paper I).

agement based on cleaning and commercial thinning requires longer leases. This is possible only for financially strong and big businesses. Small-scale businesses have no access to this market. At the local scale, forestry in Kortkeros has experienced the same new trends.

3.1.3 Changes in mind

During the entire study period the ideology behind forest landscape history swung between market and planned economy. Initially both ideologies were combined. The very first industrial interest in wood was grounded in upgrading military and trade functions. Peter the Great was interested in building a strong independent Russia with access to the European market for Russian products and foreign imports. For that he needed powerful military fleet and many trade ships. This required in turn wood of very good quality, such as large slow-growing Scot pine, which was harvested along rivers and rafted to the Arkhangelsk shipyard.

As Russia gained more military power it needed more iron. There were several iron ore reserves in Komi, also near the Kortkeros study area. A lot of energy was required to convert ore to iron, and in the 18th century wood and charcoal were an irreplaceable resource for iron production. Another important revenue came from salt production, based on salty ground water. Technology was based on heating and evaporation process, also requiring wood. The closest salt-work was placed in Seregovo (about 40 km from the Kortkeros study area).

The very first part of Soviet period is officially accepted as initial stage to communism – socialism, when people were organized into teams to harvest forest. During 1931-1935 forest industry enterprises were consolidated with forest management units to increase logging efficiency (Г. И. Редько and Н. Г. Редько, 2002). The sustainability concept was considered as foreign sabotage term aimed to stop industrialization in the USSR. As a result of state campaign against the sustainability concept, courses in forest inventory were excluded from study plans in all universities. For Soviet economists forest had no longer value unless it is cut (Knize and Romanyuk, 2006). To protect the Soviet economy during World War 2 forestry changed its course to being military-oriented. Exported goods were reduced, wood was produced for the army and heating.

The USSR economy underwent severe changes in 1965, also called as the Kosygin or Liberman reform. This reform is characterized by introducing market economy methods of management when whole state enterprises were given rights to make their own economy. Forest management units were reorganized into integrated units (Russian term: leskhoz) with not only harvesting functions but also with forestry functions like planting, cleaning, protection from diseases and fire-fighting. This was a clear step to decentralization of the economy, which resulted in further increase of wood harvest.

The collapse of Soviet Union in 1992 has changed political regime in Russia. After the collapse of the Soviet Union, the Russian federation's government changed its course to market economy again. Now market forces manage wood harvesting. This was introduced into Forest Code and forestry regulations. State forest management units today have just control and monitoring functions. All forest management operations delegated to the companies who leases forest. However, the state still propagate plans to forestry operations using regional level forest management documents and also for each FMU which are created for 10 years.

3.2 Paper II - tree growth comparative study

The major conclusions from tree growth study are following: 1) tree growth rates among Sweden and Russia are the same for Scots pine forests, 2) tree growth of Norway spruce differs significantly due to historical legacy of spruce forests in Russia when it was hard to find specimen that grow freely.

3.2.1 Tree growth rates of pines and spruces

Regarding Scots pine the results from the three-way ANOVA that included country, latitude and coarse site type did not reveal any significant difference in the length of long-shoots between NW Russia and Sweden (Paper II, Table 3 and 4, Figure 2). However, regarding Norway spruce there were a significant difference between the two countries (Paper II, Table 3 and 4, Figure 3). On poor and mesic sites the length of Scots pine long-shoots was similar at the same latitudes and increased with decreasing latitude in both countries. The only difference was in the growth of young pine at the latitude 60° on poor sites. It can be explained by the variation among the poor site types in each study area. In Sweden at this latitude poor site types included "calluna" and "lingon" site types while trees in Russia at the same latitude were measured mostly in "lichen" site type. In contrast, there is a different situation at latitude 62° when Sweden is represented by "calluna" and "lingon" site types and Russia – by "lichen" site types.

For Norway spruce on mesic sites the length of long-shoots was similar at latitude 64°, and there were considerable differences at latitude 62° and 60°. On rich sites there was similarity in the growth of young spruce among the countries at latitude 60°. At the same time in general there were not any clear pattern neither in NW Russia nor in Sweden. In Sweden spruce growth at latitude 60° did not follow the expected increasing shoot-length with decreasing latitude, and in NW Russia growth at latitude 62° was unexpectedly low.

At all latitudes and in both countries no spruce stands were measured on "lichen-rich" and "wet shrub" site types. Poor site types at latitude 64° follow the same pattern in both countries. Distribution pattern of fine mesic site types in Russia was to certain degree the same as in Sweden except of Russia's study areas at latitude 64° where 2 of 10 stands had relatively richer site type (equisetum and narrowgrass). Distribution of rich site types varied greatly among countries and latitudes. Russia's forest stands at latitude 62° were measured in much poorer soil conditions than in Sweden. At latitude 64° Swedish study area demonstrate richer site types than in Russia.

3.2.2 Silviculture in Sweden and in NW Russia

There was a clear difference in the incidence of pre-commercial thinning between the stands visited to measure long-shoots on Scots pine and Norway spruce in NW Russia (2 %, n=117) and Sweden (100 %, n=100). There was no difference among poor (n=30 in both countries), mesic (n=57 and n=40) and rich (n=30 in both countries) sites.

4 Discussion

4.1 History reveals other factors important for intensification

Results from forest landscape history analyses (Paper I) suggest that the technical ways to intensify wood production include a long process of developing forest policy and practice for increased rates of reforestation, pre-commercial cleaning and commercial thinning, as well as draining and soil fertilisation. Results from Paper I shows that road network was more advanced during the Soviet Union. Thus, intensification requires also a permanent network of transport infrastructure, including forest roads not only for wood transportation, but also to provide continuous access for repeated silvicultural treatments. A comparison between current Swedish and Russian forest management units shows a 10-fold difference in the number of necessary accesses per time unit (Elbakidze et al., 2013). The economical efficiency of forestry in Sweden, and Finland, can be explained by the high average annual growth rates that have been achieved, as well as a high level of value-added production that allows continuous investments in silviculture. For example, in Sweden the average annual growth rate is about 5.3 m^3/ha (Skogsstyrelsen, 2013), whereas in NW Russia it is approximately 1.2 m^3/ha (Anonymous, 2012a).

Additionally, social and political conditions influence the use and management of boreal forest (Lehtinen, 2006). Russia belongs to the Orthodox civilization and Sweden to the Western (Huntington, 1996). Hence, there are different systems of governance and political culture in these countries. Russia has to deal with two societal problems that hinder forest intensification. First, the top-down governance is practised which often results in gaps between needs and interests of forest companies and those who produce policies at the top (Nordberg, 2007). This can be explained by the fact that usually officials who are appointed as decision-makers at the highest level do not necessary have forestry education but are very good at managerial work, and have the right connections. Second, there is a clear gap in forestry manpower.

Due to rapid organizational changes in Russian forestry (many state organizations ceased their work) after collapse of Soviet Union, foresters has either lost their job or changed their occupation to more profitable professions.

Intensification of forestry in Russia is possible only with regard to current leasing system of forested lands. Although Russian state was the owner of forest land since 1918, starting from 1997 forest management itself became responsibility of private forest companies who rent forest land for a maximum of 49 years. Before introduction of Forest Code in 2007 small companies could rent forest land for shorter period (e.g. 1 year) to harvest wood, but after that their competitiveness dramatically decreased because the expenses associated with long-term forest management and rent are too high. For example, Swedish forest commons could contribute to establishment of better institute adapted for long-term risks in intensification of wood production (Carlsson, 2000).

First Russia's legislation on thinning operations emerged in late 1930s (Карьялайнен, 2009). Later it was further developed for different geographical regions. After collapse of Soviet Union the regulations were unified again. This led to simplification of work for foresters but wood productivity was not increased. Additionally, several attempts to introduce Scandinavian experience happened in NW Russia (Романюк and Кудряшова, 2009; Романюк, 2013).However, the results of these projects are not in use on other territories. Therefore, there should be developed a legislation mechanisms to integrate positive experience into forestry practice.

To conclude, the results from the two studies in this thesis show that intensification of wood production in Russia requires a broader perspective, which includes both the local and regional landscape history, and the introduction of pre-commercial thinning. However, this requires also a range of other measures.

4.2 No biophysical obstacles for intensification in NW Russia

The hypothesis of Paper II that young coniferous trees have the same growth rates in NW Russia and Sweden was upheld for Scots pine, but not for Norway spruce. For Scots pine on poor sites there was a clear latitudinal gradient in long-shoot length in both countries. However, there were also some inconsistencies in the lengths of long-shoots among latitudes on mesic and rich sites. Regarding mesic sites with Scots pine in the local landscapes at latitudes 60° and 62° in Sweden, the former was located just below the marine limit, which means that the glacial till has been washed when the sea level was up to 200 m higher that today. This has reduced site class productivity. Concerning rich sites with Norway spruce in NW Russia the local landscape at latitude 62° had much less low and tall herb site types than the local landscapes at latitudes 60° and 64°. Similarly, the sites at latitude 60° had a lower proportion of low and tall herb sites than latitudes 62° and 64°. I attribute the overall taller Norway spruce long-shoots in Sweden compared to NW Russia to the fact that it was very difficult to find young forest on rich sites that allowed young Norway spruce to grow without competition from deciduous trees in the Russian study areas. I argue that this is linked to the historical use of different coarse site types. For example, I showed (Paper I) that Scots pine forest first was harvested near big rivers and roads, while Norway spruce stands near rivers were left intact due to water protection regulations introduced in 1943 (Г. И. Редько and Н. Г. Редько, 2002). Thus, in NW Russia mature, ageing and old-growth spruce forest survived in protection zones near rivers and bogs as well as in nature reserves. For poor and mesic sites the length of Scots pine long-shoots increased with decreasing latitude, in spite of the gradient between Sweden's more oceanic and NW Russia's more continental climate. This does not contradict the notion that tree growth rates of young coniferous forest does depend on climate with latitude as a proxy. To conclude, the Paper II suggests that there are no any biophysical obstacles for intensification of wood production in NW Russia. Therefore other factors than related to biological factors need to be addressed when discussing how to intensify wood production in Russia.

4.3 Approaches to forest management in Russia and Sweden

During the past 150 years NW Russia and Sweden show different trajectories in the development of forest management (Paper II, Figure 4). In the mid to late 19th century both countries were in transition from wood-mining towards sustained yield forestry. In both NW Russia (Тюрмер, 1891; Орлов, 1927) and Sweden (Brynte, 2002) sustained yield forestry was advocated, practices and taught to intensify the production of charcoal and fuel wood. However, in the beginning of the 20th century the trajectories diverged. Russia was at the crossroads to choose economical independent or subsidized forestry. The communistic political course and will was initially towards subsidized forestry, i.e. the forest parcels was distributed among state stakeholders. Later, after the Russian socialistic revolution in 1917, economical factors of wood production such as wood and forest land were neglected, and wood mining re-appeared (Knize and Romanyuk, 2006). Sweden, however, continued on the road to sustained yield wood production, the implementation of which was implemented completed in the 1950s. The emphasis of Sweden's intensive forestry is on managed reforestation including silvicultural practices such as scarification, planting, pre-commercial cleaning, commercial thinning, and fertilization. About Russia – efforts to apply the Scandinavian forest management model by the forest companies and the governmental official position towards it (for example, Putin's speech in Syktyvkar in 2007).

4.4 A tool-box for intensified forest management in NW Russia

Pre-commercial thinning is a key component to remove competition between stems. However, this important silvicultural practice is poorly developed in NW Russia. Firstly, pre-commercial thinning is not wide-spread. Thinnings in Russia constitute no more than 15 % of the harvested volume (Gerasimov and Karjalainen, 2006). Secondly, the guidelines for pre-commercial thinning need further improvements. For example, so called "corridor" cleaning is used extensively in young forest stands (Anonymous, 2007). This legislation allows 3 types of thinning: regular, irregular and schematic. In regular thinning weak and depressed trees are cleared throughout the stand. Irregular cleaning means that all young trees, both coniferous and deciduous tree species, are removed. This can be made by in 3-5 m wide corridors separated by uncleaned strips of 16-120 m or in patches, both determined in the field by the operator. Finally, schematic thinning is supervised according to some predefined scheme, which can be by corridors, by stripes or by rectangular plots. This is in stark contrast to the Swedish system for pre-commercial cleaning, which is based on achieving even spacing of the desired tree species (Hamilton, 1984). This results in increased growth of trees left due to less inter- and intra-specific competition, increased light, and fertilisation from the decay of cleaned stems. The larger stem diameter reduces future harvesting costs, increases stem quality and improves stands' resilience to disturbances. A consequence of this difference is that during subsequent commercial thinning using harvester-forwarder teams in Russian forests the harvesting capacity is lower than projected.

Additionally, accessibility to forest plays an important role to implement silviculture plans on the ground. Road density in Sweden and NW Russia differ dramatically (Pekkarinen, 2005). In Sweden, rapid expansion of the road network took place 1950s (Angelstam et al., 2004b). However, in NW Russia the road network is poorly developed (Dudarev et al., 2002). Forest transportation system in Russia consists of railroads, motor roads, and forest roads and rivers. Additionally, due to Russia's short-term (maximum of 49 years) leasing system private companies do not see economical profit in building long-lasting forest roads. Therefore, their goal is to satisfy only the transport infrastructure function for final felling, but not to provide continuous access. Thus, Holopainen et al. (2006) noted that the forest network of lower hierarchy level are weak or even does not exist in Russia.

However, besides silviculture drawbacks of Russia's guidelines of pre-commercial thinning and poorly developed transport infrastructure for effective sustained yield forestry, there are critical differences in management objectives, and the systems for forest governance. The comparison of the meaning of sustained yield forest in Russia and Sweden made by Elbakidze et al. (2013) clearly illustrates this. In Sweden, the production target of forest management is a high and sustainable harvest level of annual allowable cut (AAC). By contrast, Russia's official definition of AAC has a multi-stakeholder perspective being

> "...multi-purpose, efficient, continuous and sustainable use of forests, according to the established age of final felling requirements for biodiversity conservation, maintenance of water protective and protective functions and other benefits of forests"

(Anonymous, 2011). To move forward there is need to reform forest policy and tenure system. It is important to make a long-term policy so forestry actors will benefit in the future and will be interested in sustainable development of their business and thus sustainable forest management. However, forests does not necessarily need to be privatized because it will lead to social instability and further increase of social inequality. One approach is to give more political power to regional forest authorities so they can develop regional landscape-based guidelines for intensive forestry and adapt it on the ground. Additionally, vocational training system should be considered. In order to implement sustainability and rural development goals the education has to include not only new achievements in forest management intensification but also adaptive multi-level social learning and collaboration between stakeholders (Axelsson et al., 2013).

Finally, to satisfy the idea of sustainable forest management, there is a need to intensify in a way that maintains forest landscapes' green infrastructures not only for sustained yield wood production, but also to satisfy social and ecological aspects. To satisfy the forest industry's requirement of increased sustained yield of wood and biomass, to satisfy rural livelihoods and to maintain biodiversity of forest landscapes, forest zoning approaches such as the TRIAD (Seymour and Hunter Jr, 1992) or QUAD (Messier and Kneeshaw, 1999) concepts can be applied (Nitschke and Innes, 2005). In fact, there is a long history of forest zoning in Russia. In the beginning of 18^{th} century tsar Peter the Great set aside forest territories that were of paramount importance for the country, i.e. to build ships for the navy (Г. И. Редько and Бабич, 1993). But these areas were not entirely protected but rather reserved until it was needed. The first law that actually protected forest in Russia was passed in 1888 (Anonymous, 1997). Two zones were introduced. The first was forests where forestry can be highly restricted (similar to modern national parks). The second was forests which protected headwaters as waterways. After the Russian socialistic revolution and World War I the law was amended by introducing protection zones also along railways and public roads, as well as additional zone reserved for future needs. Today forest land in Russia is divided into: 1) production zone forests, 2) protection zone forests and 3) reserve zone forests (Anonymous, 2006b). It might be rational to choose the richest sites at lower latitudes for intensive management, but the same sites are generally also rich in forest biodiversity (Lindenmayer and Franklin, 2002). Consequently, these territories has to be set aside as meso-reserves or for extensive or multiple use forestry (Messier et al., 2003).

4.5 Critical assessment of the thesis

There are several unpublished historical records used in this thesis (Paper I, Table 3). However, parts of the historical analysis is based on literature review. Thus it approximates the results but allows to see the general trend of landscape changes over time. The results have therefore sufficient significance for the purpose of study. It should be kept in mind that forest surveys and maps were done by different people with different methodology, knowledge and skills (Östlund et al., 1997). Borders of the Kortkeros FMU has been constantly changed, this implies some error in estimates of timber harvested per Kortkeros. Additionally, due to missing data in the local archive it was impossible to make bigger picture of forest landscape changes, that's why the smaller secondary study area in Kortkeros was established. When it comes to focus group methodology, it could be improved by including also passive stakeholders.

5 Conclusions

I argue that NW Russia and Sweden can both benefit from collaborative learning about how to intensify forest management (Anonymous, 1999; Forest Europe, 2011). A collaborative learning assumes that the group engages in a process of intellectual negotiation and collective decision-making (Trimbur, 1989). This certainly applies to intensification by developing sustained yield forestry based on experiences from the Nordic countries (Nordberg et al., 2013), but also social forestry in NW Russia, and Swedish experience in systematic conservation planning for biodiversity conservation (Angelstam et al., 2011). Hence, also other models for intensification than the Nordic/German approach should be considered. To ensure resilient sustainable forest management system Puettmann et al. (2008) and Messier et al. (2003) argued that in long-term zoning approach provides possible benefits both for nature and for society.

To conclude, there is a need for comparative landscape-based studies that will involve a gradient of policies, harvest intensities and conservation levels. Case study landscapes in NW Russia and Sweden provide a promising base for such studies. Moreover, intensification of forestry should be investigated also from socio-ecological perspective. It is thus necessary to diagnose the problem holistically combining economical, ecological and social dimensions of forest landscape.

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