Barriers and bridges for intensified wood production and biodiversity conservation in NW Russia's boreal forest

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Abstract

Wood production and biodiversity conservation are two key objectives of sustainable forest management policy. These goals are rival and, therefore, hard to achieve at the same time in the same area. The aim of the thesis is to contribute to the understanding of barriers and bridges for intensified wood production and biodiversity conservation in NW Russia's boreal forests. It was implemented by case study approach on both ecological and social systems of forest landscapes with different forest use histories in the European boreal biome.

I first studied the forest use history in a forest management unit in NW Russia (paper I). Second, I analysed how production and biodiversity goals are actually balanced on the ground by comparing indicators for wood production and biodiversity conservation in NW Russia, Belarus, Latvia and Sweden (paper II). Next, in order to test the hypothesis that there are no biophysical obstacles to intensified wood production in NW Russia, I compared tree growth rates at 4 latitudes in NW Russia and Sweden (paper III). Finally, I reviewed the history of forest zoning policy, which is an influential mechanism to conserve biodiversity in Russian forests, and assessed if zoning policy change towards intensification negatively affected riparian forests, e.g. biodiversity conservation (paper IV).

The barriers for intensified wood production in NW Russia include limited silviculture, poor road development and conservative mind-set of decision-makers (paper I). Bridges for intensified wood production involve existing infrastructure of forest villages and available middle-aged forests (paper I) as well as equal biophysical conditions for tree growths (paper III). Biodiversity conservation goal is achieved better than wood production in NW Russia in comparison to countries with longer forest use histories (paper II). More relaxed zoning policy is considered as barrier to biodiversity conservation (paper IV). Developed zoning system (paper IV), landscape approach initiatives and remaining intact forests (paper I) provide opportunities for biodiversity conservation.

The findings in this thesis imply that balanced sustained-yield wood production together with biodiversity conservation is possible when a landscape zoning model is employed. There is a need to engage in transdisciplinary research on the role of landscape stewardship for satisfying both production and biodiversity goals.

Keywords: zoning, continuous forestry, intensification, wood production, landscape history, Komi, NW Russia

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Dedication

To my family and friends.

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. (2016). Barriers and bridges for intensified wood production in Russia: Insights from the environmental history of a regional logging frontier. *Forest Policy and Economics*, 66, pp 1–10.

II Naumov, V., Angelstam, P., Manton, M., Elbakidze, M., Rendenieks, Z., Priednieks, J., Uglyanets, S., Zhivotov, A. Satisfying wood production and biodiversity conservation goals in boreal forests of Europe's West and East: landscape history matters. *Journal of Environmental Management.* (In revision)

III Angelstam, P., Naumov, V., Elbakidze, M. (2016) Intensifying boreal forestry after Soviet wood mining: Are tree growth rates different in NW Russia and Sweden? *Forestry*, doi: 10.1093/forestry/cpw055.

IV Naumov, V., Angelstam, P., Elbakidze, M. Open remote sensing data reveals effects of Russian zoning policy change on intensification and riparian forest conservation. *Canadian Journal of Forest Research.* (In revision)

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

I 80%

II 50%

III 50%

IV 60%

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1 Background

Sustainable forest management policy stresses the need to satisfy multiple functions of forest landscapes including both wood production and biodiversity conservation. However, portfolios of barriers and bridges for policy implementation differ among countries with different use histories and governance systems (Angelstam et al., 2011). Europe's boreal forest biome exhibits a steep gradient of forest use histories and governance systems. Due to a shortage of accessible forests caused by intensive harvesting with almost no pre-commercial silvicultural treatments in the past, intensified wood production has become a priority in Russia. At the same time, as a country with a short forest use history, NW Russia still hosts last large intact massifs of natural boreal forests in Europe (Yaroshenko et al., 2001). On the other hand, as a country with long forest use history, Sweden is successful in terms of developing economically efficient high sustained-yield forestry. Hence, the experience and development of intensive forestry in Sweden provides opportunities for knowledge production and learning for the Russian forestry industry sector. However, it is a challenging task to increase wood production and simultaneously conserve biodiversity. Sweden lost most of its pristine forests during a long history of forest use. Subsequently, efforts have been made to protect natural forest remnants and to restore biodiversity (Bernes, 2011; Helfield et al., 2012; Simonsson, 2016).

Globally, to satisfy both wood production and biodiversity conservation objectives, criteria and indicators have been developed for sustainable forest management (Anonymous, 2009). These were created in response to sustaining valuable natural resources but also to deal with global threats caused by overpopulation, climate change and severe loss of native forest species, and are described in the Rio Forest Principles (Anonymous, 1992) and by the Helsinki conference (Anonymous, 1993). These policies were further developed in European Union (Anonymous, 2013a; Anonymous, 2011), in Russia (Anonymous, 2013c) and in Sweden (Andersson et al., 2016). In both Russia and Sweden both wood production and biodiversity conservation are important long-term goals of sustainable forest management. To facilitate policy implementation at national and international levels there is thus need to understand the extent to which both objectives can be satisfied at multiple spatial scales.

Implementation of sustainable forest management policy needs to involve activities in both ecological and social systems of forest landscapes. The ecological system includes biophysical conditions and consequently forest management systems. Biophysical conditions form the base for tree growth and wood production. Climate and soils are two important components. Higher tree growth rates are observed in warmer climate with richer soils. On the other hand, ideology and government organization are social system dimensions. Ideology influences forest management through personal values, ideas and perceptions. For instance, during the Soviet era (1921-1991) it was not possible to sell forest land in NW Russia since it did not have any value according to communistic ideology. Unfortunately, social and ecological systems are often considered individually in research on sustainable forest management.

Sustainable forest management aims at satisfying both economic and ecological dimensions. 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 soil, machinery, energy and manpower to get the highest economic return from forest ecosystems. On the other hand, the ecological dimension of intensification describes degree of anthropogenic transformation caused by forest management operations aimed at wood production. 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. Forest management approaches can thus be grouped by the degree of management intensity (Duncker et al., 2012). In this thesis I understand intensive forest management as a set of silvicultural activities where economical, ecological and societal dimensions are balanced and aimed for long-term maximum sustained yield wood production (Elbakidze et al., 2013). Wood production cannot be increased without investments. Where intact forests still exist, an expanding logging frontier can be observed, which is imagined as a gradient of anthropogenic influence on forests by extensive harvesting (Smith, 1974; Nordberg et al., 2013). Forestry harvest levels drops when all accessible forests are harvested and no investments are made. This is termed as timber fall (Drushka, 2003). NW Russia has reached this level in most regions, and therefore seeks to intensify wood production. This is well described as movement from wood mining to agriculture of forest (Knize and Romanyuk, 2006).

The ecological dimension of intensification describes the degree of anthropogenic transformation of biodiversity caused by forest management operations for wood production. The concepts naturalness and natural (or historical) range of variability captures this (Peterken, 1996). Forest management approaches can thus also be grouped in relation to the extent to which they emulate natural disturbances (Angelstam and Kuuluvainen, 2004). To conserve biodiversity, functional networks of terrestrial and aquatic habitats need to be maintained by spatial planning. This is captured by green infrastructure policy (Anonymous, 2013b). In order to decide what areas to protect, manage or restore, spatial modelling is an important supporting tool for planning. One approach is to combine sufficiently detailed land cover data and evidence-based knowledge about what species require (Scott et al., 2002; Suchant and Braunisch, 2004) using Geographical Information Systems (GIS) (Andersson, 2011). To model habitat functionality the focal species approach has been proposed as a method that the can help to maintain viable populations of species (Lambeck, 1997; Lambeck, 1999). This method is comparable to the umbrella approach (Roberge and Angelstam, 2004), and is based on the idea that conservation of specialised and area-demanding species can contribute to the protection of many naturally co-occurring species (Hess and King, 2002; Roberge and Angelstam, 2004). The focal species approach combined with spatial modelling and relevant land cover data is thus an appropriate method for spatial planners to strategically identify priority conservation areas across entire landscapes and regions. A key reason is that the boreal biome is relatively uncomplicated where the compositional, structural and functional dimensions of biodiversity across landscape can be quantified using a limited number of tree species and age classes (Paper II).

The diverse boreal forest use histories on the European continent provide great opportunities for comparative studies on the role of local and regional contexts of how to satisfy production and environmental objectives in forestry. Using the gradient between Russia and Sweden regarding forest use history, the intensity of forest management and the state of biodiversity, this thesis employs a case study approach to learn about barriers and bridges for intensified wood production and biodiversity conservation in NW Russia.

2 Scope of the thesis

The overall goal of the thesis is to contribute to the understanding of how to intensify wood production in NW Russia while at the same time conserving biodiversity. This is implemented by studying ecological and social systems of forest landscapes and using a case study approach (Paper I). With production and biodiversity goals as two key forest management dimensions, I focused on NW Russia (short forest use history), while Sweden (long forest use history) played a role as a reference for sustained-yield forestry and its consequences (Figure 1). Ultimately, I see this thesis as a contribution not only towards solving Russia's demand for intensified wood production and to conserve the remaining pristine boreal forests with intact biodiversity in Northern Europe, but also to support Sweden's and other countries' efforts to restore and maintain its forest biodiversity (Andersson et al., 2016).

This thesis explores the following specific research questions:

1. What factors within ecological and social systems influence the opportunities for intensified wood production in NW Russia?

2. How functional are forest landscapes with different histories in terms of composition and structure for (a) intensified wood production and (b) biodiversity conservation?

3. Do biophysical conditions limit the application of the Swedish experiences of developing intensive forestry in NW Russia?

4. What are the current trends for intensified wood production and biodiversity conservation in NW Russia?

First, using an environmental history approach, I studied forest use history in NW Russia for the last 3 centuries to identify factors influencing wood production (paper I). Second, I developed indicators for wood production and biodiversity conservation, and applied them to forest management data in regions with different forest use histories, to understand how production

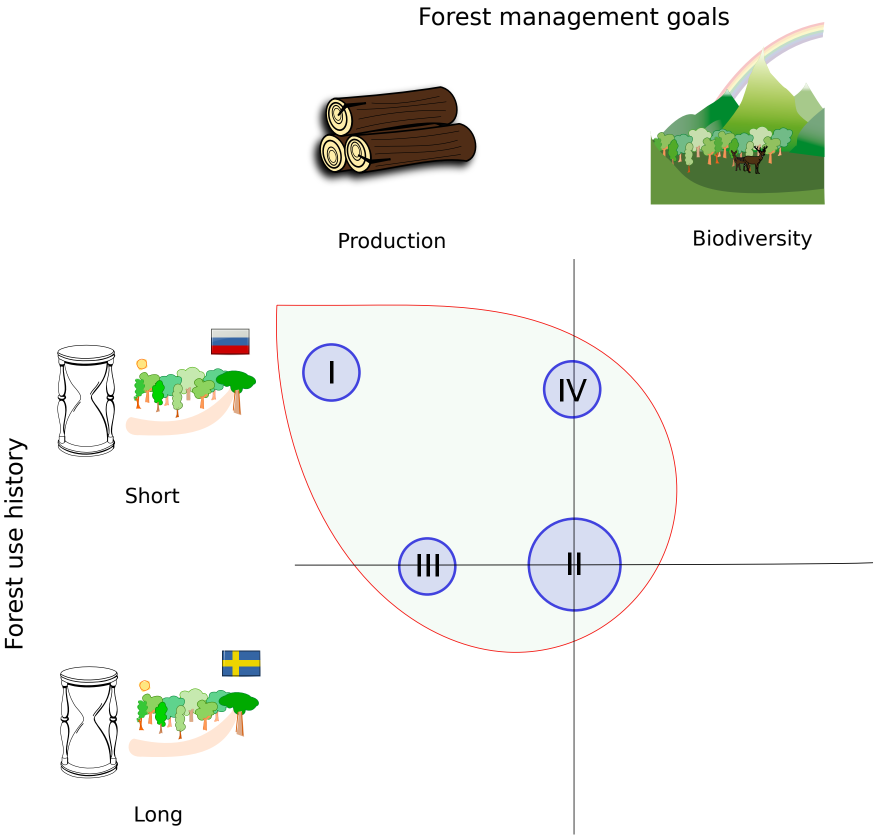

Figure 1: This thesis contributes to the understanding of barriers and bridges for intensified wood production and biodiversity conservation in NW Russia. It focuses on intensified wood production in NW Russia and uses Sweden as a role model for sustained-yield forestry, and Russia as a reference for biodiversity conservation. The Roman numerals in circles refer to the four papers in this thesis. All vector images are from Openclipart.org (public domain licence CC0 1.0).

and biodiversity conservation goals are satisfied (paper II). Third, I assessed the growth rates of young Scots pine and Norway spruce in NW Russia and Sweden (paper III) in order to understand if biophysical conditions for wood production are the same. Finally, I analysed how zoning policy change, which occurred in Russia in 2007, affected forestry intensification and riparian forests in NW Russia's Komi Republic (paper IV). I conclude the thesis by discussing how to satisfy both intensified wood production and biodiversity conservation objectives as components of sustainable forest management in different forest history and governance contexts, e.g. in Russia and in Sweden.

3 Research design

The thesis design builds on 4 articles that define barriers and bridges for intensified wood production and biodiversity conservation NW Russia using Sweden as benchmark for economically efficient forest management (Figure 1). I employed both qualitative and quantitative research methods in a total of five forest landscapes as case studies. First, there were two literature reviews. One focused on the forest use history in NW Russia (paper I), and the other - on forest zoning history in Russia (paper IV). Second, I used interviews and focus groups to gain understanding about forest use history (paper I). Third, GIS tools were used (1) to assess land cover changes (paper I), (2) to estimate wood production and biodiversity conservation indicators (paper II), and (3) to check how zoning policy affected intensification and conservation of riparian forests (paper IV). Data for paper III was collected in the field; the other papers did not involve ecological field work. In paper II and IV analytical statistics were used. I employed an environmental history framework (paper I) to assess the factors that influence wood production in Russia within both ecological and social systems.

3.1 Case study approach

The thesis uses a case study approach (Yin, 2013). Different aims can be persuaded, such as to develop a theory, to test a hypothesis or to provide description to the case. Table 1 describes case studies in different papers of the thesis depending on type of case study and its methods. The thesis focuses on NW Russia and uses gradient of forest use history on the European continent. Sweden represents a country with a long forest use history, and it was used in 2 papers whereas paper II required higher number of case studies in order to do analytical statistics.

The methods of paper IV include GIS analyses and complete enumeration of the entire case study area, covering all the 10 forested catchments in the Komi Republic today, and it is not a sample. Thus, statistical tests were

Table 1: Case studies and methods used in the thesis.

Paper	Type of case study	Names	Methods
I	Exploratory and descriptive; single	Kortkeros	Environmental history approach, literature review, interviews, GIS analysis
II	Explanatory; multiple	SE-Bergslagen, LV-Zemgale, BY-Braslav, RU-Pskov, RU-Komi	GIS analysis, analytical statistics
III	Explanatory; multiple	Sweden, NW Russia	Natural experiment, analytical statistics
IV	Explanatory; single	Komi	GIS analysis, complete enumeration

not performed. To clarify, what we use in this paper is what is termed census survey, census inquiry, or complete enumeration method (Kothari, 2004). This is characteristic to remote sensing data when an entire area is surveyed. The census survey method is a purposive sampling technique (i.e., a type of non-probability sampling) which cannot be used to make statistical generalisations about the sample being studied. However, the use of this method does make it possible to make analytical generalisations about the population being studied. In this case it is possible to draw conclusions about effects of zoning policy change on riparian forests.

This is consistent with several of studies done with open access land cover data. For instance, forest cover changes related to illegal logging in the Ukrainian Carpathians was studied utilizing the same complete enumeration approach (Kuemmerle et al., 2009). A similar study was done in the Western Carpathians where effects of heavy industry pollution and forest use history influenced the forest loss and gain (Main-Knorn et al., 2009). Likewise, the authors did not employ sampling design and statistics to analyse how forest cover changed in Poland, Czech Republic and Slovakia between 1987 and 2005. In European Russia forest cover changes were registered with Landsat and compared for period 1985-2010 with no statistical sampling involved (Baumann et al., 2012). In Russia remote sensing data and digitized traditional maps was evaluated to map land cover structures and pattern without statistical analyses (Milanova et al., 1999).

3.2 Paper I - Environmental history approach

Ecological and social systems were analysed by an environmental history framework (Worster, 1994) to study barriers and bridges for intensified wood production in NW Russia. I first recreated wood production history for the period 1719-2014, then identified the main actors that produced this history, and finally analysed what ideologies that influenced decision-making. This was done by individual interviews and several focal group interviews for the social system, as well as change detection analysis for land covers. The analysis was based on available archival forest management maps and documents from 1965 to 1992. Employing GIS I assessed how forest stands of different class ages changed over time. Forest inventory data for 1992 was used to map the spatial distribution of forest site types along a soil fertility gradient (Сукачев and Дылис, 1964; Hägglund and Lundmark, 1999). The environmental history study was divided into three epochs: the Russian Empire (1719-1917), the Soviet Union (1921-1991) and post-Soviet Russia (1991-2014) . Each epoch presents different worldviews regarding harvest level, forestry actor and ideology (Table 2).

3.3 Paper II - GIS and parametric analyses

For this comparative study I used 5 study areas in the European boreal biome. Beside NW Russia and Sweden I selected Latvia and Belarus. In the Baltic States, Latvia is approaching the same level of forestry intensification as Sweden by employing the Fennoscandian model of forest management (Vanwambeke et al., 2012). Neighbouring both NW Russia and Latvia, Belarus holds an intermediate position regarding forest management intensity. Policies in all these countries aim at sustained yield wood production and retaining remnants of near-natural forests for biodiversity conservation (Brukas, 2015). To understand how wood production (economic) and biodiversity conservation (ecological) objectives actually are satisfied in terms of structural and compositional dimensions of a forest stand, I created portfolios of indicators for wood production and biodiversity conservation (Tables 2 and 3 in paper II). Using GIS I then applied them to forest management data in Sweden, Latvia, Belarus and two regions in NW Russia (Table 3). In each case study area I randomly sampled 25 individual 100-km^2 squares with contiguous forest cover. As a parametric method I employed generalized linear models with binomial errors of response variable and logit link function (Fox, 2015) to test the hypothesis that these indicators are the same in the 5 study areas.

3.4 Paper III - Natural experiment

Sweden's sustained-yield forest management approach is presented as a role model for adoption in NW Russia. Intensification of wood production requires basic knowledge about the extent to which the biophysical prerequisites allow this. It has been questioned if Nordic experiences can be applied in Russia due to differences in soils and climate (Кузнецов, 2013). Therefore, I tested the hypothesis that growth rates of young coniferous trees in the same latitudinal and site contexts are the same in Sweden and in NW Russia. Measuring past rates of height or diameter growth are well-known approaches to predict wood production capacity (Avery and Burkhart, 1983). I used the Swedish approach to assess young tree growth using the intercept method (Martin, 1995; Hägglund and Lundmark, 1999) by measuring growth rates (length of 5 long-shoots) of Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) in young forest stands. This was done at latitudes 58°, 60°, 62°and 64°N in both countries to mirror latitudinal differences in the vegetation period (se paper III for details) and on rich, mesic and poor site types. Rich sites types are characterized by clay and silt soils as well as sites rich in calcium. Poor sites were presented on dry sandy soils with lichens (*Cladonia* spp.), lingonberry (*Vaccinuim vitisidaea* L.) and heather (*Calluna vulgaris* Hull), and finally, mesic sites types on glacial till with blueberry (*Vaccinium myrtillus* L.) and narrow-leaved grasses (e.g. *Deschampsia flexuosa* Thin). I measured 30 randomly selected specimens of each tree species for trees taller than 2.5 m. Additionally, I recorded if any pre-commercial cleaning had taken place. The data were analysed with mixed-effects three-factor ANOVA test (Gotelli and Ellison, 2012). The measured long-shoot lengths provide an estimate of potential wood production, if required silvicultural is planned and implemented.

3.5 Paper IV - Complete enumeration

Zoning of forests for different functions was practised in tsarist Russia already in the mid-19th century (Арнольд, 1895). Initially with the aim to conserve valuable forests along rivers for future harvest, during the Soviet period the zoning system developed into a fully functioning framework for protection of protective functions, and thus indirectly for biodiversity conservation. Due to several reasons (e.g., limited silviculture and insufficient transport infrastructure) wood harvest levels were not sustained (paper I). To allow logging in previously not harvested areas the buffer size of protective zones was decreased from 500 to maximum 200 m in 2006 (Anonymous, 2006a). Hence, clear-felling operations were allowed under certain conditions in the protective zones along streams (Anonymous, 2006b). These recent changes in zoning policy can thus negatively affect riparian forests and its biodiversity (Кобяков et al., 2013). To test the hypothesis that these changes increased the rate of riparian forests loss by harvesting, I accessed (1) if the changes altered the rate of riparian forest loss compared to the rest of the catchments, (2) if forest loss was the same near headwaters and main rivers, and (3) if the forest loss was the same in catchments with different degree of remoteness.

For this study I selected the Komi Republic in NW Russia (Figure 2). This area in the Russian Federation provides a gradient of different degrees of modification of naturally dynamic forest ecosystems ranging from intact forest landscapes to areas harvested by wood mining in the past. I chose the 10 largest river catchments representing full range of local forest use histories in the Komi republic (south of 65°N). To assess forest loss I used the Global Forest Change raster dataset based on remote sensing data (Hansen et al., 2013). Buffers along water bodies were created according to Russia's zoning policy before 2006: i.e. 0-200 and 201-500 m, by using GIS. Next, the relative amount of mean annual forest loss was calculated for 2 periods: 2000-2006 (period before zoning policy change took place) and 2007-2014 (after policy change towards more relaxed zoning). To assess forest loss in different stream orders I defined streams of magnitudes 1-4 as headwaters, and a compared this to the remaining river network.

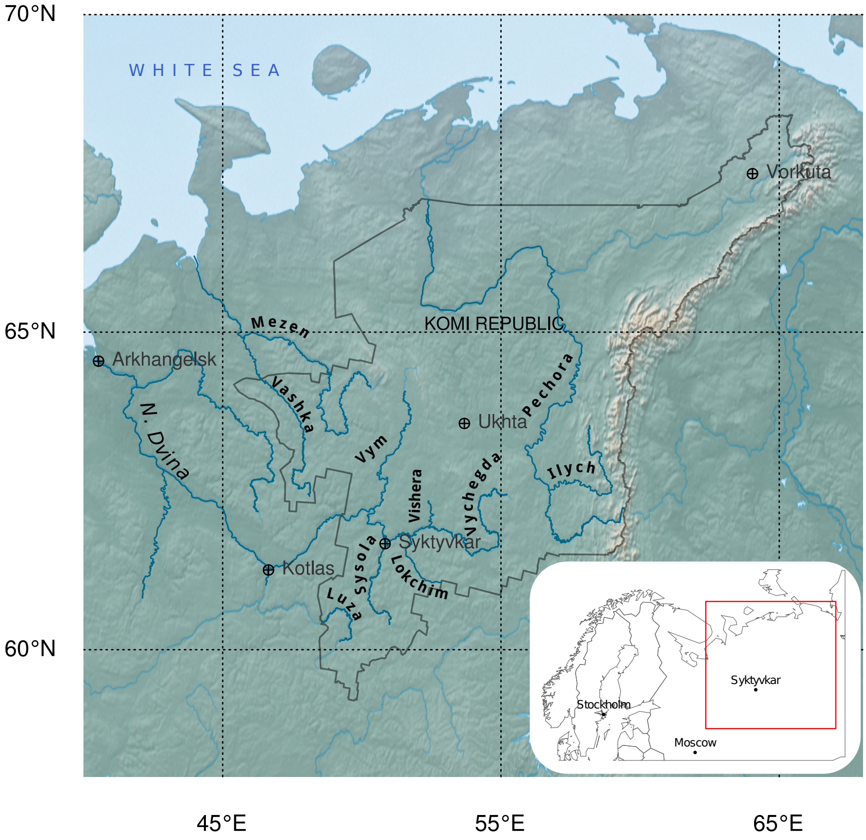

Figure 2: The 10 catchments in the Komi Republic. Inset map shows study area in NW Russia (paper IV).

Table 2: Main trends of forest landscape history in the Komi Republic with reference to national-wide historical events, divided into broad epochs and their internal phases.

Epoch	Time period	Phase	What happened? (Harvest level)	Who did it? (Forestry actors)	Ideology? (Left-Mixed-Right)
Imperial Russia	1719-1850	Ship-buildning and local iron and salt industries	Low	State	Mixed
	1850-1917	International export of wood products	Low	State and private forest enterprises (foreign capital)	Capitalism
Soviet Union	1930-1957	Gulag	Rapid increase	State (by prisoners)	Communism
	1941-1945	WW2 Slowed down	State	Militarism	
	1946-1975	After war reconstruction	Steady increase	State	Communism
	1976-1989	Economic stagnation	Decrease	State	Communism
	1990-1993	Collapse of Soviet Union	Rapid decrease	State	Mixed
Russian Federation	1993-1998	Inefficient reforms towards market economy	Low	State and forest companies	Mixed
	1999-2014	Gradual pickup	Small increase	Forest companies (also with foreign capital)	Towards right (liberal, market-oriented)

Table 3: Descriptive statistics of forest land cover proportions within the 25 individual 100-km^2 cells used as proxies for the 5 study areas.

Country	Extent of study area	Area (ha)	Forest (%)
Sweden (SE)	Bergslagen region	567614	74.9
Latvia (LV)	Zemgale planning region	420758	84.1
Belarus (BY)	Braslav, Grubok, Mior, Postav and Sharkoy districts	910191	79.0
Russia (RU)	Pskov oblast, Strugo-Krasny, Velikoluky and Kunyisk districts	562500	73.1
Russia (RU)	Komi Republic, Kortkeros district	247692	81.3

4 Results

4.1 Barriers and bridges in socio-ecological systems

The history of forest use in NW Russia can be divided into three major periods (Table 2). The first period is from 1719 when Peter the Great issued the first forestry related law to the revolution in 1917. During this period Russia developed a strong interest in sustained-yield forestry and introduced German approaches already in 1800 (Teplyakov, 1994). The second period is represented by intense wood mining of naturally dynamic forests during the Soviet era (1921-1991). This resulted in the replacement of coniferous stands with deciduous forests of low economic interest. The third period began after the collapse of the Soviet Union, and today Russia seeks to intensify wood production.

During the first period large Scots pine trees along rivers were harvested for ship-building, and fuelwood was produced for local iron and salt industries. At the end of the first period, Russia became an important exporter of wood, supplying a third of the world timber export (Генверт, 1926). During the second period forests and forest land were nationalized. This entire period is characterised as wood mining, where forest harvesting was based on objectives set by upper managerial bodies (Nordberg et al., 2013). This resulted in increased wood harvest levels (with exception for the World War II period), and which levelled off in the 1980s. Interestingly, the decrease in harvest rates started even a little earlier than the collapse of the Soviet Union (Figure 3). This phenomenon is described as timber fall, i.e. severe deficit of accessible wood and when no investments were made in silvicultural treatments (Drushka, 2003). Industrial logging began only in 1965 in the Kortkeros district; and the temporal pattern was the same as in the entire Komi Republic.

Spatial analyses of forest management data over time since the arrival of the timber frontier to Kortkeros in 1965 showed that the amount of middle-aged (31-70 years) forests available for intensified wood production (including

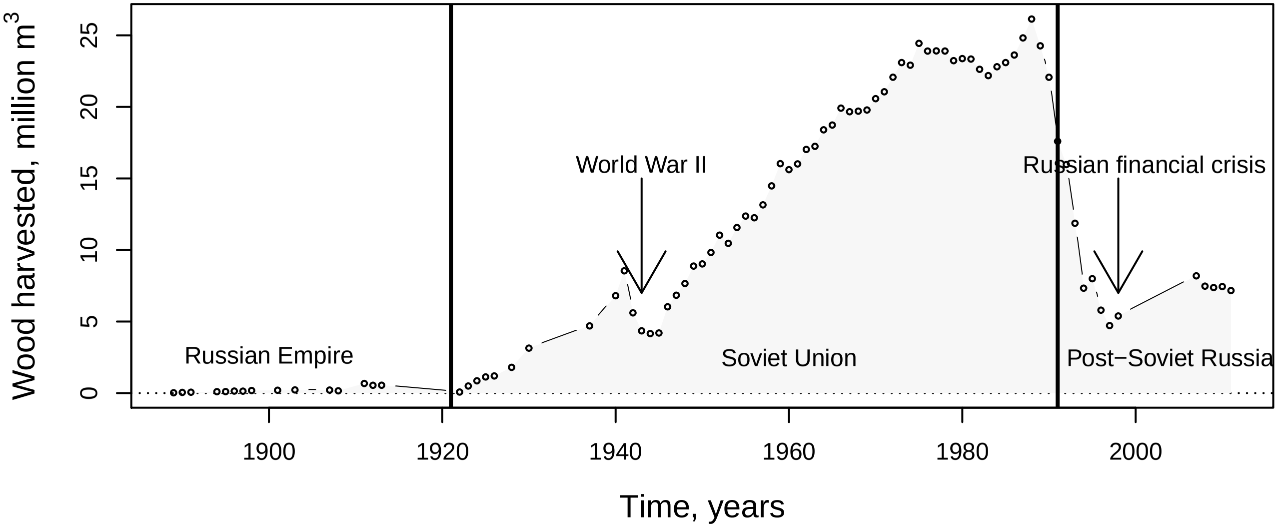

Figure 3: Wood harvest in Komi Republic during the period 1889-2014 (based on paper I).

commercial thinning) increased continuously since 1965 (Figure 4). The area

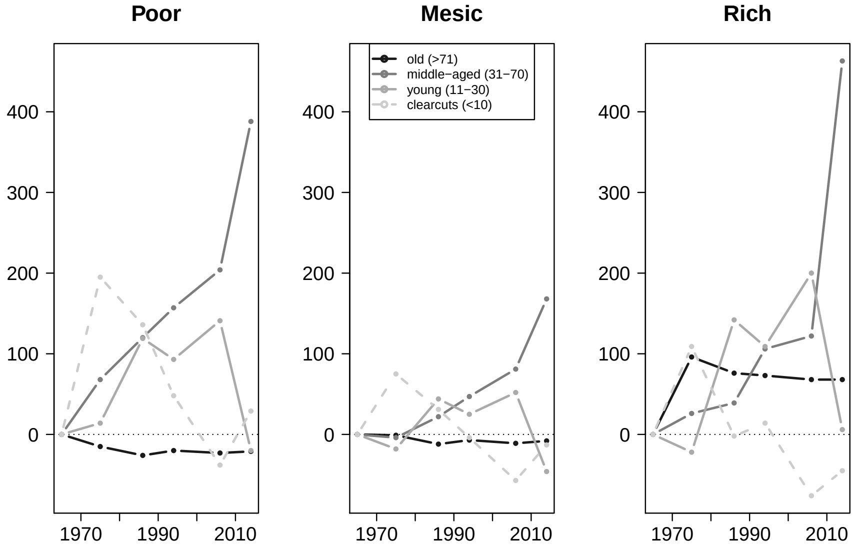

Figure 4: Trajectories in the areal change of different age classes on poor (62% of the study area), mesic (36%) and rich (2%) site types in the period 1965-2014. The y-axis shows the area change relative to the initial cover in 1965 (in percentage). The total area of the analysis is about 160000 ha (paper I).

of forests on mesic sites changed less because of their remoteness from transport infrastructure, and zoning in terms of protection of riparian forests on rich sites near streams (see Angelstam and Lazdinis (2016) and paper IV).

During the first period forest harvesting was done under the control of the state by private forest enterprises for export and for metallurgical factories in Kazhim (about 300 km from Kortkeros) and Njuvchim (about 90 km from Kortkeros). The second period is characterised by strong state political rule. Decision making was authoritative. Later wood was mainly used for the internal market when new pulp-mills were constructed, in Kotlas (350 km downstream from Kortkeros) and in Syktyvkar (50 km from Kortkeros) in the 1960s and 1970s, respectively. After the collapse of the Soviet Union (third period) private forest companies became responsible for the full cycle of forest management. These companies further improved processing operations introducing cut-to-length technology. Nevertheless, after the timber fall the harvest level is still lower than before 1991. Today, forest certification aims at facilitating sustained yield wood production as well as conservation of biodiversity and social aspects (Stryamets et al., 2015).

During the three periods, the ideology behind forest use swung between liberal market-oriented and communistic planned economy. The first industrial interest was based on military upgrades (including military and trade ship construction) as well as international trade. During the second period, the societal values and interests were cardinally changed to communistic values for community, equality and common ownership. This led to abandonment of the sustainability concept for wood production, and subsequently led to the timber fall (Drushka, 2003) with little accessible forest remaining. During the third period, Russia stepped back to the liberal ideology again but forest remained as national property. Forest is now leased to private forest companies for 10-49 years, but is controlled by the state.

4.2 Rival production and biodiversity goals

This study tests the hypothesis that forest use history affects the opportunities for achieving different forest benefits such as wood versus non-timber forest products and habitats for species including people. I found that the production indicators for coniferous wood and biomass in Sweden, Belarus and Latvia had higher values then in the two study areas in NW Russia (Figure 5). On contrary, biodiversity indicators showed the inverse pattern with NW Russia's two case study regions in the top (Figure 6). High sustained-yield wood production and biodiversity conservation are two key objectives of sustainable forest management policy. The indicators for wood and biomass production and biodiversity conservation were inversely related in the European boreal forest biome, and economic production dominated in the Western part of the studied gradient of forest use histories. In particular, intensified wood production in Sweden has caused severe reduction of both mature and old-growth forest. In Russia, even if desired, the maximum sustained-yield objective has not been realised. Thus the composition and structure of forest stands are more favourable for biodiversity conservation in the two study areas in NW Russia and BY-Braslav than in SE-Bergslagen. Being in transition from the Soviet wood-mining to the Nordic intensive forest management approach, the LV-Zemgale region performed intermediately. This is because LV-Zemgale still has legacies of the Soviet time land abandonment with deciduous forest successions, low-intensive forestry, and segregation of different forest functions, all of which that maintain the deciduous forest features.

4.3 Biophysical conditions for tree growth

There was no significant difference in the length of long-shoots for Scots pine between NW Russia and Sweden (Figure 7). In contrary, I discovered significant difference in the length of long-shoots for Norway spruce (Figure 8). This can be explained by missing pre-commercial thinning on the Russian sample sites (5% in NW Russia thinned vs. 100% in Sweden).

Regarding prerequisites of the intercept method, 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 (5%, n=156) and Sweden (100%, n=137). There was no difference among poor

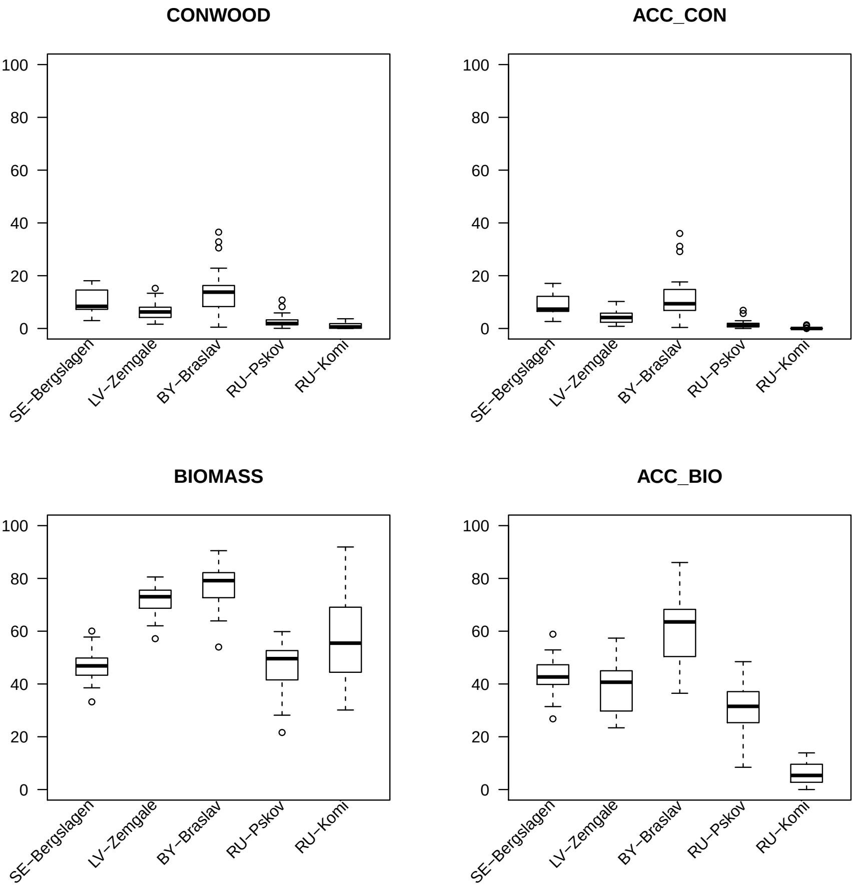

Figure 5: Production indicators in the 5 study areas with think lines as medians, low and high box borders as lower and upper quartile respectively (paper II).

(n=40 in both countries), mesic (n=76 in Russia and n=57 in Sweden) and rich (n=40 in both countries) sites.Therefore, my results falsify assumption that young coniferous trees grow differently in Sweden and Russia at the same latitude and on the same soils.

4.4 Zoning policy dynamics in Russia

The forest loss increased in buffer zones with increasing distance to streams. The policy change lead to a 10-36% increase in annual forest loss within all buffers. Forest loss in headwater buffers was higher than in main rivers (Figure 9). In the surrounding landscape (>500 m from streams) the forest loss

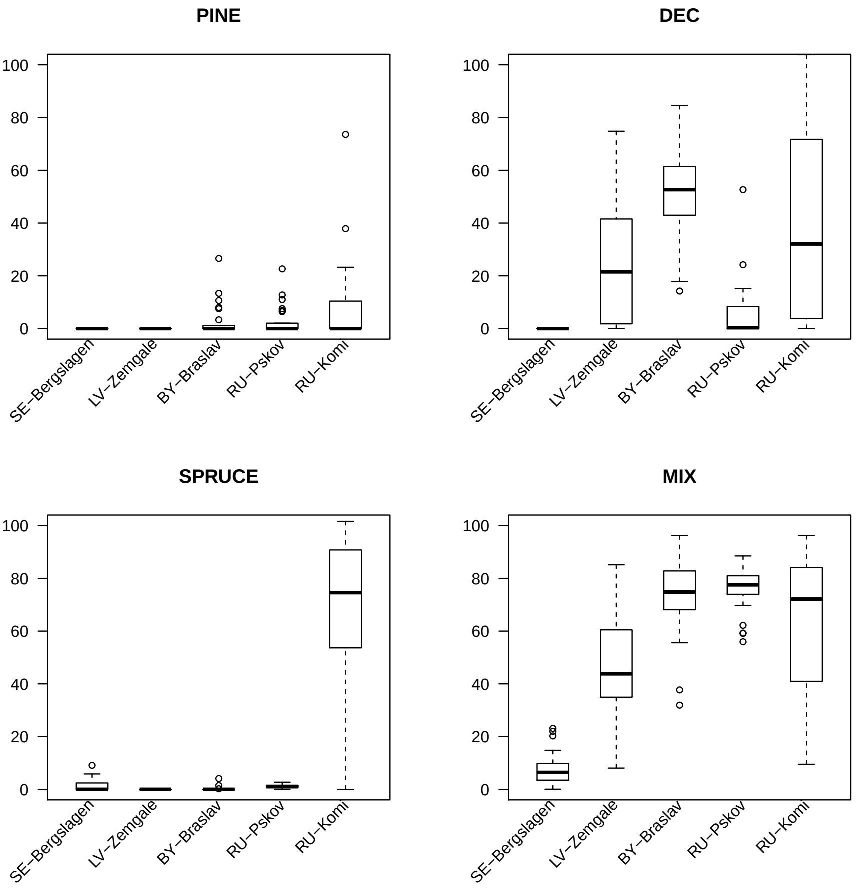

Figure 6: Biodiversity indicators in the 5 study areas with think lines as medians, low and high box borders as lower and upper quartile respectively (paper II).

actually decreased by 8.9%. At the regional level the ten catchments in the Komi Republic formed a gradient of forest loss (Figure 10). I identified four groups of catchments, which represent different stages of forest use history in relation to the advancing timber frontier in the Komi Republic (Table 4, Figure 2). The 10 catchments demonstrate a gradient in forest use history and still intact forests, as well as remoteness to the forest industry that consumes the harvested wood. For example, forests in the Ilych and Pechora catchments had low loss because there are a strict nature reserve and a national park there. On the other hand, forest loss in Luza and Sysola was high and increasing. This pattern illustrates that harvesting happens where sufficient road infrastructure is available.

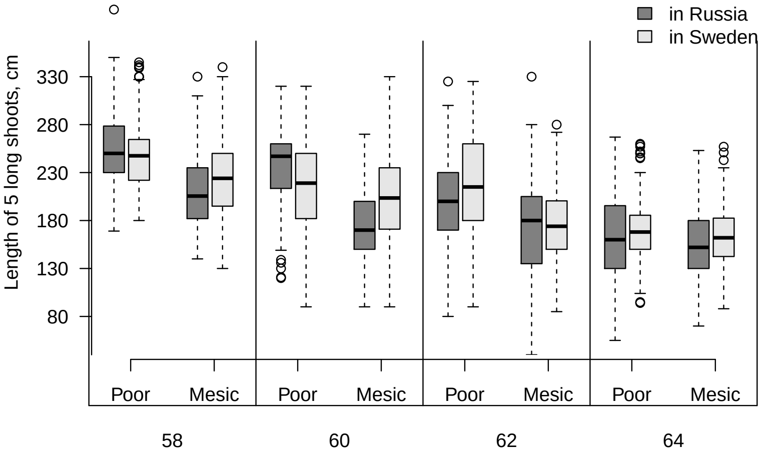

Figure 7: Length of 5 long-shoots of young Scots pine trees on poor and mesic site types. Boxes represent 50% of all observations while whiskers extend to the most extreme data points not exceeding 1.5 times of inter-quartile range of box. Outliers are shown as empty circles. Bold horizontal lines are medians. Sample size was 3000 trees (paper III).

Table 4: Four groups of different magnitudes of forest loss, and trajectories over time, among the 10 studied catchments.

	Low loss	High loss
Decrease in loss over time	Vishera, Vym (logging frontier passed in the 1980s; a correctional facility is the only large forest leaser in Vym)	Mezen, Vashka (logging frontier passed, attempts to protect large intact forest)
Increase in loss over time	Ilych, Pechora (very remote, very large proportion of protected areas)	Luza, Lokchim, Sysola, Vychegda (close to the only forest industry (Syktyvkar), no intact forest)

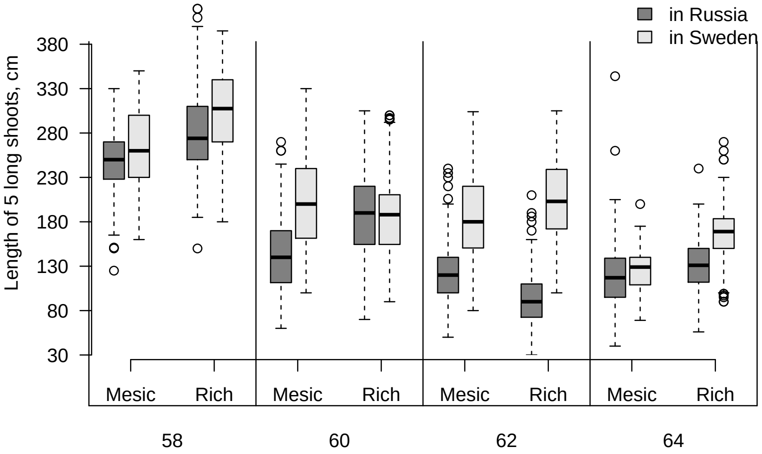

Figure 8: Length of 5 long-shoots of young Norway spruce trees on rich and mesic site types. Boxes represent 50% of all observations while whiskers extend to the most extreme data points not exceeding 1.5 times of inter-quartile range of box. Outliers are shown as empty circles. Bold horizontal lines are medians. Sample size was 3000 trees (paper III).

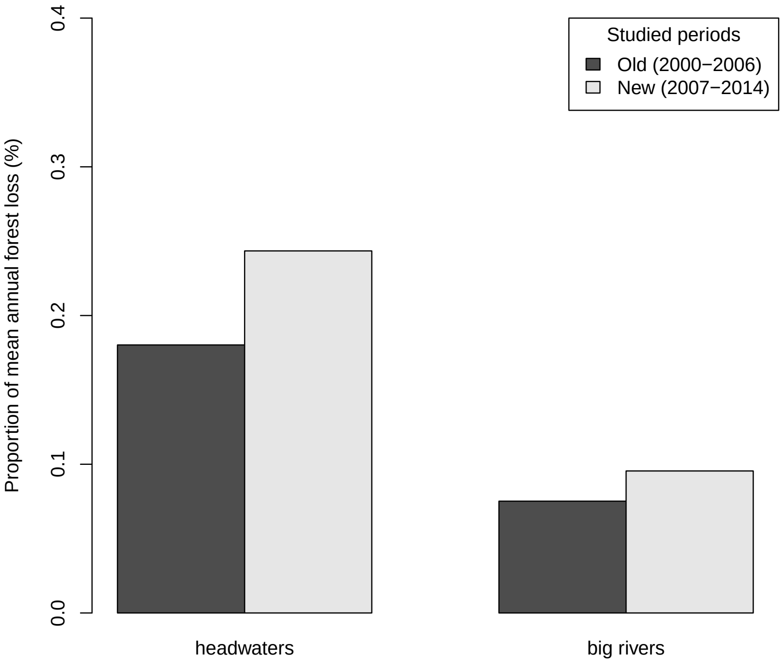

Figure 9: Proportion of annual forest loss at 0-200 m from headwaters and big rivers before and after zoning policy change (paper IV).

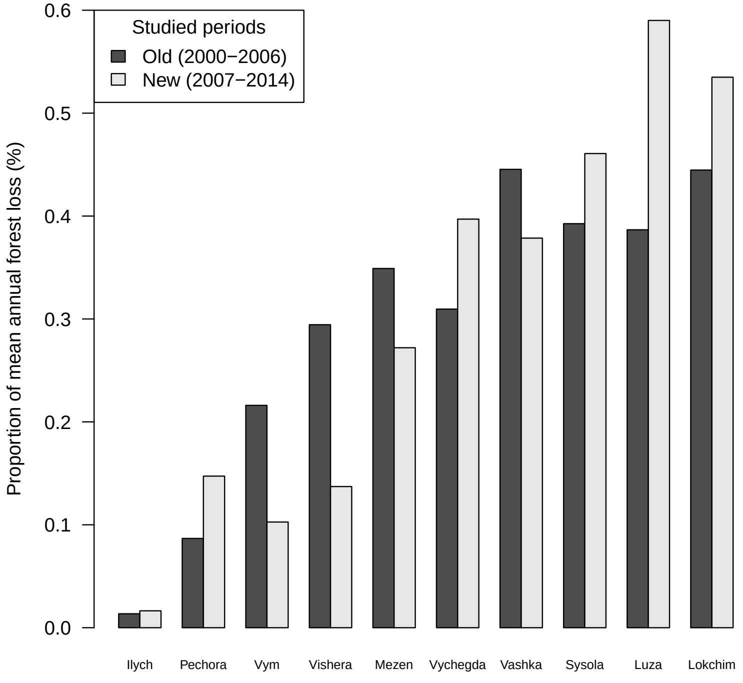

Figure 10: Proportions of annual forest loss in the 10 catchments ranked by the mean level of annual forest loss (paper IV).

5 Discussion and implications

5.1 Barriers and bridges

The results of this thesis reveal both barriers and bridges for wood production as well as biodiversity conservation in NW Russia's boreal forest. I found that intensification of forest management is hindered by poor road infrastructure (paper I). This is consistent with study by Holopainen et al. (2006) and Karjalainen et al. (2009). To tackle this barrier, better permanent roads should be developed. Due to clay and wet soils, seasonality of forest management should also be considered in road infrastructure planning. Another barrier is the very limited pre-commercial cleaning and thinning. This results in low stand volumes of trees (Knize and Romanyuk, 2006). Uncertainty regarding leasing rights and conservative mind-set comprise barriers to wood production in the social system (Table 6). While this is well known (Holopainen et al., 2006), there are discussions that the recent Forest Code potentially can allow privatization of forest land in the future (Колокольчикова, 2012). On the other hand, there are multiple opportunities for biodiversity conservation in NW Russia (Table 6). The severe obstacle is relaxed legislation for conservation of riparian forests, so called forest zoning policy. The size of protective buffers along rivers decreased from 500 m to 200 m in 2006 (paper IV). This is a trend towards returning to wood mining again (Knize and Romanyuk, 2006). This is also confirmed by (Кобяков et al., 2013). The current zoning system provides a solid base for adapting it to different forest regions and areas with different anthropogenic footprint (Кревер et al., 2009). There are still sufficient levels of biodiversity in NW Russia (paper II) without need for investments to restore it like in Western Europe (Simonsson, 2016). The results of paper II show that NW Russia lead in terms of biodiversity. It is thus cheaper to keep what still exists than to restore. There have been several landscape approach initiatives (such as Pskov and Komi Model Forests) that successfully promoted different aspects of sustainable forest management policy. Similarly, forest certification in NW Russia aims at supporing economic,

Table 5: Barriers and bridges for intensified wood production in NW Russia.

Barriers	Bridges
Ecological barriers include Soviet legacies of large-scale harvesting which resulted in a very uneven age distribution, limited silviculture and insufficient transport infrastructure (paper I). Barriers in social system comprise conservative mind-set at the policy level, uncertainty for forest use rights and ownership and limited value-added production at local level (paper I). Wood production is inversely related with biodiversity conservation (paper II). Forest use history is short. Infrastructure is undeveloped.	Bridges consist of maintenance and development of forest zoning system, collaborative learning initiatives like Model Forest concept, as well as development of predictable rules and norms (paper I). There are no biophysical obstacles for intensified wood production in NW Russia (paper III).

ecological and social dimensions of forest management (Elbakidze et al., 2011).

Table 6: Barriers and bridges for biodiversity conservation in NW Russia.

Barriers	Bridges
Logging rates in NW Russia were inversely related to the distance from streams, and increased after the zoning policy change in the buffer zones (paper IV).	Countries with shorter forest use histories have higher levels of biodiversity (paper II).
Forests in headwater buffers were harvested more than along larger rivers (paper IV).	Harvest rates in the catchments near forest industries were higher and increasing, remote catchments had lower forest loss (paper IV).
Previously unharvested riparian forests in NW Russia are decreased by changes in zoning forest policy (paper IV).	Bridges consist of maintenance and development of forest zoning system, collaborative learning initiatives like Model Forest concept, as well as development of predictable rules and norms (paper I).

5.2 To integrate or to segregate?

There is debate whether to integrate or segregate forest functions in order to implement sustainable forest management policy (Bollmann and Braunisch, 2013). What approach to choose, depends on the forest use history, land ownership and ideology (paper I). Forest zoning implies dividing a forest management unit into several zones which have specific functions, e.g., for wood and biomass production and for biodiversity conservation. The TRIAD approach offers zones for (a) intensive sustained yield wood production, (b) long-term conservation of intact forests, and c) low-intensive alternative silviculture (Seymour and Hunter Jr, 1992). Integrated approaches implies that wood production and biodiversity conservation happen on the same area and are done by selective cuttings as well as retention forestry or continuous cover forestry (Pommerening and Murphy, 2004). The solution is obvious if no pristine forests are left, and state interests hinder long-term development in forestry. The same is valid if all forest land is split into many small parts with many different forest owners. However, NW Russia still can fulfil both goals because of its short forest use history, which means that some pristine forests still remain (paper I). There are silvicultural tools and experience from Sweden about how to increase wood production efficiently. This includes scarification, pre-commercial thinning, fertilization and improved seed/plant material. In order to achieve sustainable forest management policy Russia needs to intensify wood production. Because young coniferous trees have the same growth rates in the European boreal forest's west and east, it is possible to apply Fennoscandian silviculture in Russia (paper III). At the same time Russia needs to keep its zoning system as means of conserving biodiversity. However, more relaxed zoning policy has reduced the amount of riparian forests, which negatively affects biodiversity (paper IV).

Wood production and biodiversity conservation are conflicting goals. Countries with long forest use history have lower biodiversity but higher possibilities for wood production (paper II). Using areas or countries with different forest use histories it is possible to model expected outcomes for different management scenarios. Thus, this thesis contributes to understanding the current state of economical and ecological dimensions of forest management in Sweden and NW Russia at forest management unit scale. However, further research is needed to understand how countries with multiple forest owners (such as Sweden) can develop efficient conservation strategy which satisfies also economic dimension of forestry (Andersson et al., 2016). Ultimately, application of the two management strategies is context dependent. Zoning, or the segregation approach, is efficient for large area owners, while integrative approaches might be useful where many interests exist in the same place.

5.3 Practical implications

With a short forest use history and a single forest owner, a segregative approach to forest management is an efficient method for achieving conflicting management aims. The results of this thesis suggest that Russia should keep its zoning policy with strengthened emphasis on biodiversity conservation. The same conclusion is valid for rural development whereby zoning of forest landscapes can benefit many forest villages in NW Russia by providing access to non-wood forest productions such as hunting, fishing, berry and mushroom picking (Stryamets et al., 2015). Next, the Fennoscandian experience can be used to develop own economically efficient sustained-yield forestry model. There is a positive trend in terms of increasing areas of middle-aged forests; focusing on deciduous stands on productive soils is a good base for intensification. Old-growth spruce forest along rivers and streams have good chances to remain as a protective zone for streams and for forest biodiversity (paper I). On the other hand, transport infrastructure has to be developed and maintained in harvested forest areas. Another factor to consider is Russia's leasing system which allows forest management during 10-49 years. Collaborative learning is needed to change the mind-set of Russia's decision-makers in order to make forest policy more transparent for all stakeholders. Anyhow, the changes will take some time before we can see results. Here, adaptive forest management can applied to test how new silvicultural system works. Initiatives such as Model Forests and forest certification are examples of tools that can bridge the observe barriers and facilitate sustainable policy implementation.

On the other extreme of the European forest use history gradient, Sweden should consider segregative forest management approaches (paper IV) because intensified wood production negatively influences forest biodiversity at the landscape level (Ranius and Roberge, 2011). Furthermore, the most demanding species require dead wood amount and quality that does not exist either in intensively or conventionally managed forests (Ranius and Fahrig, 2006). To encourage zoning there are several options. In Sweden several attempts were made to implement zoning at some degree. The ASIO-model was proposed to classify different site types and regions by the natural occurrence of fire (Angelstam, 1998). This model distinguishes three main disturbance regimes: 1) gap-phase Norway spruce dynamics, 2) deciduous successions, 3) multi-cohort Scots pine dynamics. The ASIO-model thus allows for a more natural division of forests for conservation and production that mimics the natural distribution of disturbance regimes in relation to the site type (Simonsson, 2016). The state-owned Sveaskog forest company initialized a system of forest landscapes called Ekoparks to set-aside representative areas. In these areas low intense forest management is practised. While efficient locally, still Ekoparks system cannot be deployed in the whole Sweden due to varied forest owner pattern. To deal with complex forest ownership pattern, collaborative learning may be needed (Angelstam et al., 2013). However, at present in Sweden societal learning is not systematic and requires transdisciplinary research (Axelsson et al., 2013).

6 Conclusions

First, this thesis shows that application of an environmental history approach applied to coupled socio-ecological systems makes it easier to reveal barriers and bridges for sustainable forest management (paper I). Second, portfolios of indicators for wood production and biodiversity are important to understand current condition of forest ecosystem (paper II). Based on my research I found that NW Russia performs better at biodiversity conservation than at wood production in comparison to countries with longer forest use history (e.g. Sweden or Latvia). This comparative approach can be used in future studies to find balance between conflicting management aims. Sweden was best at efficient wood production, while NW Russia's study area has good opportunities for biodiversity conservation. Third, Fennoscandian forestry models can indeed be adopted to intensify wood production in Russia because there are no biophysical obstacles (paper III). Finally, in order to find balance between economically efficient wood production and biodiversity conservation zonation to different functions of a forest landscape is efficient tool for biodiversity conservation (paper IV). Barriers for intensified wood production in NW Russia include poor road infrastructure limited silviculture and conservative mindset of decision makers. Bridges involve similar biophysical conditions for tree growth (Scandinavian experience can adapted in NW Russia), availability of middle-aged forests suitable for wood production and existed infrastructure of forest villages. On the other hand, barriers for biodiversity conservation is relaxed forest zoning policy that decreased the maximum size of protective zone to 200 m. Nevertheless, opportunities for biodiversity conservation in NW Russia consist of developed zoning system, landscape initiatives (such as Model Forests) and still intact forests.

I argue that NW Russia and Sweden can both benefit from collaborative learning about how to intensify forest management (Anonymous, 1999; Anonymous, 2011). 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 approach should be considered. To ensure 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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