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Barriers and bridges for intensified wood production in Russia: Insights from the environmental history of a regional logging frontier

Vladimir Naumov*, Per Angelstam, Marine Elbakidze

Forest-Landscape-Society Research Network, School for Forest Management, Faculty of Forest Sciences, Swedish University of Agricultural Sciences, PO Box 43, 739 21 Skinnskatteberg, Sweden

*corresponding author

vladimir.naumov@slu.se, per.angelstam@slu.se, marine.elbakidze@slu.se

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*Abstract
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Highlights:

1) Intensification of forestry requires understanding of social-ecological systems.
2) Frontiers of wood mining have led to regionally un-even stand age distribution.
3) Ideological dynamics has caused temporally unstable forest governance.
4) Barriers for intensification include institutional uncertainty, wood mining history, and poor infrastructure.
5) Bridges include establishing predictable rules and norms, and zoning at multiple scales.

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Keywords: Wood production, intensification, Russia, boreal forest, environmental history, forest management policy

1. Introduction

Boreal forests have the largest area among all forest biomes in the world (McLaren & Turkington, 2013), and provide essential renewable wood resources used for value-added production of considerable economic benefits for businesses, the state and employment in rural areas. Growing markets at regional, national and international levels demand more forest products, including both wood and bioenergy. Boreal forests also provide other ecosystem services necessary for biodiversity conservationand human well-being (Молчанов, 1961; Ваганов *et al.*, 2005; Stryamets *et al*., 2015). In addition, the sustainability of boreal forests for mitigation and adaptation to climate change has also been highlighted (Carlson *et al.*, 2009). Satisfying this complexity of benefits is a challenge for implementation of sustainable forest management in boreal forests, of which Russia hosts the majority (Anonymous, 2012b).

The development of forest management systems ranges from extensive to intensive (Duncker *et al.*, 2012). This gradient is uniquely well represented from West to East in the European continent's boreal biome. After initial wood mining in boreal Fennoscandia during the 19th century, intensive forest management has restored forest landscapes as wood production systems (Nordberg *et al.*, 2013). Being more remotely located, the wood mining frontier swept across NW Russia much later (Björklund *et al*., 2000; Yaroshenko *et al.* 2001).

Beginning with Peter the Great in 1719 (Редько & Редько, 2002), Russia's forestry consists of three distinct periods of societal change, which affected forest management. First, Russia developed into a major early provider of wood, amounting to about one third of world forest exports in the beginning of 20th century (Генверт, 1926), and encouraged sustained yield

forestry (Тюрмер, 1891). Second, after the Russian revolution in 1917, the socialistic ideology discarded economic factors (Knize & Romanyuk, 2006), which led to intense wood mining. Third, after the collapse of the Soviet Union 1991 market economy re-emerged which seeks to increase the yield of wood through intensification of forest management. There are thus two visions about forestry in Russia. The first is "wood mining", i.e. harvesting where the timber volume is highest and leaving clear-cuts for natural re-growth. The second sees forestry as "agriculture of timber", i.e. silviculture for maximum economical profit (Knize & Romanyuk, 2006).

There is a growing interest in Russia to increase the productivity of wood per unit area and time in already harvested areas (e.g., Nordberg *et al.*, 2013). Russia's forest industry aims for intensified wood production as an integrated part of sustainable forest management (Anonymous, 2013; Nordberg *et al.*, 2013). However, even if the ambition in Russia is to encourage intensive forest management (Elbakidze *et al.*, 2013) current Russian forestry practices can still be characterized as wood mining (Nordberg *et al.*, 2013).The Scandinavian model of intensive forest management is perceived by industrial forestry stakeholders in Russia as the best model for economically profitable forestry (Knize & Romanyuk, 2006). Consequently, there are attempts to introduce this forest management model in Russia. At the same time, Russia still hosts remotely located large intact forest landscapes (Yaroshenko *et al.* 2001; Potapov *et al.*, 2008), and there is opportunity to conserve biodiversity at near-natural levels in such areas. Intensified wood production is thought to solve several problems: (1) sustained supply of sufficient raw material for forest industry (Holopainen *et al.*, 2006), (2) protect pristine boreal forests from human intervention (Fredericksen & Putz, 2003), and (3)

mitigate societal issues like unemployment in logging villages and thus increased urbanization (Becker *et al.*, 2012).

Intensification of wood production has many definitions. The intensity of forestry may be described using both economic and ecological dimensions, which are generally inversely related (e.g., Bergseng *et al.*, 2012; Mönkkönen *et al.*, 2014). Economically, 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 (Sundberg & Silversides, 1988). Intensive forest management includes silvicultural operations aimed at increasing sustained yield wood production per area unit, e.g., scarification, planting or seeding, pre-commercial cleaning, fertilization and commercial thinning. The level of management intensity defines forest management approach (Duncker *et al.*, 2012), and can be sustained at multiple levels. Ecologically, intensification describes a higher degree of anthropogenic transformation of near-natural systems caused by forest management operations (Peterken, 1996; McRoberts *et al.*, 2012).

Countries with transition economies (Myant & Drahokoupil, 2011), such as Russia, share several challenges regarding the reformation of their natural resource use, governance and management (Holopainen *et al.*, 2006; Nystén-Haarala, 2012). This requires that past trajectories in landscapes and regions are understood. Human impact creates path dependence effects on both biophysical landscapes and societal legacies (Wilson, 2012). A wide range of scholars has therefore stressed the need to consider both social and ecological systems when studying implementation of policies about sustainable development and sustainability (Berkes and Folke, 1998, Liu *et al*., 2007, Redman *et al*. 2004). As a tool for extracting historical

lessons to help addressing today's challenges in forest landscape management and governance, Marsh (1864) very early stressed the need to study the transformation of the interaction of humans and the natural environment (Lowenthal, 2000). As an interdisciplinary field of research, environmental history is an appropriate framework for studying the dynamics of landscapes as social-ecological systems. The interest in understanding the history of landscapes as social-ecological systems has appeared in many contexts including studies in North America (Worster, 1994), South Africa (Beinhart, 1984) and in former European tropical colonies(Grove, 1989). Similarly, implementing sustainable forest management policy requires understanding the history of forest landscapes, including both their biophysical, anthropogenic and perceived dimensions (Angelstam *et al.*, 2013c). While there are numerous works on forest landscape history in different countries (Bürgi, 1999; Ericsson *et al.*, 2005; Hessburg & Agee, 2003; Steen-Adams *et al.*, 2015; Östlund *et al.*, 1997), practically no information exists on the historical dynamic of interconnections between ecological and social systems regarding Russian forestry.

The aim of this paper is to better understand barriers and bridges (see terminology in Gunderson *et al.*, 1995) for intensification of wood production in NW Russia by analysing past trajectories in a concrete representative region. Using regional and local logging frontier gradients from a large river to its headwaters in the Komi Republic as a case study we employ an environmental history approach for the period 1719-2014. First, we reviewed the forest use history, and re-created this in detail using spatial data for the period 1965-2014 when the timber frontier passed this region. Second, with a focus on the actors we reviewed the general forest use history during the entire period. Third, we analysed ideology behind the forest landscape history on international, state, regional and local levels for the same period. Finally,

based on the insights derived from the environmental history analysis, we discussed barriers and potential bridges for intensification of wood productionin both social and ecological systems in NW Russia.

2. Methodology

2.1 Framework

To understand barriers and bridges for forestry intensification landscapes' ecological and social systems need to be analysed. We used Worster's (2005) environmental history framework to study a geographical area as space and place: (1) natural environments of the past, (2) human modes of production, and (3) perception, ideology and value. This approach reflects the landscape concept's biophysical, anthropogenic and perceived dimensions (Angelstam *et al.*, 2013a; c).

The environmental history is strongly influenced by the contemporary political regime. Therefore the analysis was divided into three epochs of development in what is NW Russia today (Мунчаев & Устинов, 1998). These are the Russian Empire from the appearance of the first administrative body for forest managementin Russia (1719-1917), the Soviet Union (1921-1991) and post-Soviet Russia (1991-2014). Each epoch demonstrates different world-views having specific traits (see Table 1).

In the discussion we defined barriers to intensification as weaknesses and threats leading to ineffective forest management, and bridges in terms of current strengths and future opportunities to successfully intensify wood production. These barriers and bridges were defined based on the environmental history connecting ideology, actors and changes on the

ground in biophysical landscapes. One can thus see barriers and bridges (Gunderson *et al*., 1995) as a SWOT-analysis (Hill *et al*., 1997), but without division into present and future factors. Barriers and bridges were then sorted into those relevant for social and ecological systems, respectively.

2.2 Study area

The NW part of the Russian Federation has the longest history of timber frontier development in Russia's boreal biome. Already in the late 17th century most of NW Russia's large trees near large rivers were selectively logged for ship-building. Timber was exported to Great Britain through the seaport of Arkhangelsk, and since 1704 also through St. Petersburg (Редько & Редько, 2002). Since shipyards were located in the estuaries of Northern Dvina river in NW Russia, the expansion of logging took place gradually as a moving frontier in the upstream direction. A good example of this is Northern Dvina's largest tributary, the Vychegda river in the Komi Republic. Here industrial logging for local use commenced in the 18th century (Галасьев, 1961), and logging of large old trees and old-growth forests were intensified during Soviet period (Редько & Редько, 2002).

As a typical example of this moving logging frontier, we chose the Kortkeros rayon (an administrative unit of the second level in Russia) as a case study located in the catchment of the Vychegda river in the Komi Republic (Figure 1). The Vychegda river divides Kortkeros rayon into a northern and a southern part. The two tributaries of Vychegda in Kortkeros, Nivshera in the north and Lokchim in the south, both represent gradients in forest use created by a moving frontier of logging. Boreal forests in the Kortkeros rayon as in the Komi Republic are characterized by the tree species *Picea abies* (L.), *Pinus sylvestris* (L.), *Populus tremula* (L.), and *Betula spp*. Altitude ranges from 69 to 325 m a.s.l.

The Kortkeros rayon was established in 1939. The total area comprises about 1,970,000 ha (Турьева, 1989) which constitutes 4.7 percent of the Komi Republic. In 2012 population density was approximately 1 person/km^2 (Кудинова, 2012). Forest cover in the Kortkeros rayon is roughly 90 % and mires comprise about 7 % of the area (Anonymous, 2009). The whole rayon is one of six main logging territories in the Komi Republic (Шерстюкова, 2012). Kortkeros rayon contains 35 protected areas, which cover 15 % of the rayon and 6.3 % of the forest area excluding wetlands (Anonymous, 2011). Detailed analysis of changes in forest age distribution among site types was made within one of the forest management units in Kortkeros (Figure 1) comprising about 10 % of the total rayon area.

2.3 Methods and materials

2.3.1 What happened in nature

First, we analysed the forest use history at state (Russia), regional (Komi Republic) and rayon (Kortkeros) levels. A literature review was conducted with focus on logging, silviculture and other forest activities in the study area. The historical forest data was collected from the state forest surveys since 1965, including forest management maps, from the local archive at the Kortkeros municipal administration. The surveys contain information on age structure, species composition and standing wood volume, and reports about silvicultural measures for the past 10 years. The maps provide spatial data about tree species composition and mean stand age. Additionally, to understand the recent changes in the landscape a local history expert was interviewed, and three focus groups with forest landscape's stakeholders were arranged.

To describe biophysical landscape changes we did a detailed change detection analysis of age class distribution for the selected forest management unit from its establishment in 1965 to 2014. Östlund *et al.* (1997) stressed that forest surveys and maps from different time periods may have been done by different people with different methodology, knowledge and skills. However, forest inventories of 1965, 1979, 1981 and 1992 can be readily compared with each other. First, forest management maps for 1965 and 1992 were scanned and geo-rectified using 2^{nd} order polynomial transformation matrix with RMSE less than 10 m. Then, the maps were digitized using QGIS software (Quantum GIS development team, 2013). We used combination of dominant tree species and stand age as mapping category. The map of forest stands in 1965 was used as the base for the detailed analysis. The forest was divided into 4 categories depending on age: (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 forest (>71 yrs) (see Angelstam & Kuuluvainen, 2004). Second, in order to combine the data from forest inventories that were done according to different regulations, we used satellite images as a complement. Clear-cuts were visually digitized using forest management map (1965) as background 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, i.e. clear-cuts have stand age 0. This approach was applied sequentially for 1986, 1993, 2006 and 2014. In total we created 6 age distribution maps.

The forest inventory data for 1992 was used to map the spatial distribution of forest site types along a soil fertility gradient (Сукачев & Дылис, 1964; Hägglund & Lundmark, 1999). The forest site types were re-classified into 3 coarse site types: poor, mesic and rich. Poor site

types represent forest cover with lichens, *Calluna spp.* and shrubs on wet sites with lower rates of tree growth, mesic sites with *Vaccinium myrtillus* and *Deschampsia flexuosa* and rich site types with low and tall herb vegetation and high productivity. Finally, in order to see development of different forest stages and structures at smaller scale, the information from age distribution maps was aggregated by site type and presented as proportion to the initial land cover of the base map 1965.

2.3.2 Who did it

To identify the main actors that shaped the landscape, we reviewed regional and local literature about forest history in Komi as well as state statistical reports, forest management plans and archive documents. In order to collect information about local stakeholders we employed focus group interviews as qualitative method to understand opinions and extract knowledge about societal barriers to intensification of forest management (McLafferty, 2004). The method of focus group interviews implies that the organizer describes the topic in focus, then the role of the organizer is to facilitate the discussion among the participants, though not interfering in any way (Barbour, 2008). Three focus groups were organised with forest researchers and forest managers that represented the most active stakeholders of the Kortkeros rayon. Each group included 4-5 persons. Finally, we mapped decision-making actors, such as organizations who shaped the landscape history. There were two major actors who influenced the forest landscape history – the state and the private forest companies. Additionally, an interview with a local historian was conducted in 2013.

2.3.3 Ideology

Ideologies are linked to values and perceptions, which influence political and economic life of society. In our analysis we employed the left-right political differentiation to distinguish

between different ideologies. Ideology is often linked to aparticular economic system, e.g., planned economic system was supported by communistic (far left) ideology. This political gradient is believed (Jahn, 2010) to have roots in political theory and philosophy. Furthermore, left and right ideologies are divided by different attitudes towards equality (Bobbio, 1996). For example, left ideology seeks greater equality in society through action, and on the other hand right ideology presumes responsibility of individuals in society. Under left ideology the state tries to overcome inequalities in society by direct involvement whereas right ideology understands inequalities as a natural social phenomenon. However, no ideology can be distinguished as pure right or left. In our study it ranged from communistic (left) to liberal (right), as well as mixed. Analogously, liberalism promotes the primacy of the individual when freedom, individualism and rationalism constitute the most important values and beliefs. In contrast, communistic ideology emphasises community, equality and common ownership as keystones of societal development (Heywood, 2012). Analysis of the ideologies behind forest landscape changes was made using data from literature review, interviews and focus group discussions. The focus was on understanding (1) what interests different actors and stakeholders pursued, (2) what values the forest management decisions promoted, and (3) what market structure dominated in the study period (Table 2). Based on this we drew conclusions about left, centric or right wing ideology during the three different epochs.

3. Results

3.1 What happened

Before and during the Russian Empire period (the first epoch;Table 1) large Scots pine trees along the rivers were harvested by single-tree selection for ship-building. 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). Season also influenced logging. Due to flat and boggy terrain in the study area, winter was the best time for logging, in summer the conditions were worse, and in autumn and spring terrain transportation was impossible (Ермилов, 1888). Timber logs were rafted on the main river Vychegda, then by the North Dvina river to the 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, and thus the pressure on naturally dynamic forests by wood logging increased.

During the Soviet Union period (the second epoch) the land and forest were nationalized. Forest was harvested mainly for fuel-wood during civil war 1918-1921. A great increase in wood harvesting happened in the period from 1937 to 1940 when units in a prisoner camp system (GULag) were established in the Kortkeros rayon (A. Smylingis, pers. comm.). The wood was transported both outside of Kortkeros and the 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 (Галасьев, 1961). As a consequence, old Norway spruce forests were naturally replaced with birch and aspen on mesic and rich sites. However, Scots pine recruited well after large clear-cuts on sandy soils.Russia was involved into World War II in 1941. Logging slowed down and was concentrated near villages and rivers. After the war Russia aimed to restore the economy. 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 (Figure 2).

During the post-Soviet Russia period (the third epoch) from 1991, after the collapse of the Soviet Union, the harvest level in Komi decreased rapidly, and dropped down by 81% to 5 million m^3/year in 1998. This coincided with the Russian financial crisis in 1998, also called the Russian Flu. Afterwards, wood harvesting recovered to about 9 million m^3/year. Wood harvesting in the Kortkeros rayon followed the same pattern as in the entire Komi Republic (Figure 2 and 3).

Regarding the consequences of forest resources use for forest age distribution, our analyses show that the amount of middle-aged forest available for commercial thinning increased continuously since 1965 (Figure 4). Poor sites dominated (62 % of total area), followed by mesic (36 %) and rich (2 %). The age distributions on poor and rich sites were similar, but the area of forests on mesic sites changed less due to their remoteness from transport infrastructure.

3.2 Who did it and how

Noble persons and tsar servants employed peasants from nearby villages to cut the wood by hand. After creation of the Russian state forest service in 1719, the forest was managed for sustained yield in some central Russian estates, including logging under supervision of state officials (Table 1). Forest land was also sold to private companies who managed it themselves, usually including logging as the only forest management operation. In Komi, metallurgical factories in Kazhim (about 300 km from Korteros) and Njuvchim (about 90 km away) employed peasants from Kortkeros to harvest forest for the process of converting ore into metal (Галасьев, 1961).

In the beginning of the second epoch 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 industry needs. 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 that provided free labour, and was used as a role model (A. Smilingis pers. comm.). The GULag system existed until the death of Stalin in 1953 when the political leadership was changed. Starting from the end of the 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 (Anonymous, 1966). Mechanization greatly increased wood harvest and facilitated forest work. The establishment of logging camps contributed to a strong forest industry. Some of logging camps formed the base for temporary forest villages where the logging was the main occupation of local population. Additionally, construction of pulp-mills in Kotlas (350 km downstream from the study area) and Syktyvkar (50 km from the study area) in the 1960s and 1970s has greatly influenced wood harvesting in the study area.

During the third epoch private companies became responsible for forest management, including logging on forest areas that they have leased for 10-49 years (Anonymous, 2006). There are international forest companies operating in Komi such as Mondi international packaging and paper group as well as many small-scale forest businesses. The logging companies introduced modern technologies in forestry in terms of cut-to-length with harvester-forwarder logging groups. International and especially European markets influence

forestry in Russia. For example, forest certification was adopted by these private forest industries.

3.3 Ideology

During the entire three epochs the ideology behind the environmental history swung between right, i.e. liberalism and market economy, and left, i.e. communism and planned economy. The very first industrial interest in wood harvesting was grounded in upgrading military and trade functions requiring wood products (Table 1). Thus, mainly state interests were addressed in the decision-making process. The tsar Peter the Great was interested in building a strong independent Russia with access to the European market for Russian products and foreign imports. Forests in Imperial Russia were mostly state-owned, only a small part belonged to noble people and private companies.Market economy that served the interests of the Tsar and the rich landowners (private sector) dominated. Thus sustained yield forestry was advocated (Орлов, 1927).

In contrast, during the second epoch in the 1930s the sustainableforest use concept was considered as foreign sabotage term aimed to stop industrialization in the Soviet Union (Knize & Romanyuk, 2006). As a result of a 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 was cut (Knize & Romanyuk, 2006). All forests became public, and market economy changed to planned (see Table 2). Industry enterprises were consolidated to increase logging efficiency, and in 1931-1935 forest management units (Russian term: lespromkhoz) were created (Редько & Редько, 2002). To protect the Soviet economy during World War II forestry changed its course to being military-oriented. Exported goods were reduced, wood was produced for the army and heating. In

1943 zoning was introduced, where forests were designated for protective, multiple-use or industrial production functions. The Soviet Union's economy underwent severe changes in 1965, also called as the Kosygin or Liberman reform (Pejovich, 1969). This reform was characterized by introducing market economy methods of management when whole state enterprises were given rights to managetheir own economy. Forest management units were reorganized into integrated units (Russian term: leskhoz) that fulfilled harvesting and silvicultural (planting, cleaning, protection from diseases and fire-fighting) functions. This was a clear step to decentralization of the economy, which resulted in further increase of wood harvest. The second epoch was characterized by state (public) interest in forest management.

During the third epoch the Russia's government changed its course to right-wingmarket economy and liberal ideology again. Today market forces steer wood harvesting and forest management. Focus groups revealed that values as individualism and rationalism dominate in the modern forest management in Kortkeros. The market economy principles were introduced into the Forest Codefrom 2006 and forestry regulations. State forest management units have just control and monitoring functions (Anonymous, 2006). All forest management operations were delegated to the companies who lease forest. However, the state still definesand controls its policy through plans to forestry operations using regional level forest management documents and also for each FMU. Thus, since the state still owns all the forest land in Russia, it promotes public interests along with private interests of forest companies.

4. Discussion

4.1. A dynamic environmental history

There are numerous studies debating intensified wood production, however, very often with an economic (Gerasimov & Karjalainen, 2008, Карьялайнен, 2009), social (Nystén-Haarala, 2012) or biodiversity focus (e.g., Eriksson & Hammer, 2006; Шматков, 2013). Hence, economic, social and ecological aspects of intensification are considered independently from each other. By analysing empirically the environmental history of forest landscapes as integrated social-ecological systems, this study presents a holistic problem-solving approach to better understand barriers and bridges for intensification of forest management in NW Russia (Hadorn *et al.*, 2008). From a scientific perspective environmental history and integrated studies of social-ecological systems are two research approaches that allow simultaneous inclusion of social systems (based on for example institutional analysis) and ecological systems (based on thorough understanding of silvicultural improvements). This case study approach thus demonstrates concretely also the general scientific benefits of employing the approaches.

Our review shows the forest landscape history in the Komi Republic and its Korteros rayon has been complex, and has gone through at least three distinct epochs that differ by the governing ideology. The biophysical landscape was first shaped by the social system through relatively soft alterations in terms of single-tree selection harvest in the naturally dynamic forest (the first epoch);then with severe changes of forest cover due to intensive wood mining (the second epoch),and continued wood mining at a lower rate (the third epoch). The interest for wood production among actors (see Krott, 2005) remained constant across all three epochs, although the means were different. Our study shows that during the period of planned economy wood mining based on governmental subsidies to cover the costs of harvestingand

414 transportation, and with no investments in silvicultural treatments, was unsustainable and
415 resulted in timber fall (Drushka, 2003). Thus, when the epoch of wood mining in landscapes
416 dominated by old and old-growth forest was over, the sustained yield dropped.
417
418 We argue that ideological dynamics has caused temporally unstable forest governance.
419 Political ideology does not reflect only interests of actors involved into shaping forest
420 landscape in NW Russia, but inspire political action causing changes on the ground. With the
421 formation of USSR and its communistic ideology the central government reached very high
422 harvest levels which were impossible in decentralized tsarist Russia based on the sustained
423 yield principle (Тюрмер, 1891; Орлов, 1927). As the main actor and the only owner – the
424 Soviet state – was interested in maximizing economic profits. However, the Soviet epoch
425 ended with the collapse of planned economy and, consequently, the forest sector. These
426 ideological circumstances and new market forces had big effects on forestry. The harvest
427 level began to drop even before the start of the third epoch (1991-2014) caused by political
428 changesled by Gorbachev (Boettke, 2002). Today, the forest owner is state, but forest
429 management and harvesting is done solely by private forest companies based on a leasing
430 system. After the Russian financial crisis in 1998 forest companies gradually increased
431 harvest levels, but at a much lower level that during the Soviet epoch.
432
433 The analysis of environmental history clearly shows the urgent need to understand not only
434 technical aspects of forestry, but also past trajectories in social-ecological systems. Next, we
435 discuss barriers and bridges to intensification regarding the ecological system in terms of
436 silvicultural treatments after the wood mining logging frontier has passed in different

development stages after wood harvest, and the social system including transport infrastructure, norms and governance.

4.2. Barriers to intensification

To increase the sustained yield of wood the current focus is to intensify wood production on areas which were previously harvested, and which are accessible. Regarding the ecological system this requires forest management that includes silvicultural methods in terms of for example scarification, planting or seeding, pre-commercial thinning and even fertilization (Elbakidze *et al.*, 2013). To pay for these costs, commercial thinning usually delivers inadequate financial net values (Brukas & Weber, 2009). Thus also sufficient amounts of forests available for final felling are needed to provide a sufficient net income that can pay for silviculture in younger stands. Our study shows that in Kortkeros, as in most of NW Russia, the uneven age forest distribution with domination of large areas of middle-aged forests is a major challenge (Figure 5). In addition, different developmental stages have particular barriers.

Regarding young forests forest companies in the Komi Republic do not implement pre-commercial thinning in a way that increases the stand volume of commercially valuable trees. In Russia the pre-commercial thinning is done by the so called corridor method (Anonymous, 2007). This means that 3-5 m wide corridors are cleaned, separated by un-cleaned strips of 16-120 m. This silvicultural practice can be improved using experience of Nordic countries by introducing regular spacing of trees in the entire stand. However, at the national level there are legislation obstacles which do not allow adjust silvicultural norms to the regional conditions (Романюк, 2013). This may result in inefficient forest management and failure to intensify wood production on the ground.

461

462 Regarding commercial thinning in middle-aged forests as an element of intensive forestry,
463 innovative projects and demonstrations of commercial thinning do take place in Komi
464 (Anonymous, 2012a). Nevertheless, more that 95 % of the wood delivered to the industry
465 comes from final fellings (Козубов & Таскаев, 2000). For instance, area of cleaning and
466 thinning never exceeded 1 % of total area of Kortkeros FMU (Naumov, 2014). The amount of
467 middle-aged forest increased on all site types in the Kortkeros study area. The abundance of
468 poor and mesic site types provide good opportunities for intensification, both by providing
469 additional wood volumes today, but also improving the proportion of larger trees in the future.
470 Unless used, this resource will partly disappear due to mortality and lost growth from
471 competition among trees.

472

473 Concerning final felling forests, those are today located far away from the current permanent
474 road network (Aksenov *et al*., 2002). Additionally, some forest areas are protected and
475 therefore are not available for logging. These territories include protected areas and forests
476 along rivers and wetlands. Due to extended conservation efforts in the 1970s the area of final-
477 felling and old-growth forest has slightly increased on rich site types which are located along
478 the rivers.

479

480 Regarding the social system, the opportunity for introducing of active forest management
481 based on cleaning and commercial thinning requires longer leases. This is possible only for
482 financially strong and big businesses. Small-scale businesses have no access to this market.
483 At the local scale, forestry in Kortkeros has experienced the same new trends. Intensified
484 forest management requires also a permanent transport infrastructure, which is available not

485 only for harvesting ("lesovoznayadoroga" in Russian), including winter roads, rail-roads and
486 river log floating, but also for silviculture during the snow-free season
487 ("lesokhozyaystvennayadoroga" in Russian). Technically, there are opportunities for road
488 construction of the latter type. In the Kortkeros study area there is much sand which can be
489 used as building material for forest roads (Anonymous, 2009). In road planning hydrological
490 conditions play an important role, therefore mapping of small rivers, creeks and bogs is
491 needed. To find the best locations for roads it is necessary to make spatial analyses of the
492 study area with both economic and ecological perspectives (Seiler & Eriksson, 1995). Finally,
493 zoning of different road categories is highly relevant for the study area where natural
494 conditions for forest growth are not homogeneous. Additionally, transport cost to remotely
495 located, not yet harvested, areas need to be considered when investing in roads for harvest
496 only, or also for silvicultural treatments (Кривошеин, 2013). However, the costs are high, and
497 there are uncertainties regarding ownership and long-term maintenance. In Kortkeros rayon
498 neither the stand age distribution, nor any history of value-added wood production beyond
499 saw-milling, is favourable for intensification.
500
501 There are several other barriers that inhibit the process of intensification at the level of the
502 Russian Federation. Legislation on wood production, debated regularly among practitioners
503 and experts (Романюк, 2013), is another issue. Moreover, public participation has not been
504 developed, thus creating conflict between forest industry and rural villages (Oksanen et al.
505 2003). Pappila (2013) highlights that public participation, such as in forest certification will
506 help to build trust in Russia's forest sector. Lack of information on up-to-date national and
507 international research and practices of intensified wood production is also considered as a
508 barrier to intensification (Шматков, 2013).

4.3. Bridges towards intensification

So far, Russia's forest industry development has focused on the boreal regionas the focal ecological system. However, while the boreal biome was good for wood mining in landscapes once dominated by old and old-growth forests with large growing stocks, due to shorter vegetation periods and poorer soils, this biome is less suitable for intensification in the long term. Rather, more southern regions should be the focus for intensification because coniferous species such as Scots pine and Norway spruce grow faster in the south than in the north (Hägglund and Lundmark, 1977). Therefore, the main focus of intensification in Russia ought to be concentrated to south and hemi-boreal forest ecoregions at lower latitudes where for instance the Russian regions Pskov, Novgorod and Tver are situated. The shift in focus from wood production in north boreal to hemiboreal regions that took place in Sweden during the 20th century provides valuable experiences (e.g., Nylund, 2009). Today, the highest volumes per hectare in Sweden are harvested in the southern part of the boreal biome (Skogsstyrelsen, 2013). Indeed, after the first national forest inventory 1923-29 in Sweden Jonsson and Modin (1938) estimated how much, how and where the sustained yield of wood could increase. They concluded that by far the strongest increased could be achieved in southernmost Sweden, and not by intensification in northern regions that had been subject to the wood mining frontier.

To deal with barriers linked to poorly developedsilvicultureseveral social system bridges need to be addressed. For example, Nordberg *et al.* (2013) proposed to develop models to financially support intensified forest management of young and middle-aged forests. For example, when Sweden made the transition from wood mining to sustained wood production, economic and educational policy instruments were used in different stages of stand development after final felling, and financed both by private and state actors (Hagner, 2005).

Moreover, to satisfy economic, ecological and social dimensions of sustainable forest management policy, spatial planning of landscapes and regions are needed (Andersson *et al.*, 2013). Fortunately, to some extent the combination of a history of landscape use with large variation between logged areas and intact forest landscapes (Aksenov *et al.*, 2002), and approaches to forest zoning to satisfy different functions, has made Russia pre-adapted to applying segregated approaches to derive multiple forest benefits on the regional level. Indeed, in 1943 a forest zoning concept by dividing forests into three groups was introduced in the Soviet Union (Галасьев, 1961; Козубов & Таскаев, 2000; Редько & Редько, 2002). The first group included protected valuable forests around cities, along rivers and roads; the second group forests in high-populated regions with restricted level of logging to annual increment; and the third group unlimited harvesting of final felling of old and old-growth forests was allowed. Indirectly this provided significant contributions to maintaining biodiversity by minimising harvests on rich sites near streams and rivers. In reality this was similar to the TRIAD concept whereby forests are separated into protected areas, multifunctional areas under ecosystem management, and intensive management (Seymour & Hunter 1992). Using the zoning concept, intensive forestry could be done on areas within economically acceptable transport costs. However, the new Forest Code from 2006 partly changed the logic for zoning. The first group became a protected forest zone with more detailed restrictions. It is still completely prohibited to do any logging in strictly protected areas. It is however now allowed to make clear-felling and selective cutting in protective forest zones, e.g. along streams, when it is necessary for infrastructure development, and mining of minerals, oil and gas. The second "equal growth – equal harvest" zone of forests was removed. Finally, the third zone remained the same. Reserve zone forests emerged in

1997 where no forest management is allowed for the next 20 years (Anonymous, 2006). Additionally, in the reserve forests it is allowed to harvest forest for geological tests and for the needs of local inhabitants.

Ultimately, improving silviculture and transport infrastructure, and zoning, alone are insufficient bridges to achieve intensification of wood yields. Additionally, several other social system legacies need to be addressed. The conservative political mindset of Russia's decision-makers, tending to use mechanisms of Soviet governance, needs to become adaptive. For instance, there are still multiple top-down regulations and plans, which have to be followed at lower levels. In Kortkeros governmental forest management units and forest companies are obliged to the forest management policy at regional level including performance indicators, such as the amount of wood harvested and thenumberof planted trees. This strong subordination hinders implementation of intensive forest management on the ground. To bridge this it is necessary first to include ideas of forestry intensification into national policy and then implement them at regional and local levels (Шматков, 2013). Additionally, innovations originating from bottom-up processes need to be encouraged. Yet, road networks development, investments in pulp and paper mills, bioenergy plants and other large projects cannot be handled at local level, therefore coordination at higher levels of governance is necessary. This has to be done by deliberating policy reforms by including all interested parties and moderate state support, e.g., for construction and maintenance of forest roads, as made in Sweden to support sustained yield forestry (Nylund, 2009).The process of transforming Russia's forestry should, however, not be done without implementing explicit analysis to determine the economically optimal decisions. Such analyses should include

infrastructure limitations, labour market constrains, forest machine capacity constraints, regional market constrains and other non-local conditions (Lohmander, 2007).

5. Conclusions

Implementing policy about forestry intensification requires understanding of past trajectories in social-ecological systems. Since the 18th century Russian forest history can be characterised as wood mining. Today's age class distribution in the study area in the Komi Republic confirms this. Here logging frontiers have led to regionally un-even stand age distribution dominated by middle-aged mixed forest. Nevertheless, old-growth forest is preserved along the rivers as a consequence of the zoning concept introduced in 1943. A key observation is that ideological dynamics in the social system has caused temporally unstable forest harvesting volumes, the profile of key forest actors and forest governance. Barriers to forest intensification include the wood mining history, poor infrastructure and institutional uncertainty. Coping with these barriers require integrated approaches ranging from policy change to economic reforms. Bridges for intensification include maintaining the forest zoning concept, establishing predictable rules and norms, and focus on sustained yield wood production in regions with the best biophysical conditions. To conclude, there is a need for research of potential effectiveness of the zoning concept, especially in terms of new regulations in Russia's forest policy, and assessment of balance between intensive wood production, social forestry and conservation of forest biodiversity in boreal Russia.

Forestry intensification in the context of implementing sustainable forest management policy requires solutions in both social and ecological systems, which need to be integrated at

multiple levels ranging between local forest management unitsand the policy level. Environmental history and social-ecological system are scientific concepts that benefit the application of a holistic problem-solving approach. Together they allow simultaneous inclusion of social systems (based on for example institutional analysis) and ecological systems (thorough understanding of silvicultural improvements) to better understand barriers and bridges for intensification of forest management in NW Russia.

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878 Table 1. Main trends of forest landscape history in the Komi Republic with reference to national-wide historical events, divided into broad epochs and
879 their internal phases.

Epoch	Time period	Characteristics	What happened in nature? (Harvest level)	Who did it? (Forestry actors)	Ideology? (Left/Right)
Russian Empire	1719-1850	Ship-building, local iron and salt industries	Low	State	Centric/right
	1850-1917	International export of wood products	Low	State and private forest enterprises (foreign capital)	
Soviet Union	1930-1957	Industrialization and Gulag	Rapid increase	State (by prisoners)	Left (communism)
	1941-1945	WW2	Slowed down	State	
	1946-1975	Post-war reconstruction	Steady increase	State	
	1976-1989	Economic stagnation	Decrease	State	
post-Soviet Russia	1993-1998	Inefficient reforms towards market economy	Low	State and forest companies	Centric (in transition)

1999-2014	Gradual pickup	Small increase	Forest companies (also with foreign capital)

Table 2. Operationalization diagram (Mouton & Marais, 1988) of concept "ideology" used in this study

Concept	Variables	Operational definitions	Possible outcomes
Ideology	Interest	What interest did the forest managers pursue?	Private, public or civil
	Value	What values did the forest management decisions promote?	Freedom, individualism, rationalism – liberalism (right); Community, equality, common ownership –communism (left); and intermediate (centric)
	Market structure	What market structure dominated during the study period?	Planned economy, market economy

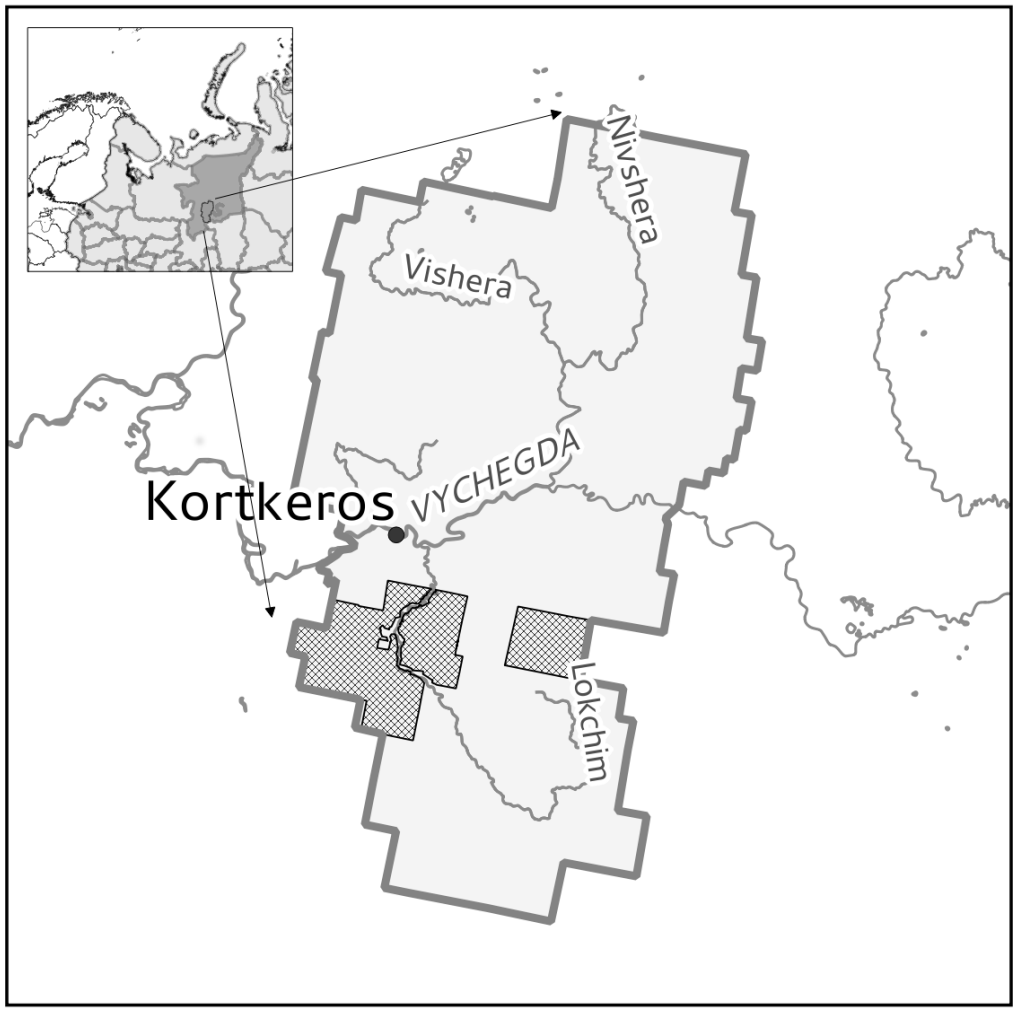

Figure 1. Map of the Kortkeros rayon study area in the Komi Republic with the area (hatched polygons) where spatial analyses summarised in Figure 4 were made. The inset map shows the location of Kortkeros rayon in NW Russia (Source of spatial data: www.openstreetmap.org).

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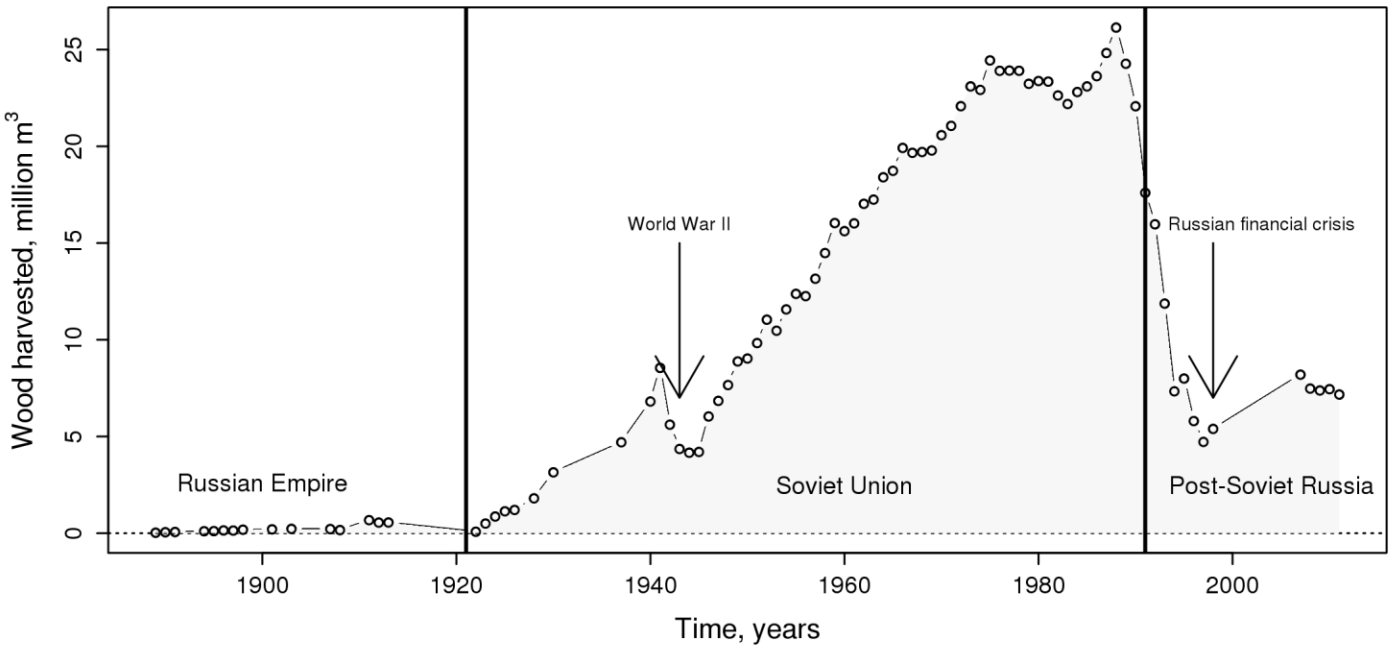

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912 Figure 2. Wood harvest in Komi Republic during the period 1889-2014. The forested area is 36 million ha. (Козубов & Таскаев, 2000; Юшкова,

913 2001; Шерстюкова, 2012).

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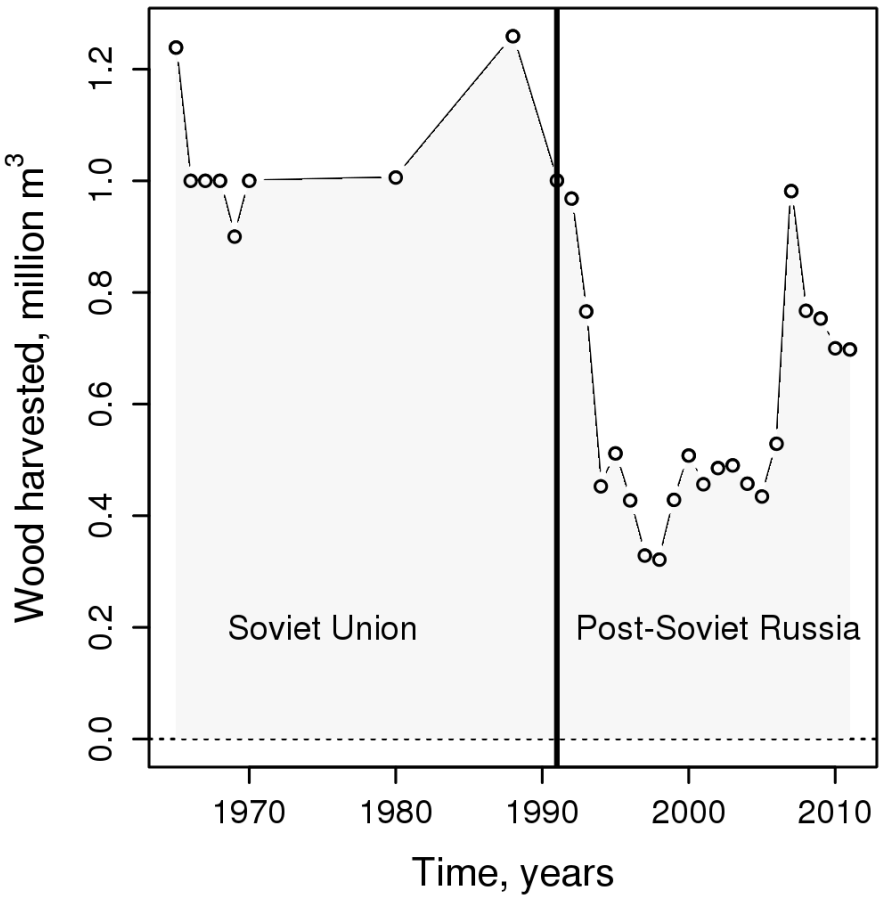
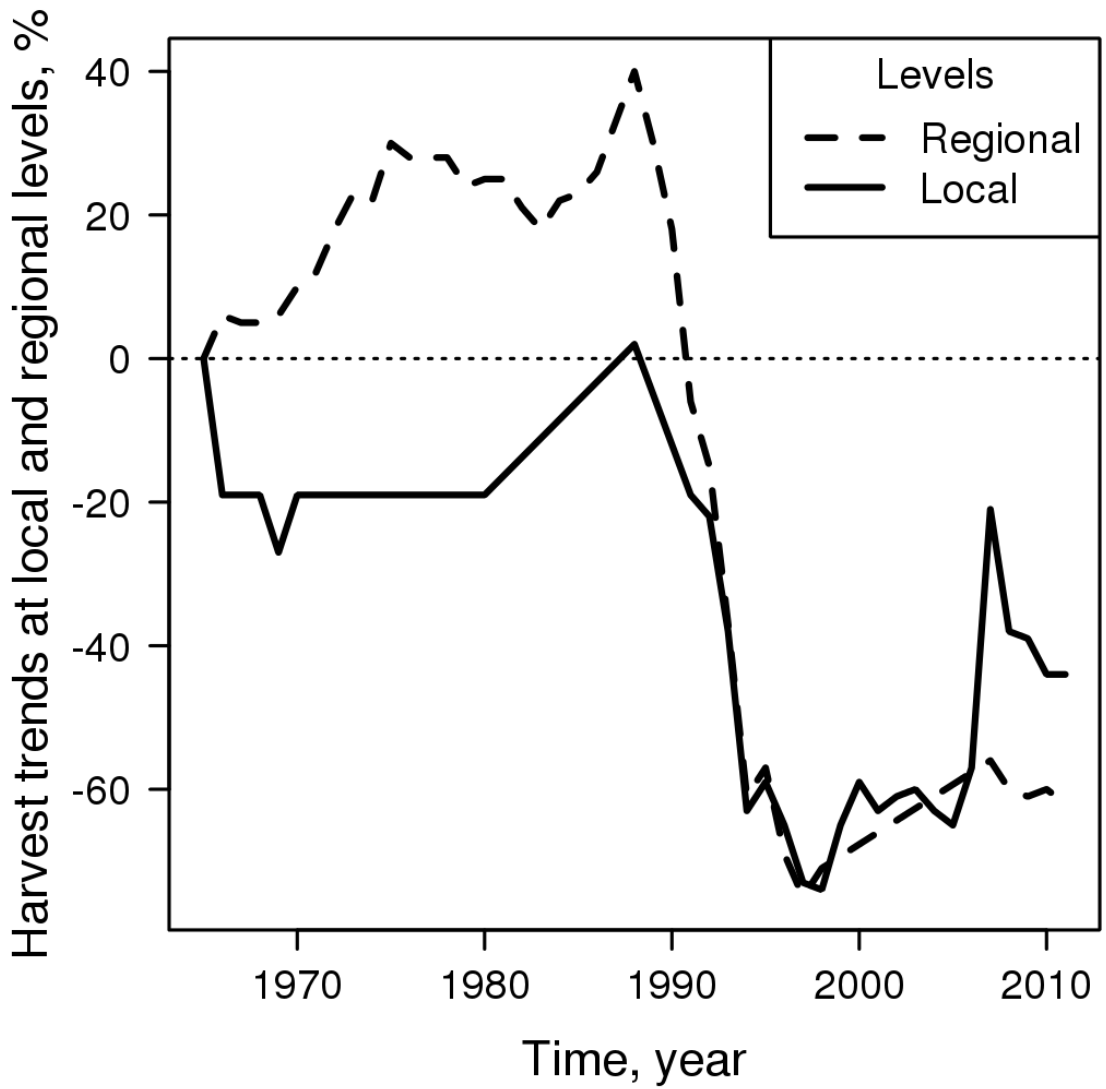


Figure 3. Wood harvest in Kortkeros rayon during the period 1965-2006 covering the end of the Soviet epoch and post-Soviet Russia. The forested area is 1.8 million ha (Anonymous, 1971, 2014; Турьева, 1989; Шерстюкова, 2012).



931 Figure 4. Harvest trends at local and regional levels relative to the reference 1965 year.

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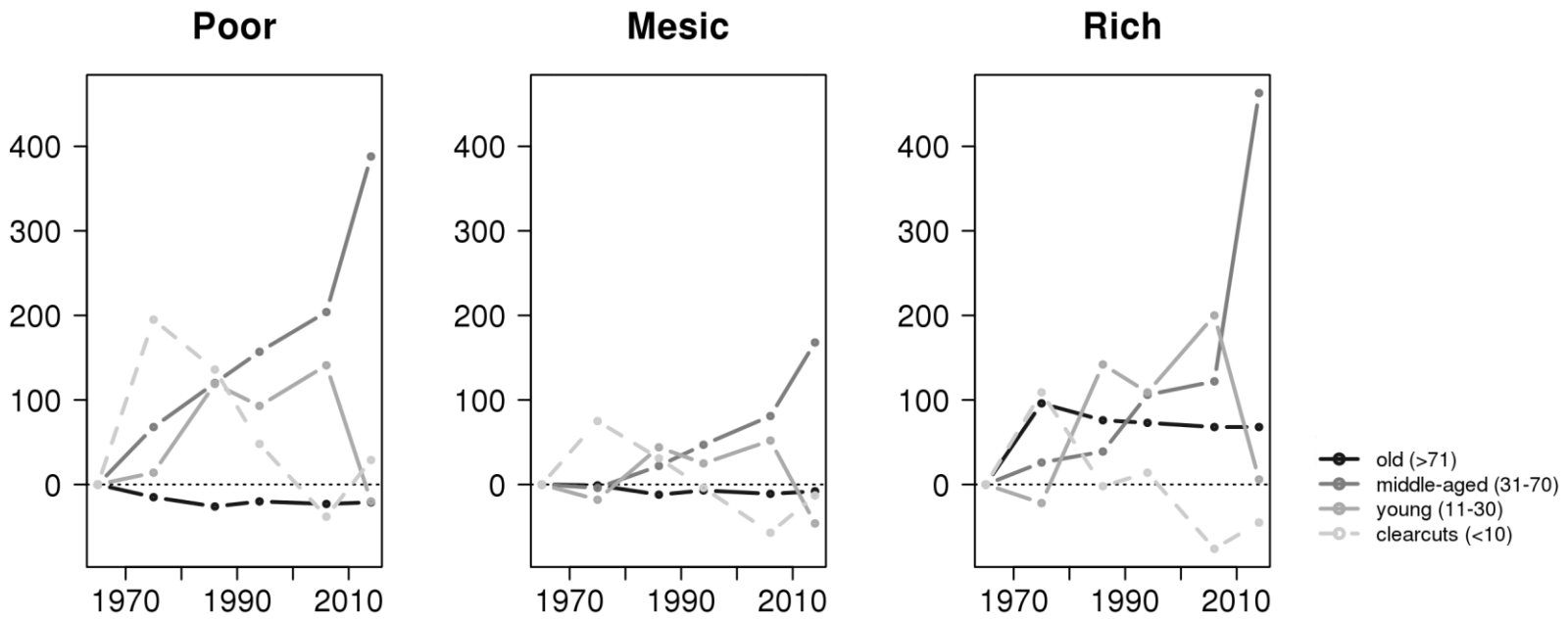

Figure 5. Trends in the area of different age classes on poor (62% of the study area), mesic (36%) and rich (2%) site types from 1965 to 2014. The y-axis shows the area change relative to the initial cover in 1965. The analysis was performed on a total area of about 160,000 ha.