Satisfying rival forestry objectives in the Komi Republic: Effects of Russian zoning policy change on wood production and riparian forest conservation

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Abstract

Spatial segregation of different forest landscape functions can accommodate rival forestry objectives more comprehensively than integrated approaches. Russia has a unique history of forest zoning separating production and environmental functions. However, the Russian Forest Code of 2006 increased the focus on wood production. We reviewed the history of zoning policy in Russia, and assessed if the recent policy change affected logging rates and conservation of riparian forests. Using Russia's Komi Republic as a case study we specifically assessed (1) if policy change led to increased logging near streams, (2) if logging rates were different in headwaters vs. main rivers, and (3) how logging changed among catchments with different accessibility to logging. Using a global open access remote sensing data set we compared mean annual forest loss as a proxy of logging rates in 10 large forested catchments in the Komi Republic in one period with strict (2000-2006) and one with moderate (2007-2014) zoning policy. Harvesting rate was positively related to the distance from streams. On the other hand, it increased after the policy change in the buffer zone, but decreased outside it. Forests in headwater buffers were harvested more as compared to along larger rivers, and harvest in the catchments near industries was higher and increasing; remote catchments had low forest loss. We discuss the opportunity for adopting forest zoning policy in different governance contexts.

Key words: forest policy change, sustainable forest management, Komi Republic, zoning, spatial planning

Introduction

The benefits of forests on the European continent vary in time and space. In the beginning of the 19th century sustained yield forestry had already been developed in Central Europe (Puettmann et al. 2008), and was soon promoted both in the Nordic countries (Obbarius 1848 about Sweden, Gyldén 1853 about Finland), and in the Russian Empire (Turmer 1891). Sustained yield forestry has been implemented with two different approaches.

The first approach is mining of wood resources in old-growth forests, which are made accessible through development of transport infrastructure, and followed by natural regeneration with minimum investments in silviculture (Knize and Romanyuk 2006). The second approach is maximising the biological growth of trees based on high-input forest management (Elbakidze et al. 2013). In the 1970s the global transition from sustained yield forestry to sustainable forest management emerged, including also ecological and social dimensions objectives (Edwards and Kleinschmit 2013).

There is a current debate whether all these dimensions of sustainable forest management policy can be achieved by segregated approaches through zoning at different spatial scales, or by integrated approaches that satisfy different functions in the same area (see Bollmann and Braunisch 2013). Forest zoning implies dividing a forest management unit into several zones, each having specific functions. The TRIAD approach is one example with three zones for (a) intensive forest management, (b) low-intensive alternative silviculture, and (c) long-term conservation of intact forests (Seymour and Hunter Jr 1992). Duncker et al. (2012) proposed a system of five forest management approaches depending on intensity and intervention methods for silviculture. Spatial segregation of different management approaches represents a zoning approach to sustainable forest management. In contrast to zoning, there are approaches to integrate economic, ecological and social forest functions at the stand level. Two examples are tree retention in clear-felling systems

(Gustafsson et al. 2012), and continuous forest cover forestry (Axelsson et al. 2007). However, recent analyses show that a segregated approach based on spatial zonation is more efficient at delivering broader portfolios of forest benefits than integrated stand-level approaches (Mönkkönen et al. 2014, Triviño et al. 2015). New policy about green and blue infrastructure (e.g., European Commission 2013) captures this by encouraging spatial planning to secure the supply of ecosystem services.

Riparian ecotones are particularly important for the delivery of multiple ecosystem services in forest landscapes (Grygoruk and Acreman 2015). One concrete approach to spatial planning by zoning within forest management units is to design riparian forests for biodiversity conservation and ecological integrity (Lazdinis and Angelstam 2005). The interface between the terrestrial and the aquatic environment contributes to the maintenance of compositional (species), structural (habitats) and functional (processes) elements of biodiversity (sensu Noss 1990) in both terrestrial and aquatic forest ecosystems (Sweeney and Czapka 2004). Riparian forests provide habitat for terrestrial and aquatic species, and supply streams with dead wood as a key structure for fish habitat, as well as affect processes such as release of humus and nutrients (Jacks and Norrström 2004). Naturally dynamic riparian forest ecotones provide suitable conditions for a wide range of vascular plants (Nilsson and Götmark 1992), substrate for lichens requiring a moist local climate (Sjöberg and Ericson 1992), and species dependent on properties of naturally dynamic forests, such as old trees and dead wood (Stighäll et al. 2011). Riparian forest ecotones also supply streams with woody debris (Bergquist 1999) and leaf litter (Cummins et al. 1989). This benefits invertebrates (Törnblom et al. 2011) and focal fish species (Degerman et al. 2004). Finally, in the aquatic system riparian forests buffer against flow peaks during snow melt and autumn rains, erosion, leakage of organic matter and nutrients (e.g., Bergquist, 1999) and affect nutrient uptakes into the aquatic food chain (Tabacchi et al. 1998). To be functional as habitats for species the riparian zones need to have sufficient quality and size, as well as to have sufficient connectivity to allow for dispersal of individuals of species and other functions. This would then satisfy policy about both green and a blue infrastructure (European Commission 2013). Headwater streams and their riparian areas, i.e. headwater systems, form particularly important and distinctly different systems compared to larger channels (Richardson and Danehy 2007).

A long-standing issue is how to design riparian buffer zones. It has been suggested that the width of riparian buffers ought to be related both to the up-slope effect and forest age distribution within a local catchment (Bergquist 1999). Others have proposed that riparian forests along streams should be sufficiently wide to effectively perform the functions of both controlling water and nutrient flows from upland to stream, and facilitating the movement of and providing habitat for upland forest interior animals and plants along the stream system (see Forman and Godron 1986, Martell et al. 2006). This can be made either by allocating protection or protective functions to entire stands, or determining a particular fixed or variable width of riparian buffers.

Russia has a long history of forest zoning. With the introduction of the revised Russian Forest Code of 2006 the rules for maintaining protective forest zones along streams and rivers became less strict and clear-felling within the protective zones is now permitted (Kobyakov et al. 2013) under certain conditions. This offers a unique opportunity to study the effects of zoning policy on forest loss both within and outside the riparian forest zones. Open access remote sensing data about forest loss and gain (Hansen et al. 2013) make this possible.

The aim of this study is two-fold. First, given the unique system of zoning in Russia, which is poorly known internationally, we reviewed the history of zoning policy in Russia since 1701. Second, we tested the hypothesis that recent changes in Russia’s forest policy have improved the opportunity for intensified wood harvesting by making more forest land accessible for logging, and conversely, that the rate of loss of riparian forests has increased. To cover the full range of regional forest history contexts in NW Russia, from intact forest landscapes to areas with wood mining and those with gradual recovery as well as areas that are subject to intensification of silviculture

(Nordberg et al. 2013, Naumov et al. 2016), we chose the Komi Republic as a case study. We assessed (1) if changes in zoning policy altered the rate of logging compared to the rest of the catchment, (2) if logging rates were different in riparian forests along headwaters versus main rivers, and (3) if logging rates changed among catchments with different degrees of remoteness in relation to the forest industry consuming the harvested wood.

Materials and methods

Study system

We selected the Komi Republic (415,900 km^2) in NW Russia as a case study because its river catchments represent a gradient in remoteness from forests that are accessible to the forest industry to large remote intact forest landscapes (sensu Yaroshenko et al. 2001) without a functioning transport infrastructure (see Figure 1, Table 1). We chose all 10 large river catchments situated in the forested area in the Komi Republic, i.e. below 65 N. The river catchments range in size from 4,500 to 30,300 km2, and represent the full range of local forest use histories in NW Russia linked to regionally expanding logging frontiers (Naumov et al. 2016). In 5 of the 10 studied catchments there are intact forest areas, covering 19-84% of the river catchments. The most remote (>300 km from forest industry) catchments are Pechora, Ilych, Vashka and Mezen, whereas the Lokchim and Vishera rivers' catchments have the shortest transport distance to forest industry (Table 1). The proportion of wetlands was low and ranged from 0.7 to 13%, with the highest proportion in the Vym river catchment and lowest in the Luza river catchment. Hence, forest is the potential natural vegetation in the vast majority of the catchments.

The annual allowable cut for the whole Komi Republic is about 33 million m^3/year (Anonymous 2011). However, the actual current harvest volume is only approximately 7 million m3/year, primarily due to undeveloped transport infrastructure (Krivoshein 2014). Prior to the current Forest Code (introduced in December 2006) the industrial wood harvest zone was 58 % of the total forested area of the Komi Republic, whereas the protection zone was 41 %. Forests with social and recreational functions close to large cities covered only 1 % (Kozubov and Taskaev 2000). Today the forested area in Komi is divided into an industrial wood harvest zone (65 %) and a protection/protective zone (35 %). This change in the proportion of different zones increased the area available for wood harvest by 7 percentage points (i.e. from 58 to 65%). Additionally, the Russian forest policy includes a reserve zone (Anonymous 2006b), but this is not represented in the Komi Republic (Anonymous 2011).

Literature review

To satisfy the first aim of this study a literature review was conducted with focus on forest zoning policy at the national (Russian Federation) and regional level (Komi Republic). The sources included books, journals and legislation documents, all in Russian. We summarized the results into a table that describes zoning rules, restrictions and whether the decision-making was passive or active. The literature review describes the period from 1701 when the very first decree was issued to 2006 when the recent major changes in policy on riparian forests were introduced.

Stratification by policy regime, distance to stream and remoteness

By policy we understand an officially agreed way of doing something (Mayor 2009). All laws, regulations and instructions are policy documents at different levels. In the context of our study, the key policy document is Russia's Forest Code and other documents that govern forest management. We analysed one strict and one moderate period in Russia's recent forest zoning policy, separated by the year 2006 when the current Russian Forest Code was accepted, and clear-felling was allowed in protective zones (see Table A1). The open access forest loss data covered the period 2000-2014. This was divided into two periods, viz. 2000-2006 (n=6) as strict zoning, and the period 2007-2014 (n=8) as moderate zoning.

First, to assess if changes in zoning policy altered the rate of riparian forest loss compared to the rest of the forest landscape in the 10 Komi catchments, we made buffers of 0-200 and 201-500 m around water bodies, independent of the length of the buffered rivers. These two buffer widths used in the geographical information system (GIS) analysis were created according to Russia's zoning policy before 2006 (see Table A1 for 1989 and 1997). The Forest Code from 2006 removed the widest 201-500 m zone. Within the total area of the 10 catchments (151,220 km^2) the proportions of forest within the 0-200 m and 201-500 m buffers vs. >500 m away from streams were 19%, 25% and 56%, respectively.

Second, we analysed if the policy change influenced forest loss rate near streams with different stream order (Strahler 1957), or stream magnitude (Shreve 1967). We focused on forest loss rates near headwaters and main rivers, respectively, because of their different function for terrestrial and aquatic ecosystems (e.g. Richardson and Danehy 2007). We employed a reverse engineering approach to identify stream orders by stepwise identification of so called dangles (loose ends of river network) according to Shreve's stream classification (Shreve 1967). The first group included streams of magnitudes (according to Shreve) 1 to 4 and depicts headwaters. The second group consisted of streams of magnitudes >4 representing the remaining network of streams and rivers. Focusing on the areas within the 0-200 m buffers we studied the effect of policy change on riparian forests around headwaters and large rivers. Within the total area of the 10 catchments the proportions of headwater buffers and buffers along larger rivers were 79% vs. 21%, respectively.

Third, to address the role of accessibility for logging of individual river catchments we measured the distance from the Mondi paper mill in Syktyvkar, the Komi Republic's only consumer of industrial wood (Figure 1). Distances to industry were estimated as the shortest distance by road from the informal centre of catchment to the Mondi paper mill in Syktyvkar. These distances were derived using Yandex routing services (www.yandex.ru).

Estimation of logging rates

To quantify the proportion of annual forest loss in each buffer zone and each catchment we used Hansen's et al. (2013) open access raster data derived from Landsat and MODIS satellite-based earth observation data, which were collected between 2000 and 2014 with 1 arc-second spatial resolution. Forest loss was defined as a stand-replacing disturbance, i.e. a loss of tree cover defined as canopy closure for all vegetation taller than 5 m in height (for details see Hansen et al. 2013). According to Potapov et al. (2015) about 93% of forest loss was attributed to final fellings. To diminish areal distortions we re-projected raster datasets to metric Albers equal-area conic projection (Bugayevskiy and Snyder, 1995). We created a new variable adjusted to FAO's definition of forests as tree cover >10%, and used it as forest mask in our calculations. The proportion of annual forest loss within the forest mask was estimated separately for each buffer and for each catchment. It was estimated in percentage relative to the total forest area of respective buffer or catchment. Finally, we computed the mean annual forest loss by dividing the old-strict policy (2000-2006) group results by 6 years and the new-moderate policy (2007-2014) group by 8 years.

The Russian Federation encompasses 85 federal subjects (administrative units at the highest level). Given the focus on policy implementation of forest zoning policy in this study, Russia's focus on intensification in NW Russia's boreal biome and the availability of spatial data of streams, we chose the Komi Republic as a case study. Because the results are based on complete enumeration of the entire case study area chosen (151,220 km^2), covering all the 10 forested catchments in the Komi Republic today, and not a sample, statistical tests were not performed. To clarify, in this paper we use what is termed the census survey, census inquiry, or complete enumeration method (Kothari 2004). This means that all the items are included in the analyses. This is very characteristic to remote sensing data (in this case the items are pixels, i.e. the minimum mapping area of forest land cover) when an entire area is surveyed. The census survey method is thus 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.

This approach is consistent with several studies done with open access land cover data. For instance, forest cover changes related to illegal logging in the Ukrainian Carpathians were 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 were evaluated to map land cover structures and pattern without statistical analyses (Milanova et al. 1999).

Results

Forest zoning: past and present

Russia has a long history of forest zoning (Table A1), which developed from one simple category to multiple categories of both protection and protective forest zones (Kobyakov et al. 2013). Commencing as early as 1701, forests along rivers were protected to secure timber for ship-building (Anonymous 1830). But after the serf emancipation reform of 1861 and the resulting lack of free labour, landlords started to sell out pieces of their private land (including forests) to timber merchants. These merchants aimed at maximizing economic profit, which led to overharvesting in large territories in Russia (Istomina 2014). This triggered the Russian government to stop uncontrollable exploitation of forests, which resulted in the first major environment protection law in 1888. Thus, in 1888 the zoning policy of Imperial Russia became stricter and more detailed than previously (Anonymous 1997a). Riparian buffer zones became aimed at securing protective functions for headwaters by restricting clear-felling and pasturing. In this directive of 1888 on "forestry survey work for the promotion of rational forest management" three categories of forestry were introduced to regulate the intensity of management. These zones were not automatically assigned, but rather there was a bottom-up process whereby any private person or societies could request the state to change the management regime of a particular piece of forest land. Imperial Russia's legislation about riparian zones continued during the Soviet period (1922-1991). Protection forest zones along major rivers were created in 1936 in watersheds of the European part of the USSR, i.e. the rivers Volga, Don, Dnepr, Ural and Western Dvina. In the Komi Republic several large rivers (see Table A1, year 1936) were designated as protective forest zones where a 2-km wide zone on both sides of the river was established.

A major revision of the protective law occurred in 1943 when forests were divided into three zones depending on the purpose, i.e. water protection and nature protection, societal services (mainly for recreation) for highly-populated areas, and industrial wood harvest. The widths of protective riparian zones ranged from 15 to 500 m depending on the length of the streams (Table A1). The function of the protective zones was to maintain regulating services (Anonymous 2005) using forests, e.g., to reduce erosion risk (Kobyakov et al. 2013). In post-Soviet Russia (1992 and onward) the restrictions changed in 2006 to a maximum buffer width of 200 m (Anonymous 2006a), and by allowing clear-felling operations under certain conditions in previously protective zones (Anonymous 2006b). Thus, in spite of all these changes over >3 centuries, there is policy continuity stating that riparian forests should not be subject to industrial harvesting.

Consequences of policy change

Overall, the proportion of annual forest loss varied from 0.15-0.23% in the 0-200 m and 201-500 m buffer zones to 0.37% in the surrounding landscape (Figure 2). The mean for all years and all zones was 0.24%. The proportion of forest loss increased with increasing distance to streams both before and after the new Forest Code was introduced in December 2006 (Figure 2). The policy change was associated to a 10.4-36.0% increase in annual mean forest loss within the buffer zones. The highest relative increase was observed in the 201-500 m buffer. In the surrounding landscape (>500 m from streams) the forest loss actually decreased by 8.9% (see Figure 2).

Next, zooming in to the loss of forest along headwaters vs. main rivers, we found that the annual forest loss in the 200-m buffer was higher in headwaters (on average 0.21%) than along main rivers (0.09 %). The magnitude of change in the 200-m buffer increased in headwaters by 35% and in main rivers by 27% from old strict to new moderate policy in 2006 (Figure 3).

Finally, zooming out to differences among catchments we found that the absolute proportion of annual forest loss and the change between the two time periods differed among the 10 catchments (Figure 4, Table 2). We identified four groups of catchments based on the current proportions of forest loss (low vs. high) and the decrease or increase over time (Table 2). The first group with a low level of forest loss and decrease over time was represented by the Vishera and Vym catchments. This can be explained as a consequence of the past logging frontier, which had passed these catchments already in the 1980s. Additionally, today, the only large organization that leases forest in the Vym catchment is a state correctional facility, and not a regular forest land leaser aiming at wood harvest. The second group with low loss and increase over time includes catchments of the Pechora and Ilych rivers. Both are very remote (about 400 km to industry, see Table 1), and 59 and 84% of these catchments, respectively, were occupied by large intact forests (see Table 1). The third group with high forest loss and decrease over time was represented by the Vashka and Mezen catchments. Here the logging frontier also passed earlier, and the proportion of large intact forest is relatively high (27% in Mezen and 35% in Vashka). The fourth group, with high forest loss and increased loss in the moderate-new zoning policy period (2007-2014), was represented by the four catchments (Lokchim, Luza Sysola and Vychegda) that were closely located to pulpmills and sawmills in Syktyvkar.

The distance from industry to catchment was inversely related to forest loss (N=10: Spearman rank -0.51515, one-tailed p=0.064) (Figure 5). When removing the two catchments of the Vishera and Vym rivers with deviating forest history and tenure (see upper left cell in Table 2) the value of R is -0.88095 (one-tailed p=0.0019).

Discussion

Consequences for intensification on logging and nature conservation

In this study we used open access satellite-based remote sensing data to test the hypothesis that that recent changes in Russia's forest policy have indeed improved the opportunity for intensification by making more forest land accessible for logging, and conversely, that the rate of loss of riparian forests has increased. The use of these data with high spatial resolution about forest loss allowed us to analyse the consequences of forest policy change for (1) the maintenance of forest cover along streams, which is important for biodiversity conservation in the terrestrial-aquatic ecotone, and for (2) forest logging intensity in our study area. Open access remote data have been successfully used to assess policy change on land use change globally (Potapov et al. 2008, Hansen et al. 2010), regionally (Main-Knorn et al. 2009, Potapov et al. 2015) and nationally (Kuemmerle et al. 2009, Baumann et al. 2011, 2012). The open access remote sensing data were used also in Russia to estimate how much of forested area had been cleared near Moscow city between 1991 and 2001 (Boentje and Blinnikov 2007). Analysis of intact forest landscapes were done by Yaroshenko et al. (2001) and Potapov et al. (2008) with help of Landsat and MODIS imagery, which are publicly available. Also changes in agricultural land can be assessed with open access data. This was successfully done for example in Northern Africa (Lenney et al. 1996), in Eastern Europe (Peterson and Aunap 1998, Kuemmerle et al. 2008) as well as in Russia (Prishchepov et al. 2013).

Approaches to production and harvest of wood in Russia have evolved through three distinct periods (Naumov et al. 2016). First, sustained yield forestry was encouraged based on even-aged stands in the 19th century (Turmer 1891). Second, after the Russian revolution in 1917, the socialistic ideology discarded economic factors (Knize and Romanyuk 2006), which led to intense wood mining. Third, after the collapse of the Soviet Union in 1991 market economy re-emerged, as well as the desire for intensified silviculture. Thus, there have been 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 and Romanyuk 2006). Currently the second vision is widely advocated and linked to a growing interest in Russia to increase the productivity of wood per unit area in previously harvested areas (Martynyuk et al. 2016, Angelstam et al. 2017). To aid this approach a zonation map of forest use in the Komi Republic was created in 2011 (Krivoshein 2014). This divided the forested territory into intensive and extensive zones of forest management. Forest type (by soils and latitude), economic profitability and transport accessibility were the major factors that influenced the identification of the intensive forest management zone. However, intensification requires considerable investments in road building (Martynyuk et al. 2016; Naumov et al. 2016), and increased sustained yield by means of active silviculture (e.g., Naumov et al. 2016; Angelstam et al. 2017). An alternative short-term avenue to increase forest harvest opportunities is by extending the area available for wood mining. Consequently, the new 2006 Forest Code opened up the opportunity for clear-felling in protection forests along streams in regions where the timber frontier already passed relatively near the industry consuming wood.

We used the open land cover change data of Hansen et al. (2013) as a proxy for logging intensity. This involves two potential caveats. In naturally dynamic forests, continuous cover forest stands with gap-phase dynamics on productive sites are often found along streams (Lazdinis and Angelstam 2005). This implies that mature forest stands would remain as an intact riparian buffer zone unless clear-felled or subject to other stand-replacing disturbance. According to our results on average 0.24% of forest loss had occurred annually in the whole study area. However, in Komi also wildfire may lead to forest loss, but not land clearing for agriculture or other purposes. However, given that the probability of fires are lower on wet sites (Furyaev and Kireev 1979), which are more common along streams than in the rest of the landscape (Angelstam and Lazdinis 2017), the proportion of forest loss along streams should be dominated by logging compared to fire. In addition, on average only 6.1% of the total forest loss area is attributed to wildfires, and 1.3% to windfalls in Eastern Europe (Potapov et al. 2015). Hence forest loss is a relevant proxy indicator for forest harvest in this region. Additionally, forests may be harvested by commercial thinning, which is not detectable by the method used by Hansen et al. (2013). However, this is a very uncommon practice in Komi and constitutes about 1% of total harvested area (Sherstukova 2012).

Our results show that the loss of riparian forest was positively related to the distance from streams, but increased in both 0-200 and 201-500 m buffers after the forest policy change. This indicates both that the zoning policy does indeed increase the probability that forests along streams remain, but also that forest harvesting was intensified when the policy changed. On the contrary, forest loss decreased in the surrounding landscape. Zooming into catchments, we found that in spite of headwater systems being particularly important for terrestrial and aquatic biodiversity conservation as well as in-stream quality (e.g., Richardson and Danehy 2007), the loss of forest along headwaters was higher than along large streams. Finally, zooming out to the entire Komi Republic the differences in the levels of forest loss among catchments before and after policy change showed that harvest in the catchments near industries was high and increasing. In contrast catchments being inaccessible due to poor forest road infrastructure and/or high transportation costs had low levels of forest loss. These results show that the idea of expanding wood mining by relaxing the zoning policy had the desired effect to increase logging rates. Kobyakov et al. (2013) argued that this forest policy change will also increase the rate of loss of the last remaining intact forest landscapes in NW Russia. While the results do not support this at the regional level among catchments, loss of local remnants of intact forests in terms of riparian forests did indeed increase, especially in headwaters. Nevertheless, the overall annual loss of old forest was low (0.15 to 0.37% per year) compared, for example, to Sweden and Finland where 0.92% (Skogsstyrelsen 2014) and 1.2% (Peltola 2014), respectively, of forests are subject to final felling annually. In addition, commercial thinning takes place in these countries, which contributes considerably to the total harvest.

Matching our results (Figure 3) with the zonation map for the Komi Republic (Krivoshein 2014), we note that the southern catchments such as Lokchim, Sysola and Luza are located in the zone where intensification of forestry is feasible. This is consistent with the proposition that once the frontier of logging old-growth forests where wood has accumulated over long time (Pennanen 2002) has passed, intensification of forest management is more likely to be successful at lower latitudes where growth rates are higher due to a longer vegetation period (Martynyuk et al. 2016; Angelstam et al. 2017).

Spatial segregation of forest functions by zoning

The extent to which riparian forests are maintained varies among forest management contexts. In Canada and the US several zoning systems occur to isolate upland activities from terrestrial near shore and aquatic areas (Lee et al. 2004). In contrast, Sweden has never practised formal forest zoning aimed at creating riparian buffers (Lazdinis and Angelstam 2005). In the circumboreal biome only Russia has a long history of comprehensive system for forest zoning. However, the history of this is inaccessible for the international audience (Algvere 1966). Zoning of forests focused on maintaining high forest along streams and rivers in Russia occurred already in 1842-1845 (Arnold 1895; see also Reymers and Shtilmark 1978, Redko and Redko 2002). However, the recent interest for intensification of forestry in Russia (Nordberg et al. 2013; Naumov et al. 2016) challenges the zoning approach. Increasing the amount of wood available to the forest industry can be achieved by (1) expansion of harvest into previously inaccessible forests (Elbakidze et al. 2013), and (2) increasing the utilisation and rate of production of industrial wood by intensified silviculture (Nordberg et al. 2013). While the latter takes a long time, permission for harvesting in riparian zones with remaining old forests is more effective in the short term, and imposes no cost in terms of investment in silviculture or management. In Russia this has recently triggered changes to the forest policy zoning system by reducing the width of protected buffer zones along streams (Kobyakov et al. 2013).

Several studies show that spatial segregation (i.e. zonation) is more efficient than integrated stand-level approaches at delivering the broad portfolios of benefits from forests requested by sustainable forest management policy (Mönkkönen et al. 2014, Triviño et al. 2015). The riparian forest buffers in Russia initially aimed at providing protective functions linked to streams and rivers rather than the riparian forest itself. Much later protection functions in terms of conservation of forest habitat types, which are not delivered by intensive forestry, and its associated species, were added as motives under the umbrella of biodiversity conservation. The lower loss of forest along streams compared to the rest of the catchment shown in this study implies that forest zoning in Russia has indeed contributed to the conservation of riparian forests that serve as a functional habitat network in forest landscapes, and thus a green/blue infrastructure (Figure 6). This is also evident from field studies. A comparison between boreal forest streams in Finland and Russia by Liljaniemi et al. (2002) showed that channel habitats were in fairly natural state in Russia whereas the Finnish sites were cleared and straightened; and the abundance of coarse woody debris in streams was 10–100-fold higher in Russia.

Another topic is to resolve how riparian forest-headwater complexes should be maintained. The issue of fixed-width or variable-width management policy for riparian vegetation has been in focus for decades (e.g., Lee et al. 2004). Kuglerová et al. (2014) argued that fixed-width buffers are not an ideal solution for sustainable forest management with an economic focus in a context with many private land owners, such as in Sweden. Taking local hydrological and site conditions into consideration, as well as maximizing the yield of wood, they argued in favour of variable-width riparian buffers. They proposed the use of groundwater discharge hotspots as an indicator for landscape elements along streams with higher ecological significance. These may be identified using digital elevation models, if sufficiently detailed, or by mapping tall herb ground vegetation (Angelstam and Lazdinis 2017) because such discharge hotspots coincide with species-rich herb vegetation (Kuglerová et al. 2015). This would benefit biodiversity and important ecosystem services such as water quality without necessarily incurring costs from a wood production standpoint (Laudon et al. 2016). For Canada and the US Lee et al. (2004) concluded that buffer widths of 15-30 m were adequate to protect the aquatic biota and habitats, but not for terrestrial communities. There is an ongoing debate in Sweden whether to use fixed-width or site-adjusted riparian zones. Nevertheless, the Swedish Forest Agency recommends leaving 15-30 m (Lindegren 2006). In contrast, Russia maintains 200-m wide riparian forest zones. We see the need for empirical studies about what maintenance of streams' and riparian forests' functions require in terrestrial and aquatic ecosystem contexts, such as on the Russian plain with flat terrain and sand, silt and clay versus on the Fennoscandian shield with shallow till soils over bedrock (Angelstam and Lazdinis 2017).

Analogous to buffer zones along streams voluntary forest certification prescribes zoning around villages in Komi to support rural livelihoods by securing the access to and maintenance of non-wood forest products such as berries and mushrooms (Stryamets et al. 2015), as well as hunting and fishing. Zoning regulations thus help to achieve human well-being. By spatially segregating forest landscapes multi-purpose forest management can be achieved at the landscape level, including biodiversity conservation, wood production and social values.

Governance and ownership contexts for applying forest zoning

The extent to which different aspects of sustainable forest management policy are implemented is determined by societal context (Angelstam et al. 2011, Elbakidze et al. 2013). A major feature of the Russian forest governance and management system is a centralized top-down planning system (e.g., Nordberg et al. 2013). The forest companies, which lease state owned forest, are requested to obey all forest regulations (e.g., the number of trees per hectare, methods for pre-commercial thinning) that are not regionally specific, and forest management is then controlled by the state. However, several regional policy documents have been adapted to local conditions in NW Russia, for example, in the Komi Republic and in the Pskov oblast. In Komi The regional forest policy in the Komi Republic promotes forest management practices that aim to emulate natural disturbance regimes (Mariev et al. 2005). In Pskov oblast new norms for balancing wood production and biodiversity conservation have been proposed. A forest conservation system was developed based on setting aside areas for conservation at tree, stand, landscape and regional scales (Angelstam et al. 2005). Regarding wood production, introduction of Scandinavian systems for commercial thinning were proposed to be implemented in NW Russia (Romanyuk et al. 2002).Zoning approaches have been developed also in other countries. For instance, Sweden's state forest company Sveaskog uses the Ekopark concept (Angelstam and Bergman 2004) in 37 locations amounting to 5% of the company's holdings. Within Ekopark areas 50% of forest land is set aside or managed for conservation and on the rest of the area wood production is the main objective. Another approach developed in Swedish forest management planning is the operational division of forest land into four classes representing a gradient from wood production, combined wood production and biodiversity conservation to biodiversity conservation based on active management and free development (Andersson 2010). By and large this corresponds to Dunckers' et al. (2012) intensity scale from intensive/high to medium and passive management. If applied throughout a landscape by spatial segregation, such approaches would benefit sustained-yield wood production, biodiversity conservation and social values such as outdoor recreation and nature-based tourism. However, protected area networks are also needed to maintain habitat for viable populations of specialised species with large area requirements (Bollmann and Braunisch 2013, Mönkkönen et al. 2014). Additionally, other instruments are needed to ensure that natural disturbances are inherently incorporated both in the beginning of succession (e.g., fire) and during the subsequent stand development (e.g., self-thinning and gap formation) (Sturm 1993).

To conclude, insights from Russia' forest policy dynamic and its consequences for intensification of logging and riparian forest conservation are little known internationally, but of considerable general interest for governors and managers. In contrast to the Russian context with a long history of state regulation of forest zoning (see review in Table A1) it is hard to introduce this segregated approach in societal contexts where land ownership is non-industrial or industrial private, and the spatial structure of ownerships is diverse, as for instance in Sweden (Rist et al. 2016). With a focus on maintaining functional riparian buffer zones along streams in general we see three options. The first is to encourage additional efforts towards maintenance of functional riparian forests on suitable site types by empirical research about buffer zone width to achieve different objectives in different contexts, and collaborative learning among forest owners and stakeholders (Daniels and Walker 2001, Elbakidze et al. 2010). Open access data can advance monitoring of policy change. The second is establishment of prescriptive forest zoning, which is easier with top-down regulation and state ownership. The third is to accept that securing both forestry intensification and biodiversity conservation is difficult unless some form a spatial planning is applied beyond the scope of individual firms or other actors. Open access land cover change data can advance monitoring of the effects of all three alternatives.

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Table 1. Basic information on river catchments in the study area located in the Komi Republic (see Figure 1).

River catchment (see Figure 1)	Informal centre of the catchment	Area (km2)	Wetlands (%)	Intact forest1 (%)	Road density2 (km/km2)	Approx. distance3 to industry (km)
Vashka	Eortom	19710	4	35	0.25	330
Mezen	Chernutjevo	15015	4	27	0.40	310
Vym	Vetju	23938	13	19	0.25	190
Luza	Noshul	10253	1	0	0.33	210
Sysola	Koygorodok	17403	3	0	0.40	190
Lokchim	Namsk	5729	1	0	0.40	100
Vishera	Bogorodsk	4494	7	0	0.30	130
Vychegda	Ust-Nem	30290	6	0	0.33	250
Ilych	Troitsko-Pechorsk	14411	6	84	NA	390
Pechora	Komsomolsk-na-Pechore	9977	2	59	NA	470

[1] The proportion of intact forest was calculated as percentage of studied river catchments based on data set by Potapov et al. (2008).

[2] Road density was retrieved by forest management unit from Forest plan of Komi Republic (Anonymous 2011), and values were averaged over catchment area.

[3] Distances to industry were estimated as the shortest distance from the informal centre of catchment to main industry customers in Syktyvkar. It was derived using Yandex routing services (www.yandex.ru).

Table 2. Four groups of magnitudes of forest loss and trajectories over time among the 10 studied catchments (cf. Table 1).

	Low forest loss	High forest 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 in Syktyvkar, no intact forest)

Figure 1.

Map of the Komi Republic (grey border), its three main catchments N. Dvina, Mezen, Pechora, and the 10 sub-catchments analysed in this study. Inset map shows borders of the main map in Northern Europe. Spatial data sources: all vector data - OpenStreetMap contributors (www.openstreetmap.org); raster data – Natural Earth data (www.naturalearthdata.com).

Figure 2. Annual rates of forest loss (%) during two periods with different forest zoning policy at 0-200 m, 201-500 m, and >500 m from streams of all stream orders within 10 catchments in the Komi Republic.

Figure 3. Annual rates of forest loss (%) at 0-200 m from streams of magnitude 1-4 (Shreve (1967); i.e. headwaters) and streams and rivers with stream magnitude >4 during two periods with different forest zoning policy.

Figure 4. Annual rates forest loss (%) during two periods with different forest zoning policy inside the forest mask in the 10 catchments ranked by the mean level of annual forest loss.

Figure 5. Relationship between mean annual rate of forest loss 2000-2014 in the 10 catchments in Komi in relation to the distance from industry to the catchment. Note the differences in forest history and land tenure of Vishera and Vym compared to the other catchments, see Table 2 for details.

Figure 6.

Satellite image of the Nivshera catchment in the case study area (see Figure 1) showing riparian corridors (dark colour) along streams. Map data: Google Inc. and USGS.

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Appendix

Table A1. Regulations and riparian forest management restrictions according to forest and water policies in Russia in the period 1701-2016.

Year of changes	Regulation name translated from Russian (original title in parentheses)	Zoning rules	Restrictions	Active or passive decision	References
1701	Directive by Peter the Great: “Regarding limitations of forest harvest in the 30 versts (1 verst=1.06 km) of riparian forests for mowing. (”Указ Петра I “О нерасчистке лесов под пашню и сенные покосы за 30 верст от рек, удобных к сгонке леса”)	-	Prohibited to harvest 30 versts from rivers for agriculture	Law	(Anonymous 1830)
1703	Regarding forest inventory of all rivers, for big rivers – 50 versts buffers, for smaller 30 (“Об описи лесов во всех городах и уездах от больших рек в сторону на 50, а от	Protect forest 50 versts from large rivers, and 30 versts from small rivers suitable for floating	Forbidden to harvest forest with oak, larch, beech and pine of minimum diameter 53 cm	Law	(Anonymous 1830)

	малых по 20 верст”)				
1888	Regulation about forest conservation (“Положение о сбережении лесов”)	1) Sustained-yield wood production zone, and 2) protection zone to protect headwaters	Clear-felling, pasturage	Regional level authorities	(Anonymous 1997a)
1914	World War I – protection regulations are cancelled.				(Yushkova 2001)
1923	Forest code of Russian Socialistic Republic (Лесной кодекс РСФСР)	1) Public forests; 2) Rural forests	-	Transferred from Imperial Russia definitions	(Anonymous 1923)
1936	Regarding establishment of forest protection and identification of protection zones around rivers (Об образовании главного управления лесоохраны и лесонасаждений при совете народных коммисаров Союза ССР и о выделении водоохранной	Protection zone for Volga, Don, Dnepr, Ural and Western Dvina river catchments	Forbidden clear-felling in 20 km, 6 km and 4 km for selected rivers (see reference). Vychegda, Vym, Sysola, Lokchim, Vishera, Pechora – 2	Law	(Anonymous 1936)

	зоны)		km (Yushkova 2001).		
1943	Regarding establishment of forest protection and identification of protection zones around rivers (О порядке отвода лесосек в лесах государственного фонда Союза ССР и о лесосечном фонде на 1943 год)	1) Protective, 2) sustained-yield, 3) industrial forest zones	In (1) protective zone clear-felling was forbidden.	Regional level authorities (oblast, republic, kraj)	(Anonymous 1943)
1989	Regulation on water protection zones in the USSR (Об утверждении положения о водоохранных зонах (полосах) рек, озёр и водохранилищ в РСФСР)	Length of river: and minimum buffer 0-10 km: 15 m 11-50 km:100 m 51-100 km: 200 m 101-200 km: 300 m 201-500 km: 400 m >500 km: 500 m	Clear-felling is forbidden	Regional level authorities	(Anonymous 1989)
1997	Forest code of Russian Federation (Лесной кодекс РФ)	Same as above	Same as above	Same as above	(Anonymous 1997b)

2006, June	Water code of Russian Federation (Водный кодекс РФ)	Length: minimum buffer 0-10 km: 50 m 11-50 km:100 m >50 km: 200 m	-	-	(Anonymous 2006a)
2006, December	Forest code of Russian Federation (Лесной кодекс РФ)	-	Clear-felling is allowed	Regional level authorities	(Anonymous 2006b)

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Satisfying rival forestry objectives ~~in forestry~~ in the Komi Republic: Effects of Russian zoning policy change on ~~forestry intensification~~wood production and riparian forest conservation

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Abstract

Spatial segregation of different forest landscape functions can accommodate rival forestry objectives more comprehensively than integrated approaches. Russia has a unique history of forest zoning separating production and environmental functions. However, the Russian Forest Code of 2006 increased the focus on wood production. We reviewed the history of zoning policy in Russia, and assessed if the recent policy change affected logging rates and conservation of riparian forests. Using Russia's Komi Republic as a case study we specifically assessed (1) if policy change led to increased logging near streams, (2) if logging rates were different in headwaters vs. main rivers, and (3) how logging changed among catchments with different accessibility to logging. Using a global open access remote sensing data set we compared mean annual forest loss as a proxy of logging rates in ~~ten~~ 10 large forested catchments in the Komi Republic in one period with strict (2000-2006) and one with moderate (2007-2014) zoning policy. Harvesting rate was positively related to the distance from streams. On the other hand, it increased after the policy change in the buffer zone, but decreased outside it. Forests in headwater buffers were harvested more as compared to along larger rivers, and harvest in the catchments near industries was higher and increasing; remote catchments had low forest loss. We discuss the opportunity for adopting forest zoning policy in different governance contexts.

Key words: forest policy change, sustainable forest management, Komi Republic, zoning, spatial planning

Introduction

The benefits of forests on the European continent vary in time and space. In the beginning of the 19th century sustained yield forestry had already been developed in Central Europe (Puettmann et al. 2008), and was soon promoted both in the Nordic countries (Obbarius 1848 about Sweden, Gyldén 1853 about Finland), and in the Russian Empire (Turmer 1891). Sustained yield forestry has been implemented with two different approaches.

The first approach is mining of wood resources in old-growth forests, which are made accessible through development of transport infrastructure, and followed by natural regeneration with minimum investments in silviculture (Knize and Romanyuk 2006). The second approach is maximising the biological growth of trees based on high-input forest management (Elbakidze et al. 2013). In the 1970s the global transition from sustained yield forestry to sustainable forest management emerged, including also ecological and social dimensions objectives (Edwards and Kleinschmit 2013).

There is a current debate whether all these dimensions of sustainable forest management policy can be achieved by segregated approaches through zoning at different spatial scales, or by integrated approaches that satisfy different functions in the same area (see Bollmann and Braunisch 2013). Forest zoning implies dividing a forest management unit into several zones, each having specific functions. The TRIAD approach is one example with three zones for (a) intensive forest management, (b) low-intensive alternative silviculture, and (c) long-term conservation of intact forests (Seymour and Hunter Jr 1992). Duncker et al. (2012) proposed a system of five forest management approaches depending on intensity and intervention methods for silviculture. Spatial segregation of different management approaches represents a zoning approach to sustainable forest management. In contrast to zoning, there are approaches to integrate economic, ecological and social forest functions at the stand level. Two examples are tree retention in clear-felling systems

(Gustafsson et al. 2012), and continuous forest cover forestry (Axelsson et al. 2007). However, recent analyses show that a segregated approach based on spatial zonation is more efficient at delivering broader portfolios of forest benefits than integrated stand-level approaches (Mönkkönen et al. 2014, Triviño et al. 2015). New policy about green and blue infrastructure (e.g., European Commission 2013) captures this by encouraging spatial planning to secure the supply of ecosystem services.

Riparian ecotones are particularly important for the delivery of multiple ecosystem services in forest landscapes (Grygoruk and Acreman 2015). One concrete approach to spatial planning by zoning within forest management units is to design riparian forests for biodiversity conservation and ecological integrity (Lazdinis and Angelstam 2005). The interface between the terrestrial and the aquatic environment contributes to the maintenance of compositional (species), structural (habitats) and functional (processes) elements of biodiversity (sensu Noss 1990) in both terrestrial and aquatic forest ecosystems (Sweeney and Czapka 2004). Riparian forests provide habitat for terrestrial and aquatic species, and supply streams with dead wood as a key structure for fish habitat, as well as affect processes such as release of humus and nutrients (Jacks and Norrström 2004). Naturally dynamic riparian forest ecotones provide suitable conditions for a wide range of vascular plants (Nilsson and Götmark 1992), substrate for lichens requiring a moist local climate (Sjöberg and Ericson 1992), and species dependent on properties of naturally dynamic forests, such as old trees and dead wood (Stighäll et al. 2011). Riparian forest ecotones also supply streams with woody debris (Bergquist 1999) and leaf litter (Cummins et al. 1989). This benefits invertebrates (Törnblom et al. 2011) and focal fish species (Degerman et al. 2004). Finally, in the aquatic system riparian forests buffer against flow peaks during snow melt and autumn rains, erosion, leakage of organic matter and nutrients (e.g., Bergquist, 1999) and affect nutrient uptakes into the aquatic food chain (Tabacchi et al. 1998). To be functional as habitats for species the riparian zones need to have sufficient quality and size, as well as to have sufficient connectivity to allow for dispersal of individuals of species and other functions. This would then satisfy policy about both green and a blue infrastructure (European Commission 2013). Headwater streams and their riparian areas, i.e. headwater systems, form particularly important and distinctly different systems compared to larger channels (Richardson and Danehy 2007).

A long-standing issue is how to design riparian buffer zones. It has been suggested that the width of riparian buffers ought to be related both to the up-slope effect and forest age distribution within a local catchment (Bergquist~~,~~ 1999). Others have proposed that riparian forests along streams should be sufficiently wide to effectively perform the functions of both controlling water and nutrient flows from upland to stream, and facilitating the movement of and providing habitat for upland forest interior animals and plants along the stream system (see Forman and Godron 1986, Martell et al. 2006). This can be made either by allocating protection or protective functions to entire stands, or determining a particular fixed or variable width of riparian buffers.

Russia has a long history of forest zoning. With the introduction of the revised Russian Forest Code of 2006 the rules for maintaining protective forest zones along streams and rivers became less strict and clear-felling within the protective zones is now permitted (Kobyakov et al. 2013) under certain conditions. This offers a unique opportunity to study the effects of zoning policy on forest loss both within and outside the riparian forest zones. Open access remote sensing data about forest loss and gain (Hansen et al. 2013) make~~s~~ this possible.

The aim of this study is two-fold. First, given the unique system of zoning in Russia, which is poorly known internationally, we reviewed the history of zoning policy in Russia since 1701. Second, we tested the hypothesis that recent changes in Russia’s forest policy have improved the opportunity for intensified wood harvesting by making more forest land accessible for logging, and conversely, that the rate of loss of riparian forests has increased. To cover the full range of regional forest history contexts in NW Russia, from intact forest landscapes to areas with wood mining and those with gradual recovery as well as areas that are subject to intensification of silviculture

(Nordberg et al. 2013, Naumov et al. 2016), we chose the Komi Republic as a case study. We assessed (1) if changes in zoning policy altered the rate of logging compared to the rest of the catchment, (2) if logging rates were different in riparian forests along headwaters versus main rivers, and (3) if logging rates changed among catchments with different degrees of remoteness in relation to the forest industry consuming the harvested wood.

Materials and methods

Study system

We selected the Komi Republic (415,900 km^2) in NW Russia as a case study because its river catchments represent a gradient in remoteness from forests that are accessible to the forest industry to large remote intact forest landscapes (*sensu* Yaroshenko et al. 2001) without a functioning transport infrastructure (see Figure 1, Table 1). We chose all 10 large river catchments situated in the forested area in the Komi Republic, i.e. below 65 N. The river catchments range in size from 4,500 to 30,300 km^2, and represent the full range of local forest use histories in NW Russia linked to regionally expanding logging frontiers (Naumov et al. 2016). In 5 of the 10 studied catchments there are intact forest areas, covering 19-84% of the river catchments. The most remote (>300 km from forest industry) catchments are Pechora, Ilych, Vashka and Mezen, whereas the Lokchim and Vishera rivers' catchments have the shortest transport distance to forest industry (Table 1). The proportion of wetlands was low and ranged from 0.7 to 13%, with the highest proportion in the Vym river catchment and lowest in the Luza river catchment. Hence, forest is the potential natural vegetation in the vast majority of the catchments.

The annual allowable cut for the whole Komi Republic is about 33 million m^3/year (Anonymous 2011). However, the actual current harvest volume is only approximately 7 million m^3/year, primarily due to undeveloped transport infrastructure (Krivoshein 2014). Prior to the current Forest Code (introduced in December 2006) the industrial wood harvest zone was 58 % of the total

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forested area of the Komi Republic, whereas the protection zone was 41 %. Forests with social and recreational functions close to large cities covered only 1 % (Kozubov and Taskaev 2000). Today the forested area in Komi is divided into an industrial wood harvest zone (65 %) and a protection/protective zone (35 %). This change in the proportion of different zones increased the area available for~~opportunity of~~ wood harvest by 7 ~~%~~percentage points ~~units~~ (i.e. from 58 to 65%). Additionally, the Russian forest policy includes a reserve zone (Anonymous 2006b), but this is not represented in the Komi Republic (Anonymous 2011).

Literature review

To satisfy the first aim of this study a literature review was conducted with focus on forest zoning policy at the national (Russian Federation) and regional level (Komi Republic). The sources included books, journals and legislation documents, all in Russian. We summarized the results into a table that describes zoning rules, restrictions and whether the decision-making was passive or active. The literature review describes the period from 1701 when the very first decree was issued to 2006 when the recent major changes in policy on riparian forests were introduced.

Stratification by policy regime, distance to stream and remoteness

By policy we understand an officially agreed way of doing something (Mayor 2009). All laws, regulations and instructions are policy documents at different levels. In the context of our study, the key policy document is Russia's Forest C~~c~~ode and other documents that govern forest management. We analysed one strict and one moderate periods in Russia's recent forest zoning policy, separated by the year 2006 when the current Russian Forest Code was accepted, and clear-felling was allowed in protective zones (see Table A1). The open access forest loss data covered the period 2000-2014. This was divided into two periods, viz. 2000-2006 (n=6) as strict zoning, and the period 2007-2014 (n=8) as moderate zoning.

First, to assess if changes in zoning policy altered the rate of riparian forest loss compared to the rest of the forest landscape in the ~~ten~~ 10 Komi catchments, we made buffers of 0-200 and 201-500 m around water bodies, independent of the length of the buffered rivers. These two buffer widths used in the geographical information system (GIS) analysis were created according to Russia's zoning policy before 2006 (see Table A1 for 1989 and 1997). The Forest Code from 2006 removed the widest 201-500 m zone. Within the total area of the ~~ten~~ 10 catchments (151,220 km^2) the proportions of forest within the 0-200 m and 201-500 m buffers vs. >500 m away from streams were 19%, 25% and 56%, respectively.

Second, we analysed if the policy change influenced forest loss rate near streams with different stream order (Strahler 1957), or stream magnitude (Shreve~~,~~ 1967). We focused on forest loss rates near headwaters and main rivers, respectively, because of their different function for terrestrial and aquatic ecosystems (e.g. Richardson and Danehy 2007). We employed a reverse engineering approach to identify stream orders by stepwise identification of so called dangles (loose ends of river network) according to Shreve's stream classification (Shreve 1967). The first group included streams of magnitudes (~~by~~ according to Shreve) 1 to 4 and depicts headwaters. The second group ~~were~~ ~~was~~consisted of streams of magnitudes >4 representing the remaining network of streams and rivers~~ networks~~. Focusing~~ed only~~ on the areas within the 0-200 m buffers we studied the effect of policy change on riparian forests around headwaters and large rivers. Within the total area of the ~~ten~~ 10 catchments the proportions of headwater buffers and buffers along larger rivers were 79% vs. 21%, respectively.

Third, to address the role of accessibility for logging of individual river catchments we measured the distance from the Mondi paper mill in Syktyvkar, the Komi Republic's only consumer of industrial wood (Figure 1). Distances to industry were estimated as the shortest distance by road from the informal centre of catchment to the Mondi paper mill in Syktyvkar. These distances were derived using Yandex routing services (www.yandex.ru).

Estimation of logging rates

To quantify the proportion of annual forest loss in each buffer zone and each catchment we used

Hansen's et al. (2013) open access raster data derived from Landsat and MODIS satellite-based earth observation data~~remote sensing~~, which ~~was~~ were collected between 2000 and 2014 with 1 arc-second spatial resolution. Forest loss was defined as a stand-replacing disturbance, i.e. a loss of tree cover defined as canopy closure for all vegetation taller than 5 m in height (for details see Hansen et al. 2013). According to Potapov et al. (2015) about 93% of forest loss was attributed to final fellings. To diminish areal distortions we re-projected raster datasets to metric Albers equal-area conic projection (Bugayevskiy and Snyder, 1995). We created a new variable adjusted to FAO's definition of forests as tree cover >10%, and used it as forest mask in our calculations. The proportion of annual forest loss within the forest mask was estimated separately for each buffer and for each catchment. It was estimated in percentage relative to the total forest area of respective buffer or catchment. Finally, we computed the mean annual forest loss by dividing the old-strict policy (2000-2006) group results by 6 years and the new-moderate policy (2007-2014) group by 8 years.

The Russian Federation encompasses 85 federal subjects (administrative units at the highest level). Given the focus on policy implementation of forest zoning policy in this study, Russia's focus on intensification in NW Russia's boreal biome and the availability of spatial data of streams, we chose the Komi Republic as a case study. Because the results are based on complete enumeration of the entire case study area chosen (151,220 km^2), covering all the 10 forested catchments in the Komi Republic today, and not a sample, statistical tests were not performed. To clarify, in this paper we use what is termed the census survey, census inquiry, or complete enumeration method (Kothari 2004). This means that all the items are included in the analyses. This is very characteristic to remote sensing data (in this case the items are pixels, i.e. the minimum mapping area of forest land cover) when an entire area is surveyed. The census survey method is thus 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.

This approach is consistent with several studies done with open access land cover data. For instance, forest cover changes related to illegal logging in the Ukrainian Carpathians were 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 were evaluated to map land cover structures and pattern without statistical analyses (Milanova et al. 1999).

Results

Forest zoning: past and present

Russia has a long history of forest zoning (Table A1), which developed from one simple category to multiple categories of both protection and protective forest zones (Kobyakov et al. 2013). Commencing as early as 1701, forests along rivers were protected to secure timber for ship-building (Anonymous 1830). But after the serf emancipation reform of 1861 and the resulting lack of free labour, landlords started to sell out pieces of their private land (including forests) to timber merchants. These merchants aimed at maximizing economic profit, which led to overharvesting in large territories in Russia (Istomina 2014). This triggered the Russian government to stop uncontrollable exploitation of forests, which resulted in the first major environment protection law in 1888. Thus, in 1888 the zoning policy of Imperial Russia became stricter and more detailed than previously (Anonymous 1997a). Riparian buffer zones became aimed at securing protective functions for headwaters by restricting clear-felling and pasturing. In this directive of 1888 on “forestry survey work for the promotion of rational forest management” three categories of forestry were introduced to regulate the intensity of management. These zones were not automatically assigned, but rather there was a bottom-up process whereby any private person or societies could request the state to change the management regime of a particular piece of forest land. Imperial Russia's legislation about riparian zones continued during the Soviet period (1922-1991). Protection forest zones along major rivers were created in 1936 in watersheds of the European part of the USSR, i.e. the rivers Volga, Don, Dnepr, Ural and Western Dvina. In the Komi Republic several large rivers (see Table A1, year 1936) were designated as protective forest zones where a 2-km wide zone on both sides of the river was established.

A major revision of the protective law occurred in 1943 when forests were divided into three zones depending on the purpose, i.e. water protection and nature protection, societal services (mainly for recreation) ~~services~~ for highly-populated areas, and industrial wood harvest. The widths of protective riparian zones ranged from 15 to 500 m depending on the length of the streams (Table A1). The function of the protective zones was to maintain regulating services (Anonymous 2005) using forests, e.g., to reduce erosion risk (Kobyakov et al. 2013). In post-Soviet Russia (1992 and ~~for~~onward) the restrictions changed in 2006 to a maximum buffer width of 200 m (Anonymous 2006a), and by allowing clear-felling operations under certain conditions in previously protective zones (Anonymous 2006b). Thus, in spite of all these changes over >3 centuries, there is policy continuity stating that riparian forests should not be subject to industrial harvesting.

Consequences of policy change

Overall, the proportion of annual forest loss varied from 0.15-0.23% in the 0-200 m and 201-500 m buffer zones to 0.37% in the surrounding landscape (Figure 2). The mean for all years and all zones was 0.24%. The proportion of forest loss increased with increasing distance to streams both before and after the new Forest Code was introduced in December 2006 (Figure 2). The policy change was associated to a 10.4-36.0% increase in annual mean forest loss within the buffer zones. The highest relative increase was observed in the 201-500 m buffer. In the surrounding landscape (>500 m from streams) the forest loss actually decreased by 8.9% (see Figure 2).

Next, zooming in to the loss of forest along headwaters vs. main rivers, we found that the annual forest loss in the 200-m buffer was higher in headwaters (on average 0.21%) than along main rivers (0.09 %). The magnitude of change in the 200-~~-~~m buffer increased in headwaters by 35% and in main rivers by 27% from old strict to new moderate policy in 2006 (Figure 3).

Finally, zooming out to differences among catchments we found that the absolute proportion of annual forest loss and the change between the two time periods differed among the 10 catchments (Figure 4, Table 2). We identified four groups of catchments based on the current proportions of forest loss (low vs. high) and the ~~trends~~ decrease or increase over time (Table 2). The first group with a low level of forest loss and decrease over time was represented by the Vishera and Vym ~~river~~ catchments. This can be explained as a consequence of the past logging frontier, which had passed these catchments already in the 1980s. Additionally, today, the only large organization~~, which~~ that leases forest in the Vym catchment is a state correctional facility, and not a regular forest land leaser aiming at wood harvest. The second group with low loss and increase over time includes catchments of the Pechora and Ilych rivers. Both are very remote (about 400 km to industry, see Table 1), and 59 and 84% of these catchments, respectively, were occupied by large intact forests (see Table 1). The third group with high forest loss and decrease over time was represented by the Vashka and Mezen catchments. Here the logging frontier also passed earlier, and the proportion of large intact forest is relatively high (27% in Mezen and 35% in Vashka). The fourth group, with high ~~annual~~ forest loss and increased loss in the moderate-new zoning policy period (2007-2014), was represented by the four catchments (Lokchim, Luza Sysola and Vychegda) that were closely located to pulpmills and sawmills in Syktyvkar.

The distance from industry to catchment was inversely related to forest loss (N=10: Spearman rank -0.51515, one-tailed p=0.064) (Figure 5). When removing the two catchments of the Vishera and

Vym rivers with deviating forest history and tenure (see upper left cell in Table 2) the value of R is -0.88095 (one-tailed p=0.0019).

Discussion

Consequences for intensification on logging and nature conservation

In this study we used open access satellite-based remote sensing data to test the hypothesis that that recent changes in Russia's forest policy have indeed improved the opportunity for intensification by making more forest land accessible for logging, and conversely, that the rate of loss of riparian forests has increased. The use of ~~this~~ these data with high spatial resolution about forest loss allowed us to analyse the consequences of forest policy change for (1) the maintenance of forest cover along streams, which is important for biodiversity conservation in the terrestrial-aquatic ecotone, and for (2) forest logging intensity in our study area. Open access remote data ~~has~~ have been successfully used to assess policy change on land use change globally (Potapov et al. 2008, Hansen et al. 2010), regionally (Main-Knorn et al. 2009, Potapov et al. 2015) and nationally (Kuemmerle et al. 2009, Baumann et al. 2011, 2012). The open access remote sensing data ~~was~~ were used also in Russia to estimate how much of forested area had been cleared near Moscow city between 1991 and 2001 (Boentje and Blinnikov 2007). Analysis of intact forest landscapes were done by Yaroshenko et al. (2001) and Potapov et al. (2008) with help of Landsat and MODIS imagery, which are publicly available. Also changes in agricultural land can be assessed with open access data. This was successfully done for example in Northern Africa (Lenney et al. 1996), in Eastern Europe (Peterson and Aunap 1998, Kuemmerle et al. 2008) as well as in Russia (Prishchepov et al. 2013).

Approaches to production and harvest of wood in Russia have evolved through three distinct periods (Naumov et al. 2016). First, sustained yield forestry was encouraged based on even-aged stands in the 19th century (Turmer 1891). Second, after the Russian revolution in 1917, the socialistic ideology discarded economic factors (Knize and Romanyuk 2006), which led to intense wood mining. Third, after the collapse of the Soviet Union in 1991 market economy re-emerged, as well as the desire for intensified silviculture. Thus, there have been 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 and Romanyuk 2006). Currently the second vision is widely ~~applied~~ advocated and linked to a growing interest in ~~the Russian Federation~~Russia to increase the productivity of wood per unit area in previously harvested areas (Martynyuk et al. 2016, Angelstam et al. ~~2016~~2017). To aid this approach a zonation map of forest use in the Komi Republic was created in 2011 (Krivoshein 2014). This divided the forested territory into intensive and extensive zones of forest management. Forest type (by soils and latitude), economic profitability and transport accessibility were the major factors that influenced the identification of the intensive forest management zone. However, intensification requires considerable investments in road building (Martynyuk et al. 2016; Naumov et al. 2016), and increased sustained yield by means of active silviculture (e.g., Naumov et al. 2016; Angelstam et al. 2017~~6~~). An alternative short-term avenue to increase forest harvest opportunities is by extending the area available for wood mining. Consequently, the new 2006 Forest Code opened up the opportunity for clear-felling in protection forests along streams in regions where the timber frontier already passed relatively near the industry consuming wood.

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We used the open land cover change data of Hansen et al. (2013) ~~open remote sensing data~~ as a proxy for logging intensity. This involves two potential caveats. In naturally dynamic forests, continuous cover forest stands with gap-phase dynamics on productive sites are often found along streams (Lazdinis and Angelstam 2005). This implies that mature forest stands would remain as an intact riparian buffer zone unless clear-felled or subject to other stand-replacing disturbance. According to our results on average 0.24% of forest loss had occurred annually in the whole study area. However, in Komi also wildfire may lead to forest loss, but not land clearing for agriculture or other purposes. However, given that the probability of fires are lower on wet sites (Furyaev and Kireev 1979), which are more common along streams than in the rest of the landscape (Angelstam and Lazdinis ~~2016~~2017), the proportion of forest loss along streams should be dominated by logging compared to fire. In addition, on average only 6.1% of the total forest loss area is attributed to wildfires, and 1.3% to windfalls in Eastern Europe (Potapov et al. 2015). Hence forest loss is a relevant proxy indicator for forest harvest in this region. Additionally, forests may be harvested by commercial thinning, which ~~are~~ is not detectable by the method used by Hansen et al. (2013). However, this is a very uncommon practice in Komi and constitutes about 1% of total harvested area (Sherstukova 2012).

Our results show that the loss of riparian forest was positively related to the distance from streams, but increased in both 0-200 and 201-500 m buffers~~,~~ after the forest policy change. This indicates both that the zoning policy does indeed increase the probability that forests along streams remain, but also that forest harvesting was intensified when the policy changed. On the contrary, forest loss decreased in the surrounding landscape. Zooming into catchments, we found that in spite of headwater systems being particularly important for terrestrial and aquatic biodiversity conservation as well as in-stream quality (e.g., Richardson and Danehy 2007), the loss of forest along headwaters was higher than along large streams. Finally, zooming out to the entire Komi Republic the differences in the levels of forest loss among catchments before and after policy change showed that harvest in the catchments near industries was high and increasing. In contrast catchments being inaccessible due to poor forest road infrastructure and/or high transportation costs had low ~~stable~~ levels of forest loss. These results show that the idea of expanding wood mining by relaxing the zoning policy had the desired effect to increase logging rates. Kobyakov et al. (2013) argued that this forest policy change will also increase the rate of loss of the last remaining intact forest landscapes in NW Russia. While the results do not support this at the regional level among catchments, loss of local remnants of intact forests in terms of riparian forests did indeed increase, especially in headwaters. Nevertheless, the overall annual loss of old forest was low (0.15 to 0.37%

per year) compared, for example, to Sweden and Finland where 0.92% (Skogsstyrelsen 2014) and 1.2% (Peltola 2014), respectively, of forests are subject to final felling annually. In addition, commercial thinning takes place in these countries, which contributes considerably to the total harvest.

Matching our results (Figure 3) with the zonation map for the Komi Republic (Krivoshein 2014), we note that the southern catchments such as Lokchim, Sysola and Luza are located in the zone where intensification of forestry is feasible. This is consistent with the proposition that once the frontier of logging old-growth forests where wood has accumulated over long time (Pennanen 2002) has passed, intensification of forest management is more likely to be successful at lower latitudes where growth rates are higher due to a longer vegetation period (Martynyuk et al. 2016; Angelstam et al. 2017~~6~~).

Spatial segregation of forest functions by zoning

The extent to which riparian forests are maintained varies among forest management contexts. In Canada and the US several zoning systems occur to isolate upland activities from terrestrial near shore and aquatic areas (Lee et al. 2004). In contrast, Sweden has never practised formal forest zoning aimed at creating riparian buffers (Lazdinis and Angelstam 2005). In the circumboreal biome only Russia has a long history of comprehensive system for forest zoning. However, the history of this is inaccessible for the international audience (Algvere 1966). Zoning of forests focused on maintaining high forest along streams and rivers in Russia occurred already in 1842-1845 (Arnold 1895; see also Reymers and Shtilmark 1978, Redko and Redko 2002). However, the recent interest for intensification of forestry in Russia (Nordberg et al. 2013; Naumov et al. 2016) challenges the zoning approach. Increasing the amount of wood available to the forest industry can be achieved by (1) expansion of harvest into previously inaccessible forests (Elbakidze et al. 2013), and (2) increasing the utilisation and rate of production of industrial wood by intensified silviculture (Nordberg et al. 2013). While the latter takes a long time, permission for harvesting in riparian zones with remaining old forests is more effective in the short term, and imposes no cost in terms of investment in silviculture or management. In Russia this has recently triggered changes to the forest policy zoning system by reducing the width of protected buffer zones along streams (Kobyakov et al. 2013).

Several studies show that spatial segregation (i.e. zonation) is more efficient than integrated stand-level approaches at delivering the broad portfolios of benefits from forests requested by sustainable forest management policy (Mönkkönen et al. 2014, Triviño et al. 2015). The riparian forest buffers in Russia initially aimed at providing protective functions linked to streams and rivers rather than the riparian forest itself. Much later protection functions in terms of conservation of forest habitat types, which are not delivered by intensive forestry, and its associated species, were added as motives~~, i.e.~~ under the umbrella of biodiversity conservation. The lower loss of forest along streams compared to the rest of the catchment shown in this study implies that forest zoning in Russia has indeed contributed to the conservation of riparian forests that serve as a functional habitat network in forest landscapes, and thus a green/blue infrastructure (Figure 6). This is also evident from field studies. A comparison between boreal forest streams in Finland and Russia by Liljaniemi et al. (2002) showed that channel habitats were in fairly natural state in Russia whereas the Finnish sites were cleared and straightened; and the abundance of coarse woody debris in streams was 10–100-fold higher in Russia.

Another topic is to resolve how riparian forest-headwater complexes should be maintained. The issue of fixed-width or variable-width management policy for riparian vegetation has been in focus for decades (e.g., Lee et al. 2004). Kuglerová et al. (2014) argued that fixed-width buffers are not an ideal solution for sustainable forest management with an economic focus in a context with many private land owners, such as in Sweden. Taking local hydrological and site conditions into consideration, as well as maximizing the yield of wood, they argued in favour of variable-width riparian buffers. They proposed the use of groundwater discharge hotspots as an indicator for landscape elements along streams with higher ecological significance. These may be identified using digital elevation models, if sufficiently detailed, or by mapping tall herb ground vegetation (Angelstam and Lazdinis ~~2016~~2017) because such discharge hotspots coincide with species-rich herb vegetation (Kuglerová et al. 2015). This would benefit biodiversity and important ecosystem services such as water quality without necessarily incurring costs from a wood production standpoint (Laudon et al. 2016). For Canada and the US Lee et al. (2004) concluded that buffer widths of 15-30 m were adequate to protect the aquatic biota and habitats, but not for terrestrial communities. There is an ongoing debate in Sweden whether to use fixed-width or site-adjusted riparian zones. ~~It is legally specified what width should be left as buffer.~~ Nevertheless, the Swedish Forest Agency ~~although~~ recommends ~~to~~ leavinge 15-30 m (Lindegren 2006). In contrast, Russia maintains 200-m wide riparian forest zones. We see the need for empirical studies about what maintenance of streams' and riparian forests' functions require in ~~different biophysical~~terrestrial and aquatic ecosystem contexts, such as on the Russian plain with flat terrain and sand, silt and clay versus on the Fennoscandian shield with shallow till soils over bedrock (Angelstam and Lazdinis 2017).

Analogous to buffer zones along streams voluntary forest certification prescribes zoning around villages in Komi to support rural livelihoods by securing the access to and maintenance of non-wood forest products such as berries and mushrooms (Stryamets et al. 2015), as well as hunting and fishing. Zoning regulations thus help to achieve human well-being. By spatially segregating forest landscapes multi-purpose forest management can be achieved at the landscape level, including biodiversity conservation, wood production and social values.

Governance and ownership contexts for applying forest zoning

The extent to which different aspects of sustainable forest management policy are implemented is determined by societal context (Angelstam et al. 2011, Elbakidze et al. 2013). A major feature of the Russian forest governance and management system is a centralized top-down planning system (e.g., Nordberg et al. 2013). The forest companies, which lease state owned forest, are requested to obey all forest regulations (e.g., the number of trees per hectare, methods for pre-commercial thinning) that are not regionally specific, and forest management is then controlled by the state. However, several regional policy documents have been adapted to local conditions in NW Russia, for example, in the Komi Republic and in the Pskov oblast. In Komi ~~intensified wood production is supported by the concept of emulating natural dynamics forest according to characteristic fire dynamic on different site types, and the resulting tree species composition (Mariev et al. 2005). This~~ The regional forest policy in the Komi Republic ~~thus~~ promotes forest management practices that aim to emulate~~cion~~ ~~of~~ natural disturbance regimes (Mariev et al. 2005). In Pskov oblast new norms for balancing wood production and biodiversity conservation have been proposed. A forest conservation system was developed based on setting aside areas for conservation at tree, stand, landscape and regional scales (Angelstam et al. 2005). Regarding wood production, introduction of Scandinavian systems for commercial thinning were proposed to be implemented in NW Russia (Romanyuk et al. 2002).

~~Other countries have also developed zoning~~ Zoning approaches have been developed also in other countries. For instance, Sweden's state forest company Sveaskog uses the Ekopark concept (Angelstam and Bergman 2004) in 37 locations amounting to 5% of the company's holdings. Within Ekopark areas 50% of forest land is set aside or managed for conservation and on the rest of the area wood production is the main objective. Another approach developed in Swedish forest management planning is the operational division of forest land into four classes representing a gradient from wood production, combined wood production and biodiversity conservation~~-~~ to biodiversity conservation based on active management and free development (Andersson 2010). By and large this corresponds to Dunckers' et al. (2012) intensity scale from intensive/high to medium and passive management. If applied throughout a landscape by spatial segregation, such approaches would benefit sustained-yield wood production, biodiversity conservation and social values such as outdoor recreation and nature-based tourism. However, ~~also~~ protected area networks are also needed to maintain habitat for viable populations of specialised species with large area requirements (Bollmann and Braunisch 2013, Mönkkönen et al. 2014). Additionally, other instruments are needed to ensure that natural disturbances are inherently incorporated both in the beginning of succession (e.g., fire) and ~~wood harvested at the later stage~~during the subsequent ~~succession~~stand development (e.g., self-thinning and gap formation) (Sturm 1993).

To conclude, insights from Russia' forest policy dynamic and its consequences for intensification of logging and riparian forest conservation are little known internationally, but of considerable general interest for governors and managers. In contrast to the Russian context with a long history of state regulation of forest zoning (see review in Table A1) it is hard to introduce this segregated approach in societal contexts where land ownership is non-industrial or industrial private, and the spatial structure of ownerships is diverse, as for instance in Sweden (Rist et al. 2016). With a focus on maintaining functional riparian buffer zones along streams in general we see three options. The first is to encourage additional efforts towards ~~maintaining~~maintenance of functional riparian forests ~~zones~~ on suitable site types ~~in terms of~~by empirical research about buffer zone width to achieve different objectives in different contexts, ~~education, learning and collaboration~~and collaborative learning among forest owners and stakeholders (Daniels and Walker 2001, Elbakidze et al. 2010). Open access data can advance monitoring of policy change. The second is establishment of prescriptive forest zoning, which is easier with top-down regulation and state ownership. The third is to accept that securing both forestry intensification and biodiversity conservation is difficult unless some form a spatial planning is applied beyond the scope of individual firms or other actors. Open access land cover change data can advance monitoring of the effects of all three alternatives.

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Table 1. Basic information on river catchments in the study area located in the Komi Republic (see Figure 1).

River catchment (see Figure 1)	Informal centre of the catchment	Area (km2)	Wetlands (%)	Intact forest1 (%)	Road density2 (km/km2)	Approx. distance3 to industry (km)
Vashka	Eortom	19710	4	35	0.25	330
Mezen	Chernutjevo	15015	4	27	0.40	310
Vym	Vetju	23938	13	19	0.25	190
Luza	Noshul	10253	1	0	0.33	210
Sysola	Koygorodok	17403	3	0	0.40	190
Lokchim	Namsk	5729	1	0	0.40	100
Vishera	Bogorodsk	4494	7	0	0.30	130
Vychegda	Ust-Nem	30290	6	0	0.33	250
Ilych	Troitsko-Pechorsk	14411	6	84	NA	390
Pechora	Komsomolsk-na-Pechore	9977	2	59	NA	470

[1] The proportion of intact forest was calculated as percentage of studied river catchments based on data set by Potapov et al. (2008).

[2] Road density was retrieved by forest management unit from Forest plan of Komi Republic (Anonymous 2011), and values were averaged over catchment area.

[3] Distances to industry were estimated as the shortest distance from the informal centre of catchment to main industry customers in Syktyvkar. It was derived using Yandex routing services (www.yandex.ru).

Table 2. Four groups of magnitudes of forest loss and trajectories over time among the 10 studied catchments (cf. Table 1).

	Low forest loss	High forest 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 in Syktyvkar, no intact forest)

Figure 1.

Map of the Komi Republic (grey border), its three main catchments N. Dvina, Mezen, Pechora, and the ~~ten~~ 10 sub-catchments analysed in this study. Inset map shows borders of the main map in Northern Europe. Spatial data sources: all vector data - OpenStreetMap contributors (www.openstreetmap.org); raster data – Natural Earth data (www.naturalearthdata.com).

Figure 2.

~~Proportion of a~~Annual rates of forest loss (%) during two periods with different forest zoning policy at 0-200 m, ~~and~~ 201-500 m, and >500 m from streams of all stream orders within 10 catchments in the Komi Republic.

Figure 3.

~~Proportion of a~~Annual rates of forest loss (%) ~~during two periods with different forest zoning policy~~ at 0-200 m from ~~headwaters (~~streams of magnitude 1-4 (~~; following~~ Shreve (1967); i.e.~~)~~ headwaters) and ~~main~~ streams and rivers with ~~(~~stream magnitude >4~~).~~ during two periods with different forest zoning policy.

Figure 4.

~~Proportions of a~~Annual rates forest loss (%) during two periods with different forest zoning policy inside the forest mask in the 10 catchments ranked by the mean level of annual forest loss.

Figure 5. Relationship between mean annual rate of forest loss 2000-2014 in the 10 catchments in Komi in relation to the distance from industry to the catchment. Note the differences in forest history and land tenure of Vishera and Vym compared to the other catchments, see Table 2 for details.

Figure 6.

Satellite image of the Nivshera catchment in the case study area (see Figure 1) showing riparian corridors (dark colour) along streams. Map data: Google Inc. and USGS.

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Appendix

Table A1. Regulations and riparian forest management restrictions according to forest and water policies in Russia in the period 1701-2016.

Year of changes	Regulation name translated from Russian (original title in parentheses)	Zoning rules	Restrictions	Active or passive decision	References
1701	Directive by Peter the Great: “Regarding limitations of forest harvest in the 30 versts (1 verst=1.06 km) of riparian forests for mowing. (”Указ Петра I “О нерасчистке лесов под пашню и сенные покосы за 30 верст от рек, удобных к сгонке леса”)	-	Prohibited to harvest 30 versts from rivers for agriculture	Law	(Anonymous 1830)
1703	Regarding forest inventory of all rivers, for big rivers – 50 versts buffers, for smaller 30 (“Об описи лесов во всех городах и уездах от больших рек в сторону на 50, а от	Protect forest 50 versts from large rivers, and 30 versts from small rivers suitable for floating	Forbidden to harvest forest with oak, larch, beech and pine of minimum diameter 53 cm	Law	(Anonymous 1830)

	малых по 20 верст”)				
1888	Regulation about forest conservation (“Положение о сбережении лесов”)	1) Sustained-yield wood production zone, and 2) protection zone to protect headwaters	Clear-felling, pasturage	Regional level authorities	(Anonymous 1997a)
1914	World War I – protection regulations are cancelled.				(Yushkova 2001)
1923	Forest code of Russian Socialistic Republic (Лесной кодекс РСФСР)	1) Public forests; 2) Rural forests	-	Transferred from Imperial Russia definitions	(Anonymous 1923)
1936	Regarding establishment of forest protection and identification of protection zones around rivers (Об образовании главного управления лесоохраны и лесонасаждений при совете народных коммисаров Союза ССР и о выделении водоохранной	Protection zone for Volga, Don, Dnepr, Ural and Western Dvina river catchments	Forbidden clear-felling in 20 km, 6 km and 4 km for selected rivers (see reference). Vychegda, Vym, Sysola, Lokchim, Vishera, Pechora – 2	Law	(Anonymous 1936)

	зоны)		km (Yushkova 2001).		
1943	Regarding establishment of forest protection and identification of protection zones around rivers (О порядке отвода лесосек в лесах государственного фонда Союза ССР и о лесосечном фонде на 1943 год)	1) Protective, 2) sustained-yield, 3) industrial forest zones	In (1) protective zone clear-felling was forbidden.	Regional level authorities (oblast, republic, kraj)	(Anonymous 1943)
1989	Regulation on water protection zones in the USSR (Об утверждении положения о водоохранных зонах (полосах) рек, озёр и водохранилищ в РСФСР)	Length of river: and minimum buffer 0-10 km: 15 m 11-50 km:100 m 51-100 km: 200 m 101-200 km: 300 m 201-500 km: 400 m >500 km: 500 m	Clear-felling is forbidden	Regional level authorities	(Anonymous 1989)
1997	Forest code of Russian Federation (Лесной кодекс РФ)	Same as above	Same as above	Same as above	(Anonymous 1997b)

2006, June	Water code of Russian Federation (Водный кодекс РФ)	Length: minimum buffer 0-10 km: 50 m 11-50 km:100 m >50 km: 200 m	-	-	(Anonymous 2006a)
2006, December	Forest code of Russian Federation (Лесной кодекс РФ)	-	Clear-felling is allowed	Regional level authorities	(Anonymous 2006b)

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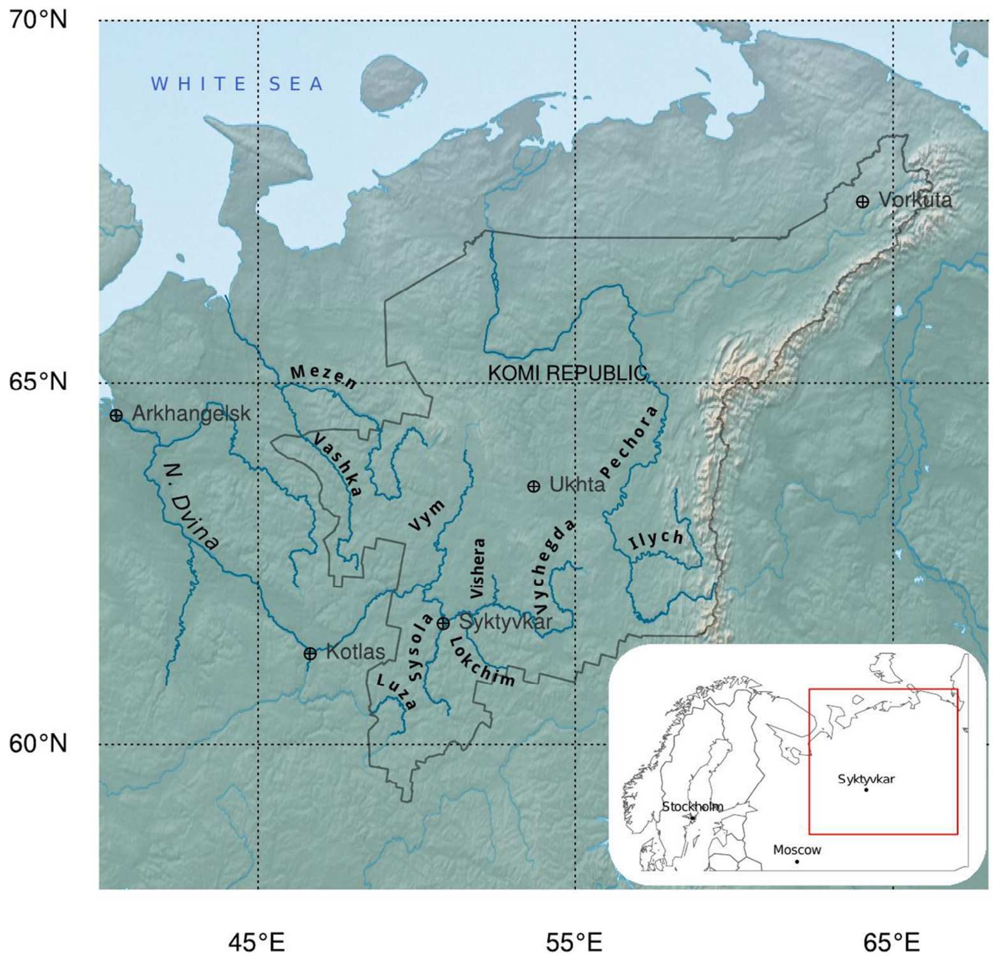

Study area

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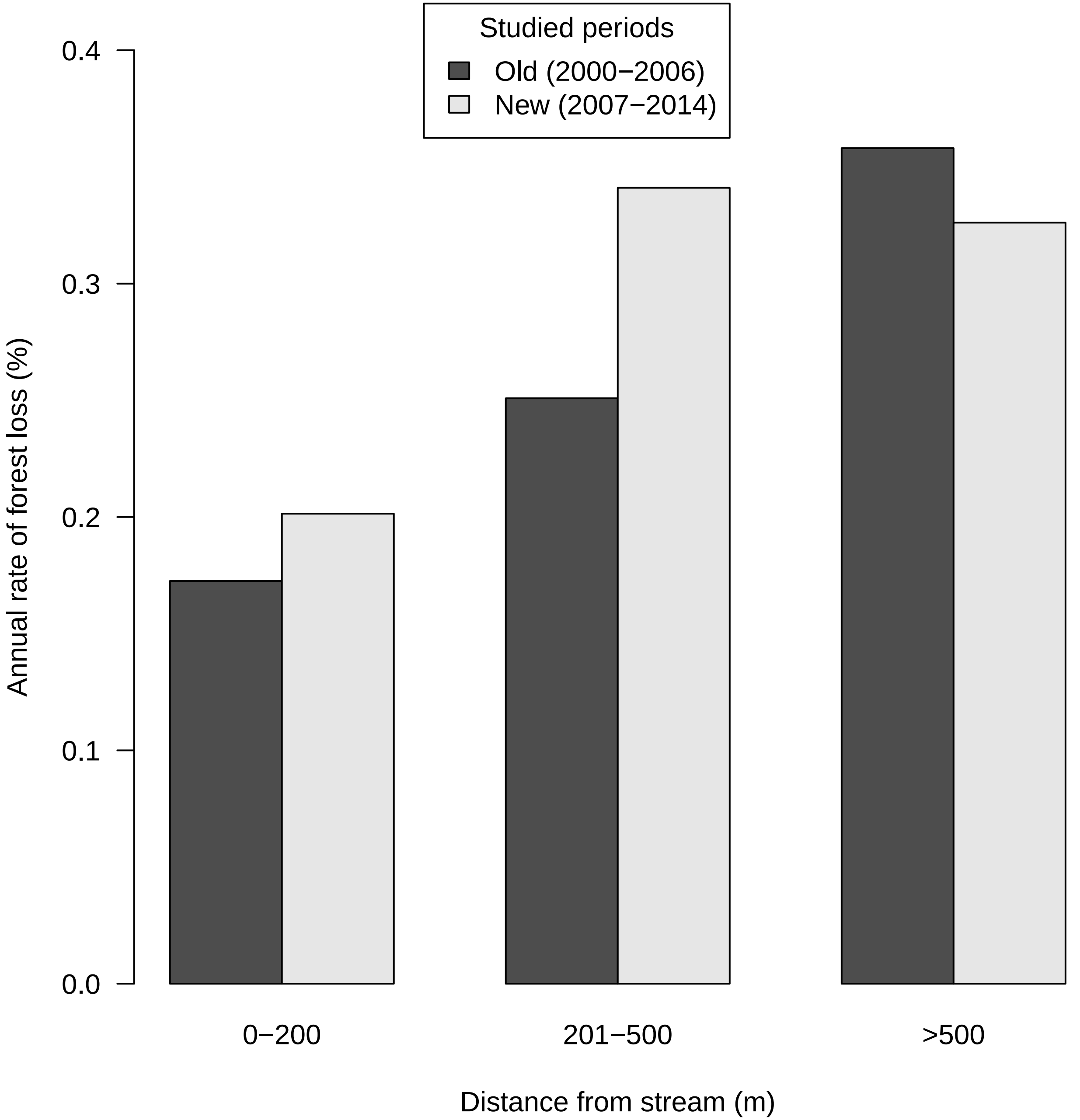
Studied periods
Old (2000−2006)
New (2007−2014)
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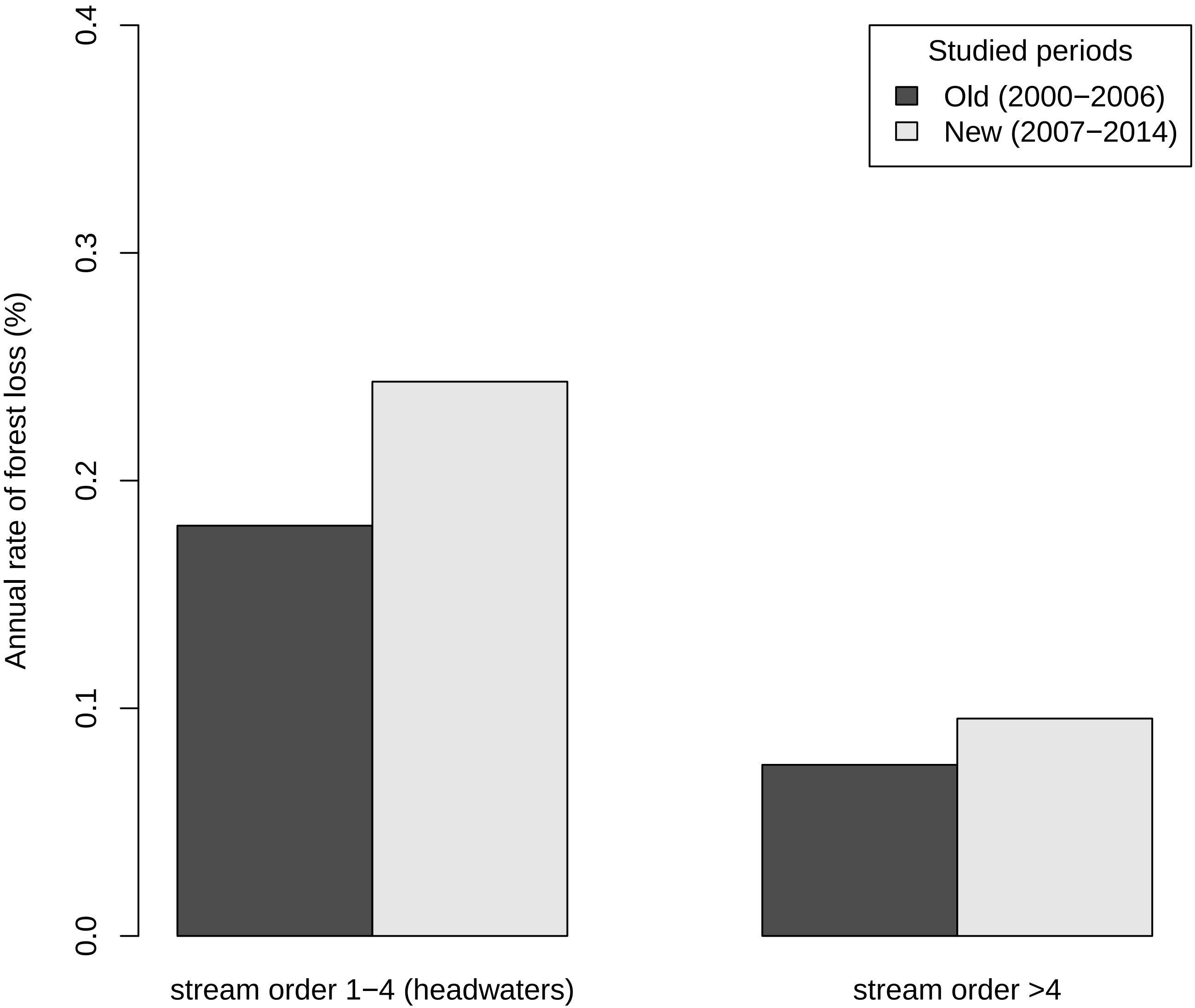
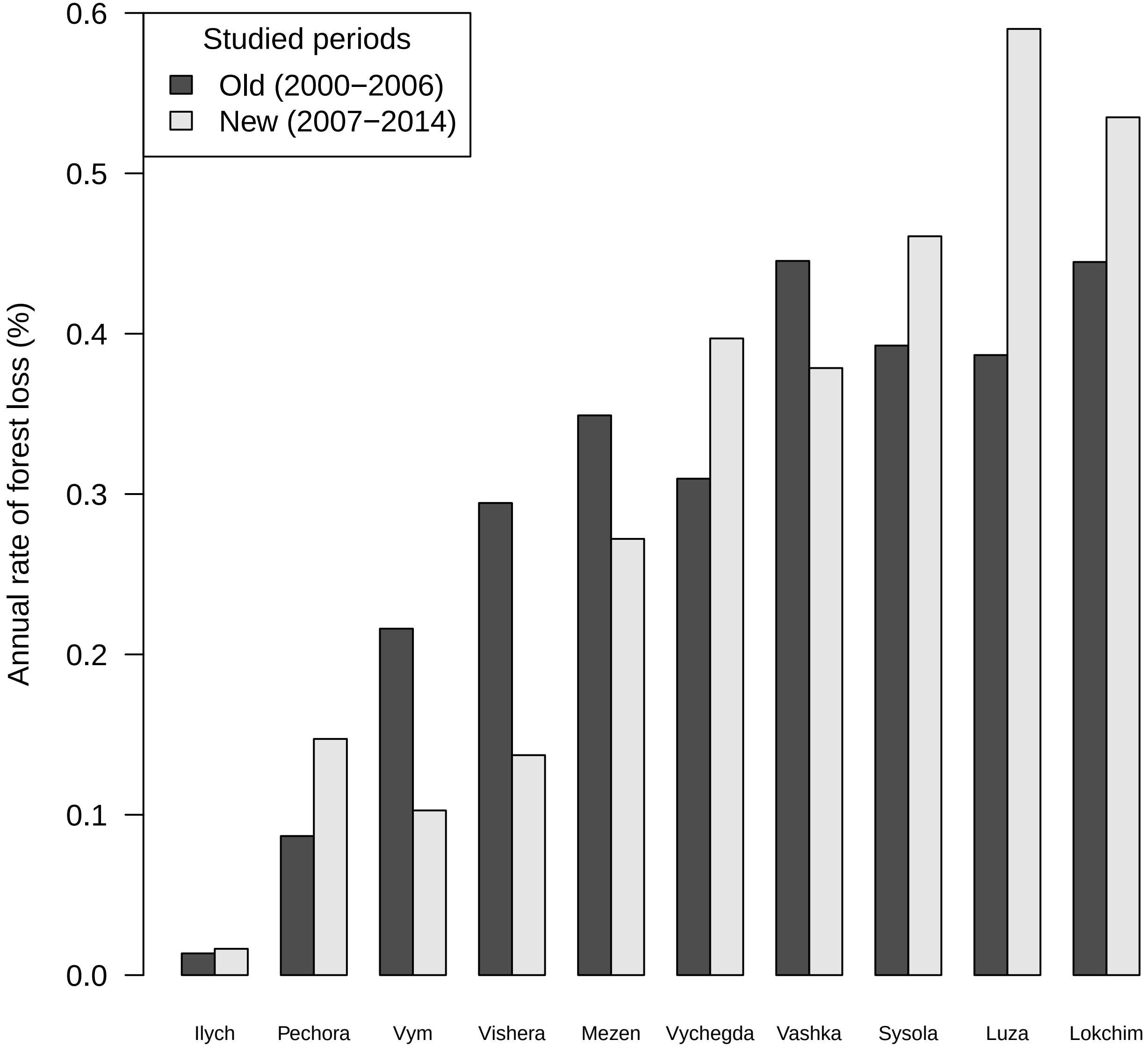
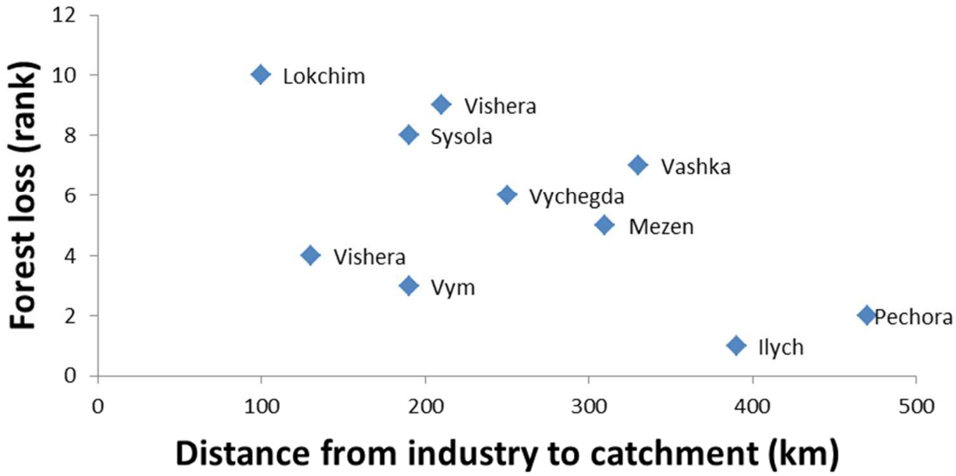
0.3
0.2
0.1
0.0
Annual rate of forest loss (%)
0−200
201−500
>500
Distance from stream (m)


0.4
0.3
0.2
0.1
0.0
Annual rate of forest loss (%)
Studied periods
Old (2000−2006)
New (2007−2014)
stream order 1−4 (headwaters)
stream order >4


Studied periods
Old (2000−2006)
New (2007−2014)
Annual rate of forest loss (%)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Ilych
Pechora
Vym
Vishera
Mezen
Vychegda
Vashka
Sysola
Luza
Lokchim



Relationship between loss and distance

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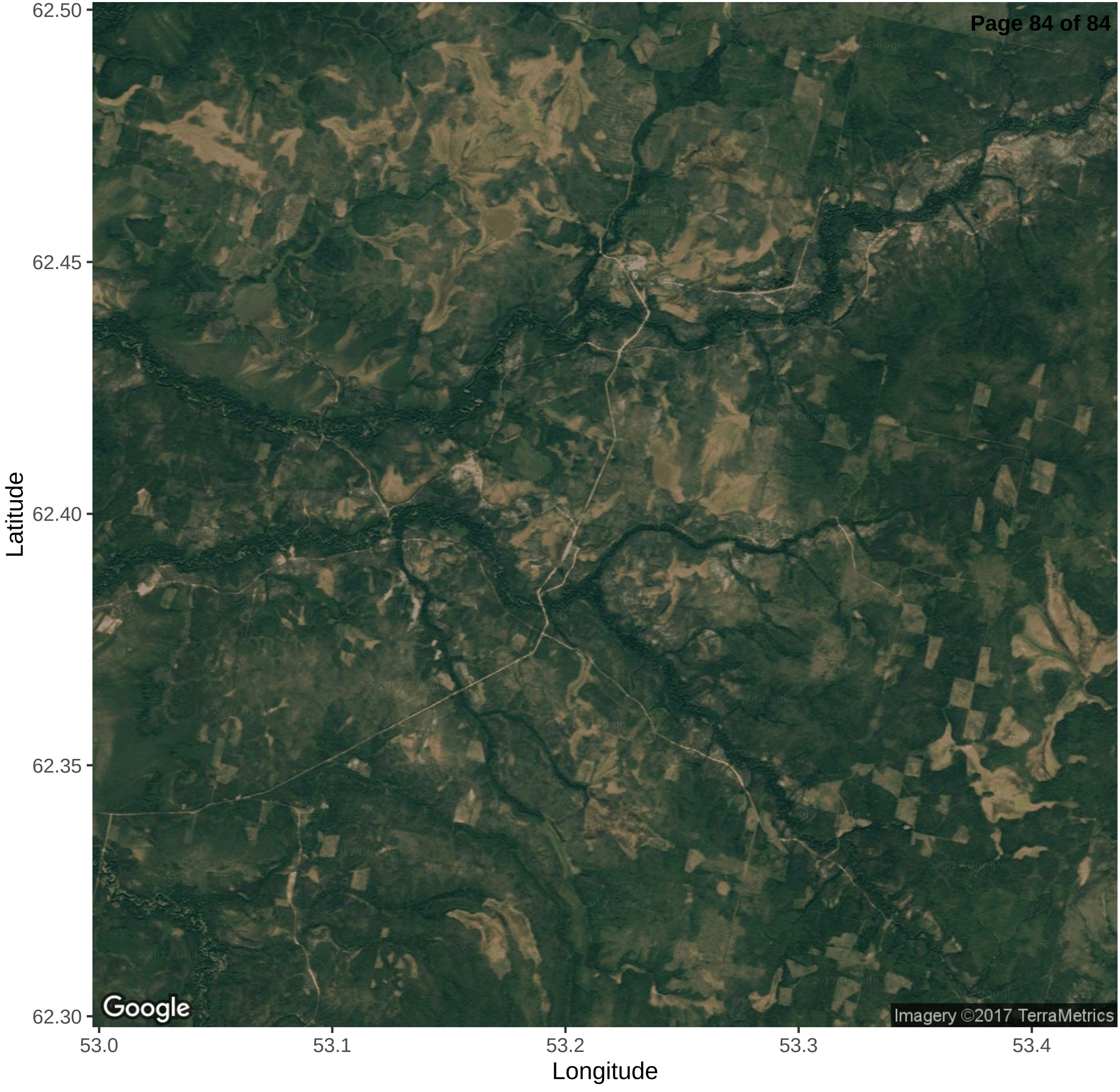
62.50
62.45
62.40
62.35
62.30
Latitude
53.0
53.1
53.2
53.3
53.4
Longitude
Google
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