Alexey Yu. Yaroshenko, Peter V. Potapov, Svetlana A. Turubanova

The LAST INTACT FOREST LANDSCAPES of NORTHERN EUROPEAN RUSSIA

Mapping of intact forest landscapes in northern European Russia using high-resolution satellite images — methods and results

GREENPEACE RUSSIA AND GLOBAL FOREST WATCH

With the support of the Biodiversity Conservation Center, the Socio-Ecological Union International and the Kola Branch of the Biodiversity Conservation Center

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This work is the first attempt at identifying boreal forest areas of minimal human disturbance (intact) using high-resolution satellite imagery that allows most forms of disturbance in the natural ecosystems to be directly identified.

The work was done at the GIS laboratory of Greenpeace Russia using, in part, materials prepared by the Biodiversity Conservation Center and the Socio-Ecological Union International.

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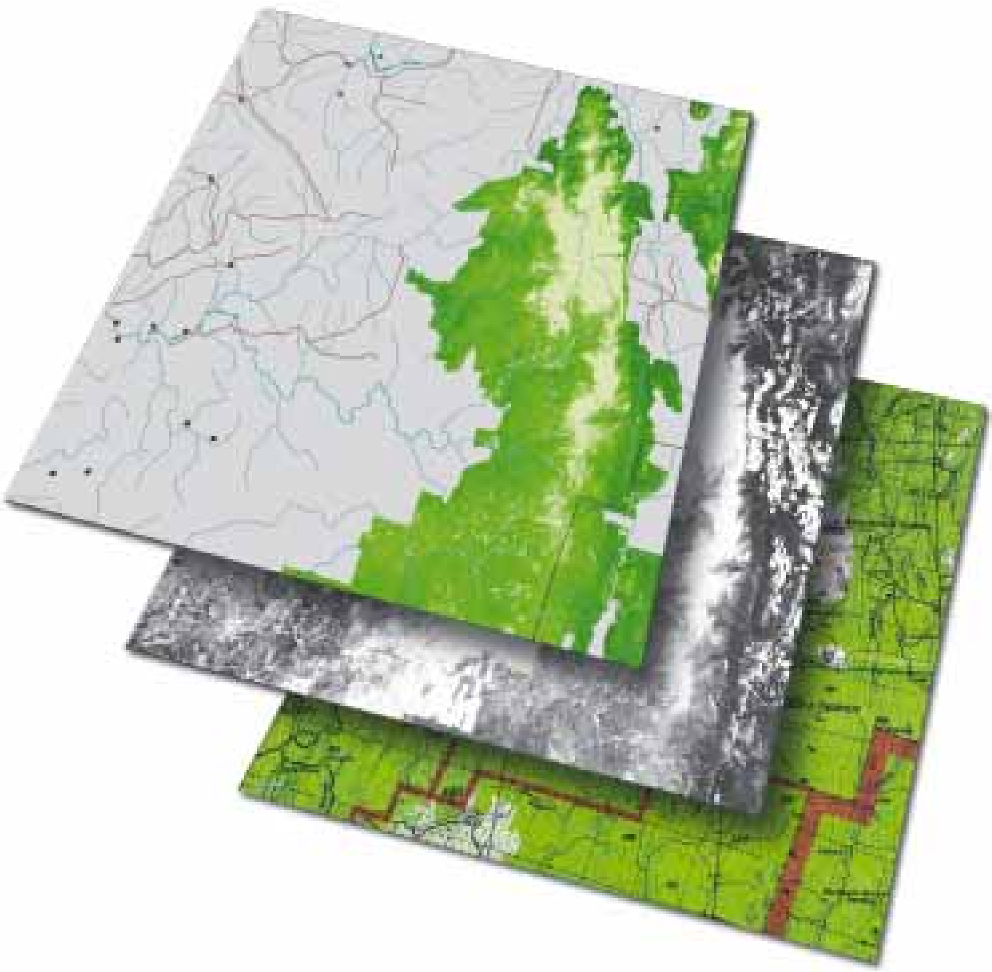

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MAIN CONCLUSIONS

1. Forest landscapes that are still intact (i.e. essentially undisturbed by human development with an area of at least 50,000 hectares) make up about 14 percent (31.7 million hectares) of the total forest area of European Russia (including the Ural Mountains). The vast majority of these areas are located in the most remote areas of the far North. No intact forest landscapes remain in central and southern European Russia.

2. The vast majority of these forests (87 percent) have a production potential of less than 1m^3 per hectare per year.

3. Remaining intact forests are poorly stocked. More than half (56 percent) has a standing inventory of less than 100 m^3 per hectare, and almost nowhere is the inventory greater than 150 m^3 per hectare.

4. The areas in the vicinity of the intact forests play a mostly insignificant role in the wood supply of the region. Less than 5 percent of the volume logged in the Karelia and Komi Republics, Arkhangelsk and Perm Regions comes from such frontier areas. Only in the Arkhangelsk Region is the intensity of logging greater in frontier forests than in more developed parts - an indication of forest depletion in the latter areas.

5. The poor stocking and slow rate of re-growth make these forests unsuitable for sustainable wood production. The necessary investments in road building and reforestation are unlikely to be offset by revenues, especially given the long distance to the market. Historical precedent in similar areas shows that subsequent investments in reforestation and silviculture often are insufficient.

6. In the perspective of northern European Russia as a whole, removing intact forest landscapes from timber production would only factor as a small reduction in the potential wood supply. The reduction may be significant, however, for some logging enterprises located near the intact forest landscapes.

7. Conservation of large intact landscapes is a robust and cost-effective way to conserve biological diversity. The remoteness and large size of these areas provide the best guarantee of continued intactness. Far fewer personnel are needed to protect and manage forests within intact landscapes than are required in developed forest regions.

SUMMARY

Many people think of the Russian taiga as an unlimited expanse of undisturbed nature. The main purpose of this study was to find out to which extent this notion is true-to answer such questions as

- How should undisturbed nature be defined?
- How can undisturbed natural landscapes be identified?
- Where are the remaining intact natural landscapes?
- What is the economic importance of these areas?
- What is the level of threat?

European Russia, including the Ural mountains, was systematically studied in order to map remaining large intact natural forest landscapes. Large was defined as no smaller than 50,000 hectares in size and at least 10 kilometers in width. One might think of this minimum area as the size of a square with a side of 22 kilometers (although no natural areas are shaped in this way).

There are three reasons for the focus on large areas. First, only sufficiently large areas are capable of conserving populations of large animals in their natural, undisturbed state, and of letting natural ecological processes such as fire, wind throw, etc take their course. Second, large undisturbed areas are important as a reference that helps in the understanding of already disturbed areas (the vast majority of forest landscapes). Third, large intact areas are often comparatively cheap to conserve, as they tend to rely on remoteness and low productivity as their main sources of protection.

Forest landscapes were mapped. The reason for mapping landscapes instead of individual ecosystems is that the boreal forest is a natural mosaic of integrated ecosystems, such as forests, wetlands, rivers, lakes, and tree-less areas. Separating these ecosystems would not only be difficult but also artificial.

The goal was to find forest landscapes with a minimum of human disturbance. Two things must be realized: that the boundary of human influence often is diffuse, and that areas which are strictly free from

human disturbance no longer remain. In this study, as area was considered to be in an intact natural state if showing no signs of permanent settlements or communications, of industrial forest harvesting during the last 60 years, or mining, land clearing, and other essential human impacts. Traces of low-intensity human disturbance were accepted in the intact areas as "background disturbance". This includes hunting and early high-grading for timber far away from infrastructure.

One of the biggest problems when delineating intact landscapes is the treatment of forest fires. Fire is a natural component of the boreal ecosystem but not all fires occur for natural reasons. Separating fire scars by cause is usually impossible. In this work fire was treated mainly as an element in the natural dynamics of the boreal ecosystem. An exception was made for fire scars and young regenerated forests on old fire scars that are located directly adjacent to infrastructure. Such areas were considered disturbed, due to the dual likelihood that the fire was caused by humans and that the infrastructure will be a cause of future human disturbance.

A three-step procedure was used in the search for remaining intact forest landscapes. To begin with, general geographic maps were used to eliminate obviously disturbed areas (cities, big roads, etc.) and to identify roadless areas large enough to meet the size requirement. In the second phase, two-season medium resolution satellite images from the Russia satellite Resurs (the MSU-SK scanner with a ground resolution of 150 meters per pixel) were used to identify tundra areas and areas with obvious clearcuts, agricultural fields, etc. In the third and last phase, high-resolution Landsat and analogous satellite images (ground resolution typically 30 meters per pixel) were used to identify additional disturbances and to draw the final boundaries of remaining intact landscapes. This approach was used because Landsat images could not be acquired for the entire area of study for budgetary reasons and for lack of availability in some areas.

Field expeditions were carried out in order to assess the actual level of disturbance on the ground in difficult areas, and to verify and improve the interpretation of the satellite images. A total of 67 areas were inspected. Many of the field expeditions included the people who were directly engaged in interpretation of the satellite images.

The result shows that only 14 percent (32 million hectares) of the forest area in European Russia remain in large blocks of intact nature. All of these areas are in the remote far north with the exception of a few large peat bogs. In the rest of European Russia, and very likely in Europe as a whole, large intact natural forest landscapes no longer exist.

Remaining intact landscapes tend to be remote, unproductive and poorly stocked in comparison to what is usually considered minimum levels for sustainable forestry. According to the official forest map of the Russian Federation, 87 percent of the intact area has an average production of less than 1m^3 of stemwood per hectare and year. More than half of the area has less than 100m^3 per hectare in mature forest and almost nowhere is the inventory greater than 150 m^3 per hectare. It is interesting to note that the Swedish Forestry Act puts all land with a productivity less than 1m^3 of stemwood per hectare and year off limits to forestry.

To level of threat to the remaining intact forest landscapes was assessed by studying the intensity of logging around their borders during the peak logging season of 1999-2000. Pairs of satellite images were used for this study, which showed that more than 95 percent of the wood in the Karelia and Komi Republics and in the Perm Oblast came from already disturbed areas, and about 90 percent in Archangelsk region. Only in the Arkhangelsk Region was the logging intensity greater near the intact areas than in the more developed parts - an indication of forest depletion in the latter areas.

The forestry significance of the remaining intact forest landscapes is low. Withdrawing these areas from timber production would only factor as a small reduction in the potential wood supply, seen in the perspective of northern European Russia as a whole. For some local logging enterprises, however, the reduction may be significant.

Conservation of large intact natural forest landscapes is an important and necessary component of a general conservation strategy, but it is not by itself sufficient. Many ecosystems have already been disturbed to the point where only small fragments, or nothing at all, remains. Mapping of these ecosystem residuals was outside the scope of this study but is an important task for the future.

INTRODUCTION

> Taiga - vast, uninterrupted forests, unpassable ancient remoteness, an absence of human dwellings over a great expanse
>
> *V.I. Dal. Dictionary of the Living Russian Language (1903)*

The boreal region of European Russia used to be regarded as a virtually unlimited storehouse of forest riches, developed or used only to a small extent and largely still "wild." It is still commonly thought that northern European Russia is dominated by old-growth forests and wilderness landscapes. However, even a preliminary assessment shows that the remaining undeveloped parts of the taiga are relatively small and rapidly diminishing (*McCloskey, Spalding, 1989; Bryant et al., 1997*). Protecting those sections of the taiga landscape that are still intact is therefore a priority issue for the coming decades. A more detailed assessment begun at the end of the 1990's by non-governmental environmental organizations (*Aksenov et al., 1999*) confirmed that most of the boreal area of Russia has been subjected to severe fragmentation or fundamental transformation as the result of human development.

> This work is the first attempt to identify remaining intact boreal forest of northern European Russia using high-resolution satellite imagery that allows most forms of human disturbance in natural ecosystems to be directly identified.

The taiga, in the broad sense of the word, consists of an entire complex of very diverse natural ecosystems located in regions dominated by boreal forests. Bogs, lakes, rivers, flood meadows, mountain tundra, rocky outcrops, rich tree stands and other various types of vegetation together form an unified natural complex known as the taiga. In such boreal forest landscapes, individual components are closely connected to each other in a variety of ways. A delineation of intact taiga that limits itself to the forest, without considering other pieces of the larger landscape, is artificial and, in the opinion of the authors, incorrect. The heavily bog-dominated landscapes of Russia's northernmost boreal region, in which forest land is sometimes no more than 20-30 percent of the total area, are no less a part of the taiga than the uninterrupted forests on the well-drained water divides to the south. Equally important components are the complexes of mountains, lakes, bogs, and forests of the Baltic Shield. To separate these areas from the forest when identifying intact areas would be totally artificial.

> The taiga in the widest sense is more than the boreal forest; it is the entire conglomeration of different natural ecosystems in the boreal forest region.

Fig. 1. Typical Baltic Shield landscape. Karelia Republic. Photo: V. Kantor.

Fig. 2. Typical taiga mountain landscape. Perm Region. Photo: P. Potapov.

In the context of this work we use the term intact forest landscape to mean entire taiga landscapes, only marginally disturbed by human activities, and without regard to the share of forest in these landscapes. By disturbance we mean the direct destruction or fundamental transformation of any particular ecosystem including the fragmentation of natural areas by infrastructure, which disturbs the connections between a particular ecosystem and the other components of the taiga landscape. Thus, by intact forest landscape we understand a seamless whole of natural ecosystems, undivided by elements of infrastructure, in which there are no visible signs of significant human activity. This work is an attempt to identify and delineate intact areas of at least 50,000 hectares with a width no less than 10 kilometers.

Before proceeding we should mention a fundamental fact: forests that are absolutely wild and completely unaffected by human development activities no longer exist anywhere in the world. All present day forests display some degree of influence of human civilization, if only from transboundary air pollution or hunting. Ancient forms of human economic activity and land uses such as hunting, clearing of meadows in the vicinity of small rivers, and shifting cultivation, existed and were fairly widely spread over the boreal region of European Russia since the end of the last glaciation. Because these disturbances have a longer history than the current landscapes, we view these activities, as well as the fires directly associated with them, not as anthropogenic disturbances but rather as anthropogenic factors that have formed the ecosystems. On the other hand, modern development activities are of such form and intensity as to create major disturbances in centuries-old equilibrium and destruction of the natural taiga landscape. In this work, all human background disturbances that were considered insignificant with regard to the designation of intactness were explicitly listed. The list includes old forms of development activities that have shaped the taiga during the course of millennia, as well as some current or recent disturbances that we perceived as fairly weak.

The mission of this work was to search the boreal part of European Russia for remaining large areas undisturbed by human development activities. Areas, which in essence retain their natural characteristics.

The authors used the same approach throughout the researched area, trying at each step to be very clear in formulating principles and criteria used. The investigation reveals that remaining intact forest landscapes cover only a small part of northern European Russia (16.3 percent of the investigated region, and 13.8 percent of the entire forest zone). All these areas could, and probably should, become part of the protected areas network of the north, given their capacity to serve as reference areas while independently sustaining their ecological integrity. In this work, the authors have not attempted to suggest any concrete, formal protection scheme for any or all of the delineated areas. This is a task for the future. For the present, the most reasonable, in the mind of the authors, would be to reserve these areas by excluding them from any industrial development or construction of infrastructure until comprehensive decisions on their value and future destiny can be made in a complete and competent manner.

GENERAL FOREST CHARACTERISTICS OF THE REGION

Russia's taiga as a whole is a complex mosaic of different ecosystems. Forests do not always dominate the landscape. Many areas are primarily bogs, sparse forest, mountain tundra, and other non-forest ecosystems. The dominance of conifers in the older forests is absolute. Conifer forests - mostly Scots Pine and Norway Spruce and to a much lesser extent Larch and Siberian Stone Pine - account for no less than 77 percent of the total forest area (*Lesnoi Fond ..., 1999*). However, these official data overestimates the share of conifers. For example, before the 1995 Forest Inventory Instruction was issued, all forests with a share of conifers greater than 0.4 by volume were classified as coniferous, even if dominated by deciduous trees. The same was true for all coniferous forest plantations, even when overgrown by fast-growing deciduous species (*Instruktsiya po ...., 1986*). Forests dominated by birch and aspen account for 23 percent of the total area, according to the official forest inventory. These are mostly relatively young secondary forests on logging sites, sometimes also on burned areas. A small amount of birch forest can also be found in a narrow band along the northern boundary of the forest. Forests in which broadleaved hardwoods dominate (oak, elm, ash, maple, linden) cover only a very small area - less than 0.01 percent of the territory, mostly in the southwest regions of Pskov and Novgorod. Broadleaved hardwoods typically grow as minor components in forests where other tree species dominate.

Fig. 3. Forest - tundra transition zone. Tumen Region, Ural Mountains. Photo: V. Korotkov.

The northern edge of the taiga is an exceedingly diffuse transition zone toward the tundra, and drawing a sharp delineation would be a very arbitrary exercise. Forest cover gradually thins and breaks up, from a more or less closed northern boreal forest to areas with only sparse forest, essentially nothing more than small pockets of trees or even solitary trees, surrounded by tundra. Narrow bands of closed forest stretch out into the tundra along the valleys of rivers and creeks. Small stands also occur in places that are especially warm or sheltered by the local topography from strong northern winds. Bogs, which cover extensive areas on water divides and river terraces in the vicinity of the northern tree line form a vast treeless expanse together with tundra. Higher elevation ecosystems of the subpolar and northern Ural Mountains are also part of this large zone. Whether or not these areas should be included in the boreal forest or tundra landscapes is a question with no clear answer. In our research, all non-forest ecosystems, which make up the forest-less expanse together with zonal tundra, have been excluded from the analysis of intact forest areas.

The southern edge of the taiga was formed by natural and anthropogenic elements in an intricate interaction. Human activities have played a decisive role here for many centuries, including shaping the very boundaries of the vegetation zones. The transition from typical southern boreal ecosystems to mixed conifer/deciduous and deciduous forests was diffuse and gradual. All areas investigated in this work are located above the southern boundary of the boreal as drawn by many authorities. Only the very southwestern corner (parts of the Pskov and Novgorod regions) is sometimes considered to belong to the zone of mixed coniferous and deciduous forests. In any case, large (greater than 50,000 hectares) areas free of infrastructure or signs of intensive economic activity for the last 50-60 years, remain only within the boreal zone.

The examined territory can be divided into the following main parts, based on natural forest vegetation characteristics:

The Baltic shield (1) is dominated by pine forests. These stands grow on outcrops of crystalline rock or sandy glacial sediments which were formed during the latter stages of the last glacial retreat. There is also an abundance of bogs and lakes which in the north form a complex mosaic within mountainous areas. The landscape dynamics of the Baltic shield is strongly influenced by forest fires. These fires are frequent but usually small-scale and rather weak ground fires due mainly to the pronounced fragmentation of the topography. The area of the Baltic shield is clearly defined on forest maps by the dominance of pine forest (see Figure 4).

The western slopes of the Ural Mountains (2) are characterized by substantial amounts of precipitation, many days with cloudy and foggy weather, and high levels of wintertime snow accumulation. This area is dominated by Spruce-Fir and Spruce-Fir-Siberian Stone Pine forests, historically only marginally affected by fire and in many cases not showing any signs of fire influence at all. On forest maps this territory is clearly visible as a uniform spruce-dominated forest, although the southern part is now dominated by birch-aspen and mixed coniferous-birch-aspen forests following clear-cutting.

The eastern slopes of the Ural Mountains (3) are characterized by significantly less precipitation and usually a more broken topography in comparison with the western slopes. The eastern slopes also differ significantly in forest composition and fire characteristics, and are dominated by fire-influenced coniferous forests in a way similar to the Baltic shield (mainly pine forests, but often with a considerable fraction of Siberian Stone Pine and larch).

The valleys of large rivers and the wide fluvioglacial depressions (4) support dry pine forests and very frequent fires, much like the Baltic crystalline shield. The high frequency of fires is connected partly with the dominance of sandy sediment in the soil, but also linked with historic disturbance as the large river valleys and forested lowlands were the first parts of the taiga to be colonized by people.

The morainic plains (5) account for the major portion of the studied territory. In the past, these areas had a relatively low human population density, and the least developed transportation infrastructure. In the northern part of the taiga most of these watersheds are characterized by extensive amounts of bogs, sometimes to the extent that open bogs and low-productive bog forests dominate them. It is in these least accessible and least productive areas that we find most of the remaining intact forests.

Timan ridge (6) interrupts these relatively uniform plains with more diverse vegetation.

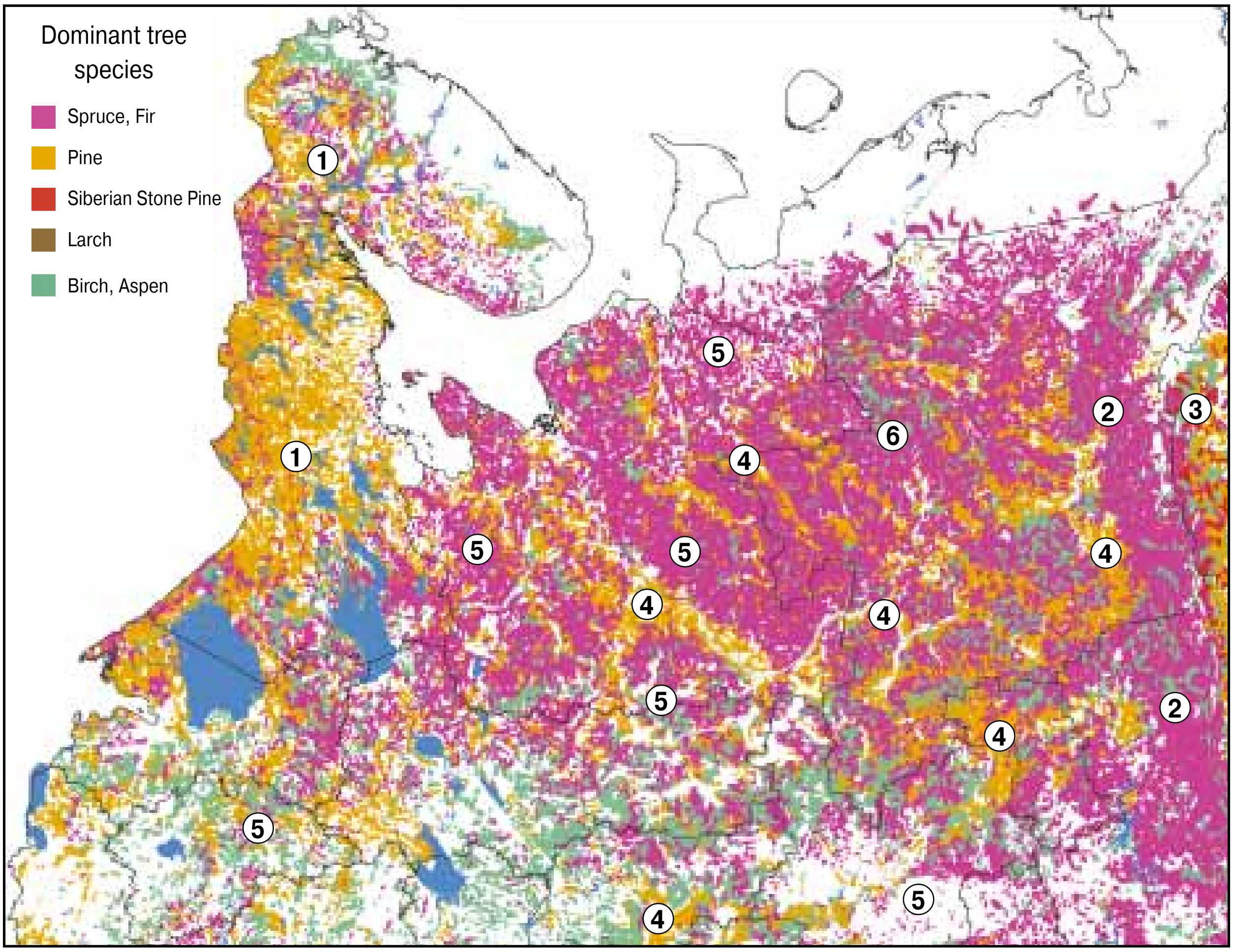


Fig. 4. Dominant tree species of Northwest Russia (State Forestry Committee of the USSR, 1990).

The taiga of European Russia is commonly considered to have pronounced zonal characteristics. Nevertheless, there are no well-defined boundaries between subtundra, northern, middle, and southern taiga. Variances within zones - depending on geology, macrorelief and quaternary deposits - are often much greater than differences between zones. Furthermore, existing evidence concerning the distribution of tree species in European Russia during different stages of the Holocene shows that the current relatively pronounced division of the forest composition into zones is a recent phenomenon - probably to a significant degree the effect of a zonal distribution of human economic activity. Today, the natural structure of the forest cover of European Russia is overlaid by a spatial structure that reflects the pattern of forest management and harvesting. The differences between stands of secondary forest that can be traced back to specific forms and techniques of logging are often greater than the differences between the zones of the taiga.

A significant part of the taiga has been subject to the indirect influence of humans during the entire history of their development. Fires have occurred much more frequently than they would if lightning had been the only cause. Lands have been periodically cleared for agriculture. Hunting and fishing have affected the population density of many species. And the list continues.

Practically all taiga territory of European Russia has at some point been affected by human economic activity, either directly or indirectly. Such disturbances include burning and shifting cultivation, hunting, harvesting and expansion of meadows along rivers, tree cutting, and air pollution. The areas chosen as references for intact natural taiga are not absolutely "wild" or "virgin," but rather those areas where human disturbance has been and remains minimal.

Fig. 5. Hunting cabin. Perm Region. Photo: A. Morozov.

Fig. 6. Ruins of 19th century hunting cabin. Arkhangelsk Region. Photo: A. Yaroshenko.

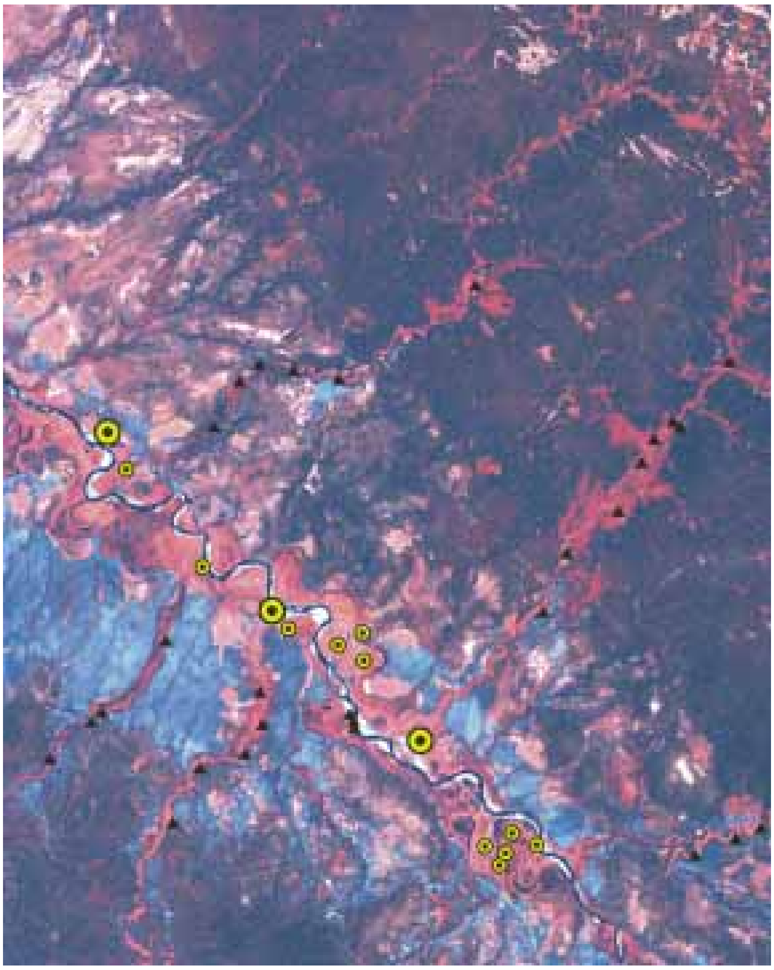


Fig. 7. Second growth deciduous forest (red), and lichen (Cladonia) type pine forest on burned areas (blue) in the proximity of villages and hunting cabins. Komi Republic, Udora District, Vashka River valley. Satellite image (Landsat).

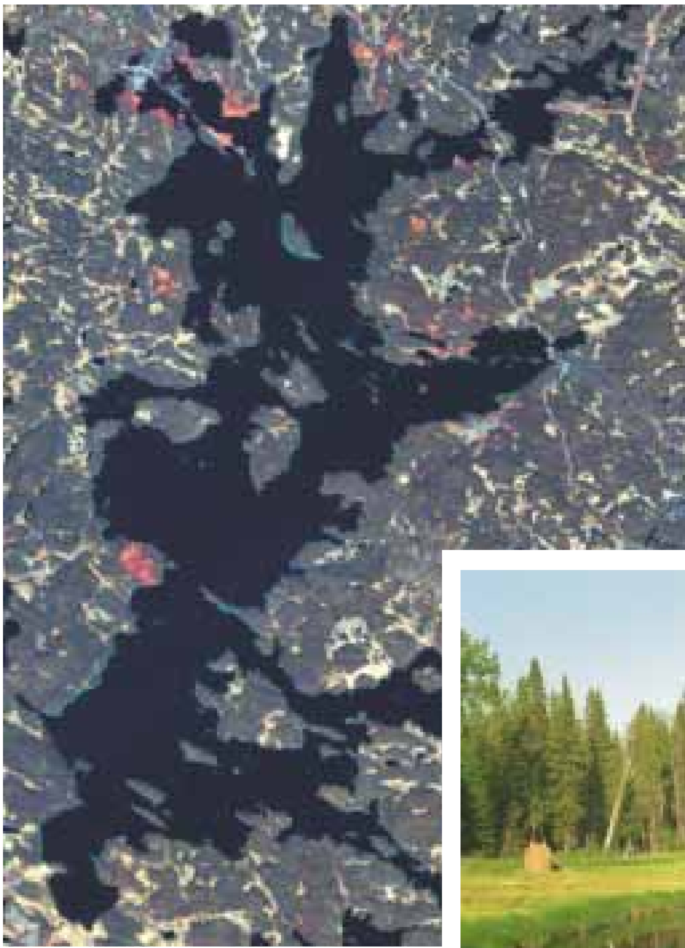


Fig. 8. Abandoned agricultural lands (red) along Kamennoe Lake. Karelia Republic, Kostomuksha Nature Reserve. Satellite image (Landsat).

collectivization and the forced discontinuation of "non-perspective" villages (see Figures 9 and 10). Much of the mountainous northern taiga was used until fairly recently as the main fodder base for reindeer herding. During the last two centuries practically the entire territory was subjected to the influence of industrial logging, although this was dispersed over large areas and oriented towards the extraction of high-value trees through selective cutting (*Denisov, 1911; Bogouslovskiy, 1912; Kublitskiy-Piottykh, Nazarov, 1913; Faas, 1922*). The few places that escaped such logging include a handful of areas within the Pechora basin as well as some of the wettest parts of the greatest water divides of the North. Thus, the taiga, even in parts

Fig. 9. Hay fields along the Vol River. Komi Republic. Photo: P. Potapov.

Many taiga territories are still used, or were used until recently, as professional hunting grounds. These areas contain a dense network of hunting cabins in various states of disrepair (see Figures 5, 6, and 7). Even inside the most wild spaces one can find the remnants of abandoned settlements (see Figure 8). Typical components of the taiga landscape are meadows alongside small rivers and creeks, used for hay production, but now mostly abandoned as an effect of

that are least disturbed by human economic activity, is a complex conglomerate of natural and human influences - intact, but showing clear indications of having been subject to traditional human influences on nature.

Modern economic activities, especially industrial logging, the development of transportation infrastructure, and mining have very little in common with traditional low-intensive forms of human influence on the taiga. The equilibrium between natural processes and sustainable human use, having evolved over the course of millennia, is destroyed. The result is that the taiga as a unified nature complex simply disappears.

Fig. 10. Abandoned village. Komi Republic. Photo: P. Potapov.

THE NATURAL DYNAMICS OF TAIGA FORESTS

"**D**ynamics of random disturbances" is a phrase that denotes a whole set of natural mechanisms that allow forests to maintain themselves over long periods of time. The essence of the concept of random disturbances is as follows: a natural forest, having developed without any catastrophic human disturbances during many tree generations, is a complex mosaic of small (in relation to the size of the area as a whole) patches, which develop without synchronization. The tree stand on any of these small patches will sooner or later die, for a variety of reasons of a more or less random nature, thus yielding space to a new generation of trees. The reasons for the death of a forest patch under natural conditions may vary considerably and include fires, pest outbreaks, disease, extreme weather conditions, or ageing. Different causes are connected with different sizes of the affected part of the stand, from the size of an individual tree up to hundreds or thousands of hectares. Each large block of natural taiga consists of hundreds or thousands of such parts, each of which is developing according to its own progression depending on the type of disturbance and the time when it took place. This cyclic flow allows a taiga block as a whole to be in a condition close to equilibrium and maintain itself for an unlimited amount of time.

Russia's intact taiga has two main types of random disturbances dynamics which are of particular importance: dynamics associated with the development of a tree population without any catastrophic disturbances (gap or tree-fall dynamics) and dynamics associated with the effect of fires (pyrogenic or fire dynamics).

GAP DYNAMICS

Gap dynamics is a basic natural mechanism for self-maintenance of taiga forests, developed over the course of many tree generations in the absence of catastrophic external influences, and most characteristic of dark coniferous forests (spruce and spruce-fir forests, sometimes with Siberian Stone Pine mixed in and usually with a component of birch). Gap dynamics is associated with the death of individual old trees, causing openings to appear in the canopy, letting in light and giving smaller trees the possibility to grow and assume a place in the stand (see Figure 11). At equilibrium, old trees die more or less evenly spread over the forest and over time. A stand will develop in which trees of all ages are present and the age distribution of woody species will be that of a sustainable population. The younger trees will be the most numerous, while older trees will be gradually less numerous with increasing age (see Figure 12). Forests with equilibrium gap dynamics are very robust over time. In the taiga of European Russia such forests are typically rather open with an abundance of gaps in the crown layer (see Figure 13). Forests with equilibrium gap dynamics are very rare and it is much more common to find forests in which gap dynamics have begun to appear but not yet reached equilibrium. This happens as stands with a more uniform structure due to some past disturbance, usually fire, start to collapse. Such stands are dominated by one or another tree generation and even in density so that gaps that appear are rather large as clusters of trees of similar age die and fall at the same time.

> Gap dynamics is associated with the death of individual old trees or tree groups, causing openings (gaps) to appear in the canopy, letting in light and giving smaller trees the possibility to grow and assume a place in the stand.

Fig. 11. Canopy gap in dark (spruce and fir dominated) coniferous forest. Perm Region, Basegi Nature Reserve. Photo: A. Morozov.

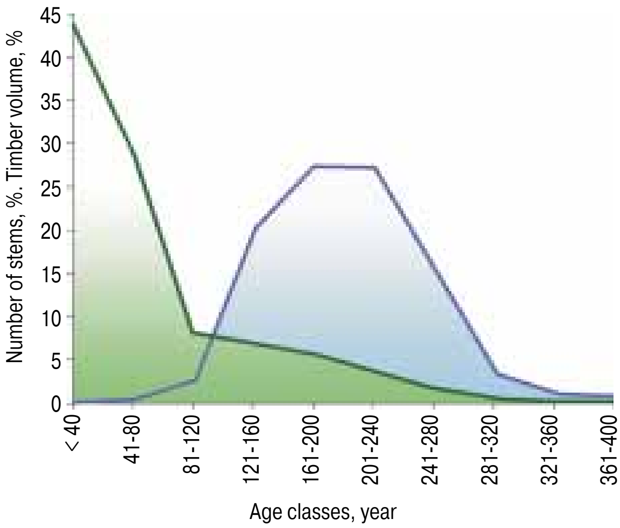


Fig. 12. Distribution of spruce trees (not including seedlings) by number (green line) and volume (blue line) over age class in an intact Myrtillus-type spruce forest. Komi Republic (S.A. Dyrenkov, 1966).

Forests with clearly developed gap dynamics make up only a small part of the total forest area of the European North of Russia. This is also true for the intact forest areas examined in this work. Gap dynamics are most common in forests on the moist western slopes of Urals, where they locally dominate the structure of the taiga landscape. Here, one can find the greatest areas of forests with gap dynamics at an absolute equilibrium, having developed without catastrophic disturbances for at least a few hundred years. Such forests are less typical of the plains of European Russian taiga where they usually appear as pockets in a much larger forest with evident signs of some relatively recent catastrophic disturbance such as fire. These pockets are generally small in size (from tens of hectares up to a few hundred or thousands of hectares). In most cases on the flatlands, gap dynamics are associated with the moistest areas, such as the floodplains of rivers, along creeks and where ground water comes close to the surface. However, pockets also exist on well-drained slopes and elevations where for centuries they have avoided the effects of fire.

Forests with gap dynamics have a large accumulation of dead wood on the ground, and of dead organic matter in the soil. They also have a special soil profile, formed as a result of the continuous falling of old trees along with their root systems. This gives them a higher soil water retention capacity and a lower amount of surface run-off during the spring thaw and heavy rains and, as a consequence, a less variable microclimate in terms of moisture and temperature under the canopy during the whole vegetation period (*Zubareva, 1967*). The special ecological conditions under the canopy - high degree of light, moisture, variety of substrates - provide forest ecosystems with a diverse plant community as well as dominance in ground vegetation of some tall ferns and

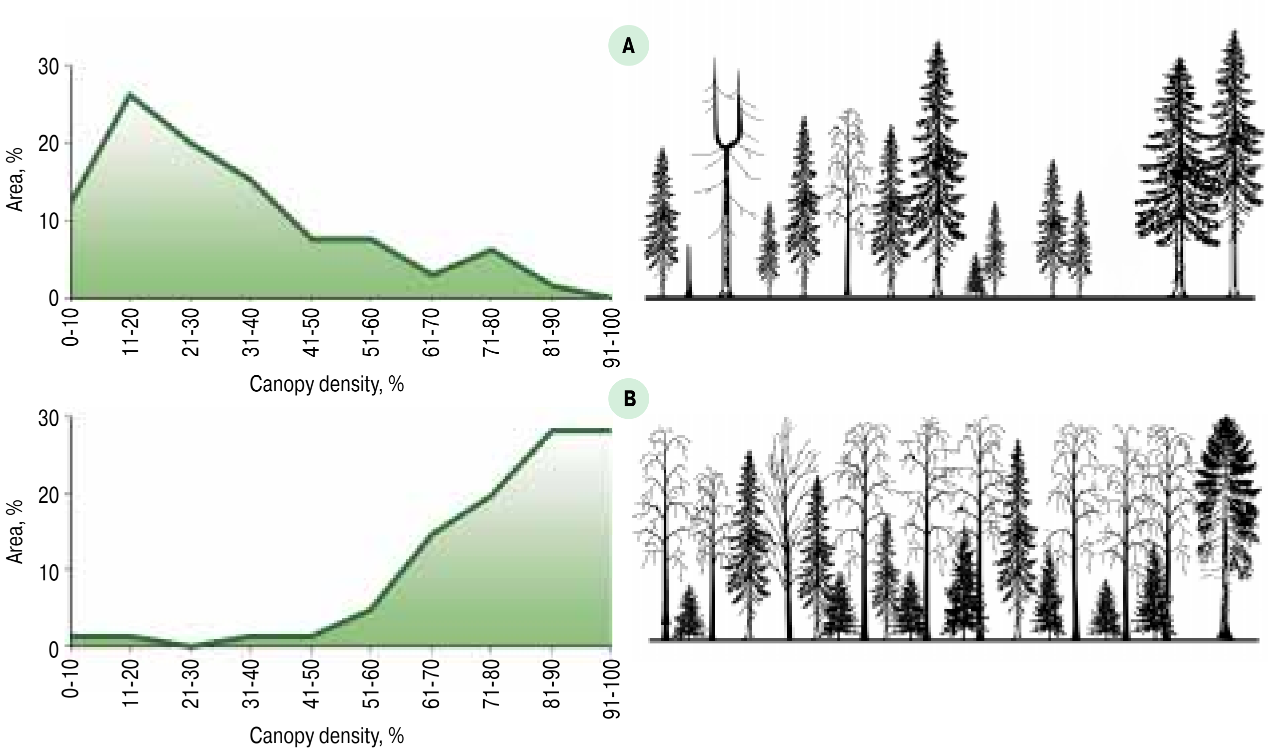


Fig. 13. Canopy density distribution, based on systematic circular 5-meter radius sample plots, and corresponding typical forest structure in two different forests on the same site type:
***A** - an intact spruce-fir forest with gap dynamics in balance*
***B** - a secondary birch-spruce forest on a 64-year old clearcut.*
Perm Region, Basegi Nature Reserve, western slope of the Ural Mountains.
The intact spruce-fir forest is dominated by sections with low and medium density canopy. The rather even-aged secondary forest, on the other hand, has a higher and more uniform density.

grasses (*Dryopteris austriaca Schinz et Thell., Diplazium sibiricum (Turcz. Ex Kunze) Kurata, Aconitum septentrionale Koelle, Delphinium elatum L.,* and others). The layer of tall grasses and ferns, sometimes reaching a height of 1.5 - 2 meters, either hinders or makes it impossible for young plant specimens to develop on the forest floor or on small-diameter fallen trees. Large-diameter fallen trees therefore play a key role for tree regeneration (see Figures 14 and 15), and their disappearance as a result of selective cutting of the largest trees may considerably disturb the natural regenerative dynamics of these forests.

Fig. 14. Regeneration of spruce on a dead fallen tree. Arkhangelsk Region. Photo: V. Potansky.

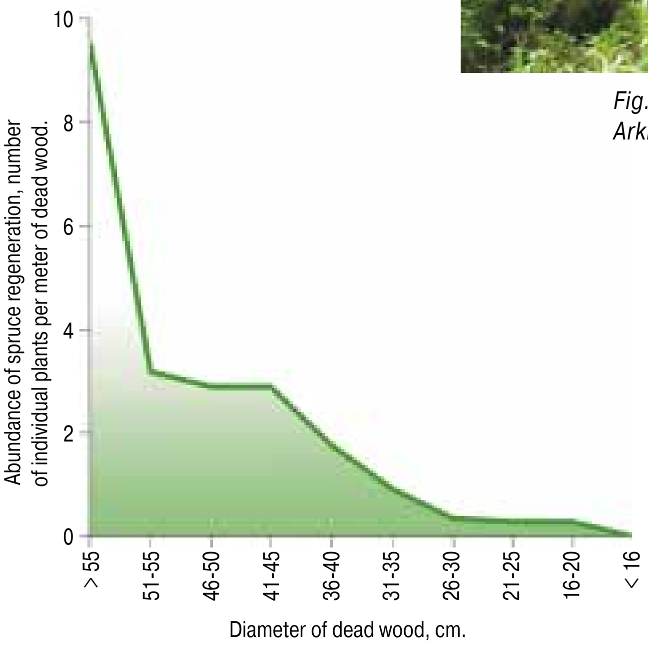


Fig. 15. Relationship between diameter of dead wood and amount of spruce regeneration (higher than 10 centimeters) growing on it under a canopy of an intact spruce-fir forest. Perm Region, Basegi Nature Reserve.

The particular characteristics of gap dynamics are regulated by various processes in the forest ecosystem and also by some external factors. Wood decomposing fungi, for example, by lowering the mechanical strength of trees and eventually causing old trees to fall down or be broken by wind or snow, sometimes while still fully alive, are usually the main regulators of the tree life span in such forests. By determining tree longevity, wood decomposing fungi have a strong indirect influence on the pace of tree generation change and the size of individual canopy gaps, and also contribute to the occurrence of large areas of wind-fall. Extreme weather conditions may encourage mass infestations of tree-eating insects, decimating sizable areas and thus producing particularly large gaps.

FIRE DYNAMICS

Fire dynamics is the main mechanism for rejuvenation of the taiga forests in the examined areas. Despite the existence and even firm documentation of individual cases in which forest fires have occurred due to lightning, this forest rejuvenation mechanism must not be regarded as entirely natural. The overwhelming majority of fires in taiga forests of European Russia are related to human economic activity, as evidenced by many historic and contemporary studies. In fact, not even in 1999, a year of extremely dry conditions and many fires, did any fires occur within the remaining intact (unpopulated, and very rarely visited by people) forest areas that was detectable in high-resolution satellite images. At the same time, the number of forest fires exceeded practically all previously recorded levels in areas with dense population and a dense transportation network.

Forest fires have always accompanied the economic activities of people, and people have lived in the taiga almost from the very time it was formed. The main cause of fire was shifting (slush-and-burn) cultivation, existing in Northern European Russia up until the end of the 1930's, in which the farmer would move to a new spot every few years and clear it by means of fire (see Figure 16). Given the fact that people have been setting fires for the entire

> Fire or pyrogenic dynamics are associated with the periodic partial or total burning of a forest as a result either of natural causes or human activities and the establishment of a new tree generation on the cleared area.

period during which the taiga forests were formed, it is reasonable to regard fires associated with low intensity human management as an ancient semi-natural mechanism for shifting tree generations in taiga forests (this excludes such frequent or catastrophic fires that are associated with the modern development of the taiga and upset the fire structure that has shaped these landscapes for centuries).

There is a big difference between forests that have been subject to frequent fires over a long period of time, and forests that have only experienced occasional fires separated by centuries of "fire-free" natural dynamics. Exposure to periodic fires for centuries or millennia favors so called "light" (fire-dependent) coniferous taiga forests in which pine (everywhere) and larch (in the north-east) species dominate. The light coniferous taiga is most typical for the Baltic Shield encompassing Karelia Republic, Murmansk and western Leningrad Regions, and also on sandy sediments of the lowlands and along large rivers. For pine and larch, fresh fire scars and forests affected by ground fires provide optimal conditions for establishment and development of new tree generations. Mature pines and larches are capable of surviving even severe ground fires (see Figure 17 and 19).

Seeds of pine and larch are rather heavy, however, and don't spread very far with the wind - usually a hundred meters at the most. When fires occur only very occasionally and new fire scars are several kilometers or more apart from older ones, other pioneer species such as birch and aspen, which have seeds capable of travelling further or which naturally are part of the forest even

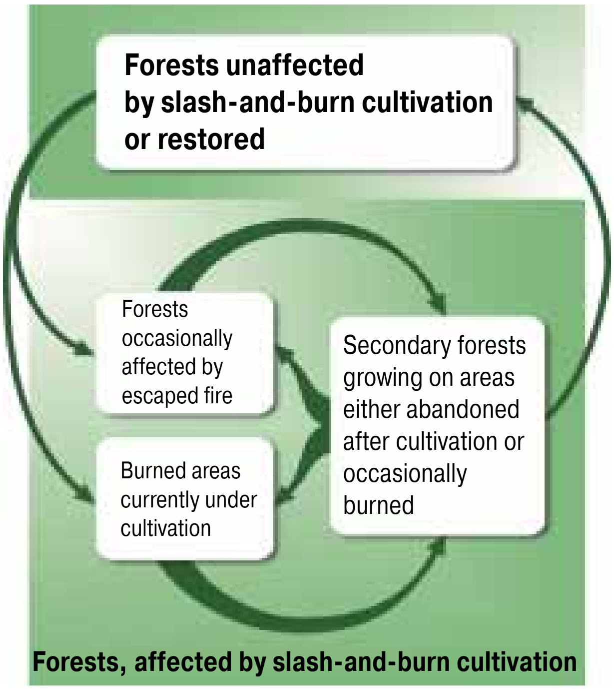


Fig. 16. Slash-and-burn agriculture had significant influence on the dynamics of taiga forest. This influence is not limited to areas of current cultivation, but extends over large areas affected by previous cultivation and occasional escaped fires. At any particular time, the affected area could exceed the current cultivated area tens or even hundreds of times. Significant parts of the southern and middle taiga were affected by slash and burn cultivation. With a low population density, influence was concentrated mainly around the most suitable areas, while remote forests were affected to a lesser degree or escaped cultivation altogether.

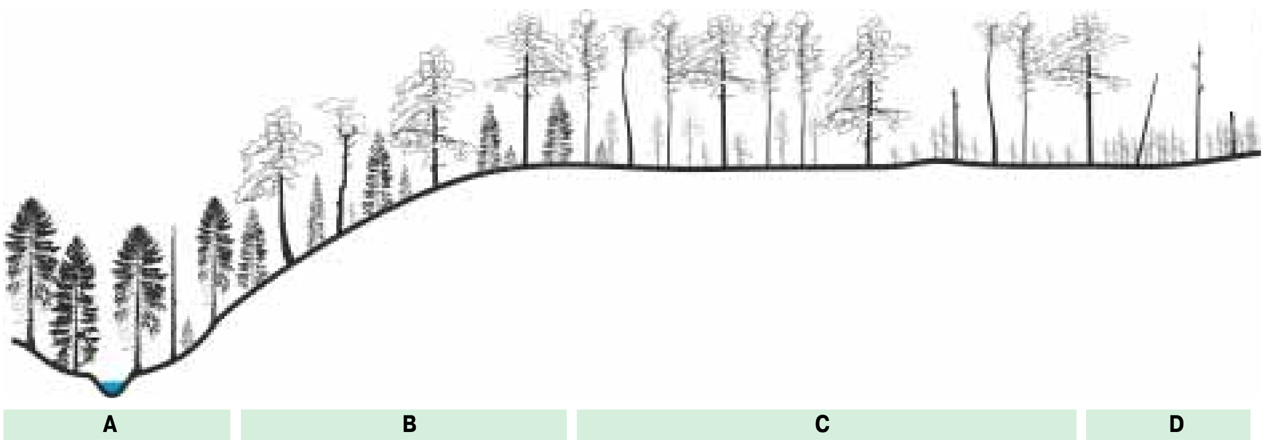


Fig. 17. Example of canopy structures in landscapes formed under the influence of forest fires

***A**. Fire refuge (area having escaped fires during a period longer than one tree generation). Such areas are usually found in moist locations along rivers and lakes but may also be found on well-drained sites.*

***B**. Areas having escaped fire long enough for a layer of spruce undergrowth to appear under the pine canopy. Spruce trees are beginning to replace old pines in the canopy.*

***C**. Uneven-aged pine forest formed by repeated ground fires. Each fire allows a new tree generation to appear, while at the same increasing mortality among the old trees.*

***D**. Area affected by crown fire which has destroyed almost the entire original stand. Crown fires promote the development of dense undergrowth of pine which eventually develops into an even-aged stand.*

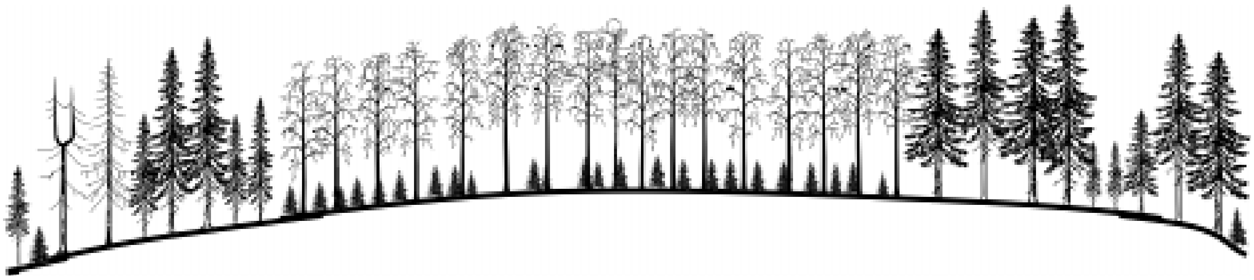


Fig. 18. Re-growth on a water divide which seldom burns. In the absence of seed trees of pine and larch, pure or almost pure stands of birch, sometimes with aspen, will develop.

without any fire, will dominate the post-fire succession. Abundant growth of birch and aspen on fire scars is common on the wide water dividers, where fires used to occur more seldom and most sources of pine and larch seeds (if they were present at all) have been cut down during the last century and a half (see Figure 18).

Taiga forests that are more or less periodically exposed to fires have the following characteristics:

1. A mosaic of parts that have been subject to different frequencies, intensities, and types of fire (ground fires, which burn only the organic layer of the ground and fallen branches, and crown fires, which burn the entire stand either superficially or totally). The effect of the fire determines the structure and dynamics of the forest, including age structure, the intensity of tree death, the amount of fallen trees and organic debris on the ground, and the composition and structure of the lower layers of the forest. The type and frequency of fire determines whether even-aged forests with homogeneous structure or multi-aged forests consisting of several different tree generations will be formed (see Figures 17 and 19). These forests are complex mosaics of parts that have burned with different frequency, which also contain fire refuges (i.e. pockets in the forest which, for some reason or another, have escaped fires for centuries and therefore display a gap structure of the stand).

2. A broken age structure for the dominating tree species. At the most fire prone sites, stands of pine or larch develop containing several clearly distinguishable tree generations, each of which was established after a ground fire. On sites that have been without fire for a long time, a secondary layer of spruce will develop. This will typically consist of groups of trees established over a rather brief period of time, usually 60-80 years. Even at sites that have escaped fires for a very long time (200-250 years and more), where spruce is often the dominating species in the stand, the age structure of the spruce is not continuous in the way that a sustainable population would be. Such spruce stands are only partially mixed ages.

The deciduous species in these forests (birch, aspen, goat willow) in most cases grow in stands with an uneven age distribution, typically with a few clearly distinguishable tree generations.

Fig. 19. Frequent fires promote uneven-aged pine forests. Karelia Republic, Kostomuksha Nature Reserve. Photo: V. Kantor.

3. A presence of downed trees of different diameters, unevenly distributed over the area as well as through stages of decomposition. Pine or larch typically account for most of the large-diameter fallen trees. Only on sites that have escaped fire long enough to establish gap dynamics is it possible to find downed spruce.

4. An absence of a thick organic layer, except for on wet sites, and a rather small amount of organic debris on the forest floor, except for those sites that are part of a fire refuge. The soil profile is more flat and less developed than in the typical forests with gap dynamics. This is connected with the fact that many trees die and gradually decompose "on the stump" instead of falling along with their root systems. Overall, these forests have a much smaller capacity for retaining moisture than forests with clearly developed gap dynamics.

5. The process of old trees dying is very different within various parts of the forest, and is regulated by several factors in concert: with the effect of fires (including superficial ground fires, which cause trees that are weak or more harmed by fire to dry out), the death of old and weak trees from pests and diseases, and the effect of extreme weather conditions (drought, which is especially significant on sites with a thin layer of organic matter).

Modern forest management leads to significant changes in forests with strong fire influences. Fires that develop around clearcuts and roads fundamentally alter structures that have been established over centuries in the taiga landscape; fire frequency is increased, fire refuges disappear, and the forest mosaic is simplified. An equilibrium that has evolved over centuries is disturbed in a catastrophic way and it is not always possible to predict how biological and landscape diversity will be affected. The large fire scars that have occurred during a brief period in areas of intensive development in the Northern European Russia are not fully analogous with wildfires, which have occurred over millennia as a result of dispersed human activity and lightning. It is also clear that any attempt at dividing fires into "natural" and "unnatural" is artificial, because it is rarely possible to tell the origin of a fire from the character of a fire scar. A discussion and description of formal criteria for separating "natural" fires, those not regarded as affecting the natural dynamics of a taiga forest ecosystem, from "unnatural" fires that are seen as a human disturbance of natural dynamics, is provided in the section *Identification and mapping of intact forest landscapes*.

SECONDARY FORESTS

The overwhelming majority of taiga forests in European Russia have been severely altered in terms of structural and dynamic organization and are therefore classified as secondary forests. However, determining the exact share of secondary forest is difficult, especially in the absence of firm criteria for classification of primary and secondary stands. There is no consensus on the stages of restoration after a disturbance in which a forest should be classified as secondary, or to what extent a forest that has been disturbed by selective cutting should be called secondary. There are some fairly universal agreements - the first forest generation on a clearcut, on abandoned agricultural land, or on a quarry are all regarded as secondary. Even if a very narrow interpretation of secondary is used, it is clear that secondary forests form the general background condition in the taiga, with the exception only of the northernmost part of the territory. While primary stands of indigenous old-growth can be found selectively scattered, a sea of secondary forest surrounds them.

In Karelia, two-thirds of the forested area was harvested during the second half of the twentieth century (*Gromtsev, 2000*), with the situation in other regions more or less the same. Already at the latitude of the Leningrad, Vologda, and Kirov Regions, spontaneously reforested agricultural lands, abandoned during the period of collectivization and later, represent a significant share of the forest, and further south it may represent as much as 20-30 percent of the total forest area. Taking all of this together, a conservative estimate finds secondary forest makes up three-quarters of the forested land in the taiga of European Russia. With inclusion of even-aged spruce forests, formed as a consequence of selective cutting of pine (see Figure 26) or even-aged stands on gigantic fire scars, the share of secondary forest becomes even larger.

Secondary forests are very diverse, not only because of site differences but also due to variations in their history of human intervention. Still, it is possible to identify a few typical characteristics that distinguish them from intact taiga.

First and foremost, severe anthropogenic disturbances, leading to the death of the stand either in substantial parts or in its entirety, create stands with a significantly simplified spatial structure. The least architecturally complex forests are formed on the most severely disturbed parts (abandoned agricultural lands or clearcuts), with a very even canopy of secondary growth trees, most often birch and gray alder (Figure 21,a). Any older forest ecosystem fragments that might have survived the disturbance (such as pockets of undergrowth, residual small-diameter trees after clearcutting, stands or trees that happen to survive fire)

Fig. 20. Young birch forest on the site of a 30-year old clearcut. Arkhangelsk Region. Photo: A. Yaroshenko.

add some complexity to the structure and composition of the new forest (Figure 21, b).

The evenness in structure and age is often carried over into the first re-growth layer, appearing under the canopy of pioneer deciduous species (see Figure 21, c). Intensive selective cutting in which all large-dimension trees are removed and mainly only undergrowth is retained also lead to the creation of simplified stands (Figure 21, d). In intact forests the main elements of spatial diversity of the stand and other forest layers at a particular site are connected with natural spontaneous disturbances; in secondary forests they are most often generated by diversity of technical interventions such as skid lines, landings and roads (*Pautov, 1992; Yaroshenko et al., 1998*).

The majority of inarguably secondary forests are characterized by a considerable mixture of pioneer deciduous tree species (birch, aspen, Gray Alder, Goat Willow), the seeds of which are easily carried over large distances by the wind and the seed production of mature trees is very large. Forests with an absolute domination of pioneer deciduous species are especially typical of the large (landscape size) clearcuts of the 1950's through 1980's. Then, the living conditions (microclimate, ground cover, etc.) of the trees were radically changed, while at the same time practically all sources of coniferous seeds were removed.

The simplified and homogeneous stand structure in secondary forests is associated with significant changes in other forest layers. Many microhabitats disappear under the forest canopy, such as fallen trees and features of micro-topography, formed when trees fall over along with their root systems. Also, the mosaic of gaps and illumination under the canopy is simplified. The result is a drastic reduction in the diversity of ecological conditions under the canopy, impoverishing the local flora and causing the gradual disappearance of individual species. It has been established that the disappearance of at least some species is connected not so much with the dramatic changes in ecological conditions that occur during the first years after a radical disturbance as with the simplification of the habitat diversity that follow the establishment of a closed secondary stand (*Yaroshenko, et al., 1998*). The restoration of the original structure of grasses and mosses is delayed in a similar fashion in comparison with the re-establishment of the original structure of the tree layer. Many forests in which the original stand structure has been restored following radical anthropogenic disturbances may still hold some characteristics typical of secondary forests such as the layer of grasses and mosses. We conclude that an assessment limited to the tree layer does not allow a full measurement of the degree of anthropogenic disturbance in a forest ecosystem or the degree to which its natural structural and dynamic organization has been restored.

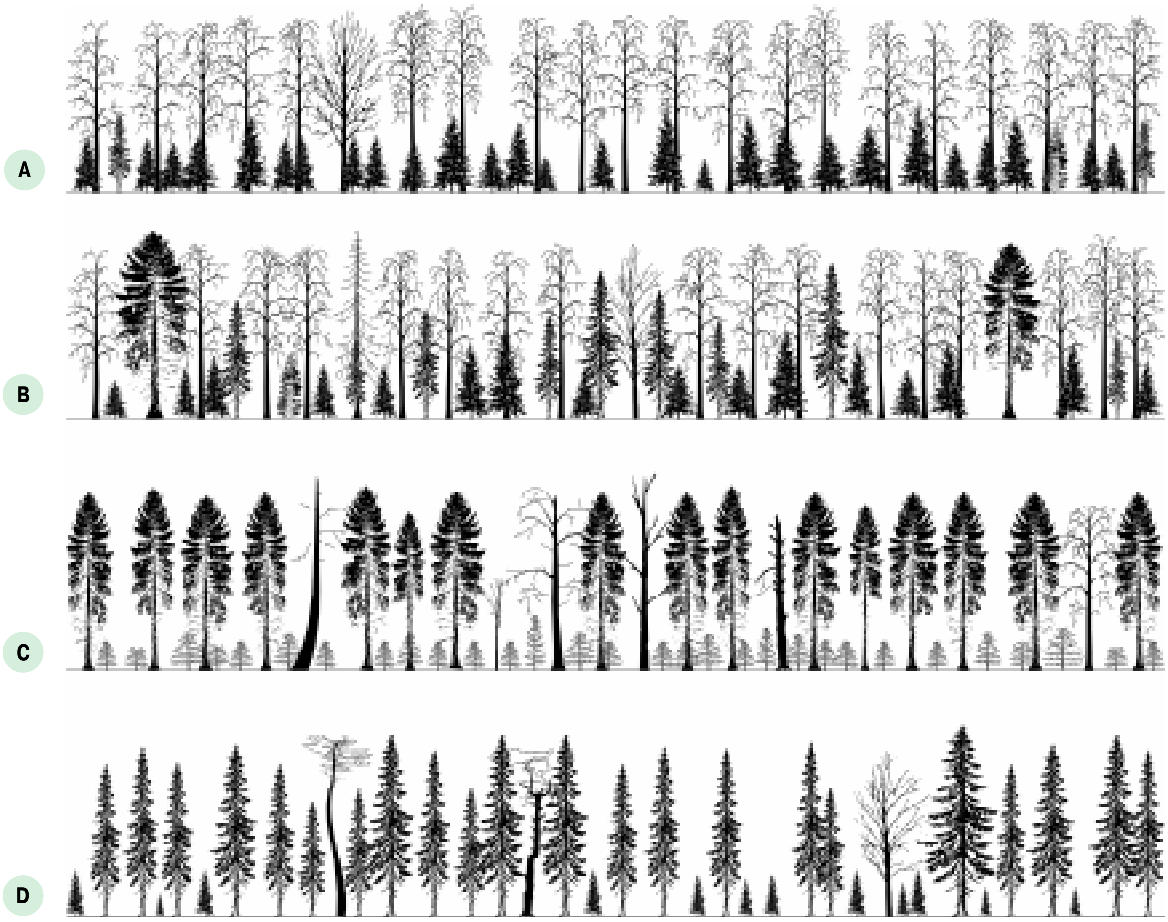


Fig. 21. Secondary forest structures. See body text above.

ANTHROPOGENIC INFLUENCES ON FORESTS

Human influence on the northern forests of Russia developed in two key stages, divided by the advent of intensive industrial growth. In time, the boundary between the two is fluid, shifting between regions that are populated and close to big markets to those more remote. In some pockets, development began in the 17th and 18th centuries in connection with industrial production of salt, charcoal and other goods. However, most of the area saw little growth until the middle of the 19th century, when wood exports from the northern ports to Europe fueled a rapid expansion.

Despite the influence of pre-industrial human activity on the structure and dynamics of the taiga landscape, it is, for the purposes of this work, treated as a historical factor in forming the taiga rather than as anthropogenic disturbance

Each period has brought its own peculiarities of human influence on Russia's natural landscape. It would be wrong to say that the influence of humans before industrial scale exploitation was small enough to be negligible. From the very start, human settlements have been, at the very least, a considerable additional source of forest fire, thereby contributing in no minor way to the formation of taiga ecosystems. Later, slash and burn agriculture, harvesting of grass on the flood beds of creeks, logging, hunting and fishing for local needs, and other practices of natural economy played an important role.

Many forms of pre-industrial resource management continued to be practiced during the better part of the second, industrial growth stage. Slash and burn agriculture existed up until the 1930's, ending mainly as a result of collectivization and liquidation of single-family farms. A system of hunting cabins still exists and is even maintained in some areas, although the density of cabins and the frequency of their use has declined. And while production of hay on small flooded fields along small rivers and creeks continues sporadically, the majority of such fields have been gradually abandoned since the beginning of the 20th century. These traces of pre-industrial utilization including overgrown grain and hay plots, remnants of old hunting cabins, and sometimes even small villages, can be found in the middle of what is today wild and absolutely unpopulated territory.

Despite pre-industrial human activity's influence on the structure and dynamics of the taiga landscape, it is, for the purposes of this work, treated as a historical factor in forming the taiga rather than as anthropogenic disturbance (see the section *Background human influence*). Therefore, infrastructure from this period (villages, transportation corridors, production centers) have been excluded from designation of intact areas.

Russia's natural ecosystems have been manipulated to a much greater degree during the second phase of human utilization, associated with intensive industrial development of boreal forest resources. A more detailed account of this phase and its main stages is given below.

Fig. 22. Log drive. ("Forest to the new building" - Sovietskoe Foto, 1959, No. 11. Photo: Yu. Barmin and V. Savostyanov)

THE INDUSTRIAL DEVELOPMENT OF THE TAIGA AS A WOOD RESOURCE

Industrial development of the taiga's forest resources has always been extensive. This general direction has followed the continued exploitation of old-growth areas rather than the development of intensive reforestation management within areas already developed and closer to markets. Forestry in Russia has developed an unsustainable ethos more similar to that of mining than to classical forestry, which is directed towards the utilization of renewable resources.

High grading in various forms has historically been the main form of logging in the taiga, with little or no consideration of long-term consequences. Convenience of location and prevalence of desired species have governed the choice of logging site, on which only the most commercially attractive species and tree individuals have been cut.

The forests of the North have long been regarded as a massive, inexhaustible deposit of wood, the partial destruction of which could easily be compensated by the exploitation of another part. The time period foreseen for exploitation of any particular natural forest area is short in relation to the time required for renewal of the forest in that same area, given the level of silvicultural practice.

The industrial development of the taiga as a forest resource has been characterized by "skimming", also known as "high grading", the exploitation of the most valuable, best located resource, without serious consideration of long-term consequences. Consideration of location and quality have been used for allocation of logging tracts, while selective cuts focus on the best trees in terms of product yield.

Forestry in the taiga shows gradual "logging creep" from the most accessible areas close to consumption points or transport infrastructure to more and more remote areas. Three different time periods can be distinguished within the process of logging creep connected with a gradual increase in logging intensity and a decrease in the quality constraints on the extracted wood. Each period involved logging of increasingly lower quality stands, including stands that had been passed up by previous logging efforts. As a result the creep away from accessible forest was sometimes repeated over the same area.

1. The high-grading period involved the harvesting of only the best individual trees from a product-yield point of view. In Northern European Russia this phase lasted from the beginning of industrial forest exploitation through the end of the 1920's and was characterized by an absolute dominance of high-grading and individual cutting of the best trees. A rapid increase in management intensity took place during the period from the 1880's to 1913. A rather sharp decline then followed due to the First World War, the Socialist Revolution, and the subsequent Civil War (export fell drastically during this period while internal markets mostly demanded low-quality fuel-wood that was supplied from forests in regions with high populations and comparatively good transportation infrastructure). The highest logging intensity was reached in 1912-1913. The volumes then removed from the European Russian taiga was at the same level as today - more than 40 million cubic meters of wood per year. The average logging intensity in government-owned forests in European Russia (the overwhelming majority of which were located in the taiga zone) was about 0.5 cubic meters per hectare, per year (*Godzishevskiy, 1924*) - roughly one third of the total potential increment in the entire North. Large areas in the Pechora valley remained more or less untouched during this time, while the forests in the vicinity of the Baltic and White seas were intensively logged at a level much higher than the regional average. The harvest was concentrated on pine forests, as pine wood and products enjoyed the highest demand in export markets. Already during the beginning of the 20th century a significant deficit of accessible large-diameter high-quality pine forests was felt in the basins of the Baltic and White seas. Harvesting operations were forced to move up to the very sources of rivers suitable for log driving as well as onto the major water divides - the least accessible areas for transportation. Continuously decreasing tree diameters in selective cutting at the timber frontier forced loggers to return for a second and even third time to areas they had already passed through. As the supply of large trees

Fig. 23. Traditionally large houses in northern European Russia demanded considerable amounts of wood for construction and heating. Photo: M. Shlychkov.

diminished, the forest industry's demand for the largest logs also went down.

Harvesting by local populations of firewood and building timbers made an additional contribution to the intensity of forest utilization during this period. These harvesting volumes were seldom accounted for in official forest statistics because they were usually removed from agrarian forests in the vicinity of villages - areas not under the control of the forest authorities. This contribution appears to have been rather significant, given the cold climate of Northern Russia and the traditionally large sizes of dwellings and other buildings. In 1923-24, the annual consumption of firewood in the Vologda Region was approximately 9.7 cubic meters per person in rural areas (*Bykov, 1925*). This translates to some 42 million cubic meters in total for the Vologda region (current size of the Vologda Region is several times less than in 1923). Based on these numbers, the total consumption of firewood in northern Russian territories can be estimated at 100 million cubic meters or more of wood per year, 2.5 times the annual harvest of industrial wood. Althought this number seems to be exaggerated, it is evident that the contribution of the local population to the intensity of forest use was significant, and in combination with commercial cutting, over-harvesting was taking place in large areas of Russia's European North.

Characteristic of this high-grading period is the absolute dominance of river floating for secondary transportation of wood. Even the very smallest of rivers were often used - routes where logs could pass only if carried by spring floodwaters. Primary transportation was completed by horse. A distance from the logging site to the river landing of up to 15 km was considered acceptable, while a distance less than 8 km was thought convenient. In other words, almost the entire basin of the White Sea, Baltic Sea and Volga River was accessible for logging and extraction of high-grade logs. Traces of low intensity selective logging from this period were visible almost throughout the entire area of these basins, including on the sites furthest removed from transportation infrastructure and points of wood consumption.

For this project, all logging that took place during the high-grading period is regarded as background disturbance, having occurred virtually everywhere and being a historical factor in shaping the taiga landscape.

State forests of Northern European Russia were managed exclusively according to the concept of "even use" annual allowed cut. The usage was determined for each forest district by dividing its area by the number of years in a forest rotation (for uneven-aged management the period between interventions, for even-aged management the stand age at final felling). Over-cutting of the annual area was formally not tolerated. Nevertheless, partly due to poor data and partly because of the continuous reduction in rotation time (associated, among other things, with a decrease in minimum diameter for saleable wood) the "even use" cut remained a rather blunt regulation instrument, without correspondence with the real productivity of the forest.

An overall low degree of extraction due to high-grading in combination with the use of horses for in-woods transportation down to river landings, account for the fact that this logging had a comparatively minor influence on the structure of the forest ecosystem.

The main factor of human disturbance during this period was not so much the logging itself as the fires that were caused by careless loggers. In fact, in many of the remotest areas from current settlements and transportation routes, the majority of forest fires (by area) can be dated to the end of the 19th and beginning the 20th centuries while traces of more recent fires either are totally absent or are estimated in much smaller numbers.

Fig. 24. The depletion of easily accessible forests in inhabited regions forced logging up onto the big water divides, far away from rivers suitable for driving logs. Stump of a large Siberian Stone Pine 10 km from river. Perm Region. Photo: P. Potapov.

The weak effect of these early cuttings on the forest structure, in combination with the considerable time that has passed since the high-grading period ended in this part of Europe, make it difficult to identify their traces. In many cases, especially in the southern and middle taiga and in spruce-fir forests, special investigations (analysis of the growth pattern of the undergrowth, digging up bumps on the forest floor in search of stumps, analysis of down trees and logs by degree of decomposition, etc.) are needed to uncover signs of the high-grading felling of the period. Slow decomposition in the North makes stumps and logging debris discernable from the ground. In any case, identification of traces of forest utilization from this period requires detailed observations on key plots. For our research purposes, all cuttings from this period are treated as background disturbance as they can be found more or less everywhere across the entire studied area and are a historical factor that has shaped the development of even the most undisturbed parts of the taiga.

2. The period of landscape-size clearcuts and expansion of transportation access begun after Russia's Civil War, and continued through the restoration of forest management and rapid industrial development, came to an end with World War II. During this time, timber logged and processed in northern European Russia became the backbone of Russian export, accounting for about 30 percent of the total value of exported goods during the 1930's. A successive retreat from the notion of sustainable forestry and a transition to an economic norm of exploitation was justified by a push to meet industrial needs. Thus, the chief of the "People's Commissariat" (ministry) for the forest industry, S.S. Lobov, clarified the new direction: "The necessity of a decisive and conclusive uncovering of the opportunistic and, in essence, harmful theories and practices of the kulaks (rich peasants) and capitalists, based on the principle of sustainable forest use, which until recently have been reflected in the science of silviculture and forest management. The basic principle of forest utilization during the second five-year plan must be clearcuts of unrestricted size" (quoted from: *Two Hundred Years of the Forest Department, 1998*).

Typical of the clear-cutting period is the introduction of a great number of different formulae to calculate the annual allowable area of cut, providing a "scientific basis" for maximizing the volume of harvest during a short time. Many of these formulae made it possible to achieve an annual cut area 5-6 times greater than the annual area of sustainable utilization. And while some calculations have subsequently been withdrawn, several of them still remain in force (such as the so-called 1st and 2nd age-based annual areas, allowing the justification of annual allowed cut exceeding even utilization sometimes by 2-2.5 times). Along with harvest regulation tools providing a "scientific basis" for a drastic increase in the levels of forest utilization, over-cutting the annual allotment became common practice.

This phase of forest utilization culminated during the second half of the 1930's (Figure 25). Towards 1940, the average logging intensity in the boreal forest of northern European Russia reached approximately 2.5-2.7 cubic meters per hectare - almost twice the potential annual growth in these areas. Keeping in mind that the losses of wood in these operations were significant and cut allotments were often ignored, it is reasonable to assume that the real logging intensity was even greater, perhaps as much as 3 times the stand growth rate. As always, forest utilization in easily accessible areas in the south and west was considerably more intensive than in remote areas of the northeast and the Pechora River basin. The intensity of logging in remote areas decreased significantly during the Second World War, most cutting taking place in densely populated central areas of the country, in forests that had been more or less conserved during peacetime.

The primary logging practices during this period were clearcutting and cuts with residual low-value trees

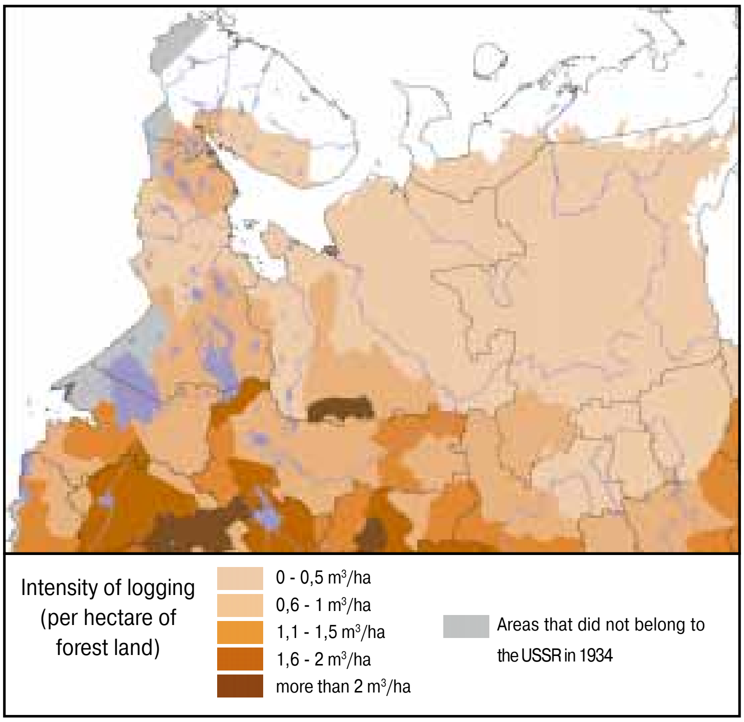


Fig. 25. Intensity of logging by forest districts in 1934 (Atlas Mira, 1935).

known as "conditional clearcuts", usually forming enormous landscape-size clusters. Horse logging dominated until the 1940's, and a considerable amount of coniferous undergrowth and saplings were retained, as well as deciduous trees due to lack of demand. As a result, many of these landscape-size clearcuts with residual trees are now already covered with mature or over-mature conifer-dominated stands - often not very productive, however, as they developed from residual small-diameter and wounded trees (Figure 26). Despite the total dominance of clearcutting, high-grading and selective cutting was

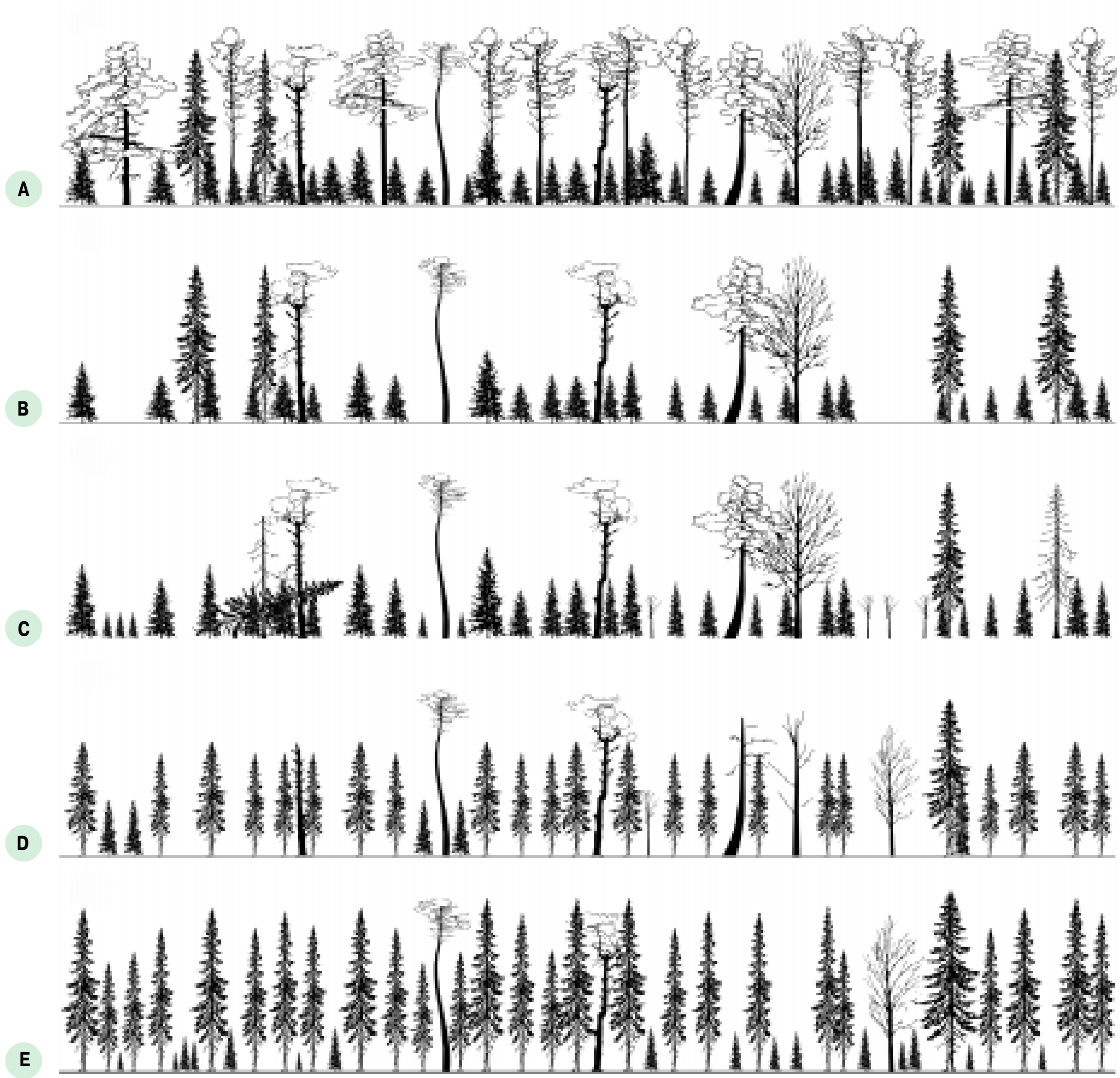


Fig. 26. Development of a spruce stand from undergrowth after intensive selective cutting.

A*. Original stand.*

B*. Intensive selective cutting with removal of all pines except cull trees, a common practice in the late 19th to early 20th centuries in northern European Russia. Logging was usually done during the winter, as the work force was busy in agriculture during the summer. Horse logging on snow cover allowed most of the undergrowth to remain unharmed.*

C*. 10-15 years after logging. Some trees from the old stand have died off on the stump along with parts of the undergrowth. Most of the undergrowth remains and begins to grow rapidly in height. Undergrowth of deciduous species (birch, aspen, willow) appears in spots where the field layer and the undergrowth have been harmed.*

D*. 40-60 years after logging. Remaining spruce undergrowth is beginning to form a closed stand. Some of the remaining old pines are beginning to dry out as an effect of diseases and insects, or from logging damage. Surviving deciduous trees from the old stand are also beginning to die off.*

E*. 80-120 years after logging. A closed spruce forest has developed from the surviving undergrowth. A few pines and deciduous trees survive from the old selectively cut stand (usually with clearly visible defects: rot after fire damage, crooked stems, double tops).*

Many "primary" forests of northern European Russia share a similar history. In particular, most of the old spruce forests of the White Sea watershed owe their existence to a selective removal of pine in the past which left old trees and undergrowth of spruce untouched for lack of commercial value.

still used in remote areas. Traces of selective cutting are not as evenly spread as from the earlier high-grading period. Still, they can be found in many regions far from transportation routes and settlements. They were particularly widespread over the water divides draining into the rivers Northern Dvina, Pinega, Vashka, and Mezen, and almost everywhere in the Baltic Sea and Volga basins. Pine was the most desirable tree in selective logging, but larch is also actively used. These cuttings had in places a significant effect on the species composition of coniferous forests (Figure 26). Many spruce forests, especially in the basin of the White Sea, owe their species' dominance to the systematic removal of pine.

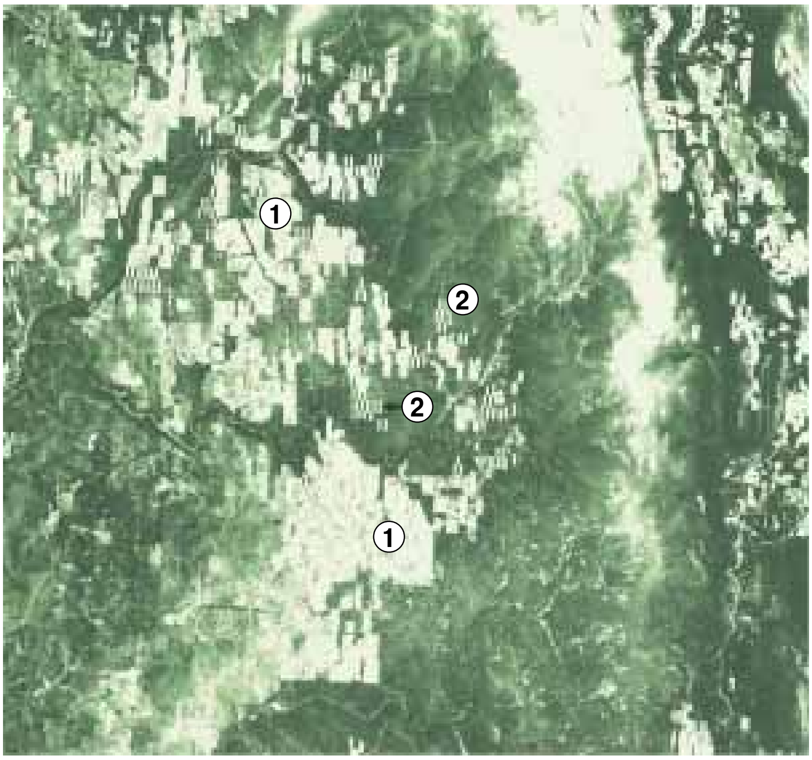


Fig. 27. Clearcuts in spruce and fir forest in the Middle Ural foothills. Satellite image (Landsat).
***1**. Landscape size clearcut clusters - each clearcut up to 200 ha (up to 1993).*
***2**. Clusters of clearcuts of 50 hectares each (from 1994).*

River drive remained the main kind of long-distance transportation for most of this second period. Towards the end of the 1930's, transportation along roads by machines and horses attained greater use.

Resin tapping of pine was actively developed in northern European Russia. Earlier, resin tapping had a non-industrial character, serving mostly local needs and to a smaller extent export. In 1926, resin tapping started to be developed at an industrial scale, and by 1930, a network of specialized state enterprises for resin tapping was created (the so-called *khimleskhozy*, or chemical forest enterprises). In 1938, the application of chemical stimulants is introduced. The vast majority of forests were logged after the tapping of resin had ceased.

For the purposes of this work, the concentrated clearcuts of this period must be considered human disturbance of the natural boreal landscape. The scattered high-grading and selective cutting that took place in remote forests, however, was not substantially different from the practices of the previous period and was therefore as background anthropogenic disturbance, not affecting the ecological intactness of the landscape.

3. The period of developing mechanized state logging enterprises holds an industrial essence similar to the previous period. However, growing demand for small-diameter and low-quality timber for pulp and mining industries, along with the significant depletion of the forest during the previous decades, led to an increase in cutting intensity. Clearcutting continued to dominate, and the amount of residual trees decreased significantly. Stands that developed out of the residual undergrowth and small wood left by conditional clearcuts of the previous period became available for harvesting. High-grading and intensive selective logging of remote forest lessened and soon disappeared.

The practice of landscape-size clearcuts continued until 1994, when new regulations were issued, establishing a maximum size of 50 hectares for clearcuts in industrial forests (group III forests). In some sense the landscape-size cutting practices still continue as the required minimum time lag between adjoining clearcuts is short (2-8 years depending on conditions, in rare cases more) and corners of clearcuts may adjoin at all times. These rules make it possible to clearcut an almost unlimited area in a short period (see Figure 27).

Tree removals grew rapidly, reaching a maximum of 90 million cubic meters in the late 1960's and early 1970's. (*Lesopolzovanije v ..., 1996*). The logging intensity during this period reached a level of 1.25-1.35 cubic meter per hectare, approximately 10 percent more than the level of potential growth.

As before, there were great variations in intensity between different regions. During 1966 in Karelia the logging intensity was 2.4 cubic meters per hectare, almost double the level of potential tree growth. In the Murmansk, Vologda and Arkhangelsk Regions, however, the logging intensity was only a few percentage units higher than the growth rate, and the Komi Republic was only 0.8 percent of the growth. The real logging intensity ratio was greater than the numbers indicate, because large areas of Group I forest were excluded from industrial logging (thinning was allowed in these forests, but was rare at that time) as well as protected areas. For Group II and III forests the logging intensity exceeded growth for all regions of Northern European Russia. These areas had been subject to massive logging during previous periods, while reforestation efforts were lagging significantly behind. Logging therefore led to a critical depletion of the forest, making a further increase in removals impossible. The early 1970's saw the beginning of a gradual decrease in removals in northern European Russia as well as a process of closing down state logging enterprises. Individual enterprises reduced operations through the following stages:

Lespromkhoz (large state logging enterprise with a large volume of harvest)

Lesouchastok (a subdivision of a *lespromkhoz* with a moderate volume of harvest)

Lesopunkt (a small subdivision of a *lespromkhoz*, employing one or few logging teams, with a small volume of harvest)

Abandoned logging village

Typical of the previous period was a continuous transition from the most intensively developed areas (which were gradually being cut through) to the least intensively developed (with dispersed sporadic cuttings). The current period, on the other hand, witnessed an occurrence of a solid front of clearcuts in the boreal landscape, from the center of the *lespromkhoz* towards more and more remote forests within its territory. By the end of the 1980's, with the requirement of having a time lag between adjoining clearcuts in practice, strategy shifted to logging in two passes: first a "chessboard" cut, then, after the required lag time, a "residual" cut of remaining forest.

To provide some protection to the forests, zoning restrictions on logging were reintroduced in 1943 with the designation of all forest land into three categories with different management restrictions. Protection forests of various kinds were designated Group I status which allows only salvage logging. In 1943, many of the most important forests from an ecological perspective were placed in this category along with severely depleted forests along major rivers, railroads and roads, and around population centers. Thus, the introduction and gradual increase in size of the Group I zone was, for practical forestry, a very important forest protection initiative. The restrictions pertaining to the Group I management zone have since been gradually eased, however, and about half of the forests in this zone are now managed more or less for wood production.

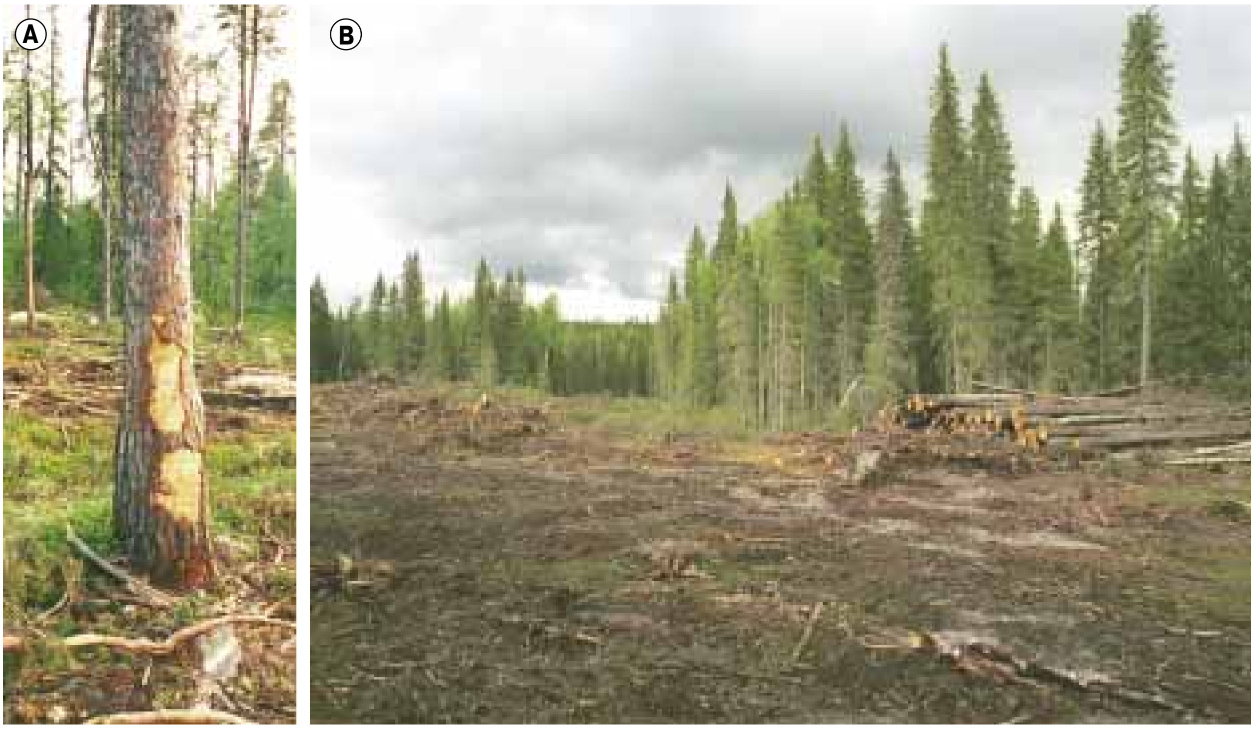


Fig. 28. Conventionalv tractor skidding typically produces significant ground disturbance at the logging site, destroying undergrowth and small trees.
***A**. Skidding damage on pine caused by selective "salvage" cutting. Murmansk Region. Photo: A Yaroshenko.*
***B**. Ground disturbance caused by tractor skidding. Arkhangelsk Region. Photo: V. Potansky.*

The formulas for calculating annual allowable cut that had made possible almost limitless logging have gradually been rescinded. The annual allowable cut nevertheless significantly exceeded growth well into the 1980's in most of the territory of study; and in some places this is still the case. Some of the harvest regulation formulae simply do not provide for sustainable uninterrupted wood production. While many foresters consider these formulae to be scientifically based norms for forest utilization, the classics of Russian forest science raised serious objections to the underlying calculation principles. In general, many forms of forest utilization that seemed primitive and thoughtless to Russian foresters during the first third of 20th century have brought into practice during subsequent periods of forest utilization and eventually become accepted as a norm.

The role of river drive for long-distance transportation of wood gradually decreased, although it remained the most important form of transportation into the late 1970's. Nowadays, the importance of river drive is limited.

Rapid mechanization of the work process replaced horses with winches and tractors for skidding (winches have since fallen out of use). Tractor skidding in particular, brought considerably more ground disturbance at the logging sites, destroying significantly more undergrowth and small trees in the process (Figure 28). Intensive die-back of residual trees and undergrowth were not observed at sites of "conditional" clearcuts and selective logging, due in large part to damage from mechanized skidding. In addition, strict rules required clearcuts be cleaned of logging debris. Later, with little follow-up tending, the majority of regeneration was made up of pioneer species, mostly aspen and birch. The introduction of thinnings has proceeded slowly with very little industrial significance into the 1990's. In truth, logging continues to be based on primary forest, in addition to cutting natural regrowth on the sites of earlier logging. Silviculture and logging do not form a closed cycle as harvesting is based on forest of natural origin.

After the Second World War, active efforts were initiated to drain bog forests of northern European Russia. Draining had taken place since the end of the 18th century, and until the 1950's, mostly in densely populated regions of central and western Russia. All in all, some 5 million hectares of bogs and wet forests were drained, about half located within the territory of study. In our analysis, drained areas were considered to be sufficiently disturbed to be excluded from the intact landscapes.

Resin tapping in pine forests continued to be actively developed through the end of the 20th century (Figure 29). A zone of mandatory resin tapping was introduced, where final felling could not take place until the resin tapping had been concluded. Specialized state enterprises for resin tapping were active in all regions with significant amounts of pine. The full range of forests were being used for resin tapping, from road-side stands to the remote locations, where some of the tapped stands survive to

Fig. 29. Tapping of pine resin. Karelia Republic. Photo: A. Yaroshenko.

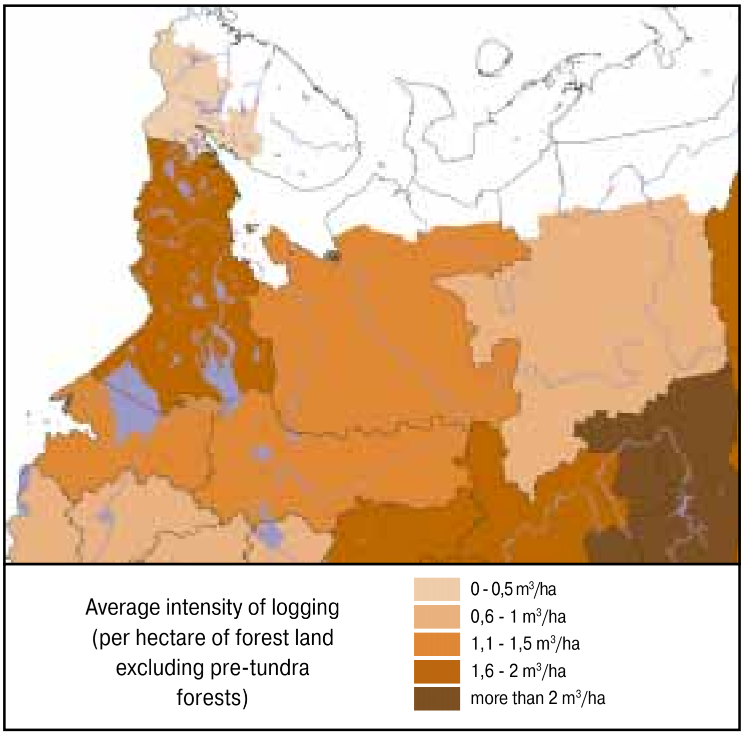


Fig. 30. Average intensity of logging for different regions during 1963-1982, annual averages.

this day. Resin tapping is somewhat similar to a severe ground fire in its effect on tree vitality. Part of the living tissue of the stem is destroyed, causing the more wounded trees to die while the less wounded eventually restore their vitality. As part of this work, a study made in the Kalevala forest of Karelia compared the condition of stands in which tapping ceased at least five years ago with stands that were untapped (but affected by at least one ground fire during the last 30 years). There was no noticeable difference in tree distribution in terms of condition and rate of mortality.

The 1990's forest development boasts important characteristics. Most significant is the drastic decrease in removals - a drop of two to four times that of the previous decade (Figure 31). Reasons for this reduction range from the critical depletion of forest resources due to over-exploitation to the breakdown of technical integration of industries along the wood chain, and the reduction in government support to economically inefficient enterprises. Similar to war times the logging effort shifted noticeably towards more densely populated and accessible areas during the end of the period. The construction of new roads slowed down considerably.

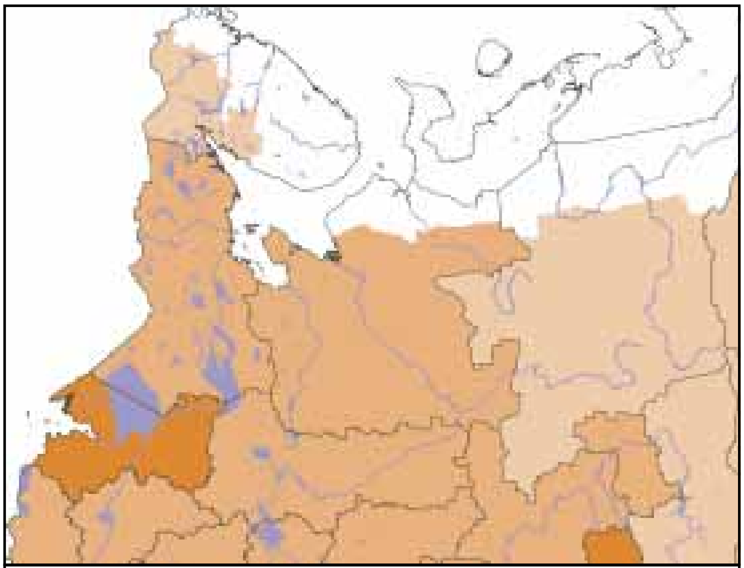


Fig. 31. Annual intensity of logging in different regions, 1999.

Fig. 32. Leaving behind groups of confers during final felling will result in mixed forests of conifers, birch, aspen and willow. Arkhangelsk Region. Photo: A. Yaroshenko.

Overall, this period saw an increase in so-called "revenue cuttings" (an unofficial term for silvicultural cuttings). These are intermediate cuttings for the purpose of providing the state forest service agencies with additional funds by selling wood. The occurrence of these cuttings is connected with the decision in 1993 to separate the state silvicultural agencies from the state forest industry system. Unfortunately, this division was carried out in the usual political manner: the silvicultural agencies received a great deal of responsibilities (from the delineation of logging sites to reforestation and silvicultural cutting) without a sufficient budget allocation to fulfill the tasks. As compensation, the leskhozes (local silvicultural state agencies) were given the right to sell wood from all sorts of logging except final felling and use the revenue for their own needs. Many leskhozes responded by turning themselves into unofficial commercial logging enterprises. This led to a drastic increase in the quantity of intermediate cuttings, but in most cases also to a similarly drastic decrease in their quality. According to our own estimates, no less than 90-99 percent (depending on the region) of the thinnings during this period can be characterized as high-grading causing a drastic reduction in the quality and stability of the residual stand (see Figure 28). These activities took place in the most densely populated regions, especially in forests that had been set aside from industrial utilization (belonging to Group I). In more remote areas this practice has not been widely spread, with some local exceptions.

IDENTIFICATION AND MAPPING OF INTACT FOREST LANDSCAPES

THE NATURAL VALUE OF LARGE BOREAL FOREST LANDSCAPES

Researchers recognize the special value of large natural areas for preserving all strata of biological diversity (*McCloskey, Spalding, 1989, Bryant et al., 1997, Noss, 1990 etc.*). For many cases of conservation, reserve size is vital to success. These cases include stable populations of large animals that are especially sensitive to human impact or habitat changes, lakes and wetlands as objects of reference, and the natural dynamics of forest ecosystems associated with large-scale disturbances such as fire or wind damage. It is also a fact that the central parts of large reserves are better protected from "edge effects," influenced by disturbance of neighboring areas. Edge effects can take different forms. Typical examples include biological contamination (such as "immigrant" plants intruding from adjoining roads or logging sites with associated risks of changes in ecosystem structure and dynamics), hydrological changes caused by the draining or waterlogging of neighboring areas, and collapsing forest walls of neighboring logging sites. Also important is that people rarely visit the central parts of large intact areas, making them less likely to be affected by poaching or anthropogenic fires. This assumption is supported by the total absence of blazes during the fire year of 1999 - the most destructive in recent record - within all intact forest landscapes identified as part of this study.

It's impossible to pinpoint the smallest area required for indefinite preservation of all natural components of a forest landscape. Different size habitats are needed to support a diversity of bio-components. These areas also depend on a vast variety of local conditions with best guesses approximating needed space (Figure 33). What can be said for certain is that the greater the area, the greater the number of organisms and natural properties that can be preserved. Also of note is the knowledge gap regarding spatial relationships among the components of boreal ecosystems. The same is true for the mechanisms that govern the survival of particularly sensitive plant and animal species. Protecting large areas is therefore a matter of reasonable precaution as it promotes the conservation of all species, both those well studied and those as yet unknown.

Conservation of large taiga territories itself requires significantly lower expenses than protection of numerous small fragments located within areas transformed by industrial activities. Experience gained by Russian forestry institutions and protected areas managers indicates a need of at least 10-20 employees per 10,000 hectares of conserved area within a fragmented and highly populated territory with a developed road network in order to ensure sufficient

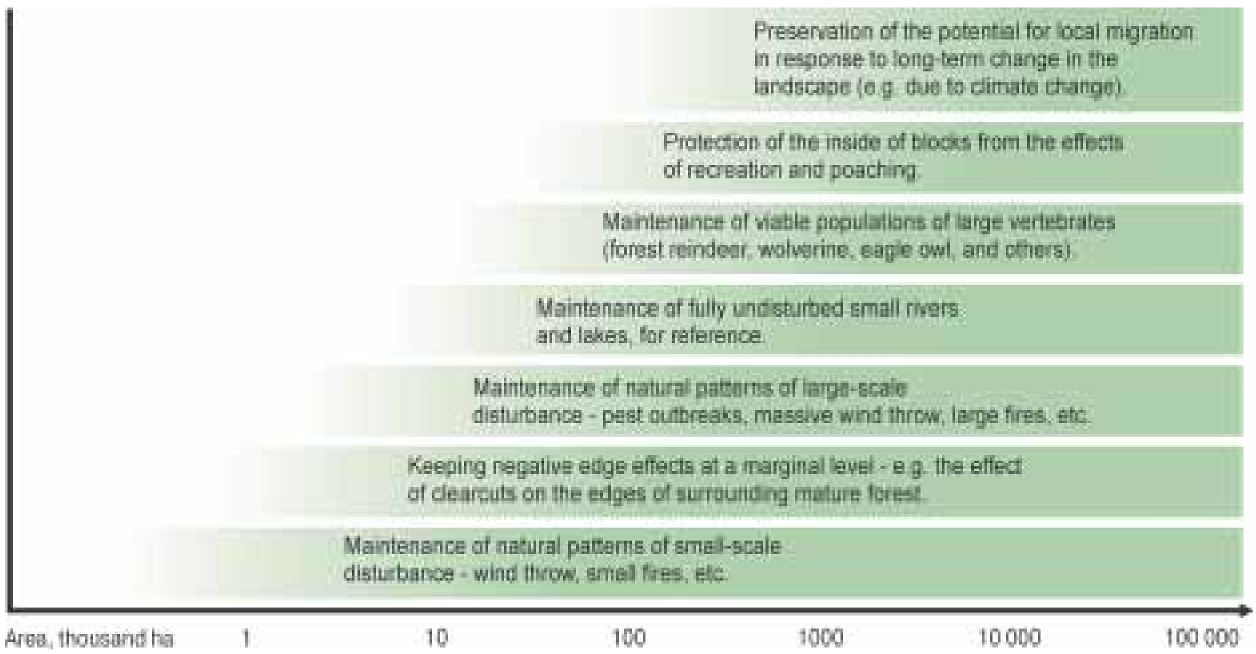


Fig. 33. Block size needed to sustain some important conservation functions.

protection and maintenance. Protection of large intact boreal landscapes, on the other hand, without any internal road network, requires no more than 7-10 employees for areas of dozens or even hundreds of thousands of hectares.

Protecting large intact boreal landscapes is significantly less expensive than protecting many small fragments within an otherwise heavily transformed landscape. At the same time the environmental benefit is greater.

In this study, large intact areas were defined as landscapes greater than or equal to 50,000 hectares, internally undivided by infrastructure, and with a minimum linear dimension no smaller than 10 kilometers. Such spaces are capable of maintaining most natural values and functions of a self-sustaining boreal landscape, including the following:

- Small-scale (the falling down or death of individual trees) and large-scale (fire, insect infestations, extreme weather conditions) random disturbances;
- Self-maintaining populations of plant and animal species especially sensitive to human disturbance;
- Intact catchment basins around rivers, bogs and streams;
- Spatial patterns of ecosystems and habitats;
- Rare or extremely sensitive ecosystems, that disappear in fragmented landscapes as a result of permanent human influence.

These dimensions sufficiently buffer most edge effects such as the collapse of the forest edge of logging sites, outbreaks of pest insects in logging debris, changes in water regime due to draining or waterlogging of neighboring clearcuts, and the effects of intensive hunting and fishing.

BACKGROUND HUMAN INFLUENCE

The idea that the some of Earth's forests or other natural ecosystems exist free of the impacts of human activities, is a significant simplification of reality. As a matter of fact, each forest is affected by human activities - even if the impacts cannot be directly measured. Typical examples of such wide spread human impacts are global atmospheric pollution, changes in population size of game animals (including those that are important ecosystem-forming components of forest landscapes) or changes in forest fire frequency resulting from changes in human population density and life style in forest regions. Thus, any criteria determining areas "undisturbed" by human economic activity in forests implies the presence of some background level of human impact, which is regarded as insignificant within the measured scale.

The Russian Forestry Standard (*OST 56-108-98 "Forestry. Terms and Definitions"*) defines virgin forest as a "natural forest that has not undergone perceptible human impact, changing over a period of many generations of tree species due only to natural processes". Such an approach apparently brings about a certain degree of subjectivism at detecting virgin forests according to the above definition.

Fig. 34. Many spruce forests, especially in the White Sea basin, owe their existence to selective logging for pine during the late 19th century - early 20th century. The picture shows a spruce forest on a site where pine canopy was cut during the beginning of the 20th century. Photo: A. Yaroshenko.

Detection of "perceptible" signs of human impact depends on the methods employed, degree of exploration intensity, and professional skills of the staff. Remote sensing will detect different levels of impact than ground exploration. For example, a forest area in the valley of Vuokijoki River in middle Karelia was described by several explorers as a "virgin" *Myrtillus*-type spruce forest (fig. 34). However, another exploration unearthed micro-swellings within a 20x100 meter trial plot. The excavation revealed 27 large pine stumps (some with signs of sawing), and partially decomposed tree crowns - presumably from an early 20th century cutting. Visual estimation of the forest resulted in the assumption that the forest is virgin, but detailed exploration revealed signs of selective logging within the last 100 years. In general, implicit determination of background anthropogenic impacts that are found insignificant results in incomparable findings in different regions and irreplicable results.

In this study, certain influences and disturbances were considered background effects, of no significance to the identification of intact landscapes. These background disturbances include the following:

- Ancient forms of human activity, occurring during the period prior to the industrial "development" of natural resources of the northern European Russia:
  - shifting slash-and-burn agriculture, widely spread in the southern and middle taiga right up till the 1930s;
  - fires, except for present day fires, adjacent to industrial and transportation infrastructure (see also the section "Methodology for the identification of intact forest landscapes");
  - hunting (including the construction of seasonally inhabited hunters' cabins), fishing, mushroom and berry gathering, scattered recreation (without permanent infrastructure);
  - grazing of more or less domesticated animals (reindeer, cows, goats);
  - cutting down single trees for the purpose of local construction needs or for firewood;

    clearing haylands in flood plains of rivers, haying.
- Scattered forestry activities of the past:
  - industrial selective cuttings of 18th - 19th centuries and the beginning of 20th century (until the late 1930s), as well as side-effects of those cuttings (increased frequency of fire near logging areas);
  - tapping trees for resin collection.
- Global and regional changes in the Earth's ecosystem (global and regional air pollution, climate change, ubiquitous changes in the population size of certain animal species, acclimatization and spread of exotic species, as well as unknown or underestimated global and regional changes).

MATERIALS AND SOURCES OF INFORMATION

Various information sources were used to detect intact forest landscapes. Consecutive processing of these materials in order to increase detail and accuracy made it possible to arrive at more and more precise boundaries of the these landscapes. The study used four major information sources:

General topographic maps

General topographic maps were used for mapping basic elements of infrastructure, such as towns and villages, industrial facilities, and permanent transportation infrastructure (see the section *Methodology for the identification of intact forest landscapes*). The basic goals of this mapping were:

- to exclude the most industrially disturbed and fragmented areas from further analysis;
- to divide the taiga zone of northern European Russia into discrete areas, separated from each other by elements of industrial infrastructure.

The maps were also used for georeferencing of middle resolution satellite imagery (*see below*).

An obvious weakness of general maps is the low accuracy in the representation of certain objects. Inaccurate mapping displaced roads 2-5 km, while some pipelines were off by as much as 10 km. General maps were therefore only used for mapping some very basic elements of infrastructure and later - borders of woodless bogs and highlands within intact forest areas.

The study made use of general geographic maps in scales ranging from 1:1,000,000 (northern regions) to 1:200,000 (southern regions), produced by the Federal Service of Geodesy and Cartography of Russia, 1993 - 1996 editions.

Thematic maps

The second main source of information was thematic maps. The study used the "*Map of Vegetation in the European Part of the USSR*" (1974) and the map "*Forests of the USSR*" (1990), as well as local and regional forest maps highlighting dominant species. These materials were used to aid the interpretation of the satellite imagery.

Middle resolution satellite images

The third major source of information was middle resolution images (approx. 150 meters per pixel) from the MSU-SK scanner on the Russian satellite Resurs-O-3. These images were used to exclude considerable areas, obviously affected by human economic activities (agricultural fields, large clearcuts, young second-growth forest), from further analysis, thus reducing the need for the significantly more expensive and thus less accessible high resolution imagery.

High resolution satellite images

The fourth major source of information was high-resolution satellite images. The study used Landsat ETM+, Resurs-O MSU-E, and SPOT HRV images with a spatial resolution of 15-35 meters per pixel. High resolution imagery made it possible to detect disturbance from smaller scale human activities, and was also used for fine-tuning the boundaries of intact forest landscapes.

Maps and middle resolution satellite images don't have enough detail to allow all significant forms of human disturbance to be detected. High resolution imagery (primarily Landsat ETM+) has sufficient detail, but access to complete coverage was blocked by financial constraints and the absence of summer-time cloudless images for all relevant areas.

Available maps (general geographic maps, topographic maps, and thematic maps) have certain weaknesses when used to detect disturbances in the natural landscape:

- There is a lack of general geographic and topographic maps that are both current and sufficiently detailed and precise. These maps do not by themselves allow current sources of disturbance, such as logging roads and strip roads, to be reliably detected.
- Forest maps are updated infrequently (every 10 years or even more seldom) and are of inconsistent quality. Reliable maps do not exist for certain legal categories of forest, such as forests belonging to agricultural enterprises, remotely located reserve forests, etc. Regional level maps are often either missing or not accessible. The underlying forest inventory is in many cases not sufficiently precise. For these reasons it is not possible to produce a sufficiently detailed and current forest condition map of northern European Russia by relying exclusively on forest management maps and data, or the federal state of the forest accounts.
- The area of northern European Russia is divided among many different administrative agencies. There is no unified system for data collection among these agencies. Data is collected and processed with varying degrees of precision and efficiency, even within individual regions. The result is a lack of unified cartographic information on the status and utilization of lands belonging to different agencies.
- Some maps suffer from insufficient objectivity (i.e. are distorted on purpose). Certain facilities that are indicated on the map, particularly roads, may in reality be either abandoned, destroyed or have never existed in the first place.

Available maps and middle resolution satellite images don't have enough detail to allow all significant forms of human disturbance to be detected. High resolution imagery has sufficient detail, but access to complete coverage was blocked by financial constraints and the absence of summer-time cloudless images for all relevant areas

Medium resolution imagery (Resurs MSU-SK) does not provide sufficient detail to detect many significant features, such as linear disturbance (roads and transportation corridors in the forest), small clearcuts, agricultural fields and secondary forests appearing in their place, small quarries, etc. This is particularly pronounced in mountainous and hilly terrain, where ecosystems often appear naturally in small fragments and the intricate pattern of shadows adds to the difficulty. Nevertheless, the previous study on intact forest areas in northern European Russia (*Aksenov et al., 2000*) showed that it is possible to identify intact areas rather precisely using medium resolution imagery, despite certain unavoidable mistakes in their delineation.

SATELLITE IMAGES USED

Two main types of satellite imagery were used in this study:

- medium resolution images, taken by Russian satellite Resurs-0-3 (the MSU-SK scanner).
- high resolution images, taken by the American satellite Landsat-7 (the ETM+ scanner). In addition, some high resolution images from the Russian satellite Resurs-0 (the MSU-E scanner) and the French satellite SPOT (HRV scanner) were also used.

This section describes the different types of images used and how they were interpreted.

Resurs MSU-SK satellite images

MSU-SK satellite images have a spatial resolution of 140x170 meters per pixel and a view range of approximately 600 kilometers. Such images may be used in drafting thematic maps with a scale of up to 1:1,500,000 (*Kravtsova, 1995*). The MSU-SK images used in this study had undergone primary geographic adjustment and been transformed into a uniform resolution of 150x150 meters by the space engineering firm Scanex in Moscow. The MSU-SK scanner has four spectral channels: channels 1-3 in the visible spectrum range, and channel 4 in the near infrared range. This allows a large number of natural and man-made objects to be detected (Fig. 35, 36).

This scanner has some drawbacks: there are no algorithms for atmospheric adjustment or for adjustment of illumination and terrain-caused distortions. This made it more difficult to interpret the species composition in forest stands and made it impossible to use some standard indices and algorithms (e.g. the vegetation index). Another serious drawback is the absence of an algorithm for precise geographic adjustment of the images. Aligning the MSU-SK images with various cartographic materials required that the images be georectified to a uniform topographic basis. This produced an inaccuracy between 200 and 500 meters that was considered acceptable at the early stages of the work. Several of the images had only two channels and reduced spatial resolution (due to some peculiarities of the satellite's transmission device). Such images were used only as a last resort, in the absence of cloudless 4-channel images, and their application was therefore limited to a handful of small areas.

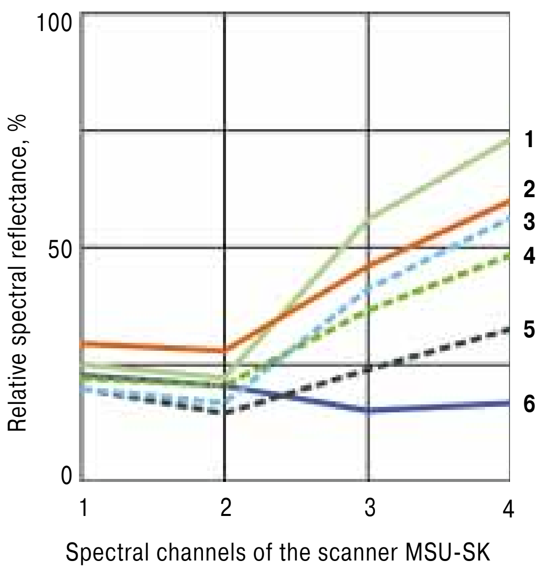


Fig. 35. The relative spectral reflectance from natural objects in a summer image from the scanner MSU-SK:
1. Hay field. 2. Sphagnum bog 3. Birch, aspen and willow on a clearcut. 4. Recent clearcut. 5. Closed spruce and fir forest. 6. Open water surface.

The MSU-SK images were used for two main purposes: to identify large-scale disturbances in forest cover due to human economic activity (large clear-cuts and agricultural areas, fire scares adjacent to infrastructure), and to map the northern border of the forest. Winter and summer images were both used.

Winter images were used to separate forested and unforested areas, to determine stand density, and to identify freshly cut areas (by comparing wintertime images from different years). The lightest areas in the winter images represented woodless areas; the darkest areas represented closed coniferous forests as well as deciduous forests with closed canopy of coniferous undergrowth. The small differences among different channels in the winter images made it possible to rely solely on channel 4, which was the most informative. Images from February to April gave the best results, as the height of the sun above the horizon was sufficient to provide minimum terrain shading.

Summer images were used to determine the composition and character of the vegetation, as well as the presence of open water surfaces and exposed minerals. Color synthesis of spectral channels aided interpretation. Red was used to represent the fourth channel, green the second channel, and blue the first channel (or the second one in the case of two-channel images), making it possible to distinguish differences in brightness in the visible (first and second spectral channels) and near infrared (fourth channel) spectral bands. To simplify the interpretation process and enhance the contrast between heterogeneous contours, we processed brightness histograms. The morphological and texture characteristics of objects were taken into account in visual interpretation. Summer images provided clear differences between water bodies (minimum brightness values in all

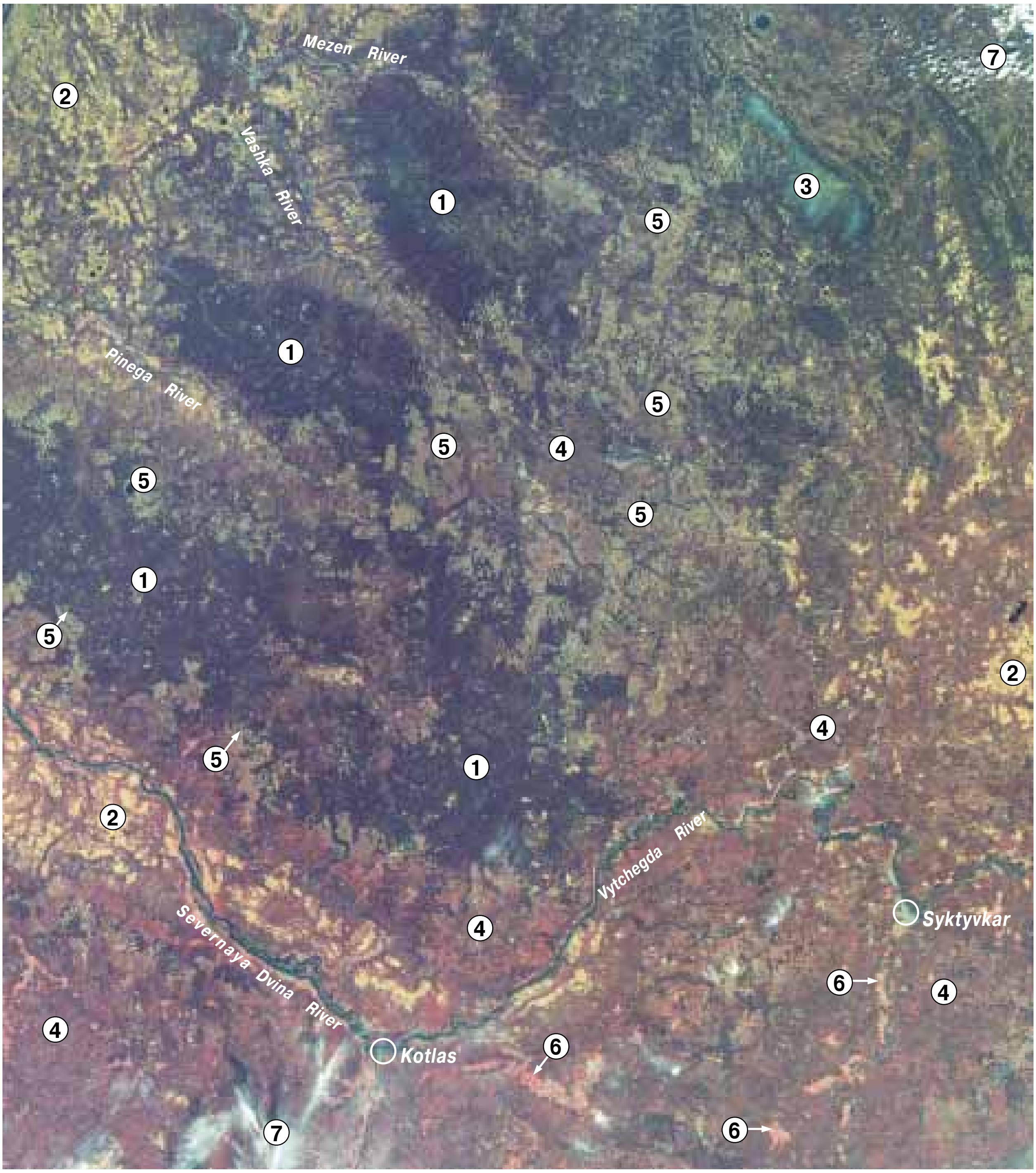


Fig. 36. Natural objects classified in a satellite image from Resurs MSU-SK (printed in reduced scale): 1. Coniferous forest without visible traces of human disturbance. 2. Open and forested bogs. 3. Sparse forest on low mountains (the tree crowns are covered with snow). 4. Secondary deciduous, mixed and pine forests. 5. Clearcuts, either recent or not covered by a closed regeneration of trees. 6. Agricultural land. 7. Clouds. Arkhangelsk Region and Komi Republic (the river basin of the Severnaya Dvina and Mezen). 6 June 1997.

channels), forests (generally low brightness values with significant differentiation in the infrared channel), swamps, and open grass communities including lowland sedge moors, meadows, and agricultural lands (generally high brightness values with differentiation in the visible and infrared channels - see Figure 36).

Summer images allow classification by species composition. Coniferous and deciduous forests are clearly distinguishable by spectral characteristics. "Light coniferous forests" (fire-dependent, mainly pine) and "dark coniferous forests" (spruce and fir dominated) were distinguished using image interpretation in combination with forest maps. Deciduous species such as birch and aspen could not be distingushed from each other, however.

Species composition is a good indicator of human disturbance as original coniferous forests are replaced by secondary deciduous forests after clearcutting and other large-scale forms of disturbance (Fig. 36). Only summer images taken after the full development of the leaves of birch and aspen over the entire territory were used. Using early summer images could have produced an overestimation of coniferous forest, as deciduous stands with coniferous undergrowth might incorrectly be classified as coniferous if the leaves of the upper storey have not yet developed.

Landsat ETM+ satellite images

Landsat ETM+ satellite images with a spatial resolution of 30 meters per pixel (spectral channels 1-5 and 7) and 15 meters per pixel (eighth panchromatic channel) and a view range of 183x170 kilometers were used to identify minor, fresh and dispersed disturbances not distinguishable in MSU-SK images, and for mapping the borders of intact forest landscapes with greater precision. The high spatial resolution of the images and the low amount of georeferencing inaccuracy (not exceeding 250 meters) allowed the final map to be drafted at a scale of 1:500,000. The ETM+ scanner determines the brightness of reflected light in six spectral channels, of which the channels of the visible spectrum range (1-3), as well as the near (4, 5) and medium (7) infrared ranges were used in the analysis. Again, summer images were used to classify species composition. The following color synthesis was used for summer images: 4 (red) -2 (green) -1 (blue) or 5-2-1, respectively. However, due to incomplete or unclear coverage of some regions, wintertime images, visualized through the panchromatic channel, were used for the analysis of Northern Urals. In the analysis

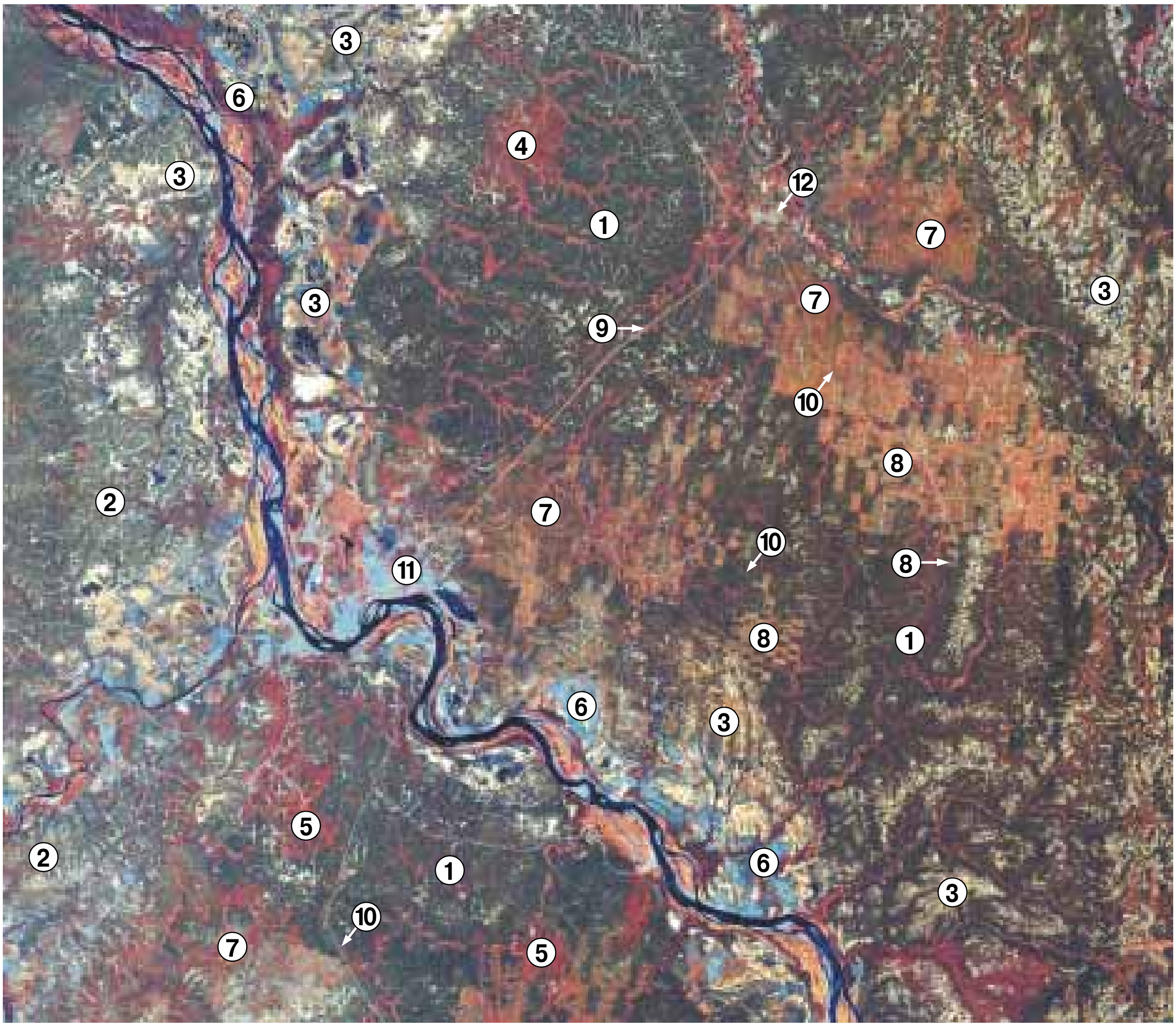


Fig. 37. Example of natural objects that can be identified in a summer image from Landsat ETM+ (northern foothills of the Ural mountains): 1. Spruce and fir forest without signs of disturbance. 2. Wet pine forests. 3. Bogs and forested bogs. 4. Secondary deciduous forest on burned areas located beyond the boundary of current infrastructure. 5. Secondary deciduous forest on burned areas, located in the vicinity of current infrastructure. 6. Burned areas in Cladonia type pine forests. 7. Secondary deciduous forest and grass vegetation on old clearcuts. 8. Relatively recent clearcuts, mostly covered with grass and regrowth of deciduous species. 9. Railroad. 10. Logging roads with prepared surface. 11. Large settlement (the city of Pechora and surrounding industrial buildings). 12. Small settlements. Komi Republic, middle part of the Pechora basin. 26 June 2000.

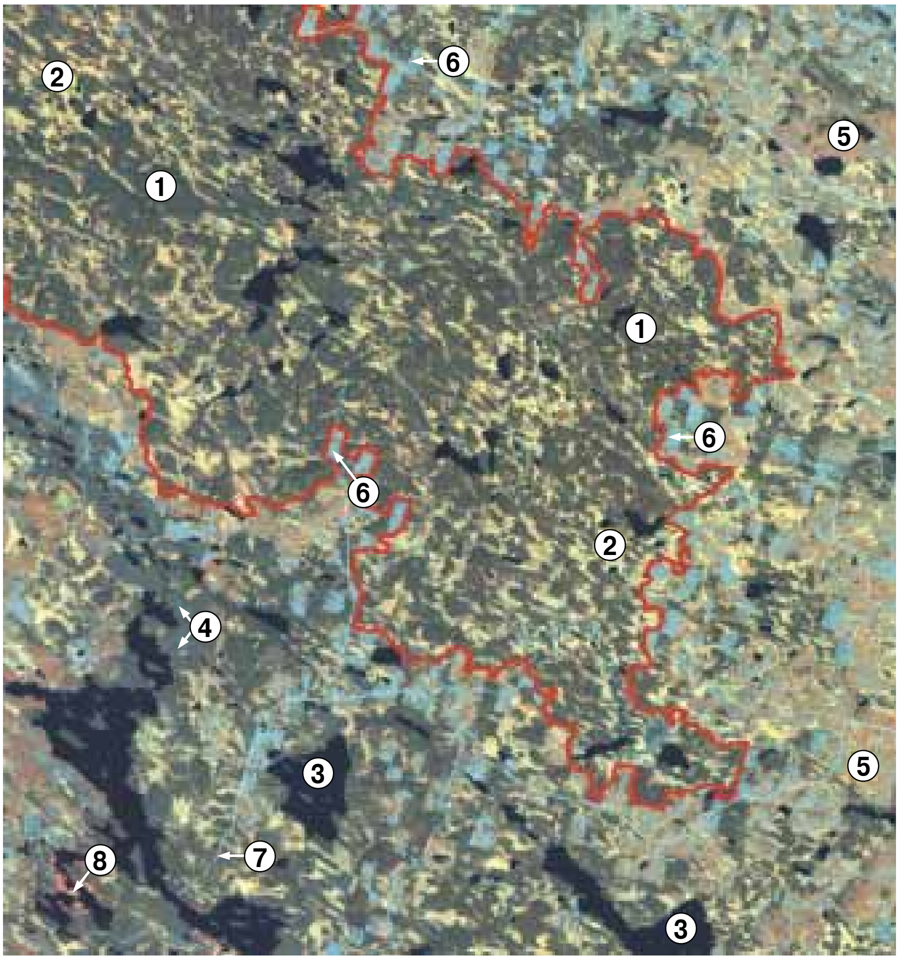


Fig. 38. Example of natural objects that can be identified in a summer image from Landsat ETM+ (western Karelia):

1. Coniferous forest without signs of disturbance.

2. Bogs and forested bogs.

3. Lake.

4. Pine forest affected by recent ground fires.

5. Grass vegetation and regrowth of deciduous species on clearcuts.

6. Recent clearcuts, clearly visible due to exposed mineral soil.

7. Logging roads.

8. Agricultural lands (hay fields and overgrown pastures around abandoned farm).

The boundary of intact landscape is shown in red.

Karelia Republic, Muezerskiy District. 28 June 2000.

of autumn (October) images, only infrared channels were used (instead of the channels of the visible spectrum range).

Summer images visualized in color synthesis 4-2-1 were used to distinguish natural objects in much the same way as with MSU-SK images. The images provide clear differences between several categories of objects: objects with low brightness in the reflected light, such as deep clean water bodies, water-filled swamps, hardwood forests and bog-moss and green-moss pine forests; objects with high brightness in the red and near infrared range, such as deciduous birch-aspen forests in logged and burned areas, willow groves and riverside meadows, and agricultural lands; and objects with generally high brightness, such as Cladonia-type pine forests, *Sphagnum* bogs, open grounds in freshly cut areas, roads, settlements and mines. Dry surfaces of exposed mineral ground and fire-sites covered with ground lichens have a conspicuous light blue hue in the given color synthesis (Fig. 37, 38, 39). The high resolution of the images allowed us to use the morphological (chiefly different types of edges) and texture attributes of the objects more fully to identify dispersed and discrete disturbances such as selective and shelterwood fellings, and dried swamp areas. Landsat images allowed a large number of linear anthropogenic

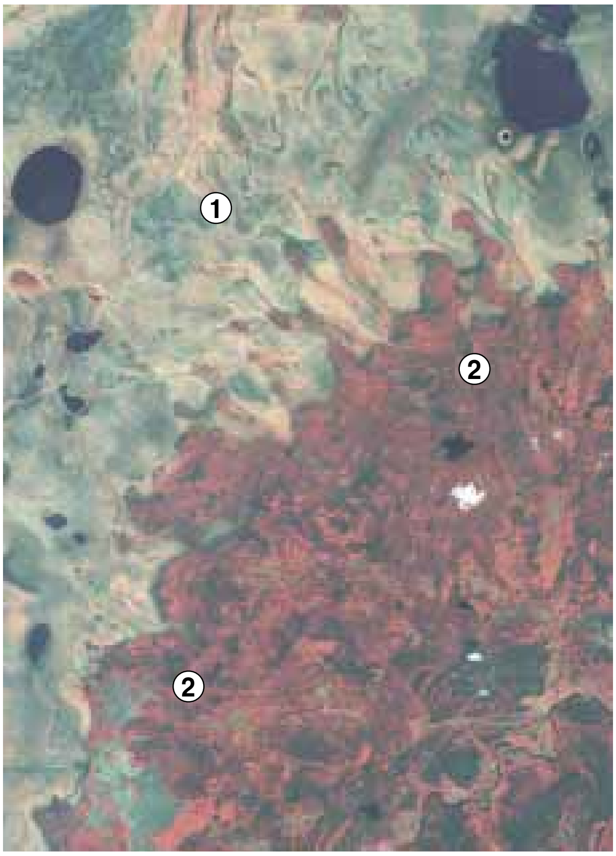


Fig. 39. Bogs (1), surrounded by secondary deciduous forest on clearcuts (2). Summer image from Landsat ETM+. Novgorod Region, Polisto-Lovatskiy bog. 6 June 1999.

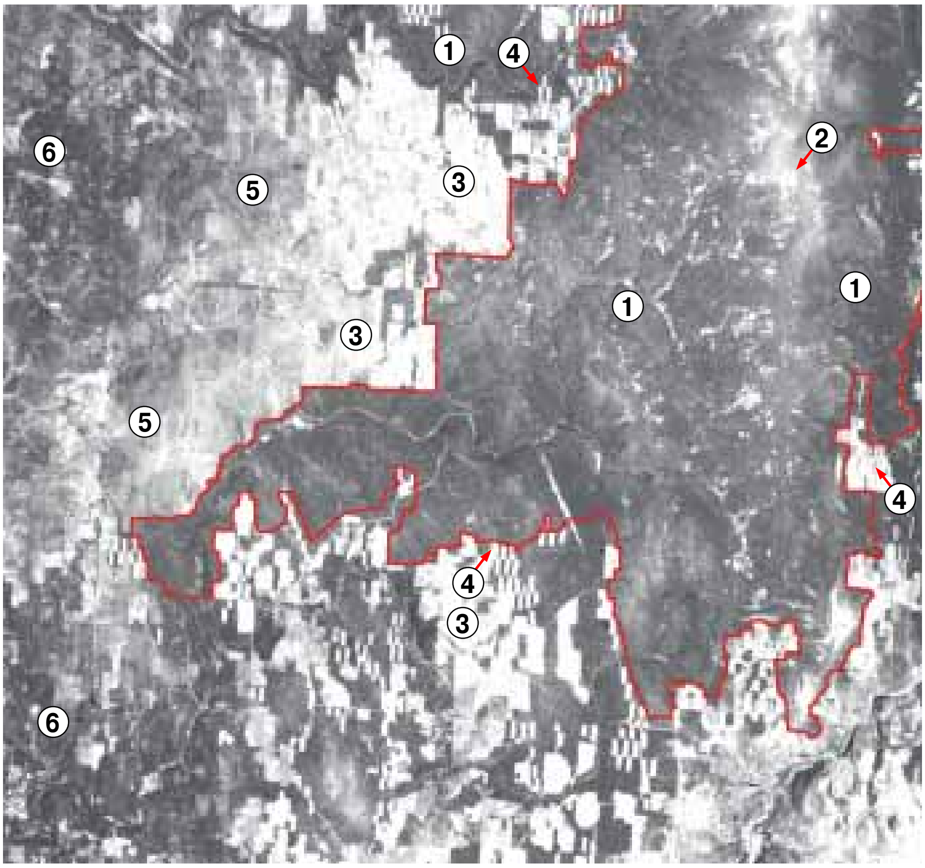


Fig. 40. Example of natural objects that can be identified in a winter image from Landsat ETM+ (panchromatic band).

1. Coniferous forest without signs of disturbance.

2. Highland open landscapes.

3. Clearcuts not covered by secondary forest.

4. Recent clearcuts.

5. Secondary deciduous forest.

6. Secondary deciduous forest with coniferous undergrowth, pine forest on old clearcuts.

The boundary of intact landscape is shown in red.

Perm Region, Krasno-visherskiy District. 18 April 2000.

objects to be detected, such as high-voltage power lines, motor roads, railways and pipelines.

Winter and early spring Landsat images were less informative and did not always allow an unambiguous differentiation between coniferous and deciduous forests, especially in cases with a dense undergrowth of spruce. Contours based on such images was adjusted using medium-resolution summer images. Scenes shot after the complete development of the leafes in the canopies of birch and aspen stands made it possible to avoid underestimating of the amount of deciduous forest. The major criterion for interpretation of winter images was the presence of an open snow carpet, which clearly demarcated freshly cut areas, burned-out tracts, swamps, frozen water bodies, agricultural lands and various types of linear anthropogenic objects (fig. 40). Winter images were used successfully to revise the edges of intact forest landscapes to exclude fresh disturbances, but could not be used as the sole source of information for drafting specific map segments.

For areas not covered by Landsat satellite images, other high-resolution satellite images were used: SPOT (1996) and MSU-E (1997-99). Both types of images were visualized through standard color synthesis 3-2-1, 3 being the near infrared channel, and the processing similar to that of Landsat images (fig. 41). When using old (1996-97) images, the contours obtained were verified repeatedly using recent medium-resolution images (MSU-SK).

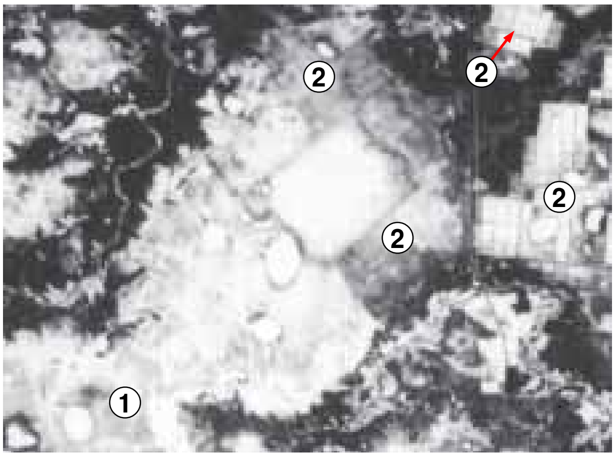


Fig. 41. Drained parts (2) of a bog (1). Winter image from Resurs MSU-E. Vologda Region, the Mokh bog. 2 Feb. 1997.

INTERPRETATION

Expert visual interpretation was the major method of interpreting satellite images. Interpretation was carried out in an ArcView GIS environment with the simultaneous use of satellite images, results of cartographic analysis, thematic hydrographic layers, the road network, communities, and other anthropogenic objects, drafted on the basis of general geographic maps (fig. 42). The chosen GIS allowed for a rapid switch among various layers of data, changing the color synthesis of interpreted satellite images and using brightness histograms. ArcView was also used to assess the area of the territory, to identify swamps and woodless highlands, and to prepare the final maps for publication. The initial space image processing and the georeferencing of scanned maps were made using ERDAS Imagine GIS.

The purpose of the interpretation was to identify areas affected by rather strong and relatively recent anthropogenic disturbances (e.g. construction and ploughing work, the building of pipelines and power lines, logging, consequences of anthropogenic fires). Different sets of identification criteria were used for the three different types of land concerned: forest ecosystems, wetland ecosystems, and unforested highlands.

1. Forest ecosystems occupy the largest portion of the studied area and are characterized by the predominance of coniferous forests with relatively small deciduous outcroppings in the upper canopy. The main kinds of disturbance in forests remote from permanent human infrastructure are logging and fire (recently disturbed areas covered by grass, at times with exposed mineral soil), changes in the species composition (from coniferous to deciduous or mixed coniferous-deciduous), and intensive selective cuts, sometimes associated with changes in ground cover. Areas of this kind were identified based on characteristics in color (relative spectral brightness in the channels used), morphology (size and shape of contours, peculiarities of borders and transition zones) and texture (internal) associated with relatively homogeneous, visually distinguishable landscape contours. Color attributes were used to characterize species composition (coniferous/deciduous ratio) and ground vegetation (only in intensively thinned stands). Morphological attributes were used in many cases: to detect logged areas which regenerated without notable change in species composition, to distinguish between felled and burned areas, and to identify new roads and pipelines and other anthropogenic objects not indicated on general geographic maps. Texture characteristics were used in medium-resolution images to identify secondary mixed forests and in high-resolution images to detect selectively cut areas and ground fires.

Regrettably, analysis of satellite images cannot determine the age of a stand. Significant errors may therefore occur in the interpretation of disturbances in areas dominated by open forests formed by fire. Cartographic or field materials were therefore used to support the interpretation in these rather rare cases. A number of clearly identifiable disturbances were finally admitted into the category of intact landscape as background disturbance, such as abandoned meadows and fire scares not adjacent to modern infrastructure.

2. Major disturbances of **wetland ecosystems** include the occurrence of transit roads, peat mining, ditching and peat fires near infrastructure. Areas adjacent to sites of oil and gas extraction and associated pipelines were considered disturbed and thus excluded from consideration.

3. Two kinds of anthropogenic disturbance are common in the **unforested highlands**: fragmentation by transportation infrastructure, and sites of mining. Disturbed tracts were identified by color and morphological criteria, as well as on the basis of expert data. Significant inaccuracies may occur in the delineation of river valleys disturbed by gold mining. Grazing - mainly by reindeer - was considered background disturbance for the purposes of this study and was admitted into the intact category.

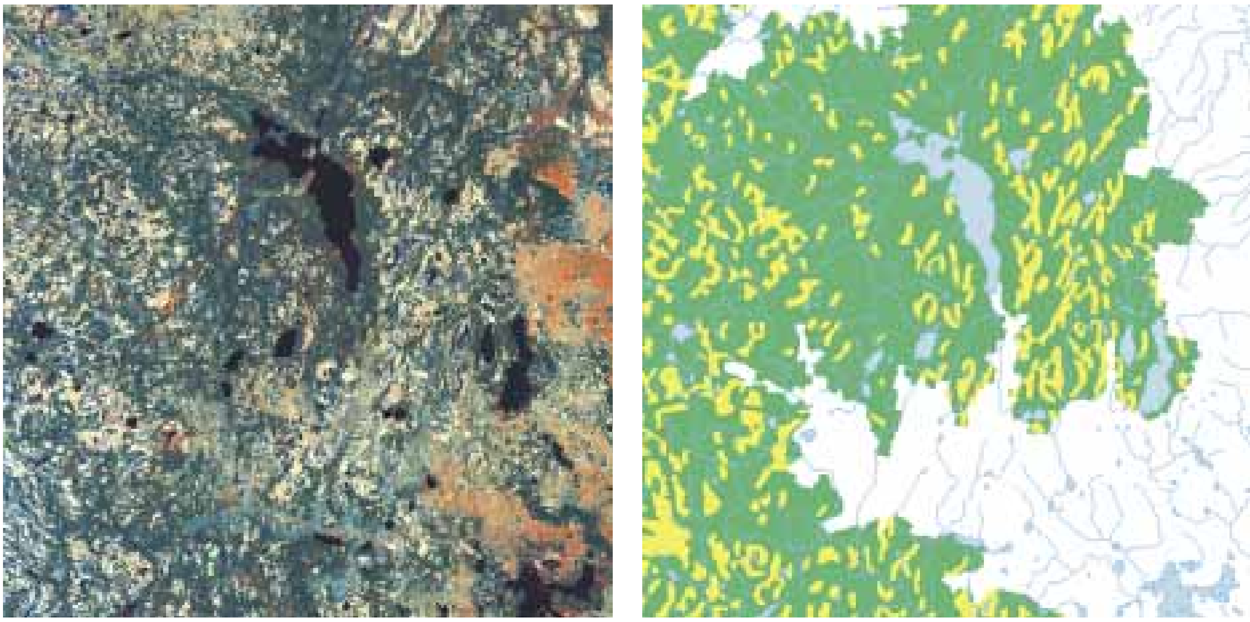


Fig. 42. Satellite image from Landsat ETM+ (left) and a map prepared on the basis of this image (right, intact forest shown in green). Bogs located within the intact forest (shown in yellow) have been added using information from a topographical map.

FIELD DATA COLLECTION IN KEY AREAS

A significant amount of field work was carried out in order to guide and verify the mapping. Fieldwork was located to edges of areas tentatively classified as intact based on medium resolution imagery, and also to areas for which sufficient information for a dependable classification was missing. Areas adjacent to intact areas were also described from the ground in order to detect any mistakes in their classification. A number of field expeditions were also made especially to disturbed areas for the same purpose.

Teams organized by Greenpeace Russia, Pushchino State University, the Biodiversity Conservation Center and the Socio-Ecological Union International carried out field inventories between 1997 and 2000. All teams applied a uniform methodology for data collection. Potentially intact areas located in the vicinity of sources of disturbance such as infrastructure, settlements and sourcing of wood were examined more intensively. Potentially intact landscapes along the northern forest boundary in areas with scarce or no population were examined with less intensity, due to the lower probability of disturbance. A total of 67 key areas were examined (fig. 43).

Within each key area or tract, an area of no less than 10,000 hectares was examined (with the exception of key areas located within disturbed forest landscapes). For each key area, a description was prepared of the general state of human disturbance as well as the current character and condition of the landscape. Additionally, a number of sample plots within each key area were described in more detail. These sample plots were located in different ecosystems, representing different degrees of anthropogenic influence (Fig. 44). No less than 30 sample plots were described for each key area. The location of each sample plot was placed on a satellite image and used as a reference for interpretation. (For disturbed areas this was done only in case an erroneous classification of undisturbed area as disturbed was discovered.)

Certain key areas were made subject to more detailed analysis with the purpose of identifying signs of past activity and reconstruction of the history of use in certain parts. In particular, data were collected that would permit a reconstruction of the history of logging during the preceding 100-120 years, based on growth analysis of the current forest stand, the distribution of deadwood in terms of decomposition stages and

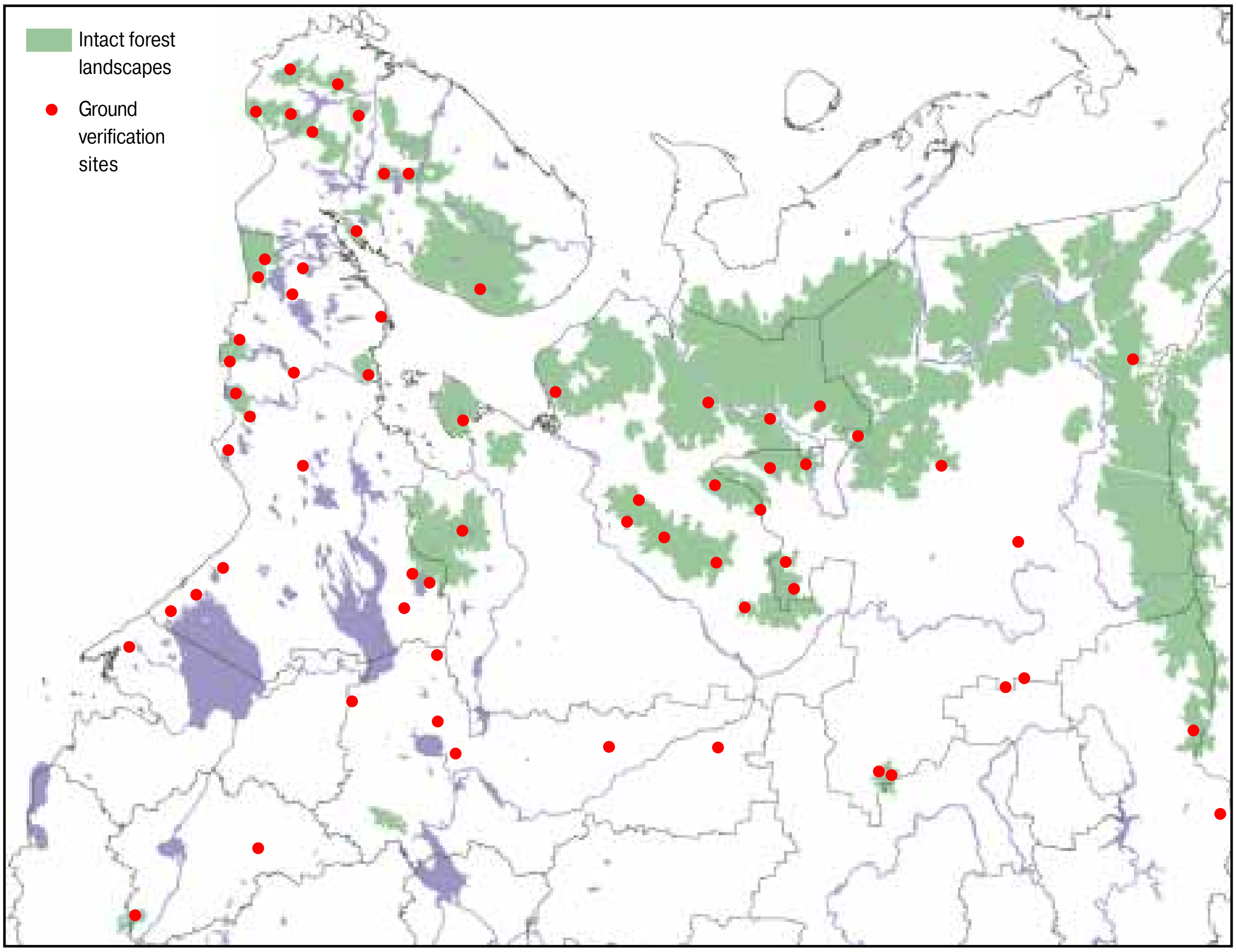
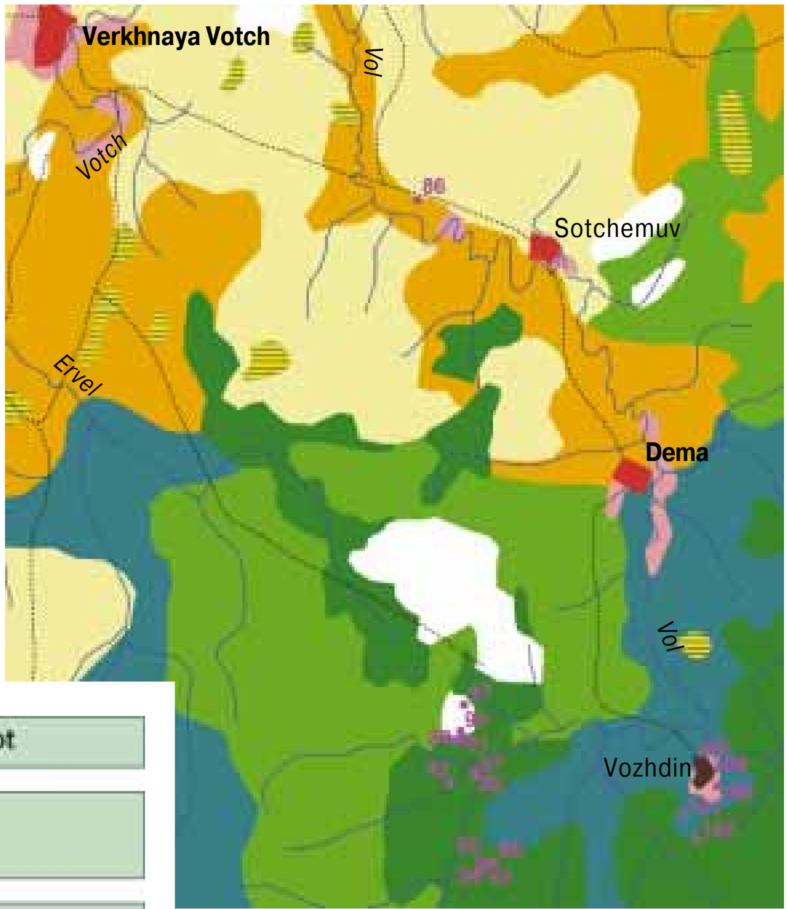


Fig. 43. Location of key areas surveyed by field expeditions 1997-2001.



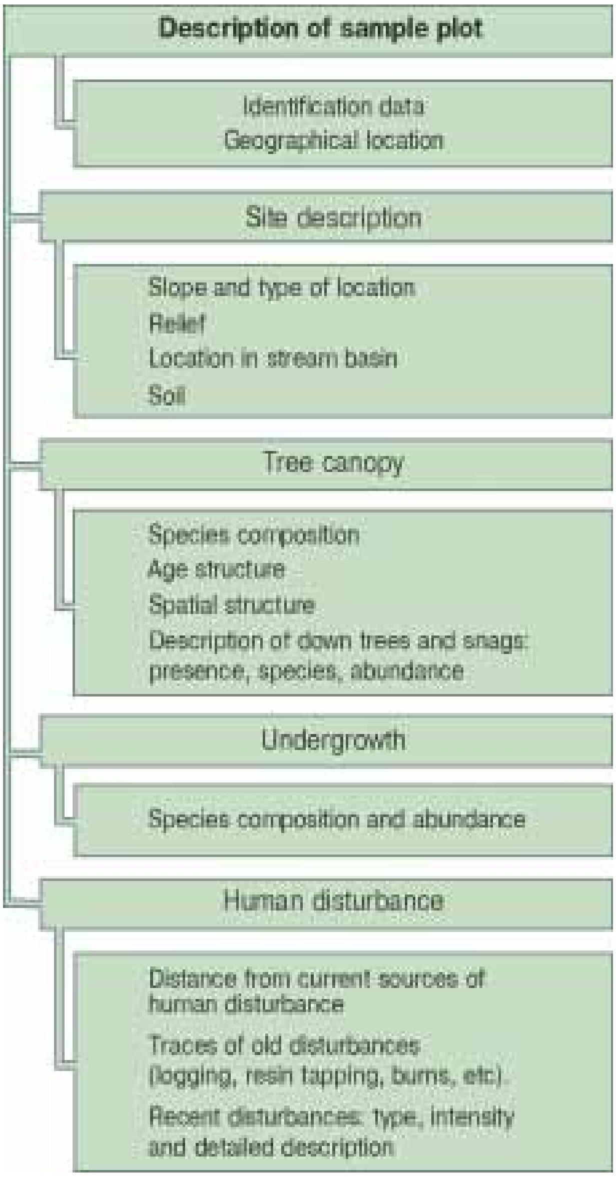


Fig. 44. Observations made on sample plots.

Fig. 45. Many ground verification sites were mapped in detail using satellite images, field trips, and detailed descriptions of key plots. This map shows forest types and the location of key plots in the upper part of river Vol (Komi Republic).
Scale 1:250.000

species composition, the quantity and degree of decomposition of stumps and logging residue (Fig. 45). Traces of other forms of economic activity were also identified and studied, such as agricultural clearings, resin tapping, fires emanating from logging sites dating back to the 19th and first half of the 20th centuries and from former settlements, etc. Their proliferation within potentially intact landscapes was also assessed. Similar studies were made in several smaller tracts of forest that had not been subject to modern economic activity. This information was used to determine the list of human disturbances that were to be recognized as background effects, of no significance to the identification of intact landscapes for the purposes of this study (see chapter *Background human influence*).

METHODOLOGY FOR THE IDENTIFICATION OF INTACT FOREST LANDSCAPES

A stratified approach was used in the identification of intact forest landscapes. The area under consideration was successively reduced in three steps or phases, while the amount and quality of information for the remaining area was increased. The purpose of the first two phases was to exclude obviously disturbed areas from further consideration using overview information. Phase one relied on available maps and some medium-resolution satellite images while phase two used two-season medium-resolution satellite images. This approach was chosen due to financial constraints - the budget did not allow the purchase of high resolution imagery for the entire area of study. Excluding a significant portion of northern European Russia from the analysis based on less costly information decreased the cost of the work significantly without reducing the detail or accuracy of result.

Whenever unclear cases were encountered (e.g. insufficient information to classify a road as belonging to a particular category, or to establish the presence or absence of logging in a particular tract), their resolution was postponed until the subsequent, more detailed phase. The methodology for each phase is described below. Additional explanations with regard to methodologies are given in the sections *Background human influence* and *Materials and sources of information*.

Phase 1.

In the first phase, major roads, railroads, etc. were used to divide the landscape into big fragments, using general maps and medium resolution satellite images. The goal was to identify fragments greater than 50,000 hectares in size, the inside of which are free from major elements of infrastructure and potentially may contain intact parts. Medium resolution satellite images were used to exclude tundra areas.

General geographic regional maps in scales between 1:200,000 and 1:1,000,000, published between 1993 and 1996, were used. These maps provided information about communities, industrial facilities,

Table 1. Types of infrastructure considered in the first (overview) phase of work, and corresponding buffer zones used along or around them (meters)

Type of infrastructure	Type of map object	Size of buffer zone (meter)
Federal and regional roads	Linear	1000
Other public roads, as well as land management roads that serve in practice as public roads (connecting settlements and/or public roads)	Linear	500
Corridors of pipelines or power lines	Linear	500
Land management and forest roads (except winter roads and non-prepared terrain roads), narrow-gauge railways	Linear	0*
Wide-gauge railroads	Linear	1000
Navigable rivers, lakes, dams, ocean shores	Linear	1000
Cities with a population greater than 500 thousand	Area	10000**
Cities with a population from 100 to 500 thousand	Area	10000**
Cities with a population from 50 to 100 thousand	Area	5000**
Settlements with a population from 10 to 50 thousand	Point	1000
Settlements with a population from 2 to 10 thousand	Point	500
Settlements with a population less than 2 thousand	Point	500

** This type of infrastructure was regarded as a significant disturbance factor only if it fully divides (cuts through) an otherwise undisturbed area, bordered by other types of infrastructure.*

*** In all cases, the buffer zones around these types of cities overlapped with buffer zones associated with other types of infrastructure or with small landscape fragments bounded by such buffer zones.*

road networks and pipelines. While incomplete and inaccurate, these maps were still sufficiently good for the purposes of this phase, and their deficiencies were compensated for by the use of more detailed information at later stages.

This first analysis phase did not take into account temporary winter roads and tractor (cross-country) roads, or roads along the national border which are not public. We considered navigable those segments of rivers, lakes and artificial water reservoirs which were indicated as such on maps with the scale of 1:1,000,000.

The following tasks were carried out during the first phase:

1. Digital mapping of infrastructure (as indicated in table 1) over the entire territory under study as well as an adjacent zone with a width of of at least 100 kilometers.

2. Drafting of buffer zones along the different elements of infrastructure (table 1). The buffer zones were established for different types of infrastructure by estimating their respective minimal penetration of disturbancies into the landscape. In case no estimate

Cities and settlements:
From 2 to 10 thousand inhabitants
Less than 2 thousand inhabitants

Roads:
Regional roads
Other public roads and land management roads
Winter roads

Railroads:
Double track railroads
Single track and narrow-gauge railroads
Areas undivided and not directly affected by permanently functioning roads and settlements.

Fig. 46. Types of infrastructure used in the first phase of the work (road network, navigable waterways and lakes, and settlements).

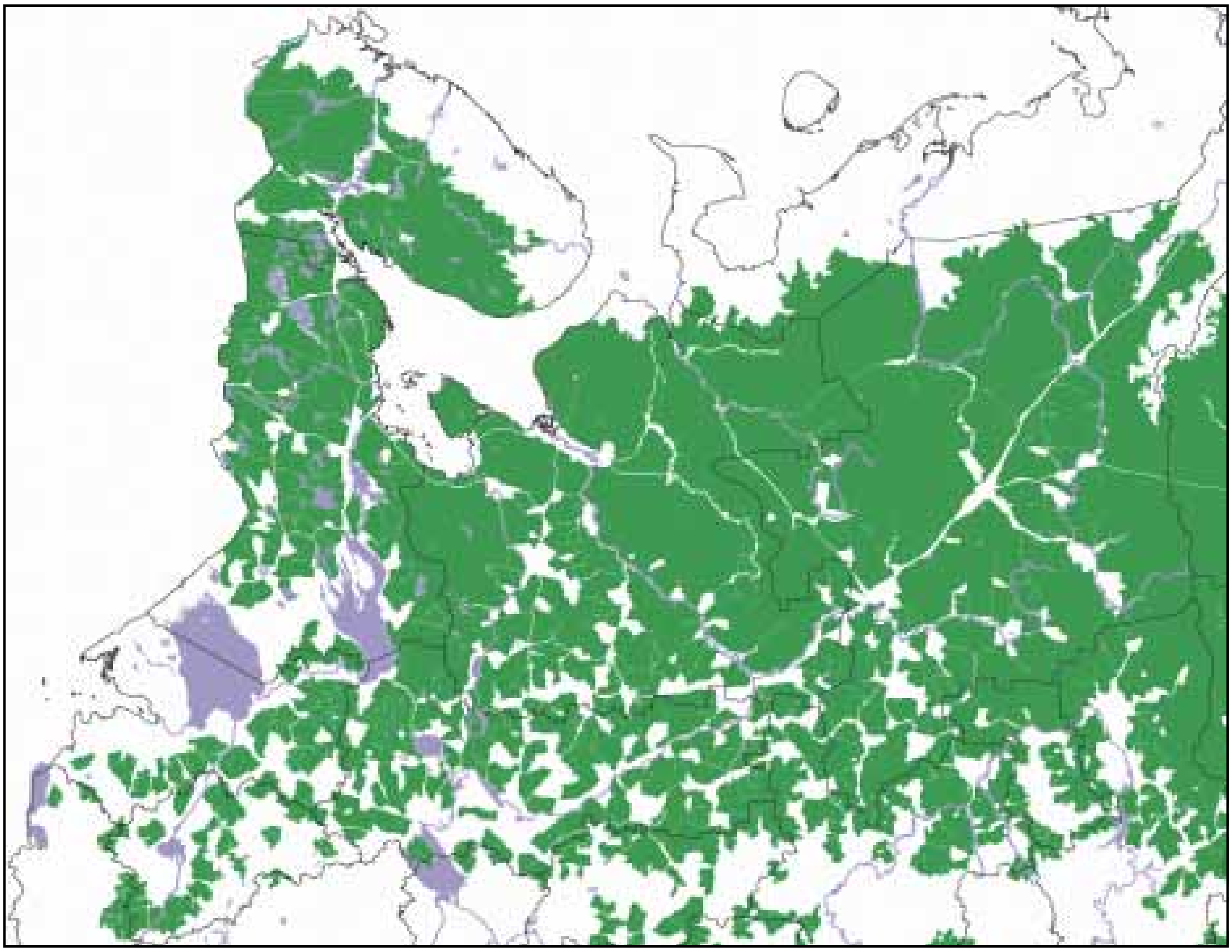


Fig. 47. The result of the first phase of the analysis: a map of large areas (greater than 50,000 hectares) in the forest zone of northern European Russia (exluding the tundra zone) undivided and not directly affected by permanently functioning roads and settlements.

was available a buffer zone of 500 meters was established.

3. Mapping parcels outside the buffer zones and excluding from further consideration those that do not meet the predetermined size (50,000 hectares) and width (10 kilometers) criteria.

4. Elimination of tundra and adjacent woodless wetland and highland areas from the forest landscape of study. Narrow strips of forest (less than 2 kilometers wide) were not considered to be part of the forest zone.

The result of the first phase was a draft map of large forest landscapes in European Russia located beyond major elements of infrastructure. This area (the remaining area of study) was no longer a single whole landscape but rather a multitude of separate roadless areas (Fig. 46, 47). Forty-four percent of the initial area was eliminated at this stage.

Phase 2

In the second phase of the work, medium resolution satellite images were used to exclude large areas clearly disturbed by forestry, agriculture, etc.

The goal of this phase was to eliminate areas where disturbances could be positively identified in medium resolution images.

At this stage, summer and winter medium-resolution satellite images were used (Resurs MSU-SK) .

The second phase involved the following tasks:

1. Exclusion of areas disturbed by intensive forest harvesting, as positively identified in medium-resolution satellite images. Recently cut areas and old cut-overs were eliminated. Also eliminated were tracts of forest and other natural ecosystems with a width of less than 2 kilometers, if located either among new and old cut-overs or among cut-overs that occur in combination with infrastructure.

2. Exclusion of fire scars and young and middle-age stands on growing old anthropogenic fire scars. Since an unambiguous distinction between "anthropogenic" and "natural" fire scars cannot be made, a formal decision rule was adopted. Fire scars and forests of early successional stages adjacent to infrastructure or other forms of anthropogenic disturbance were classified as anthropogenic. Blocks of other forest types and non-forest natural ecosystems were also

Table 2. Interpretation characteristics of areas affected by different types of human influence, as observable in satellite images of medium resolution (paired summer and winter images).

Type of disturbance	Interpretation characteristics	Comment
Recent individual clearcuts	Presence of exposed mineral soil. Artificially straight angles in the boundary of the non-forest area. Presence of logging road or strip roads.	For identification or verification of recent clearcuts, the most recent image was compared to the oldest medium resolution winter image in which blocks of closed forest can be identified most clearly. In case of doubt, individual clearcuts were not delineated at this phase, unless adjoining other recent or older clearcuts.
Clusters of recent clearcuts	As above, plus the structure of the cluster (chess-board patterns of cuts, location of cuts on elevations within a mosaic of bogs, cuts of conifers among clusters of aspen-birch-willow forest, clearly visible boundaries of water-protection areas). Developed transportation network, existence of all-season roads.	To verify the correctness of interpretation, the most recent winter image of medium resolution was compared with the oldest.
Old clusters of clearcuts of different types	Signs of change in dominating species (domination of aspen, birch, willow) - except in areas bordering on the forest line in the north or at high elevations. Presence of linear structures, artificially straight angles, chess-board patterns. Signs of old or functioning roads. Clearly visible boundaries with areas not zoned for logging (mainly protection forest along rivers and lakes).	Information on old logging roads from topographical maps was used as additional evidence. Burned areas located inside clusters of old clearcuts were included into this category of disturbance.
Mines, quarries	Exposed mineral soil. Presence of roads. Signs of severe pollution in associated bodies of water.	Data from topographical maps on roads and mines were used as additional evidence along with literature and expert advice.
Recently burned areas	Presence of exposed mineral soil with signs of ashes and scorching. Non-linear boundaries.	Recent burns, along with young and middle aged forests on old burns, were classified as disturbed territory only when adjacent to infrastructure or associated buffer zones.
Young and middle-aged forest on burned areas	For areas where spruce-fir forest dominates: Signs of change in dominant species (dominance of aspen. birch, willow) - except in areas bordering on the tree line in the north or at high elevations, unless signs of logging were detected. For areas where pine and larch dominate: Dominance of areas with signs of recent fires (ashes, scorching, abundance of lichens in canopy gaps, sparse forest).	
Agricultural lands, hay fields	Areas with grass vegetation, associated with settlements and valley of major rivers. Cultivated areas.	Data from topographical maps on agricultural lands were used as additional evidence. Hay fields along smaller rivers were not classified as disturbance, unless connected with other anthropogenic structures.

excluded, if less than 2 kilometers wide and located within areas of "anthropogenic" fire scars and forests in early stages of post-fire rehabilitation.

3. Exclusion of areas which do not meet the minimum requirements for area and width. Large undisturbed areas connected with each other by a similarly undisturbed isthmus were considered separate if the width of the isthmus at any point was less than 2 kilometers.

The result of this phase was that heavily disturbed areas were excluded from further consideration. A total of seventy-nine percent of the initially considered territory was thus eliminated after two phases. All tracts that could not be positively classified as

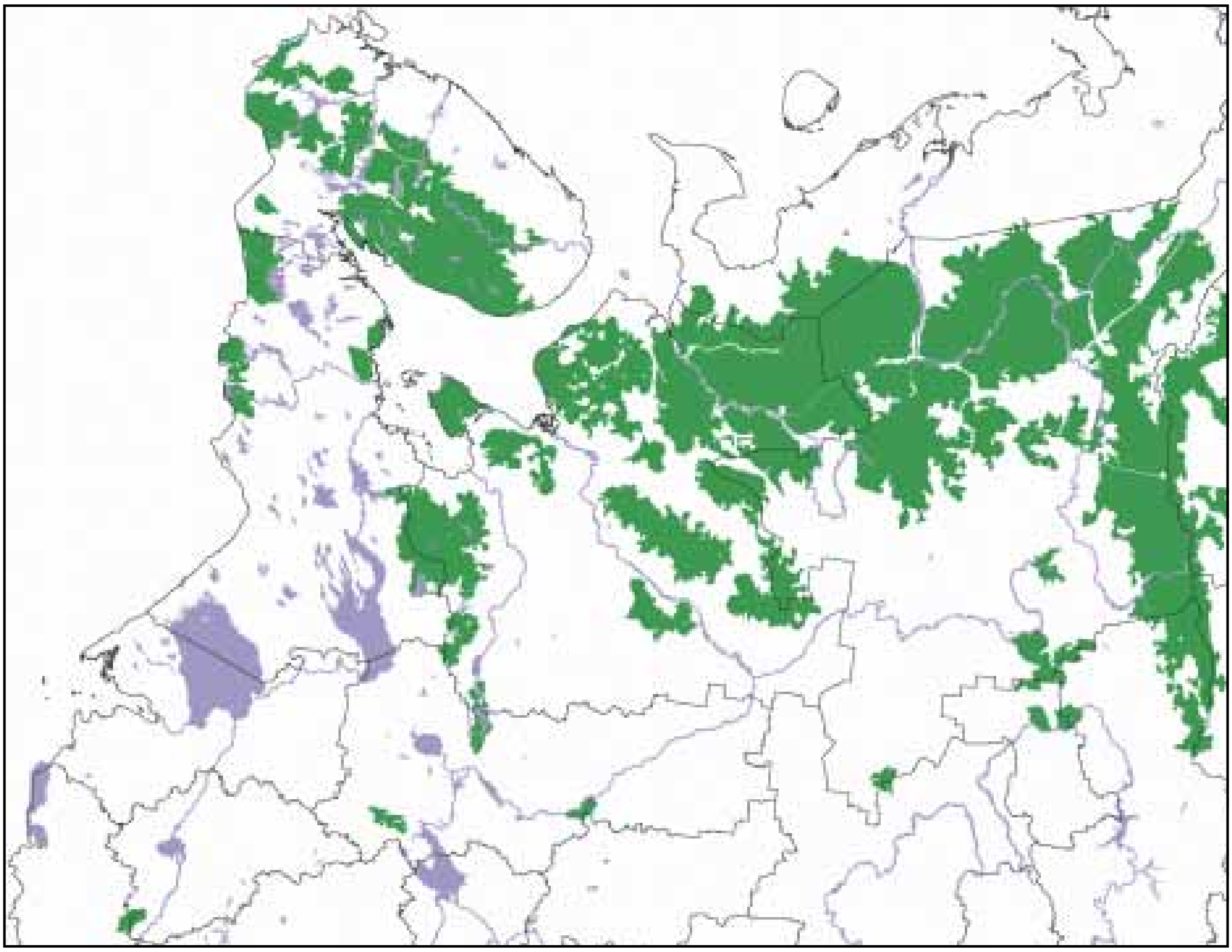


Fig. 48. The result of the second phase of the work: a map of potentially intact forest landscapes.

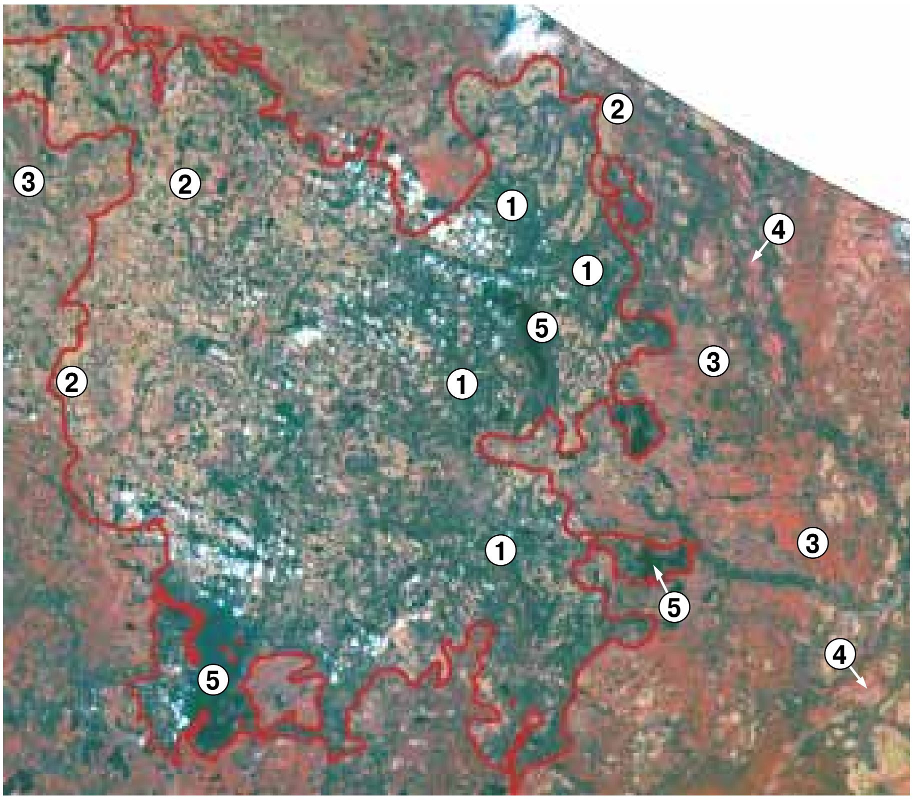


Fig. 49. Boundary of potentially intact forest landscape (shown in red). Areas with clear evidence of anthropogenic disturbance have been eliminated, while areas far away from sources of permanent human disturbance have been retained. Medium resolution satellite image (Resurs MSU-SK). Visible in the image:
1. Coniferous forest.
2. Bogs.
3. Secondary deciduous forest.
4. Agricultural lands.
5. Lake.

disturbed in this phase (due to inadequate resolution or lack of ground data) were retained for further analysis in the next phase. The result of the first two phases was a preliminary map of intact forest landscapes of northern European Russia (Fig. 48).

Phase 3

In the third phase, high resolution satellite images were used to exclude additional areas of intensive economic activity and to establish the final boundaries of the intact forest landscapes.

The goal of this phase was to finalize the map by excluding such disturbed areas as could be positively identified in high-resolution images and by fine-tuning the draft boundaries of intact areas.

For this last phase, high-resolution (15-35 meters) summer and winter images were used.

The third phase included the following tasks:

1. Exclusion of areas that could be positively identified as disturbed on the basis of high-resolution satellite images, such as logged areas, developed mineral deposits, quarries, areas disturbed by intensive geological exploration, drained swamps, agricultural lands, and areas with buildings. As in the previous

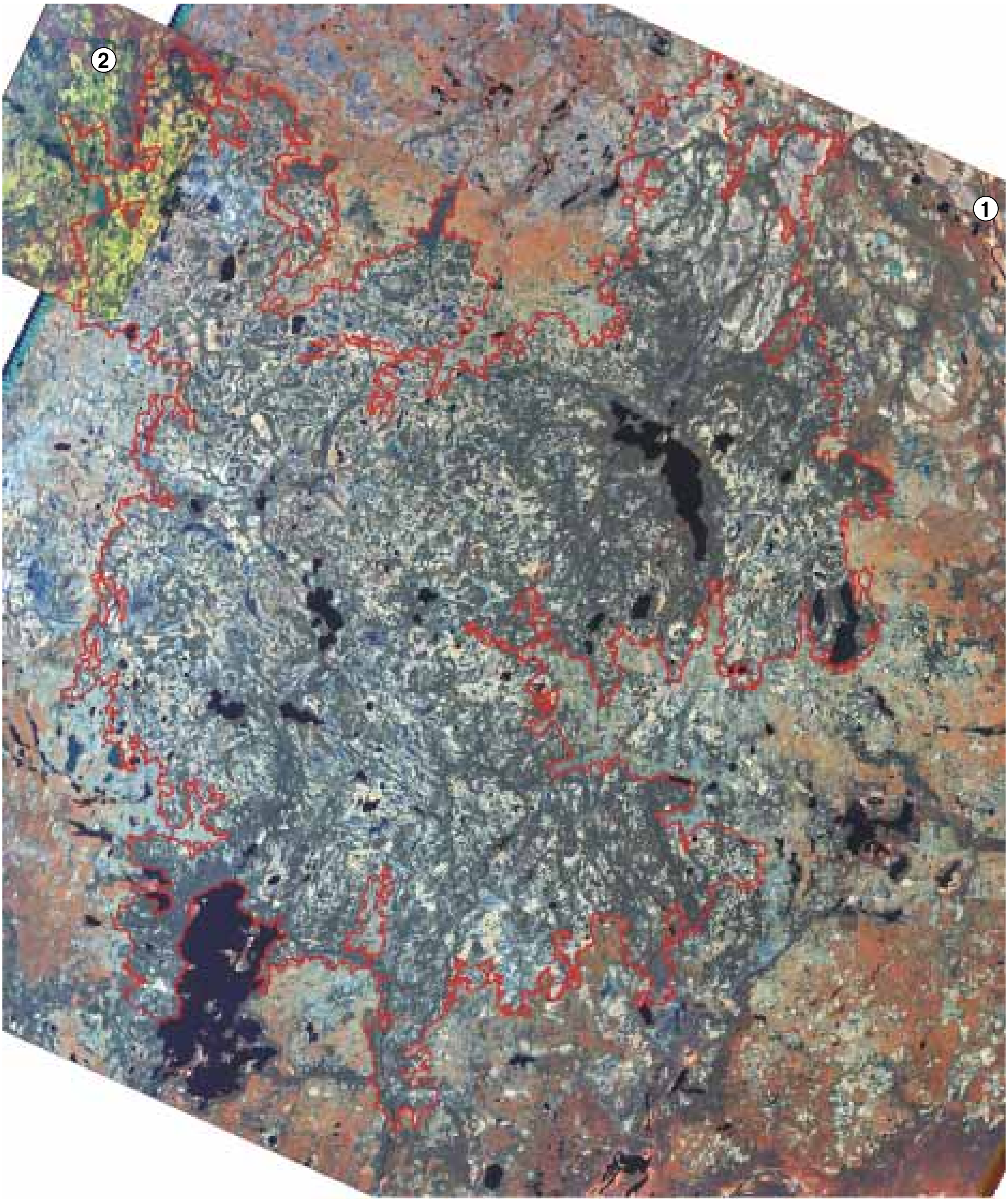


Fig. 50. Establishing the final boundary of an intact forest landscape (shown in red), using high resolution satellite images (1 - Landsat, 2 - Resurs MSU-E).

phase, undisturbed areas less than 2 kilometers wide were eliminated if located among disturbed areas.

2. Identification and exclusion of remaining anthropogenic fire scars and young and middle-aged forest stands. To separate "natural" and "anthropogenic" fire scars, the rule employed in the second phase was used.

3. Revise the location of roads, pipelines and other elements of infrastructure, as well as the borders of intact forest landscapes.

4. Map elements of infrastructure that were not previously identified and draft pertinent buffer zones. Not all elements of infrastructure were considered significant disturbance. Presence of any of the following types of infrastructure did not cause an area to be classified as disturbed:

- tractor roads and temporary winter roads currently out of use;
- industrial roads (including special-purpose roads, which are not public), which do not connect sources of disturbance with each other.

Fig. 51. Part of an intact forest area in a high-resolution satellite image (Landsat). Shown by numbers: 1. Coniferous forest. 2. Bogs. 3. Lakes. 4. Recent clearcuts. 5. Secondary deciduous forest. 6. Agricultural lands (hay fields).

Table 3. Interpretation characteristics of different types of area disturbed by human influence, as observable in high resolution satellite images (mostly summer images).

Type of disturbance	Interpretation characteristics	Comment
Recent individual clearcuts	Presence of exposed mineral soil. Signs of technogenic disturbance (strip roads, landings and processing points, formations of seed trees, etc.). Artificially straight angles in the boundary of non-forest area. Presence of logging road or strip roads. Characteristic spatial structure of selectively cut areas (either distributed or geometric selection).	Some kinds of selective cutting may remain unidentified even in high-resolution images. This kind of logging, however, occurs almost exclusively in first category (protection) forests as an effect of exhaustion of the supply of third category forest (zoned for industrial logging). Logging of this kind practically does not occur in the potentially intact forest areas.
Clusters of recent clearcuts	As above, plus the structure of the cluster (chess-board patterns of cuts, location of cuts on elevations within a mosaic of bogs, cuts of conifers among clusters of aspen-birch-willow forest, clearly visible boundaries of water-protection areas). Distributed system of roads and strip roads.	To verify the correctness of interpretation, high-resolution images were compared with old (1997) medium-resolution images as well as with topographical maps and forestry maps. This kind of verification was necessary when the clearcuts were small or the shape not rectangular (in mountainous or very boggy areas).
Old clusters of clearcuts of different types	Signs of change in dominating species (domination of aspen, birch, willow) - except in areas bordering on the forest line in the north or at high elevations. Presence of linear structures, artificially straight angles, chess-board patterns. Signs of old or functioning roads, strip roads, signs of logging-related structures (lines of seed trees, landings). Clearly visible boundaries with areas not zoned for logging (mainly protection forest along rivers and lakes).	Information on old logging roads from topographical maps and forestry maps was used as additional evidence. Burned areas located inside clusters of old clearcuts were included into this category of disturbance.
Quarries, mines infrastructure associated with mining and intensive geological prospecting.	Exposed mineral soil. Presence of roads, pipelines, other means of transport. Drilling sites. Network of prospecting corridors. Signs of severe pollution in associated bodies of water.	Prospecting corridors were not classified as significant disturbance if either isolated or in a sparse network (more than 2 km between corridors).
Roads, pipelines	Narrow linear objects, connecting different kinds of infrastructure either to each other or to possible places of extraction, displaying spectral signatures characteristic of exposed mineral soil (recent roads, either planed ground or with prepared surface) or of aspen, birch and willow, or bushes or grass (old roads).	The location of roads and pipelines that suggested boundaries of intact forest areas in previous phases were adjusted based on high-resolution images with corresponding changes in associated boundaries.
Recently burned areas	Presence of exposed mineral soil with signs of ashes and scorches. Non-linear boundaries.	Recent burns, along with young and middle aged forests on old burns, were classified as disturbed territory only when adjoined with infrastructure or associated buffer zones.
Young and middle-aged forest on burned areas	For areas where spruce-fir forest dominates: Signs of change in dominating species (dominance of aspen. birch, willow) - except in areas bordering on the forest line in the north or at high elevations unless displaying signs of logging.	
Agricultural lands, hay fields	Areas with grass vegetation, associated with settlements and valley of major rivers. Cultivated areas.	Data from topographical maps on agricultural lands were used as additional evidence. Hay fields along smaller rivers were not classified as disturbance, unless connected with other anthropogenic structures.

5. Exclude remaining areas which do not fit the minimum criteria for area and width. As in the previous phase, undisturbed areas connected by similarly undisturbed isthmuses were considered separate if the width of the isthmus at any point was less than 2 kilometers.

This phase produced the final version of the map (Fig. 54).

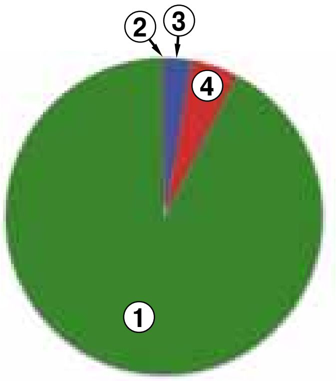


Fig. 52. Area of intact forest landscapes, the boundaries of which were determined from satellite images of high resolution (1. Landsat ETM+, 2. SPOT HRV, 3. Resurs MSU-E) and medium resolution (4.Resurs MSU-SK).

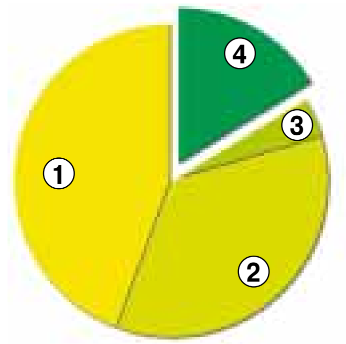
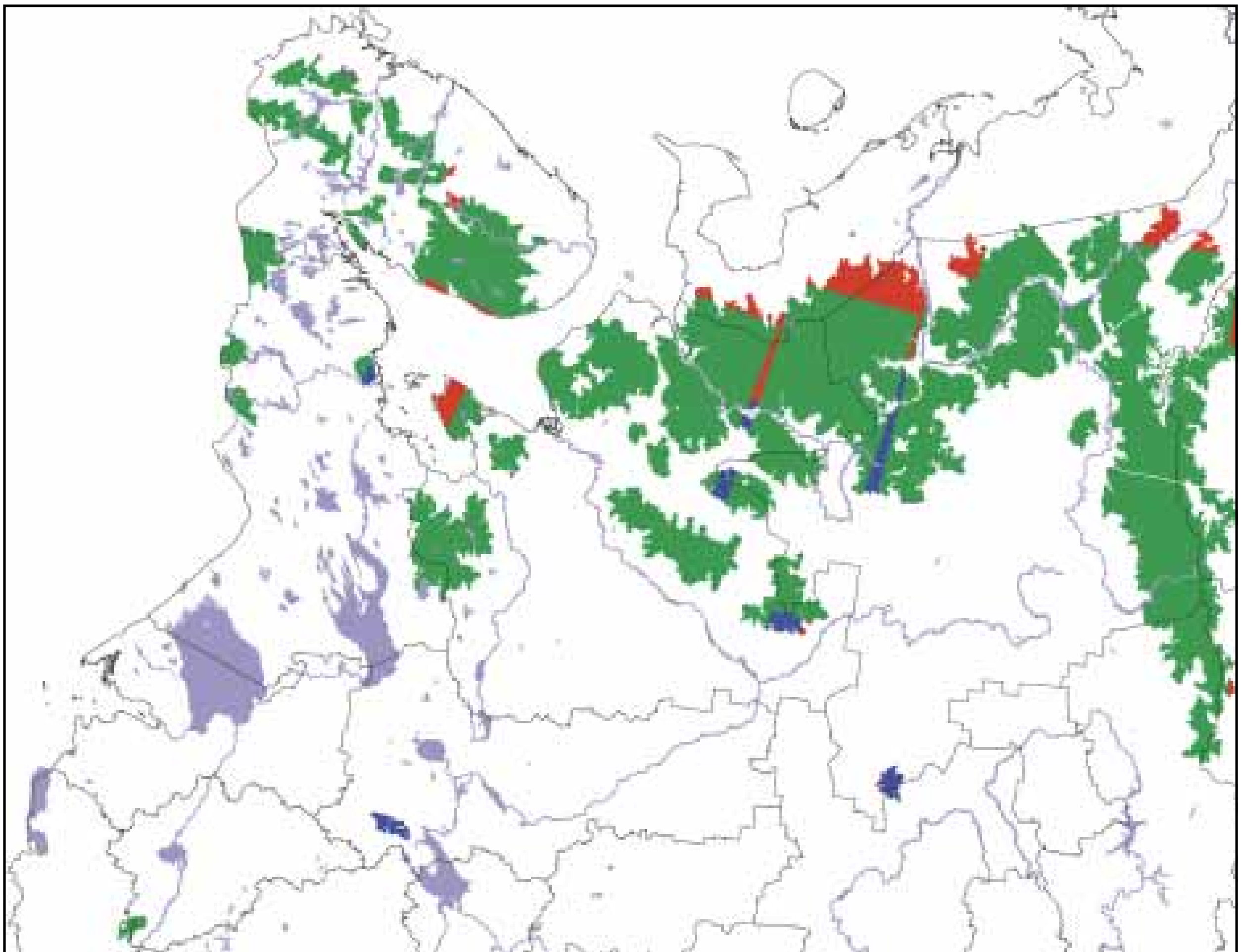


Fig. 53. Area of intact forest landscapes (4) and the areas eliminated as either disturbed or tundra during the three phases of the project (1-3, respectively).



The sources of satellite imagery used to determine the final boundaries is indicated by different colors:

High-resolution images: Landsat, ETM+; Resurs, MSU-E; SPOT, HRV

Medium-resolution images: Resurs, MSU-SK

Fig. 54. The result of the third and final phase of the analysis: a map of large intact forest landscapes (greater than 50,000 hectares) of northern European Russia.

LIMITATIONS AND DEFICIENCIES OF THE MAP OF INTACT FOREST LANDSCAPES

While we believe this study is a useful step towards identifying the last wilderness land of Europe, it must be pointed out that the resulting map has a number of limitations. These are due to insufficient information, to the low quality of the images for some areas, and to inaccuracies inherent in the methods employed. The limitations and deficiencies of the map are further described below.

1. There is a certain degree of subjectivity in boundaries across transition zones. Two cases are of particular importance.

1a. The transition from forest across forest-tundra to tundra (and also to alpine ecosystems adjacent to the latter) is extremely gradual. In some cases it stretches for several dozen kilometers, without any conspicuous threshold. In such cases the demarcation between "forest" and "non-forest" is arbitrary and the decision on where to place the boundary may depend on the quality and season of the image used as well as the formal decision criterion employed. The northern boundaries of intact forest landscapes are all vulnerable to this kind of subjectivity.

1b. The transition from intact to disturbed forest landscape may also be gradual. In most cases this is not the case - the boundary clearly suggests itself, due to the absolute predominance (in the least populated areas) of logging in primary forest over the last six decades. However, in some forests (especially those subject to the most intensive logging during the first half of the 20th century), there is a clearly developed gradual transition from greater to lesser disturbance. In these cases, the border of intact areas was mapped on the basis of change in predominant tree species.

2. Some of the satellite images were of inadequate quality and resolution in relation to the analysis for which they were used:

2a. The northern boundaries of intact forest landscapes (fig. 54) were drawn often from medium-resolution images (Resurs, 150 meters per pixel). As these areas are virtually uninhabited and show no signs of industrial development, the resulting inaccuracy may be considered relatively unimportant. In the scale of the maps printed in this atlas (1:1,500,000) it is not significant.

2b. For some parts of the territory, pairs of medium-resolution 2000 images and high-resolution 1997-1999 images were used (no high-resolution images were available for the year 2000). When such image pairs were used, minor shifts in boundaries occurring between 1997 and 2000 may have been overlooked and thus may not be reflected on the map. Only a small fraction of the boundaries were mapped on this basis (fig. 52, 54), and the vast majority of these areas of concern with a very slow rate of exploitation of new natural areas (such as wetlands in the southern and middle zones of the taiga, surrounded by areas logged in the preceding decades, and the most remote wooded and waterlogged areas of the northern taiga). The possible inaccuracies can be considered negligible given the scope of this research. However, when detailed maps (1:200,000 or greater) are drafted for the purpose of economic decision-making for specific areas, such inaccuracies should be corrected where possible.

2c. For part of the territory, for lack of other images, Landsat ETM+ high-resolution images were used that were known to contain distortions by atmospheric conditions, specifically mists or scattered cloud cover. This is true for the eastern part of the Kola Peninsula, and the eastern slope of the Urals within the Khanty-Mansi Autonomous District. The inaccuracies in which the boundaries of intactness have been mapped may be greater for these areas than the average for the map as a whole.

3. The use of identical criteria of disturbance for the entire region under study - from the southern taiga to pre-tundra taiga. On the one hand, the use of standardized criteria made it possible to strictly formalize the identification of intact forest landscapes and assess the degree of degradation of the natural taiga cover in various regions of the taiga zone. On the other, due to the same identical criteria, the analysis of the southern taiga regions did not allow some interesting areas to be shown on the map, such as some large uninhabited and unfragmented areas with a rather low degree of human disturbance (e.g. subject to unsystematic logging in the 1950's and 1960's but not affected by economic activities since). In addition, valuable intact areas of less than 50,000 hectares were not identified in this project. Areas whose value depend on other characteristics than intactness were also not identified. Thus, when regional systems of protected areas are designed, it is necessary to rely on other sources in addition to this one in order to fully assess the conservation value of individual areas. The results of this analysis are best used as input to the process of planning the protection of intact natural landscapes, particularly in the northernmost regions of European Russia including the Karelia and Komi Republics, the Murmansk and Arkhangelsk Regions, and the northern part of Perm Region.

4. Uncertainty in the knowledge base guiding the choice of minimum viable area. The authors selected 50,000 ha relying heavily on expert opinion. This issue needs to be addressed further in future work.

TIMBER RESOURCES OF REMAINING INTACT FOREST LANDSCAPES

Despite the seemingly immense area of intact forest landscapes in northern European Russia, totaling 31.7 million hectares, timber resources are relatively small and hard to access. A significant proportion of timber stands has already been excluded from exploitation by being designated as Group I forests (in the category of "*pre-tundra* forests"). Even those tracts which in theory are available for industrial exploitation are in fact difficult to access economically due to significant swampiness, low stocking and poor timber quality.

The 52 percent of intact forest landscapes that are pre-tundra forests are already exempt from industrial use by designation as first-group forests (in the absence of formal protection status they are often considered simply as wastelands). About 20 percent of the intact area is made up of treeless wetlands and water bodies (Fig. 55, 56), including the10.2 percent of the intact area that does not formally belong to the *pre-tundra* forests. Alpine treeless areas (primarily in the zone of pre-tundra forests) occupy another 2.6 percent of the intact area. Only 41 percent of the intact forest landscapes are proper forests, located south of the *pre-tundra* forests. These forests are difficult to access, which provides the most likely reason why they have survived as intact areas. The high level of swamping and natural fragmentation has kept development out (Fig. 55). The low average stocking (Fig. 59) and low potential increment (Fig. 58) make cost-effective sustainable forestry an unlikely prospect. Commercial interest is also kept down by the low timber quality: stem decay is common, the northern climate keeps the trees small and the frequency of cull trees significant. The low degree of commercial attractiveness is supported by the assessment of current logging intensity in the vicinity of intact forest landscapes (table 4). The logging intensity is even lower than in the largely depleted, long ago accessed and logged forests of boreal European Russia. Only a few intact forest landscapes, mainly the southernmost ones, are of notable significance to modern forestry.

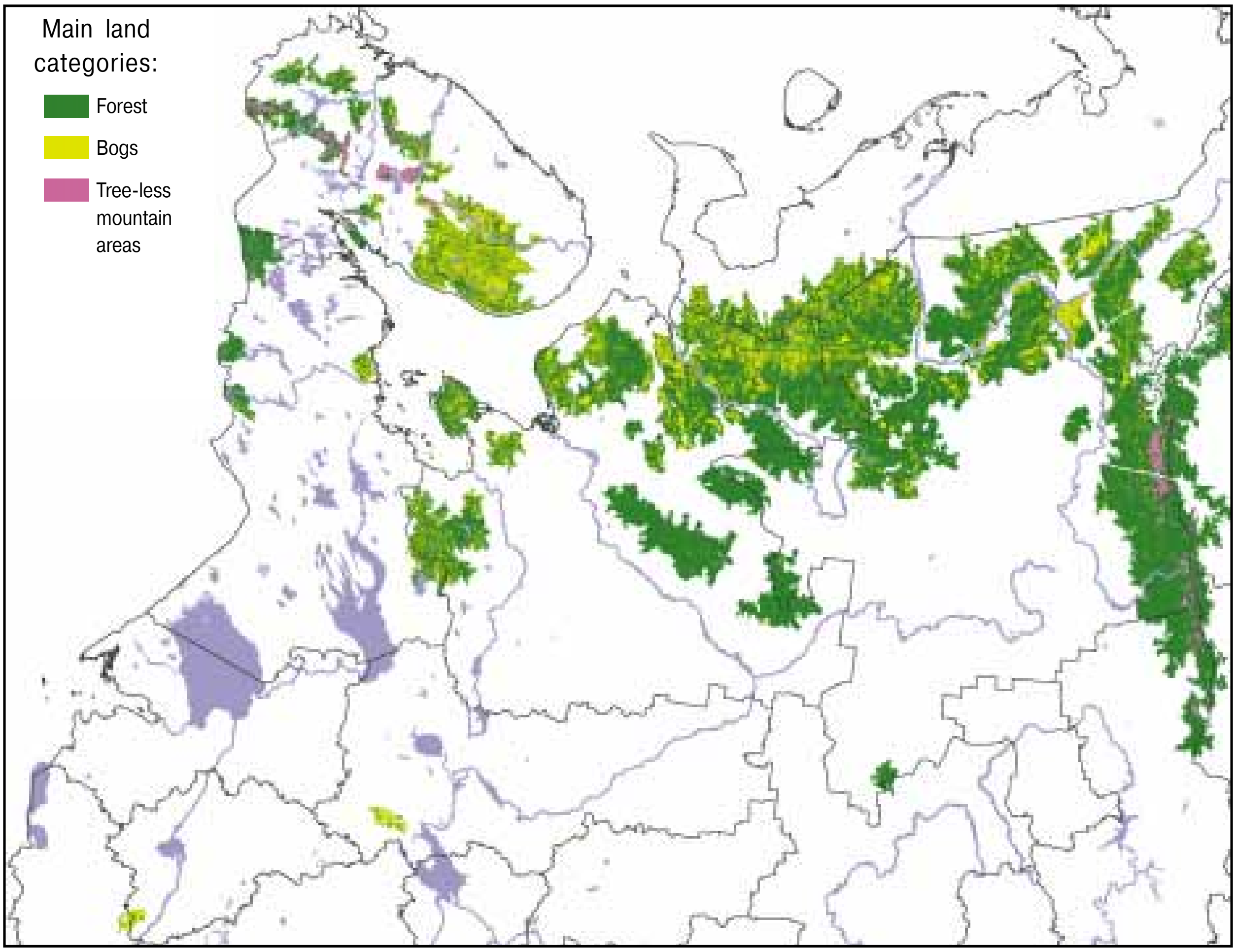


Fig. 55. The main land categories of intact forest landscapes.

The results (*see below*) suggest that even full protection of intact forest landscapes will not cause any critical detriment to Russian forest industry (although it may certainly have a considerable effect on individual logging companies). The share of timber logged in the vicinity of the remaining intact forest landscapes may be estimated (in the period following the 1998 crisis) at not more than 10 percent of the total volume logged in the regions of Northern European Russia. Only in the Arkhangelsk Region may the share be greater than 10 percent.

Thus, a hypothetical exclusion of these areas from exploitation is unlikely to cause any major consequences for the forest industry at the level of northern European Russia as a whole. At the same time, the continued exploitation of these forests as it is currently practiced may deprive Russian timber producers of access to environmentally concerned markets in Western Europe. The value of such a loss would be considerably higher than the loss incurred by excluding the intact forest landscapes from further commercial exploitation.

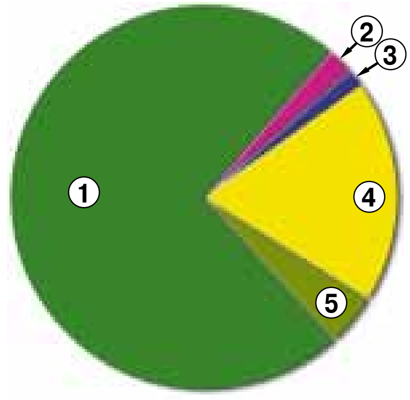


Fig. 56. Area relationship among the main land categories within the remaining intact forest landscapes: 1. Closed forest. 2. Tree-less mountain areas. 3. Bodies of water. 4. Tree-less bogs. 5. Forested bogs.

For these reasons, preserving the intact forest landscapes appears to be important also for the environmental integrity of these areas and the long term marketability of the Russian timber exports.

LOGGING INTENSITY IN THE VICINITY OF REMAINING INTACT FOREST LANDSCAPES

The level of threat to remaining intact forest landscapes depends largely on the extent to which they are needed to supply wood to the forest industry. A study was therefore made of the logging intensity in the vicinity of these landscapes.

Recent logging activities within a 2-kilometer wide buffer zone around each individual intact area were studied (for those areas for which the necessary pair of satellite images were available). Logging sites that were active from around mid-1999 till mid-2000 were identified. The result was adjusted to reflect the length of the inter-image period, as this was different for different intact areas. The studied areas are shown in Fig. 57.

The study was carried out for the Republics of Komi and Karelia, and for the Arkhangelsk and Perm Regions. Murmansk Region could not be studied due to the relatively low quality of available Landsat ETM+ images and the type of logging activity there: small clear cuts, unsystematic selective salvage cuts, and silvicultural cuts with diffuse borders. The Nenetsky Autonomous Region was also excluded from the study due to the absence of industrial felling there. Remaining regions were excluded because the unsystematic types of logging that are common there were difficult to delineate given the resolution of available satellite images. Besides, in these southern-most regions intact forest landscapes are made up mostly of wetlands which have been logged up until the very edge of the peat deposits. In these cases the intensity of logging near the borders is not a relevant measure of significance to the forest industry.

The width of the buffer zone was determined so as to reflect conditions of transportation access similar to those at the edges of intact areas. Another factor determining the width of the buffer zone was the need to significantly exceed the greatest linear size of an individual logging site. Inaccuracies in the threat assessment due to technical logging constraints (e.g. logging temporarily not taking place in an area due to the need for a time lag between adjacent logging sites) could thereby be avoided.

Logging intensity was assessed according to the following procedure:

1. A buffer zone of 2 kilometers was drafted along the outer edges of an intact forest landscape.

2. A pair of satellite images were selected for each buffer segment: a Landsat ETM+ image taken approximately in July 2000 and a Resurs MSU-SK image taken approximately in July 1999.

3. Logging sites conducted during this period were identified for each segment of the buffer zone. The edges and the area of a specific plot were determined from Landsat ETM+ images, whereas Resurs MSU-SK images were used to establish precisely which plots had been logged during the interimage period. For active sites already partially cut at the time the Resurs image was made, the edges and area of the logging site were determined so as to exclude the areas already cut. The maximum total inaccuracy in determining the size of these logging sites, given the used resolution of images (Landsat ETM+), was ± 11.5 percent.

4. Logging sites were classified with regard to the type of cut and reliability of the identification. Many logging sites could be positively identified as clearcuts (i.e. the Landsat ETM+ images contained structural and textural characteristics specific to clear cuts); such sites made up 79.1 percent of the total area cut. A small number of selectively cut areas of various types were also identified, including the first stages of shelterwood cuts. The average intensity of cut for sites of selective and partial cuts was estimated at 50 percent. The area of in-woods landings and processing sites is included in this estimate. In a few specific cases, logging sites classified as doubtful were also included. These were areas which may have been either clearcuts or wind-throws. A correction factor of 0.5 was applied to these areas (i.e. they were included in the category of selectively cut areas). The maximum error possible in the area of estimation, taking into account errors caused by the resolution of the images and the assumption made, was ± 10.4 percent. The maximum total error in the estimate of the logged area does not exceed 23 percent. This error estimate takes into account the resolution of the images used and all assumptions made. An error of 23 percent or less can be considered acceptable for the purposes of this study.

5. The estimate of logged area was adjusted to reflect a period of one year. The logged area of each segment of a buffer zone was divided with the time period between the images used to assess it, expressed in years. Seasonal differences in logging intensity could not be taken into account due to absence of information. The possible error should be insignificant, however, as the period between images was close to one year in all cases (10-14 months).

6. Logging intensity was calculated in cubic meters per hectare and year for the entire buffer zone. The area estimate was multiplied with regionally specific estimates of the average stock of exploitable mature and overmature stands. The resulting estimate of annually logged volume is probably somewhat too high. The areas remaining as intact landscapes tend to have a lower stocking than the regional average due to a high proportion of bogs, low productivity, and a location in the north of the area to which the regional average applies. This applies specificially to the Komi Republic and the Arkhangelsk and Perm Regions).

7. The proportion of the total wood supply in each region that comes from the buffer zones around intact forest landscapes was calculated.

The results are shown in Table 4.

It must be noted that the results represent a time of high profitability of logging and of the forest industry in general, due to the devaluation of the ruble in 1998. The intensity of roadbuilding and logging in remote areas grew rapidly in comparison to the mid-1990's. After the end of this period (approximately since August 2000) the intensity of roadbuilding and logging has gone down in many areas. The result of this study therefore represents a situation of maximum logging pressure in the remote regions of northern European Russia, and thus also in the vicinity of intact forest landscapes. It is likely that the role of these areas in the regional wood supply will decrease significantly in the near future.

Table 4. Intensity of logging within the 2-kilometer zone immediately outside the areas of intact forest landscape in the Karelia and Komi Republics, Arkhangelsk and Perm Regions.

	Annual rate of logging within the 2-km buffer zone, area %	Intensity of logging within the 2-km buffer zone, m^3/ha	Intensity of logging within forests zoned for industrial forestry (including intact areas, actual regional removals), m^3/ha	Removals within the 2-km buffer zone relative to total removals in the region (July 1999-July 2000, estimate), %
Karelia Republic	**0,59**	**0,50**	**0,89**	**1,3**
Komi Republic	**0,20**	**0,21**	**0,39**	**2,6**
Arkhangelsk Region	**0,97**	**0,98**	**0,66**	**9,8**
Perm Region	**0,28**	**0,32**	**0,59**	**1,7**
Total	**0,58**	**0,59**	**0,59**	**4,7**

The result shows the rate of logging in the vicinity of intact forest landscapes to be rather small in all the four studied regions, varying within the limits of 1.3 percent of the total harvest in the Komi Republic and 9.8 percent in the Arkhangelsk Region. The low intensity in the Komi and Karelia Republics and in Perm Region is due to the general remoteness of the remaining intact areas. The very reason they have survived as intact is the low profitability of logging and other utilization. The low volume of logging in the buffer zones of Karelia is due in part to the moratorium, in force since 1997 and supported by some Russian and foreign companies, on purchasing old-growth timber there. In Arkhangelsk Region too the intact forest landscapes that have remained are in very remote areas. However, the extreme depletion of the forest resource base in other parts of the region is forcing industry to go after even the most remote and economically inaccessible areas. A fact of essential importance is that the intensity of logging in three of the four regions is greater in the already developed parts than in the near intact parts. Thus, the forests around the remaining intact forest landscapes, due to their inaccessibility, are of less interest to the forest industry than the forests in other parts of these regions.

The results suggests the conclusion that the intact forest landscapes still remaining in the Karelia and Komi Republics and in the Perm Region are of small importance to the regional supply of wood and, consequently, that a exclusion of these areas from the exploitable land base would not cause any significant decrease in the annual logging volume, at least not in the near future. For the Komi and Karelia Republics and the Perm Region, such a decrease would be no greater than a small percent of the annually logged volume. Only in the Arkhangelsk Region might a withdrawal of the remaining intact areas from the exploitable landbase cause a more significant decrease (around 10 percent of the volume logged, or slightly more). In no case can the decreases be regarded as critical. The variation in the volume logged during the last decade is many times greater than these reductions. Thus, a withdrawal of the remaining intact forest landscapes in northern European Russia from the exploitable landbase would not cause any significant economic damage and may even be justified from an economic point of view.

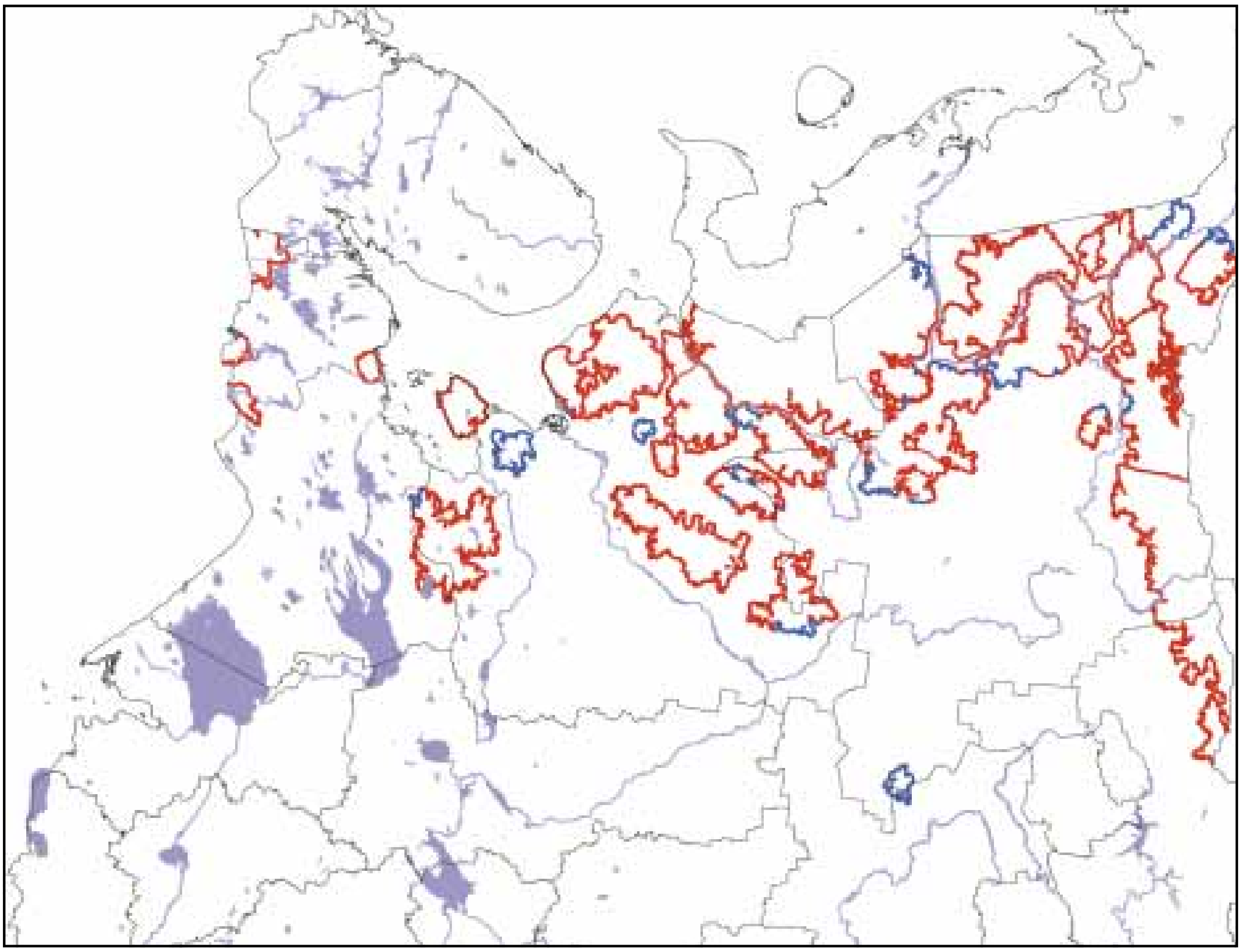


Fig. 57. Buffer zones, 2 km wide, around intact forest landscapes. Areas shown in red were analyzed for evidence of recent logging, whereas areas shown in blue were not analyzed for lack of data (Komi and Karelia Republics, Arkhangelsk and Perm Regions only).

FOREST PRODUCTIVITY IN REMAINING INTACT FOREST LANDSCAPES

One of the factors determining the attractiveness and suitability of an forest area for sustainable use is its productivity. The productivity of the remaining intact forest landscapes was therefore assessed.

The productivity assessment relied on official data from the forest administration in Russia, based on forest inventory data. Unfortunately, the latest available official data at the regional level were published nearly thirty years ago (*Forest Atlas of the USSR, 1973*). However, forest productivity (potential forest increment) changes very slowly over time, especially in such areas where no forest management is taking place. The latest official data were therefore used.

The remaining intact forest landscapes are made up of the least productive forests of European Russia. This is the very reason they remain intact.

A comparison of the map of remaining intact forest landscapes with the map of potential coniferous forest increment shows that intact ecosystems have been preserved mainly in the areas with the least site productivity for tree growth. Thus, 87 percent of the remaining intact areas have an average increment for coniferous trees of less than 1 m^3 per hectare per year (including the 18 percent of the area which has an average annual increment of less than 0.5 m^3 per hectare). The experience of some foreign countries indicate that sustainable forestry in such areas cannot be justified. The *Forestry Act of Sweden*, for example, stipulates that: *"... Land shall be considered suitable for wood production if, on the basis of accepted principles of assessment, it can provide an average yield of at least one cubic meter of stem wood per hectare per annum"* (*Article 2*). Thus, a major part of the remaining intact forest landscapes are unsuitable for production forestry. Any profitable forestry in these areas is likely to be based on the "cut-and-run" principle, i.e. the mining approach to forestry which is long established in northern European Russia. Even such shortsighted use may prove unprofitable, however, due to low stocking levels (*see next section*) and the fragmentation of the forest by bogs in many areas.

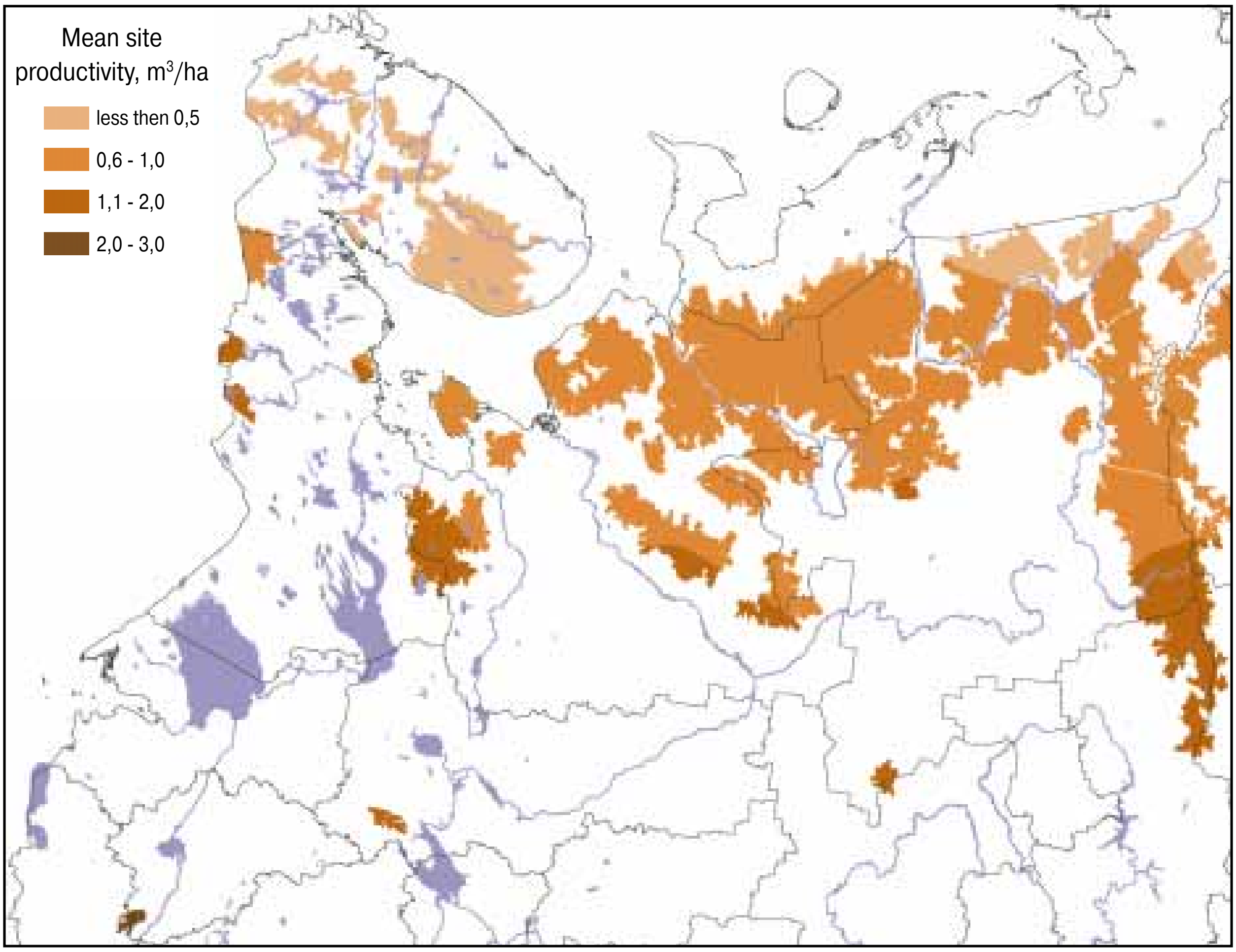


Fig. 58. Mean annual increment for coniferous species in remaining intact forest

Only 13 percent of the remaining intact forest landscapes are in areas with a potential coniferous increment greater than 1 m^3 per hectare per year. More than 75 percent of these forests are located either in boggy areas or inaccessible forests of the western slopes of the Ural mountains. Thus, the remaining intact forest landscapes are made up of the least productive forests of European Russia. This is the very reason they remain intact.

TIMBER STOCK IN REMAINING INTACT FOREST LANDSCAPES

Another factor that determines the attractiveness of an area for exploitation is the amount of forest there, i.e. the level of stocking. The latest available regional estimates of stocking are more than 30 years old (*Forest Atlas of the USSR, 1973*). No logging has taken place in the intact areas, however, and the forests are mostly of the kind which is in approximate equilibrium over time. Any changes should therefore be small.

The map of remaining intact forest landscapes was compared with the official map of stocking levels. The result shows that a significant part (56 percent) of the intact areas have an average standing inventory of less than a hundred cubic meters per hectare. Exploitation of forests with such low levels of stocking can rarely be justified economically, especially if extensive road building is required.

Forests with an inventory greater than a hundred cubic meters per hectare make up the other 44 percent of the remaining intact forest landscapes. Three quarters of this area are in low-productivity forests in which substantial timber reserves have accumulated over several hundred years, due to the long lifespan of the major species. Only 11 percent of the intact forest landscapes are forests in which reasonably high stocking levels (more than 100 m^3 per hectare) combined with a reasonably high level of productivity (more than 1 m^3 per hectare per year) to justify sustainable forestry operations. A significant part of these areas contain technical obstacles to exploitation, due to their location in areas which are either heavily boggy or mountainous.

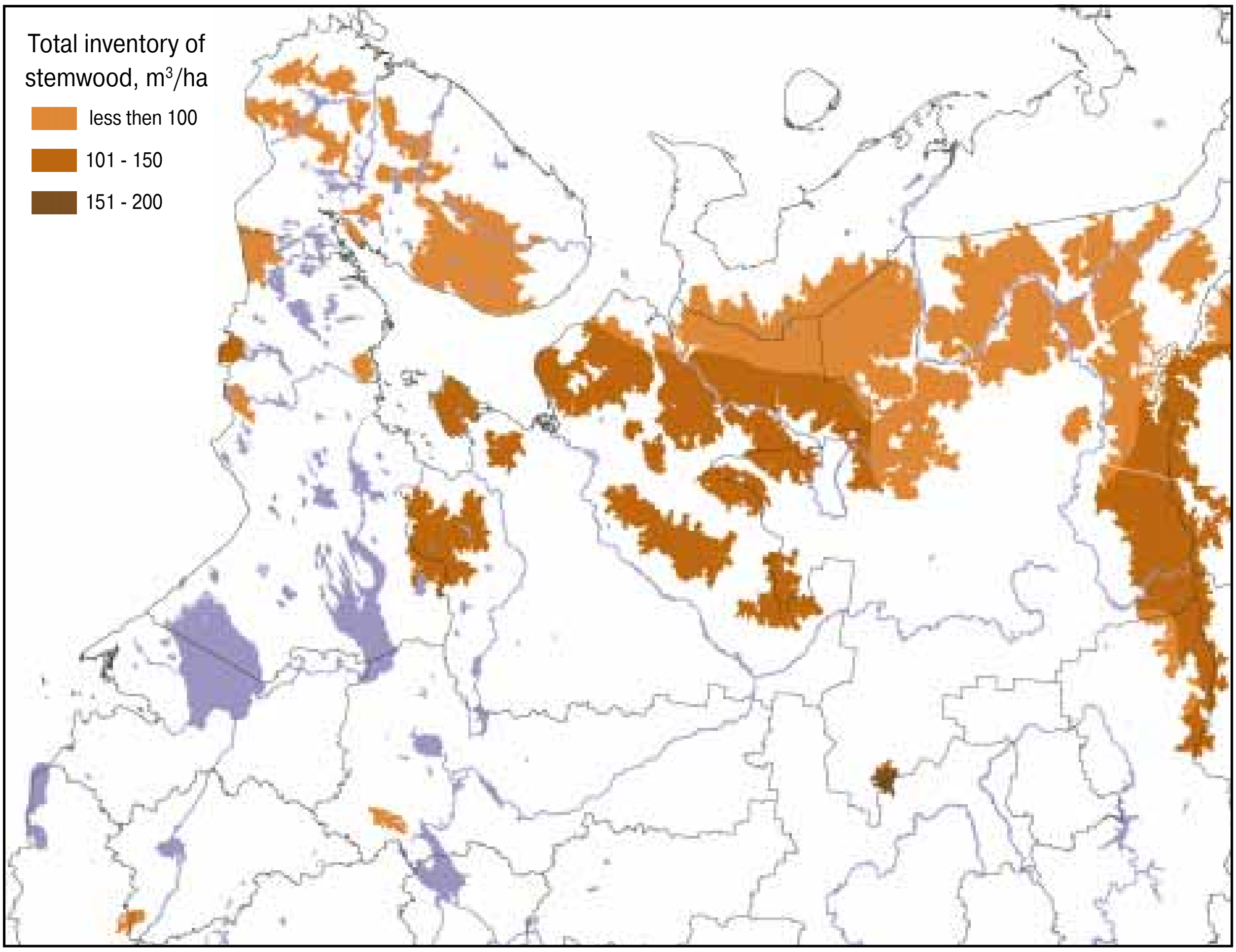


Fig. 59. Total standing volume of stemwood in remaining intact forest landscapes.

CONCLUSION

Northern European Russia still contains a number of large areas of intact natural boreal forest (or taiga) landscapes. These landscapes retain natural values that have been lost or diminished in developed areas. Among them are populations of large animals that are particularly sensitive to human influence, undisturbed watersheds around small and medium-size rivers, swamps and lakes, migration paths of many species, and balanced patterns of random disturbances. The very size of these areas is key to the preservation of many of these values, as only a sufficiently large territory can insulate the intact natural ecosystems from disturbing "edge effects" from surrounding areas.

Most of the forest landscape has been fragmented by infrastructure, and the once intact forest within these fragments has been replaced by secondary forest. These changes are not yet well understood by science. Preserving the ecological integrity of the last remaining large intact natural surroundings is not only a measure of reasonable caution but also an investment that will allow future scientists to observe and learn more about the nature of boreal ecosystems.

Withdrawing remaining intact areas from the production base would lead to some economic loss. This loss appears to be small, however. Most of these areas are remote and their exploitation is fraught with technical obstacles — this is indeed the reason why they remain intact. The threat to these areas is caused not by their inherent commercial attractiveness, but rather by depletion of the more attractive forest resources in other parts of northern European Russia. There is a risk that these areas will become subject to "cut-and-run" forest practices, as the return on investment in active reforestation and silviculture in these remote and low-productivity areas will be low and distant indeed.

Conservation of large intact natural forest landscapes is an important and necessary component of a general conservation strategy, but it is not by itself sufficient. Many ecosystems have already been disturbed to the point where only small fragments, or nothing at all, remains. Mapping of these ecosystem residuals was outside the scope of this study, but is an important task for the future.

Efforts have been made to preserve some of the most valuable of the remaining intact natural landscapes, and proposals for several new national parks exist: Kutsa and Hibiny (Murmansk Region), Kalevalsky (Karelia Republic) and Onezhskoye Pomorye (Arkhangelsk Region). Unfortunately, all of them appear to be frozen in the administration of the regional governments. Meanwhile, logging continues in the vicinity of some of the most valuable areas: between the Severnaya Dvina and the Pinega rivers, between the Pinega and the Vashka rivers, and in the close vicinity of the national parks Vodlozersky, Paanajarvi and others. Geological surveying and mining activities have increased sharply in the Timan, the Ural mountains, and the Pre-Ural Region.

The devaluation of the ruble following the 1998 financial crisis has made it very profitable to extract raw materials for export. The rate of exploitation has grown steeply, reaching its highest levels in a decade. Remaining intact forests face a real threat of destruction and protective measures are urgently needed if these areas are to remain intact. All levels of government need to get rapidly involved in this discussion, along with local forestry agencies, industrial enterprises and the citizens of Russia. In the end, only a collective effort, supported by society as a whole, can sustain the existence of the last surviving fraction of natural taiga in European Russia. The alternative would be sad indeed: the loss of the last large wilderness areas of Europe.

Fig. 60. Intact forests of Nothern Urals. Perm Region. Photo by P. Potapov

APPENDIX A

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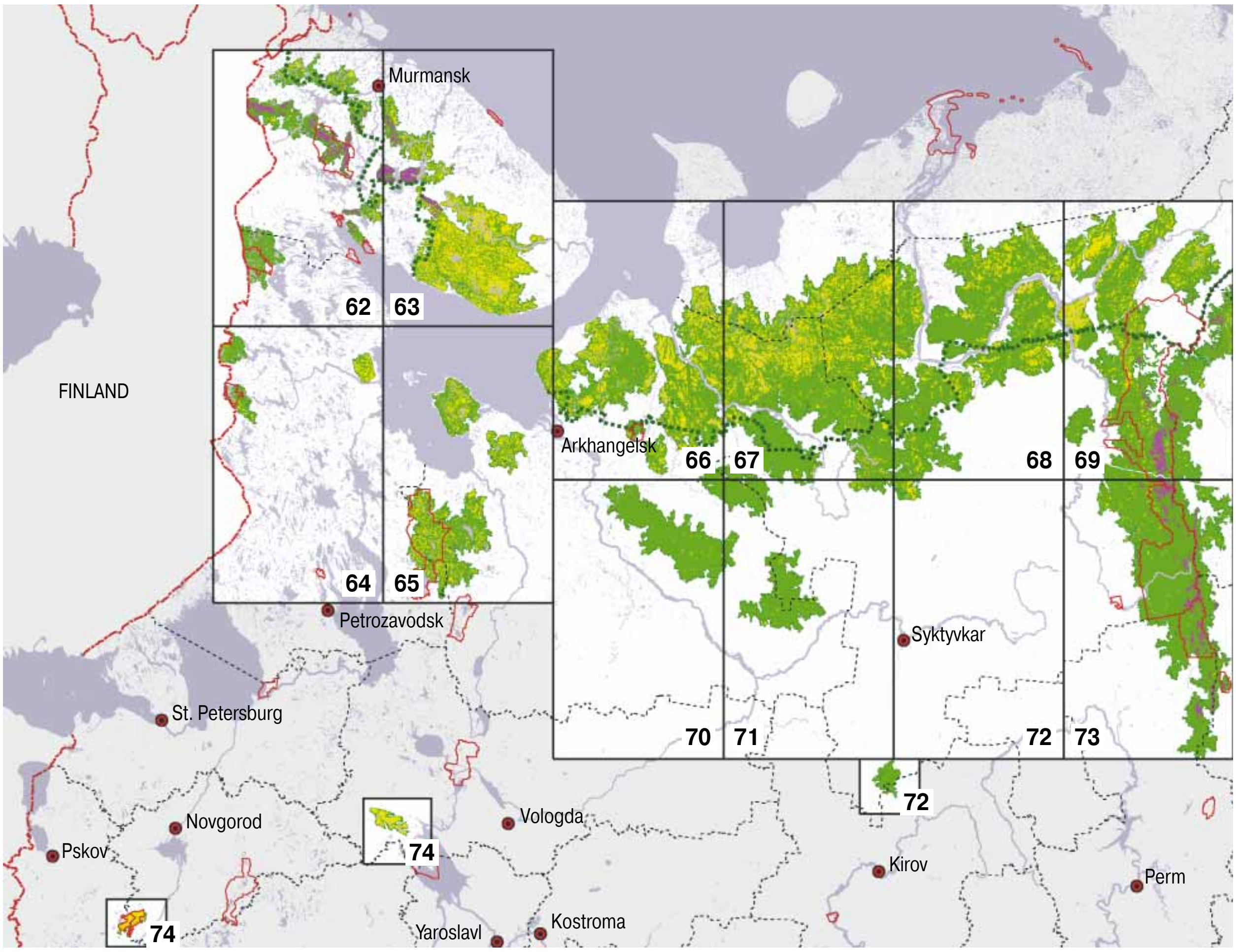
APPENDIX B

MAP OF INTACT FOREST LANDSCAPES



LEGEND

- Country borders
- Regional borders
- Regional centers
- Towns with population over 50 thousand
- Other settlements
- Roads
- Railroads
- Rivers
- Lakes
- Federal level nature protection areas (nature reserves and national parks)
- Subtundra forest border (unproductive forest excluded from industrial exploitation)
- Borders of intact forest lanscapes

MAIN LAND CATEGORIES OF THE INTACT FOREST LANDSCAPES:

- Forest
- Bogs
- Treeless mountain areas

Map of intact forest landscapes for August 2000

Scale for all sheets 1:1,500,000


MURMANSK
Kola
Tuloma
Lotta
Verkhnetulomskoye reservoir
Kola
Olenegorsk
Laplandsky Nature Reserve
Montchegorsk
FINLAND
Kovdor
Tumcha
Imandra Lake
Apatity
Polyarnye Zori
MURMANSK REGION
Kandalaksha
Alakurtti
Kandalakshsky Nature Reserve
Kolvickoe Lake
Knyazhegubskoe reservoir
Kandalakshsky Nature Reserve
WHITE SEA
Paanayarvi National Park
Tiksheozero Lake
Pyaozero Lake
KARELIA REPUBLIC
Loukhi
Pyaozersky
Topozero Lake
28°
29°
30°
31°
32°
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32°
33°
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68°30'
68°00'
67°30'
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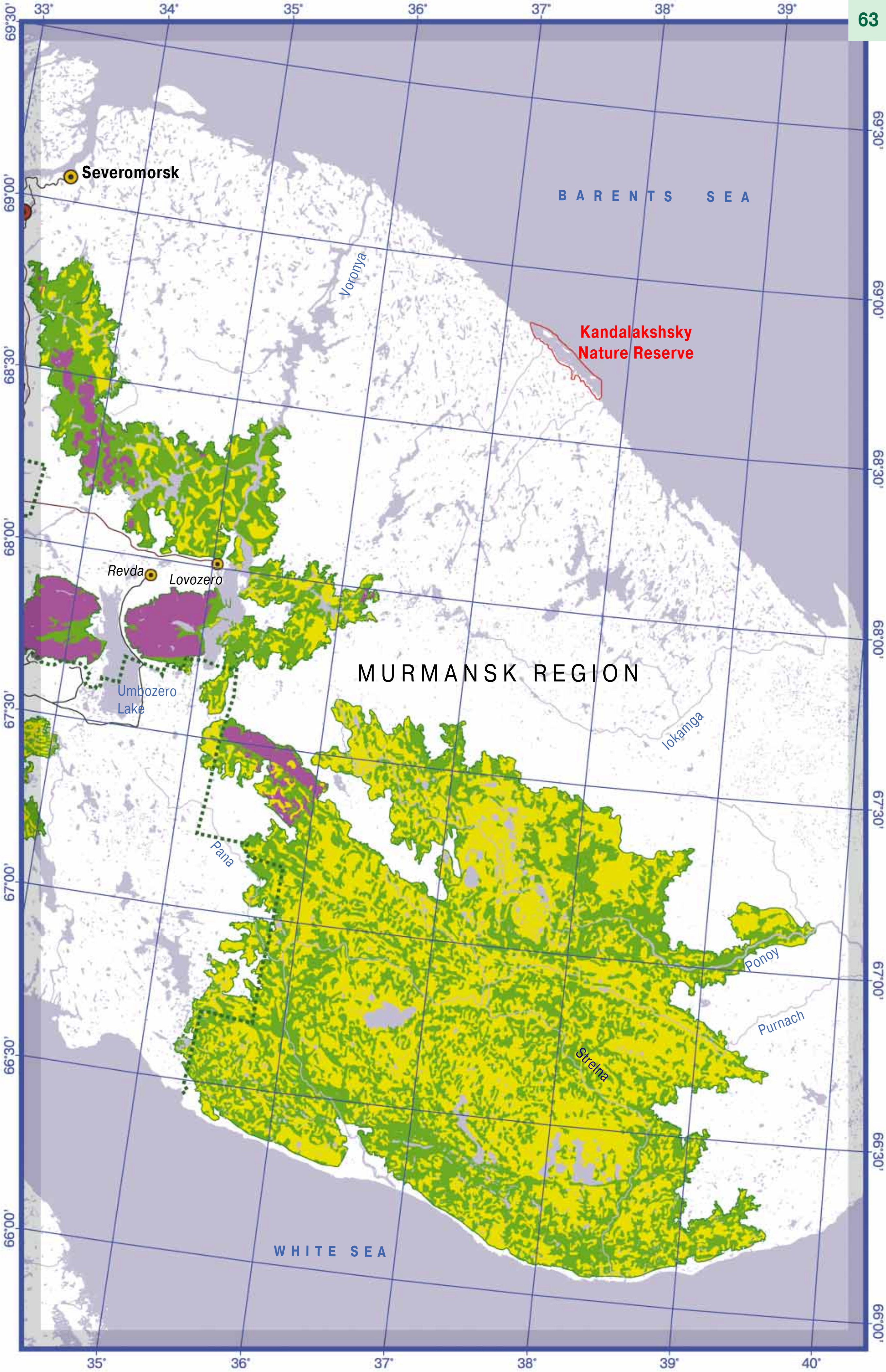
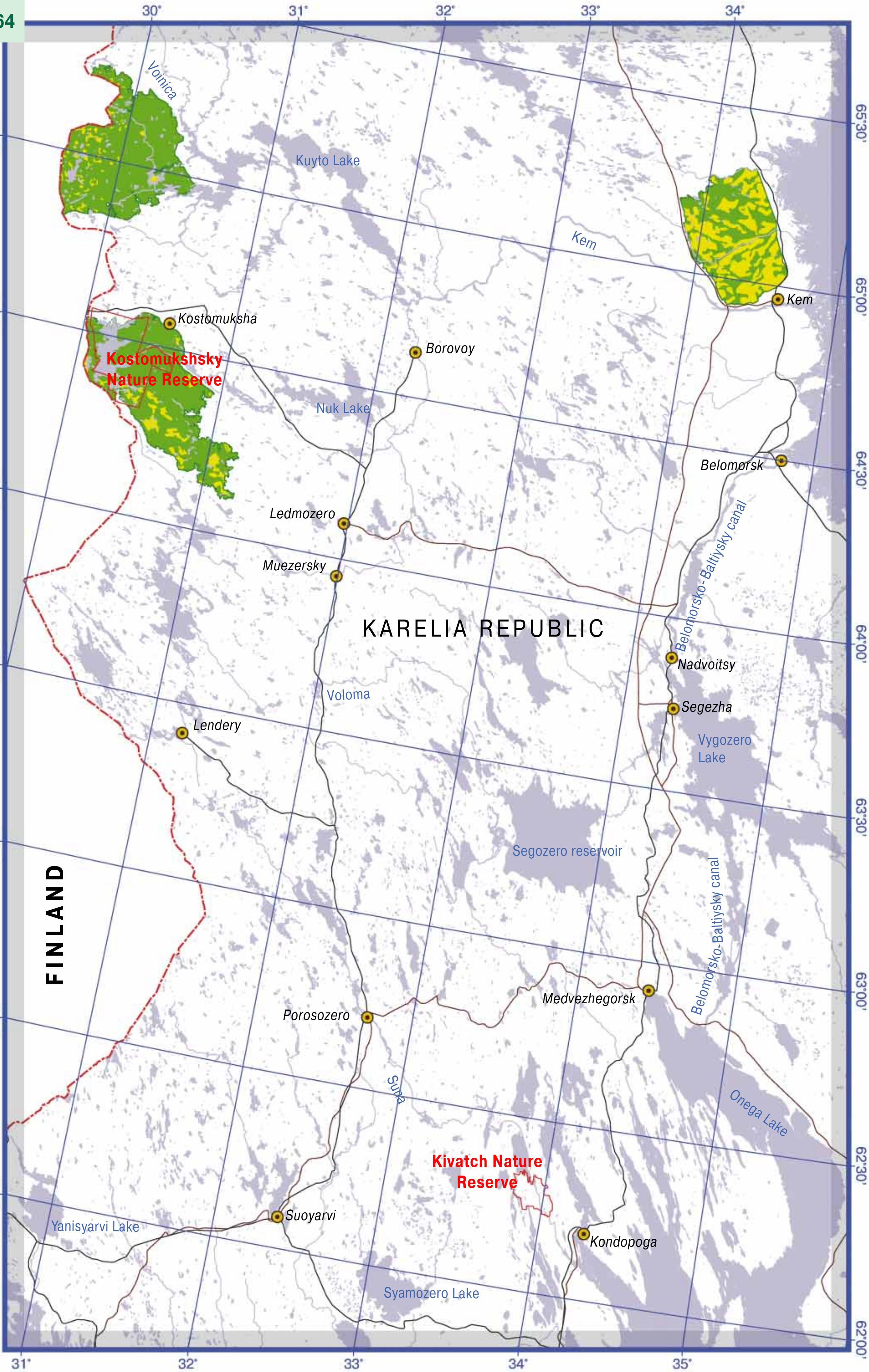

BARENTS SEA
Severomorsk
Voronya
Kandalakshsky
Nature Reserve
Revda
Lovozero
MURMANSK REGION
Umbozero
Lake
Iokamga
Pana
Ponoy
Purnach
Strelna
WHITE SEA



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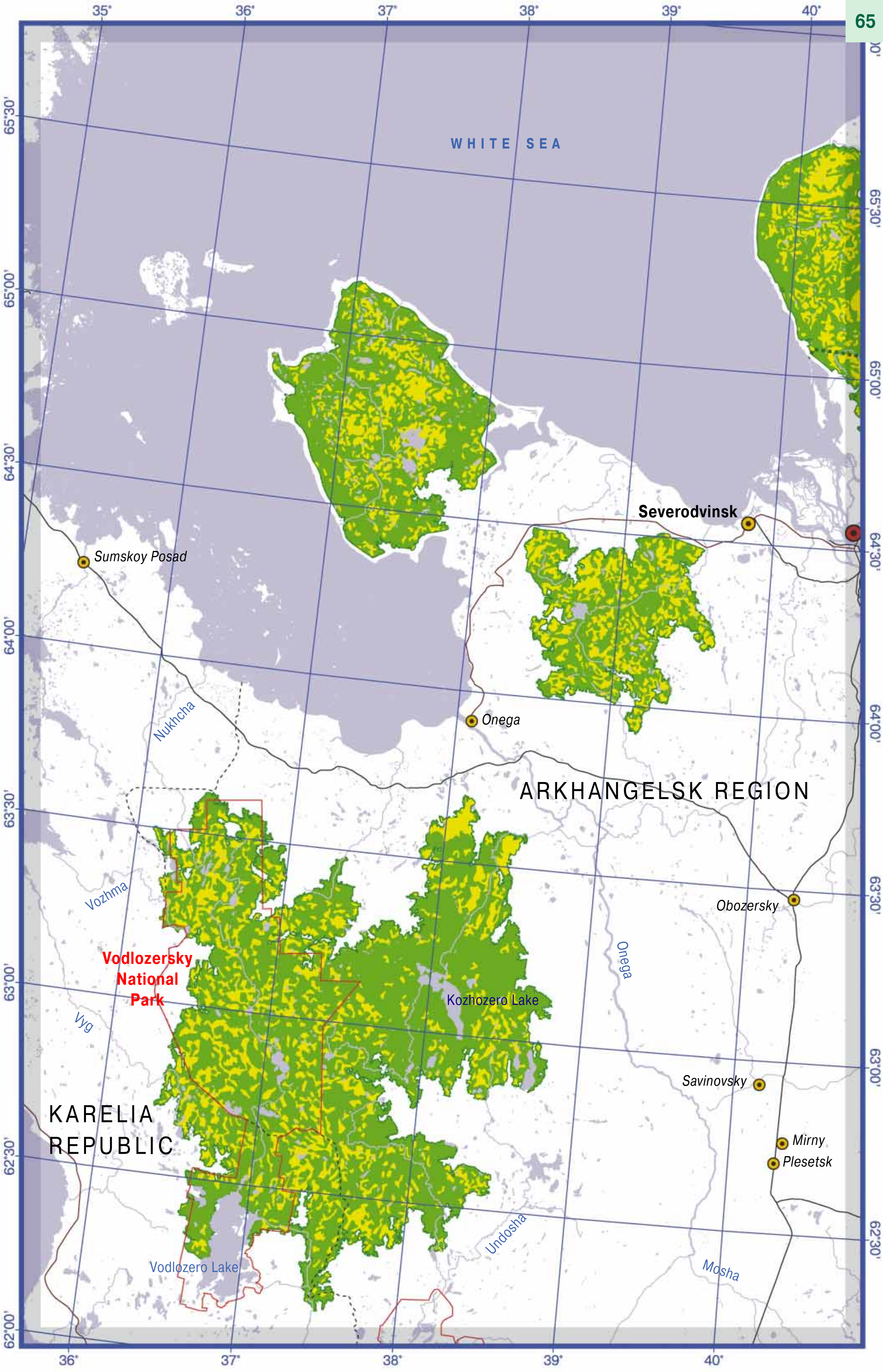
Voinica
Kuyto Lake
Kem
Kem
Kostomuksha
Kostomukshsky Nature Reserve
Borovoy
Nuk Lake
Belomorsk
Ledmozero
Muezersky
Belomorsko-Baltiysky canal
KARELIA REPUBLIC
Nadvoitsy
Voloma
Segezha
Lendery
Vygozero Lake
Segozero reservoir
FINLAND
Medvezhegorsk
Porosozero
Suna
Onega Lake
Kivatch Nature Reserve
Suoyarvi
Yanisyarvi Lake
Kondopoga
Syamozero Lake


WHITE SEA
Severodvinsk
Sumskoy Posad
Onega
ARKHANGELSK REGION
Nukhcha
Vozhma
Obozersky
Onega
Vodlozersky National Park
Kozhozero Lake
Vyg
Savinovsky
KARELIA REPUBLIC
Mirny
Plesetsk
Undosha
Vodlozero Lake
Mosha
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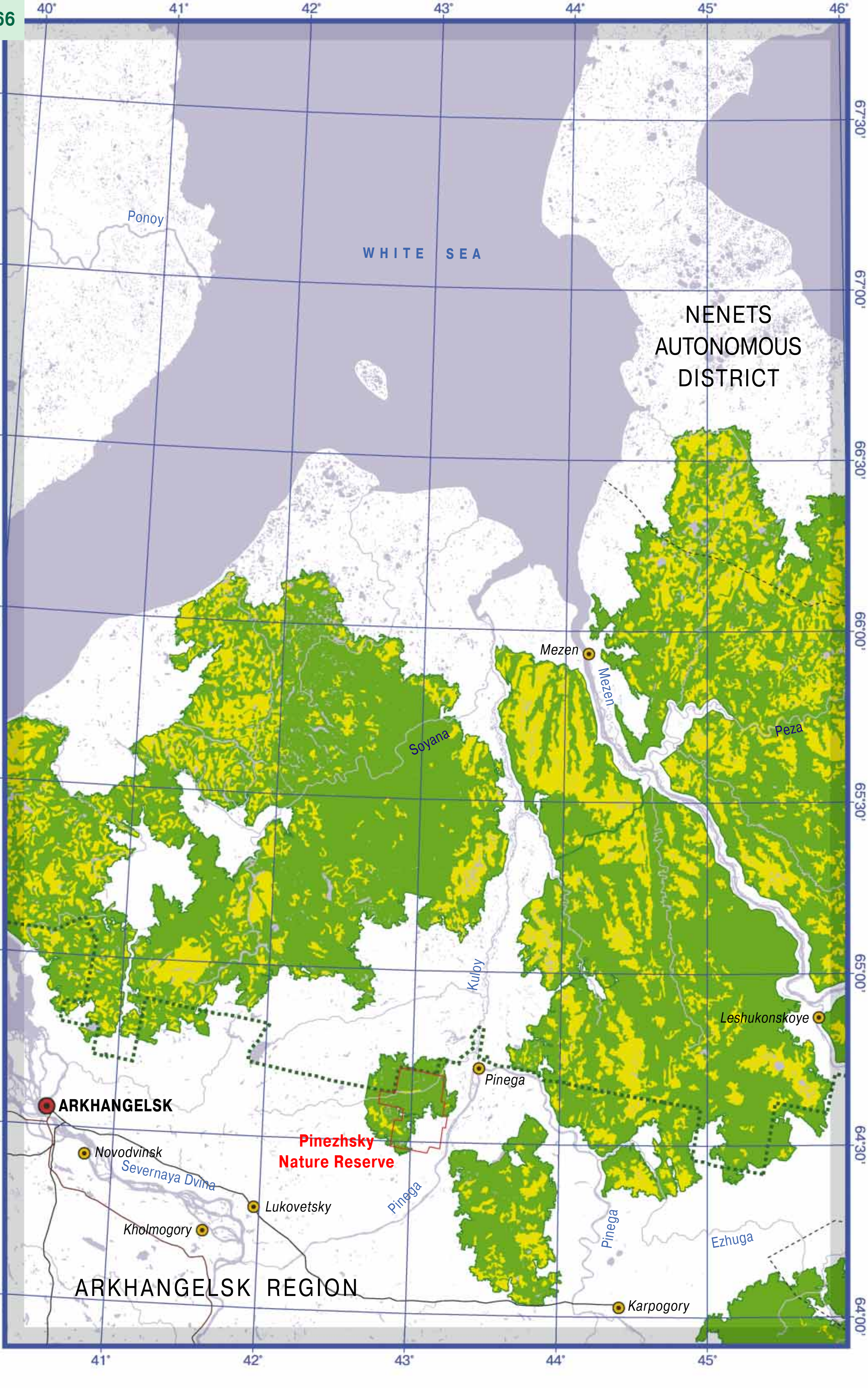
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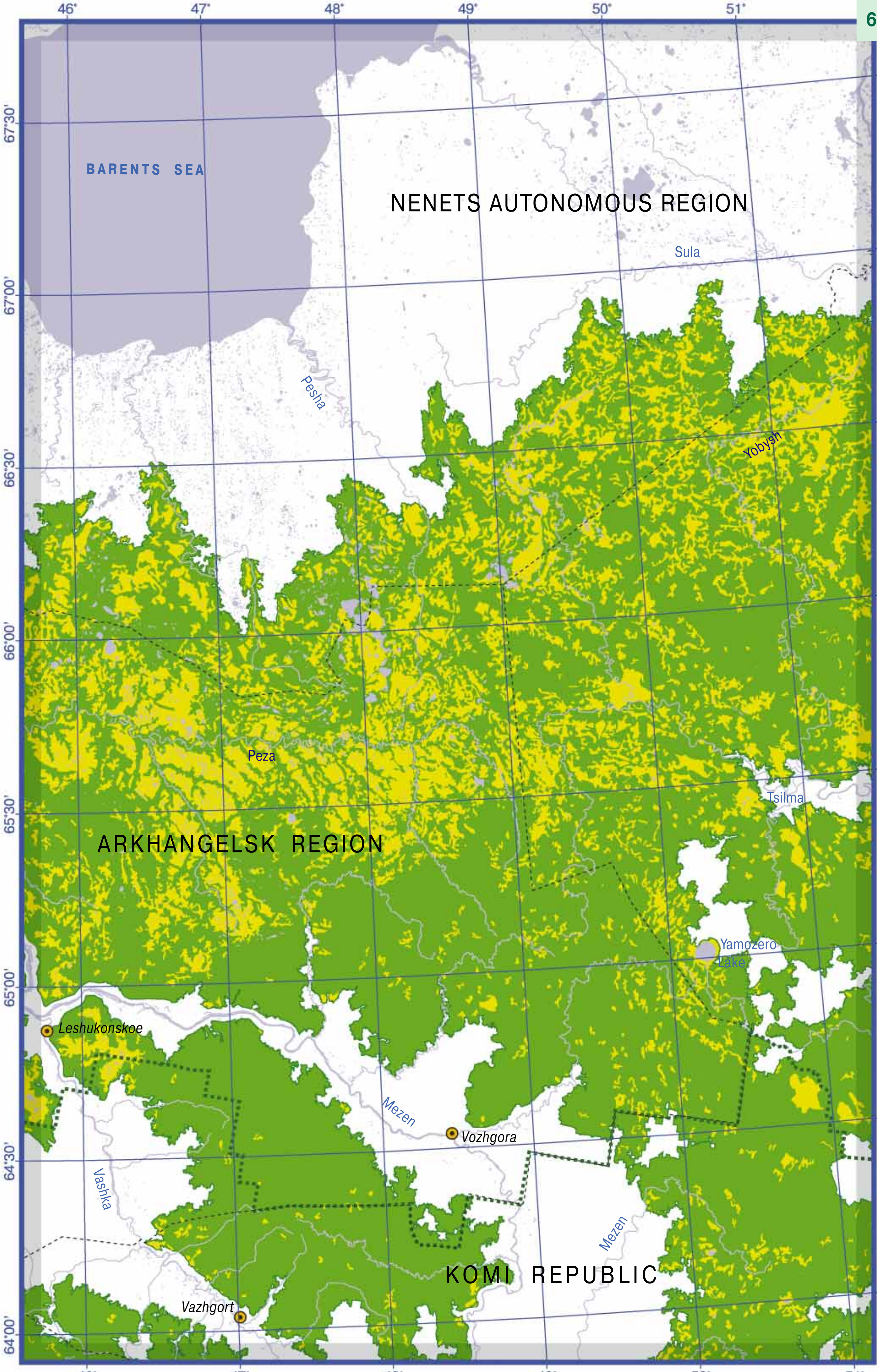
Ponoy
WHITE SEA
NENETS AUTONOMOUS DISTRICT
Mezen
Mezen
Peza
Soyana
Kuloy
Leshukonskoye
Pinega
ARKHANGELSK
Pinezhsky Nature Reserve
Novodvinsk
Severnaya Dvina
Lukovetsky
Pinega
Pinega
Kholmogory
Ezhuga
ARKHANGELSK REGION
Karpogory


BARENTS SEA
NENETS AUTONOMOUS REGION
ARKHANGELSK REGION
KOMI REPUBLIC
Sula
Pesha
Yobysh
Peza
Tsilma
Yamozero Lake
Mezen
Mezen
Vashka
Leshukonskoe
Vozhgora
Vazhgort
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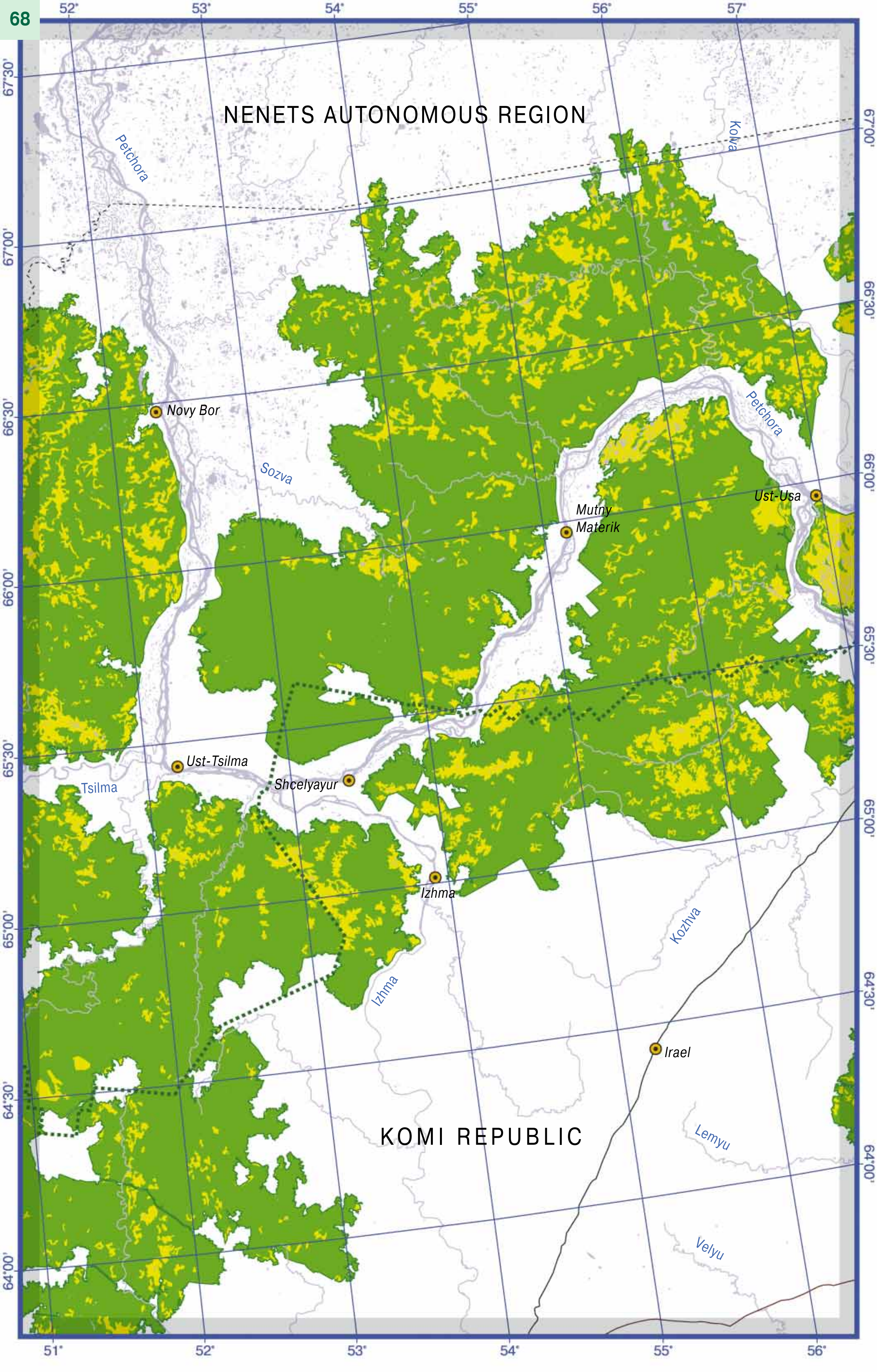

NENETS AUTONOMOUS REGION
KOMI REPUBLIC
Petchora
Kolva
Sozva
Novy Bor
Mutny
Materik
Ust-Usa
Ust-Tsilma
Tsilma
Shcelyayur
Izhma
Kozhva
Irael
Lemyu
Velyu
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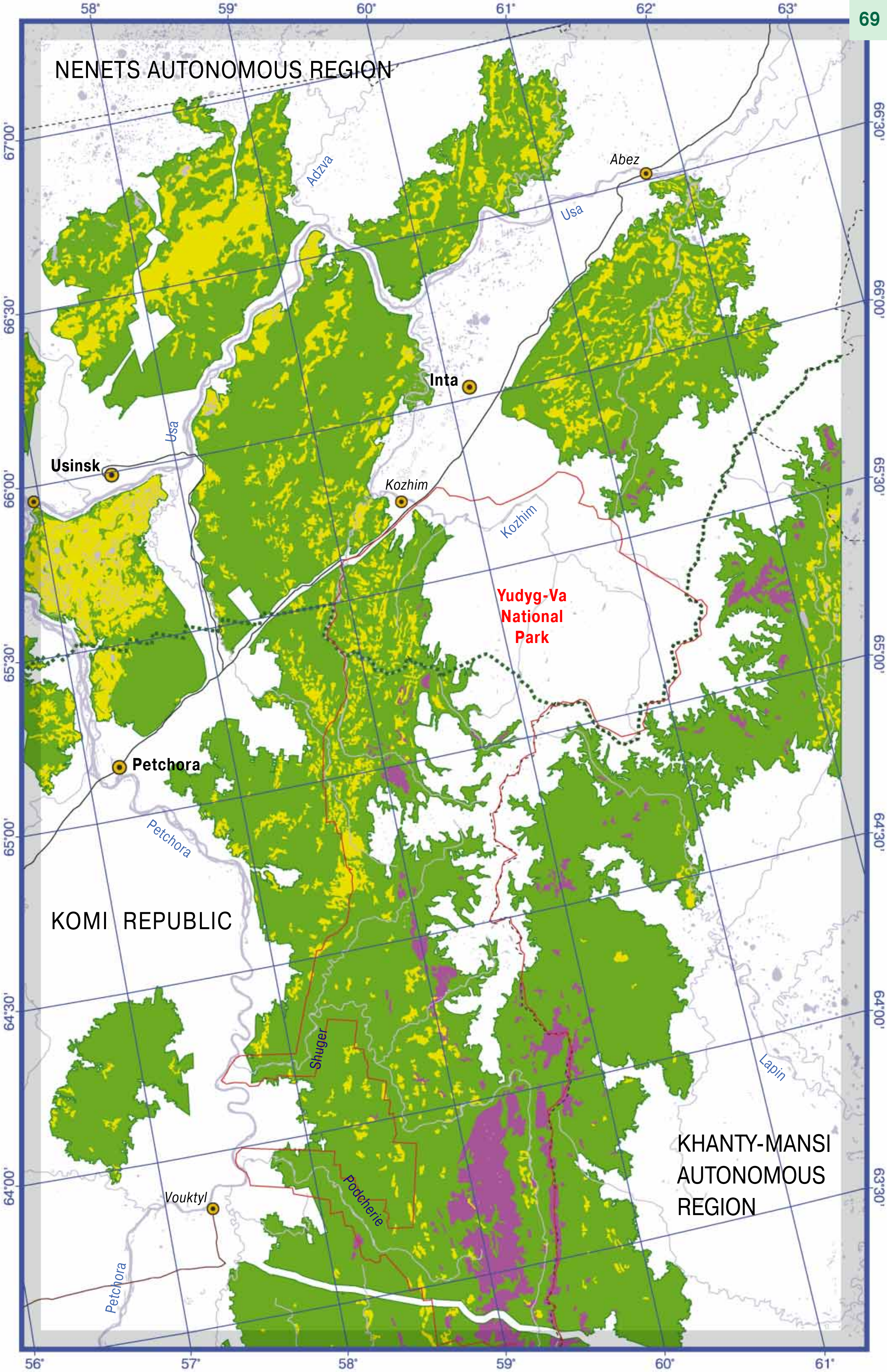

NENETS AUTONOMOUS REGION
Adzva
Abez
Usa
Inta
Usa
Usinsk
Kozhim
Kozhim
Yudyg-Va
National
Park
Petchora
Petchora
KOMI REPUBLIC
Shuger
Podcherie
Lapin
KHANTY-MANSI
AUTONOMOUS
REGION
Vouktyl
Petchora
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Pinega
Emetsk
Sura
Emtsa
Ust-Vaenga
Bereznik
Vaenga
Severnaya Dvina
Rochegda
Led
Dvinskoy
Shenkursk
Vaga
ARKHANGELSK REGION
Ustia
Solginsky
Velsk
Oktyabrsky
Kizema
Kuloi
Sukhona
VOLOGDA REGION

KOMI REPUBLIC
ARKHANGELSK REGION
KIROV REGION
VOLOGDA REGION
Kotlas
Usogorsk
Blagoevo
Mezhduretchensk
Mikun
Zheshart
Koriazhma
Vytchegodsky
Visinga
Veliky Ustug
Lusa
Obyatchevo
Demianovo
Podosinovets
Vashka
Mezen
Pinega
Pinega
Ilesha
Yarenga
Vym
Vytchegda
Uftuga
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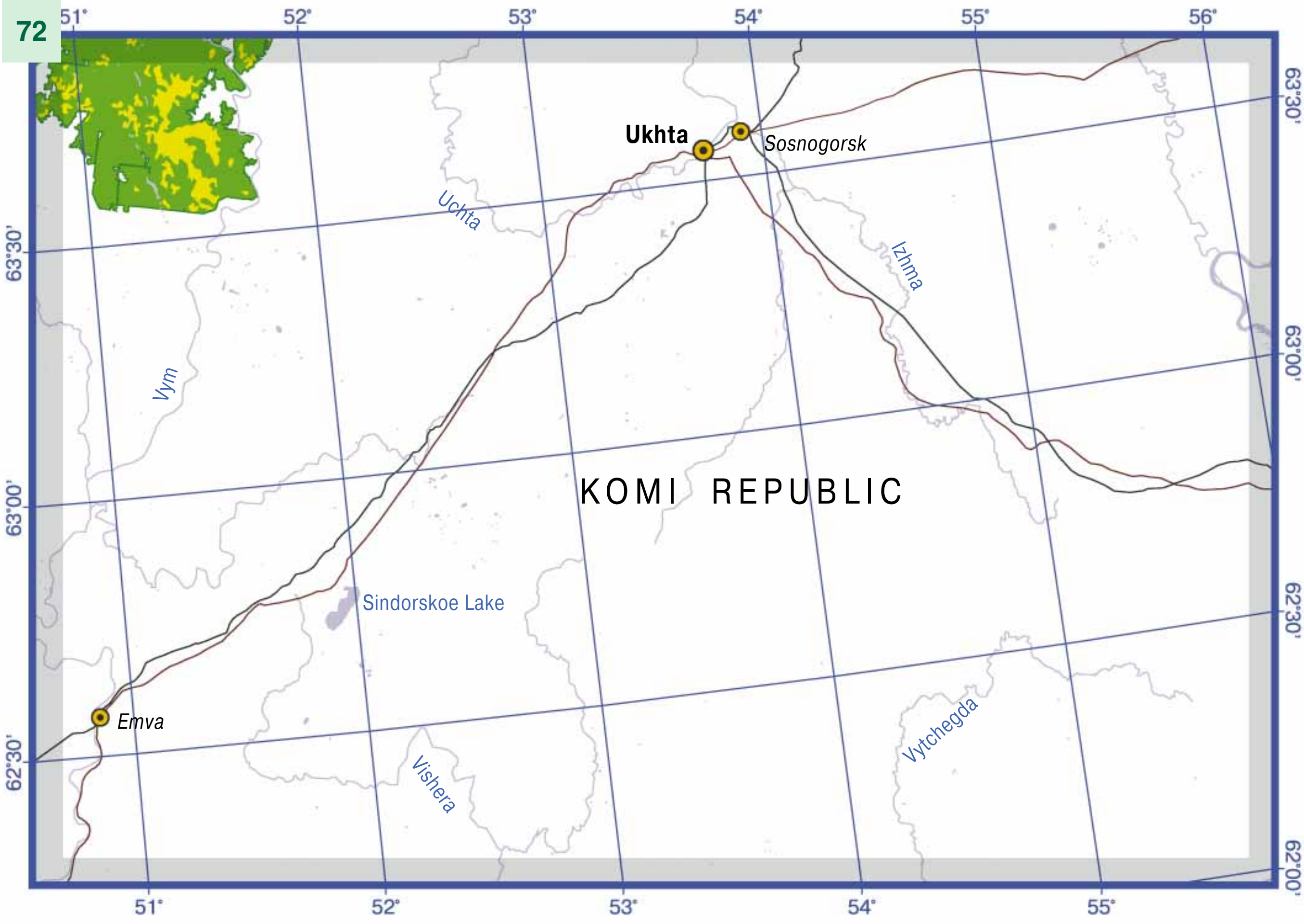
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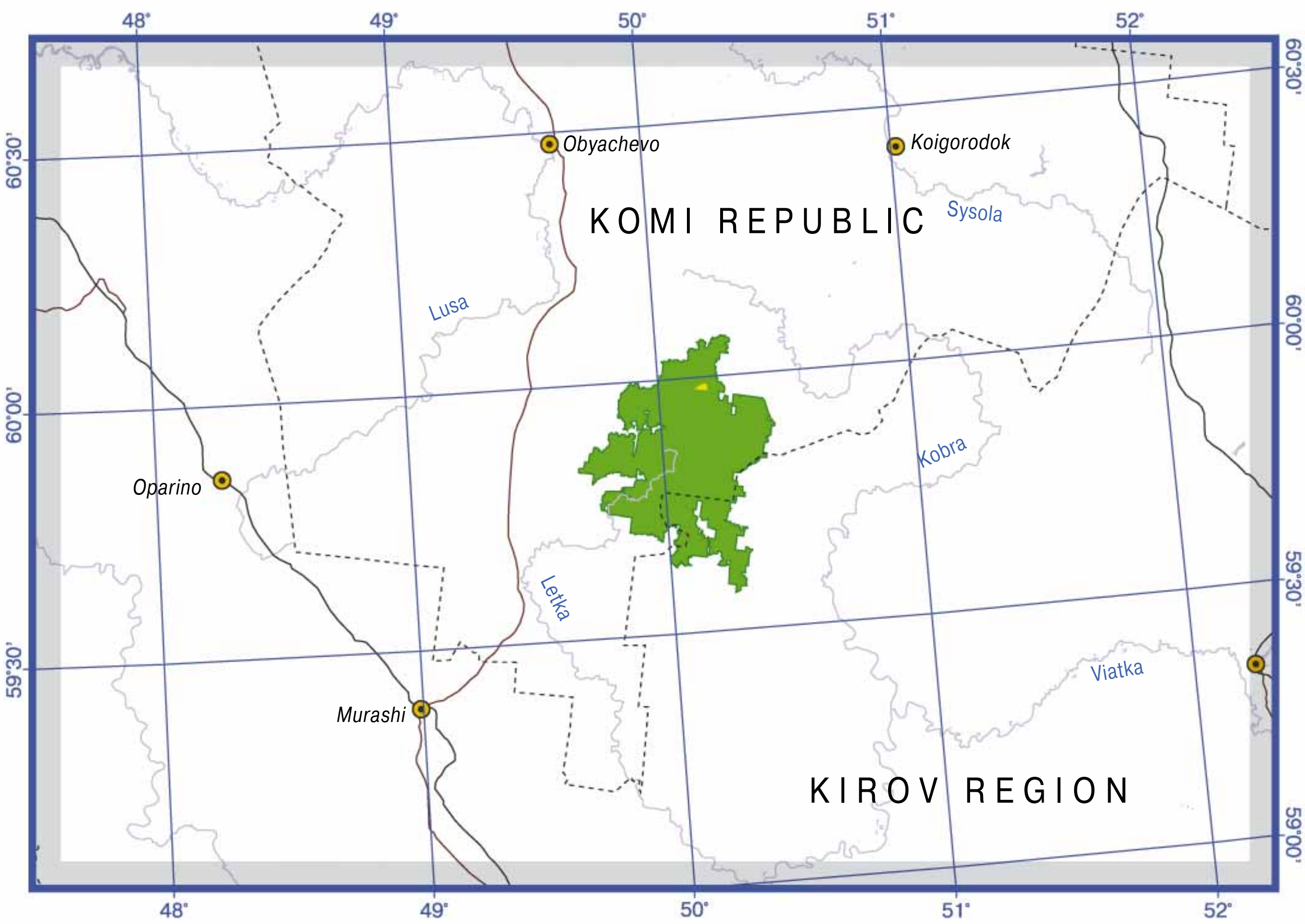
Sosnogorsk
Uchta
Izhma
Vym
KOMI REPUBLIC
Sindorskoe Lake
Emva
Vishera
Vytchegda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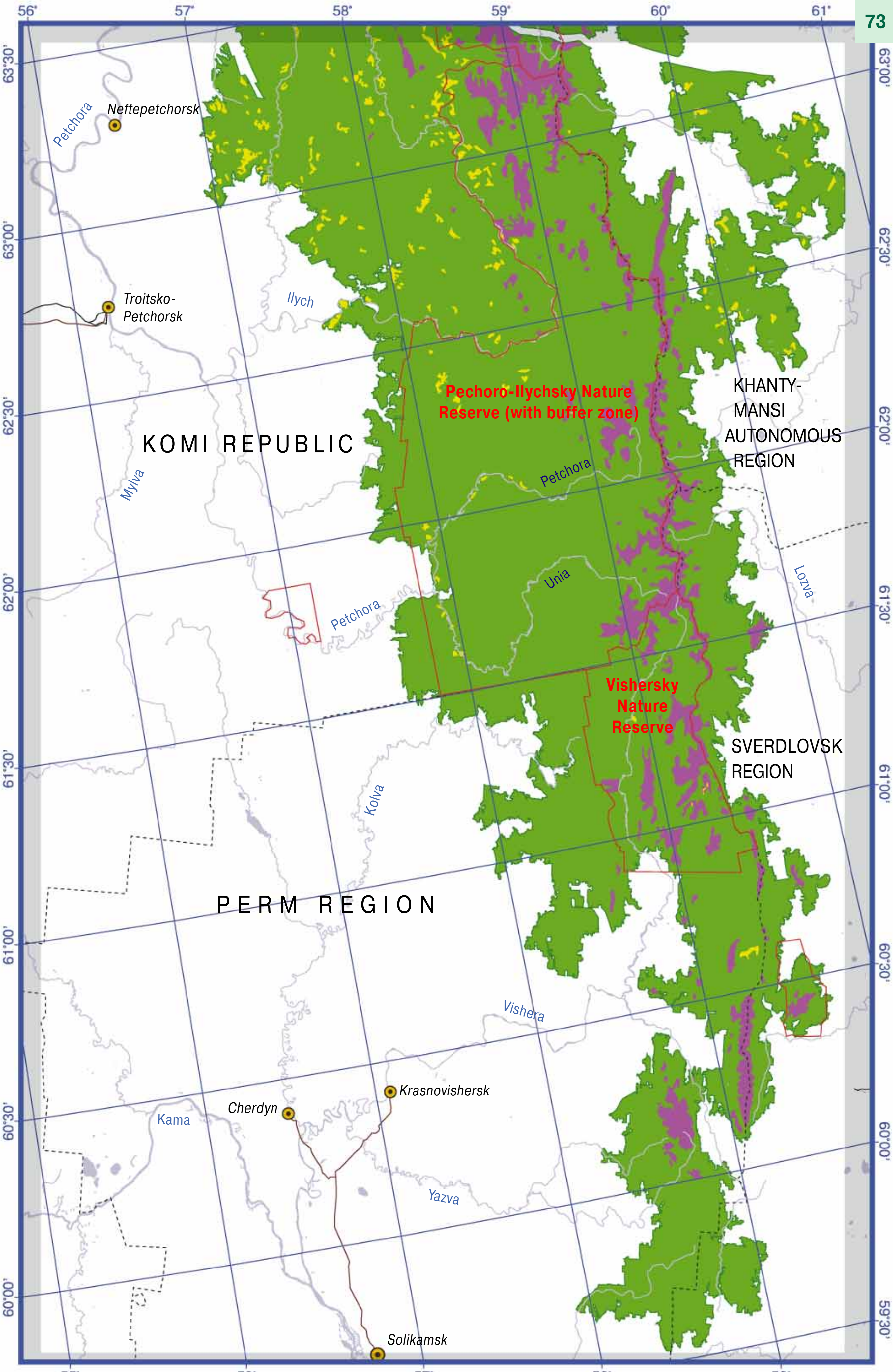
Obyachevo
Koigorodok
KOMI REPUBLIC
Sysola
Lusa
Oparino
Kobra
Letka
Viatka
Murashi
KIROV REGION



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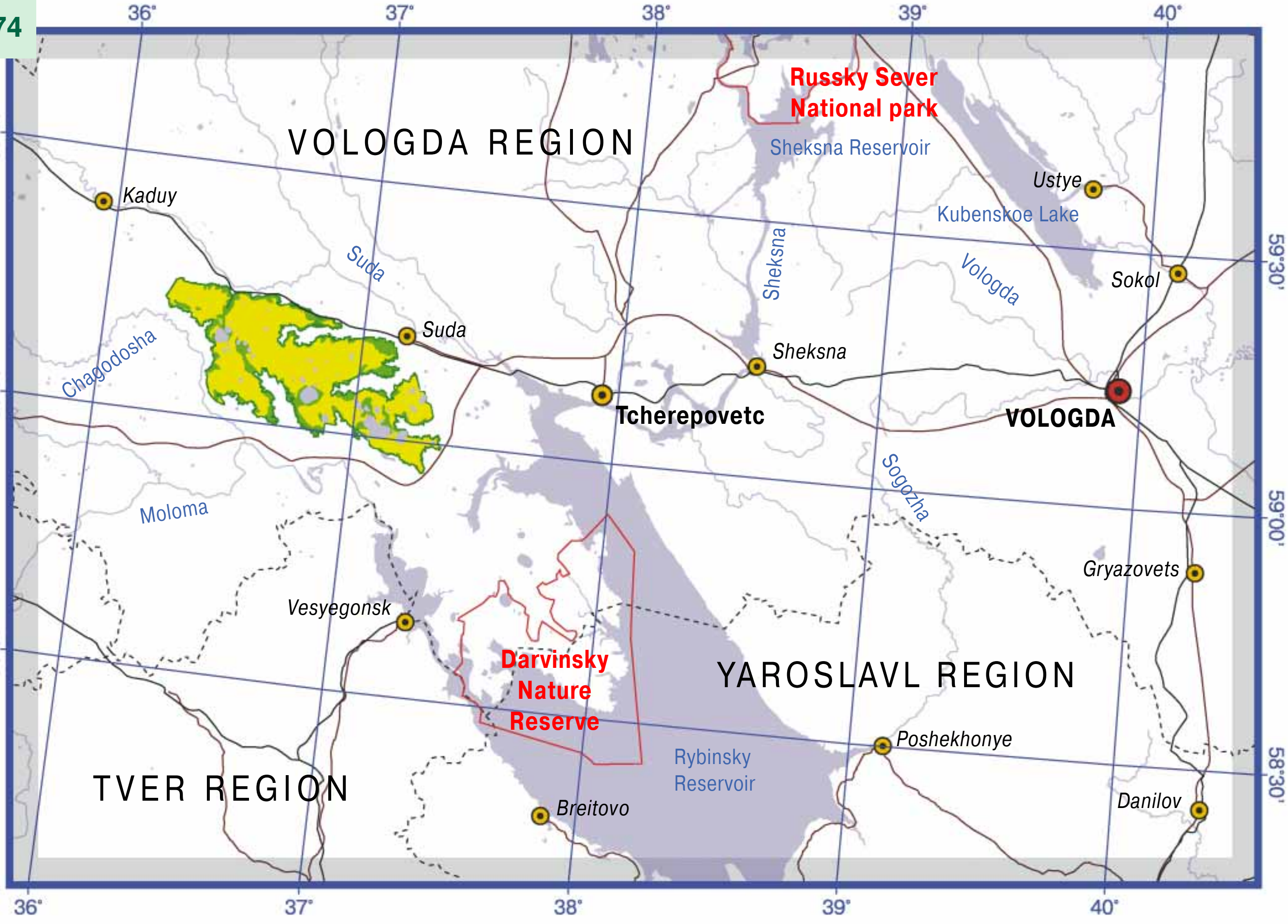
Neftepetchorsk
Petchora
Troitsko-
Petchorsk
Ilych
KOMI REPUBLIC
Mylva
Pechoro-Ilychsky Nature
Reserve (with buffer zone)
KHANTY-
MANSI
AUTONOMOUS
REGION
Petchora
Unia
Lozva
Petchora
Vishersky
Nature
Reserve
SVERDLOVSK
REGION
Kolva
PERM REGION
Vishera
Krasnovishersk
Cherdyn
Kama
Yazva
Solikamsk


36°
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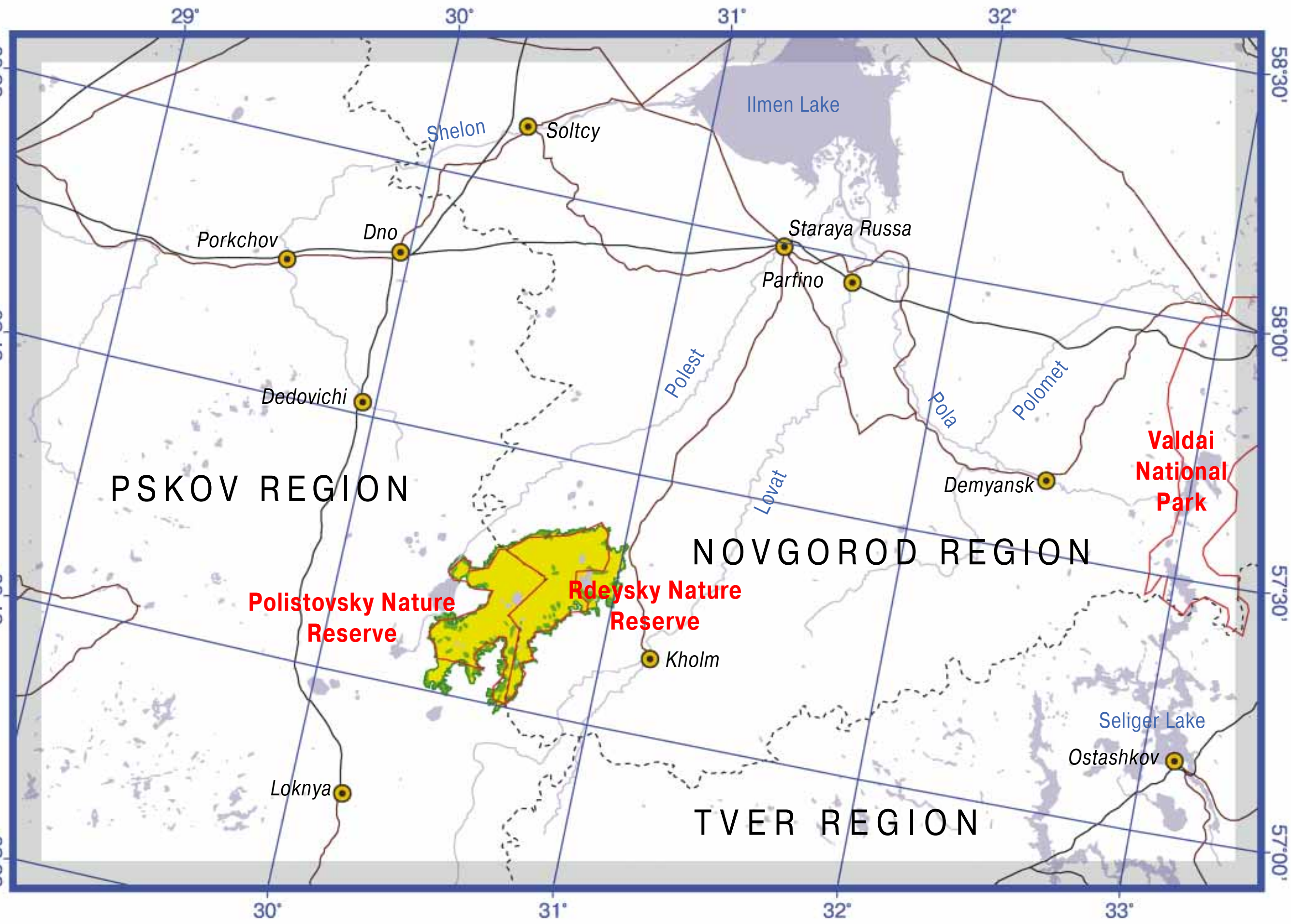
VOLOGDA REGION
Russky Sever National park
Sheksna Reservoir
Ustye
Kubenskoe Lake
Kaduy
Suda
Sheksna
Vologda
Sokol
Suda
Chagodosha
Sheksna
Tcherepovetc
VOLOGDA
Sogozha
Moloma
Gryazovets
Vesyegonsk
Darvinsky Nature Reserve
YAROSLAVL REGION
Poshekhonye
Rybinsky Reservoir
TVER REGION
Breitovo
Danilov


29°
30°
31°
32°
58°00'
57°30'
57°00'
56°30'
58°30'
Ilmen Lake
Shelon
Soltcy
Porkchov
Dno
Staraya Russa
Parfino
Dedovichi
Polest
Pola
Polomet
Valdai National Park
PSKOV REGION
Demyansk
Lovat
NOVGOROD REGION
Polistovsky Nature Reserve
Rdeysky Nature Reserve
Kholm
Seliger Lake
Ostashkov
Loknya
TVER REGION
33°

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