Biological Diversity in the Sikhote-Alin Forests and Measures of its Conservation

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Abstract.—Forests occupy 80-90 percent of the Sikhote-Alin mountain forest region. Cenotic and species diversity of its forest vegetation is the highest in Russia. In the Sikhote-Alin forests, about 200 species of trees and shrubs and 6 species of lianas grow; about 1,000-1,100 species of grassy plants and more than 450 species of mosses and lichens are registered. In one phytocenosis of broad-leaved and coniferous forests, up to 15-20 tree species, 10-15 species of shrubs and lianas, 50-70 species of grasses, 12-15 species of mosses and lichens, etc. occur. About 20 tree species make up the forest formations occupying large areas and including forests with *Pinus koraensis, Picea ajanensis, Larux* spp., *Quercus mongolica, Fraxinus manchurica, Ulmus propinqua, Betula* spp., and other species. In the forest formations of Sikhote-Alin, more than 150 primary and old-growth forest types in 64 groups were revealed. Non-sustainable exploitation, forest fires, and other factors of anthropogenic impact caused the greatest damage to the forests of *Pinus koraensis* and *Fraxinus manshurica*. Their areas have been reduced by half over the last 50 years. An adverse anthropogenic impact on the Sikhote-Alin forests results in losses of biodiversity at all levels. Reducing losses and possibly restoring biodiversity and sustainable development of forest territories requires a prompt complex monitoring of current changes in the forests and appropriate correction of forest resource use; complex multifunctional inventorying of the forest resources as a basis for multipurpose use of forest resources; and specifying of a sustainable harvest providing a long-term continuity of resource use and sustainable development of forest territories.

PHYSICAL AND GEOGRAPHICAL CHARACTERISTICS

The mountain-forest region of the Sikhote-Alin stretches along the coast of the Tatar Strait and the northwestern coast of the Sea of Japan. It consists of a complex system of mountain ridges and plateaus, intermontane depressions, and mountain river valleys. The main watershed of the Sikhote-Alin divides the basins of the right tributaries of the rivers Ussuri and Amur and the rivers falling into the Sea of Japan and the Tatar Strait.

The length of the Sikhote-Alin region is about 1,300 km or almost 10° (42°20'-51°25') by geographical latitude. Its largest width is about 300 km (fig. 1). In the central part of this region, its highest sites are situated—Tardoki-Yani Mountain (2,078 m) and Ko Mountain (2,004 m)—where the obvious traces of the late Quaternary mountain glaciation are observed. In general, the height of the mountains in the Central Sikhote-Alin does not exceed 1100-1200 m. The river net is well developed. Its average density is 0.6-0.8 km/km^2, generally decreasing to 0.4 to the west and increasing to 1.0-1.2 at some sites on the slopes.

The climate of the region is influenced by cold winds from the mainland in winter and by cool, damp oceanic winds in summer. Annual precipitation ranges from 700 to 800 mm at the western foothills to 100-1,100 mm at the eastern macroslope and reaches 1,300 mm (probably more) in the upper mountain belt. Mean winter precipatation makes up 18-20 percent of total annual precipitation. Most rain is observed in the second half of summer in the form of heavy showers, when daily rainfall can exceed 200-250 mm.

Because the territory of the Sikhote-Alin extends far from south to north, the temperature in its different parts varies significantly. Mean annual air temperature in the northern part of the region is +1 to -2°C and in the southern part +4 to +5°C. Absolute minimum temperature ranges from -30 to -52°C; absolute maximum temperature ranges from +35 to +41°C. The warmest months are July and August with mean temperature to +20°C. The coldest month is January with mean temperature from -14 to -20°C. A general tendency is observed: with an increase in height above sea level, the air temperature decreases, on average,

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Figure 1.—*Elevations in the Sikhote-Alin region.*

by 0.5°C for each 100 m of the height increase in summer, and it increases by 1.5 to 2°C in winter with an average winter correction factor of 0.1 to 0.3°C.

Forests are common in the Sikhote-Alin region from their upper border to the foot of the mountains. In different parts of the Sikhote-Alin, they occupy 85-95 percent of the total area and, thus, are the main landscape-forming component in this mountain-forest country.

The position of the upper border of straight-boled forests (FUB) in the Sikhote-Alin varies greatly and depends mainly on the geographical latitude of the locality, height, and massiveness of the mountains and their remoteness from the sea. In the southern part of the Sikhote-Alin close to the coast, FUB passes at a height of 1,100-1,300 m. Farther from the sea, it increases to 1,450-1,550 m in the area of the main watershed and to 1,550-1,600 m to the west of it (Oblachnaya Mt.).

In the central Sikhote-Alin, on the largest mountain—Tardoki-Yani Mountain—separated from the sea by high watershed, the forest goes up to 1,450-1,550 m above sea level. Closer to the sea, FUB goes down to 1,000-900 m and less.

The position of FUB in the northern Sikhote-Alin varies more dramatically. At the mountains remote from the sea, it passes at a height of 1,100-1,300 m, and closer to the coast of the Tatar Strait, FUB goes down to 750-800 m above sea level. At the northern end of the Sikhote-Alin close to the latitude 52° north at the capes protruding into the Tatar Strait, FUB is clearly expressed at the hills at an absolute height of only 300 m.

Noteworthy, FUB in the Sikhote-Alin passes significantly lower than in other mountain systems of Eurasia situated at the same latitude. The decrease in the upper border of the distribution of straight-boled forests takes place from the south to the north in two "parallel" rows, one of which passes at the heights of the eastern macroslope of the Sikhote-Alin close to the sea coast, and the other passes along the northwestern macroslope at the heights that do not experience the direct cooling effect of the sea.

Other types of vegetation occupy small areas in the Sikhote-Alin. On the highest mountains, a belt of moss-lichen-bush mountain tundra ("goltsy") is well-expressed. Above FUB, thickets of *Pinus pumila, Rhododendron aureum,* and *Veigela middendorfiana* grow; in the southern part, *Microbiota decussata* and other shrubs and low-lying plants grow. In the Sikhote-Alin there is no belt of typical Alpine meadows, but small sites with mountain lawns are found on wide, flat, and slightly convex saddles and watersheds. In the central parts of the mountain plateaus, sites of oligotrophic swamps with sparse wood and individual trees of *Larix* spp. are observed.

In the forest belt of the Sikhote-Alin, several height bands are distinguished. The upper band is formed of mixed forests of *Betula lanata, Picea aianensis,* and *Abies nephrolepis*. Below, mixed forests with *Picea ajanensis* and *Abies nephrolepis* occupy large areas. The next narrow forest band is formed by *Picea ajanensis* and *Pinus koraiensis*.

With a decrease in height, the contribution of *Pinus koraiensis* increases up to its predominance in the forest stand. Only 35-40 years ago, forests with *Pinus koraiensis* occupied second place in area after forests with *Picea ajanensis* and *Abies nephrolepis*. By now, in the significant part of these forests, *Pinus koraiensis* has been cut out, and *Tillia* spp., *Betula costata,* and other deciduous wood species dominate.

Forests with *Larix* spp. occupy significant areas only in the central and northern Sikhote-Alin. The primary *Larix* forests grow on the overmoist sites of wide river valleys and intermontane depressions and mountain plateaus, and they occupy small areas. The forests with *Larix* spp. that were formed in the place of other forests after fires and felling occupy much greater areas.

In the lower mountain belt of the Sikhote-Alin, the forests occupy significant areas with a predominance of *Quercus mongolica*. A great part of them formed after felling and fires in mixed forests with *Pinus koraiensis* and *Quercus mongolica* and broad-leaved forests with a participation and predominance of *Quercus mongolica*.

The complex of the valley forests is a combination of ecological rows stretching from the low floodplains to the high floodplain river terraces and gently sloping mountain trains. On the low and middle terraces that are constantly flooded by high waters from rain, the forests with *Chosenia* and *Salix* spp. grow. On the rarely flooded terraces, mixed forests of *Chosenia, Populus* spp., *Fraxinus mandshurica, Ulmus*, and others grow. On the intermediate and low above floodplain terraces and slope trains, the forests develop with a predominance of *Fraxinus* and *Ulmus* and complex broad-leaved forests. Other forest formations occupy small areas and are distributed sporadically among the main formations.

STRUCTURE OF BIOLOGICAL DIVERSITY OF FORESTS

In this paper, "structure of biological diversity (BD) of forests" means composition and relationship of levels of formation and manifestation of diversity of wood vegetation.

In this project three levels of BD have been studied in detail. Under the low level, the authors consider an absolute and relative diversity of species composition of forest phytocenoses (in other words, species diversity and species richness). The middle level is diversity of forest types and their primary formations—groups of forest types. As the high level, we include diversity of forest subformations and formations.

Among the mentioned levels of BD, there is, of course, an uncertain number of intermediate as well as lower and higher BD levels, but these three BD levels of forest vegetation are of the most important scientific and practical significance. Besides, the vast materials of state inventories of forest vegetation are available for their evaluation.

The absolute diversity of species composition of forest phytocenosis of the Sikhote-Alin is the greatest in Russia and one of the greatest in the northern temperate belt of Eurasia. In the forests of the Sikhote-Alin, according to different information sources, 1,000-1,300 species of grass vegetation are registered as well as more than 450 species of mosses and lichens. The most diverse species composition is that of broad-leaved coniferous forests. Sometimes up to 20 wood species, 15-20 species of shrubs and wood lianas, 50-70 grass species, and 12-15 moss and lichen species are included in one phytocenosis.

In the forests of the Sikhote-Alin, about 200 species of trees and shrubs grow. Some of the genera are represented by several species: *Acer* (6 species), *Populus* (5), *Betula* (4 or 5), *Tilia* (3), *Picea* (3), *Lonicera* (5), *Ulmus* (3), *Larix* (3), *Rhododendron* (4), *Ribes* (4), *Salix* (more than 10). In the southern Sikhote Alin in the broad-leaved coniferous forests, six species of wood lianas are registered, including *Schizandra chinensis*, *Actinidia arguta*, and *A. kolomicta*. The latter species penetrates into the northern part of the Sikhote Alin and up the mountains to a height of 1,400-1,450 m above sea level The family *Araliacea* is represented by three living forms of plants: grass—*Panax gingseng*, shrub—*Eleuterococcus, Acanthopanax, Echinopanax,* and tree—*Kalopanax.*

The modern BD in the forests at the level of types and groups of types of forests formed as a result of multicentury interaction of ecotopes and bioecological characteristics of the species forming forest phytocenoses. The main determining factor was, and still is, the complex interactions of forest-forming wood species—edificators and ecotopes that determine the course of forest-forming processes: initiation of forest cenosis, its changes with age, destruction and restoration after natural degradation or after felling or fires. The diversity of forest types is closely connected with the diversity of habitat types and forest-growing conditions (ecotopes) corresponding to them. For this reason, the evaluation of diversity of forest types is based on the determination of diversity of habitat types and forest-forming processes in them.

The continuity of natural phenomena determines the necessity of the choice of "scale of division of continuum for the evaluation of BD at cenosis levels. This scale, in our case, is determined by a notion "volume of forest type" discussed below—forest formation.

One forest type includes forest sites occupying similar habitats and having similar productivity. The main forest-forming factor(s) on these sites is one wood species or a stable union of two or more species. The term "forest type" includes all age and short-term restoration stages of development of forest phytocenoses in similar habitats. One group of types combines forest types according to the similarity of their habitat and productivity.

In the forests of the Sikhote-Alin, more than 150 primary and continually stable secondary forest types are distinguished and fixed by forest inventory and planning. Differentiation to the level of forest type is not always necessary for practical purposes, and sometimes it is impossible in industrial conditions. For this reason, the types of forests that develop in relatively similar ecotopes and that have similar productivity were combined into 64 groups of forest types. The highest of the studied levels of diversity of forest vegetation in the Sikhote-Alin includes, according to different sources of information, from 25 to 30 forest formations and subformations.

Fixation of types of forests, forest formations, and subformations by means of forest inventory and planning makes it possible to determine the measures of conservation of BD for certain objects and certain localities, which increases the practical implementation of the measures of exploitation and nature conservation to a significant degree. At the generalized level, 23 primary and stable secondary forest formations and subformations are fixed by means of forest inventory and planning. The rules of felling of general use and improvement thinning are differentiated in accordance with them.

In addition to these forest formations that occupy significant areas, forest inventory and planning take into consideration the forests with a predominance of *Betula lanata, B. mandschurica et B. platiphylla, B. costata, B. dahurica, Salix rorida, S. rotundifolia, Chosenia arbutifolia, Populus amurensis, P. koreana, P. maximowiczii, P. davidiana, Alnus hirsuta*, and thickets of *Pinus pumila* when developing forest management plans.

In the transition bands between territorially and ecologically contiguous forest formations, there are always forests with stable and variable correlation in their composition of the main forest-forming species—edificators of contiguous formations. Such complexes of forest ecosystems are related to the category of subformations. To the same category of subformation can be also related the forests that represent the long-term restoration changes in the primary formations with a participation of long-living pioneer species (for example, forests with *Pinus koraiensis* and *Larix* spp.).

Forest inventory and planning also fixes and characterizes the subformations of mixed forests of *Picea ajanensis et Betula lanata, Pinus koraiensis et Picea ajanensis, Larix* spp. *et Picea ajanensis, Abies holophylla et Pinus koraiensis,* and *Larix* spp. *et Pinus koraiensis.*

In the latter part of the 20th century, the primary main forest-forming species were destroyed by fires and felling on significant territories. When there is no restoration of the primary forest-forming species, their role transfers to the "pioneer" species that settle on the post-felling and post-fire areas. They form secondary but continually stable forests that are classified as independent formations (for example, forests with *Quercus mongolica, Betula costata*, etc.).

The existence of narrowly distributed forest formations is also observed. Some of them, for example the forest formations with *Pinus funebris*, *Alnus japonica*, groves of *Taxus cuspidata* and others, are sporadically distributed on very small areas and are of great botanical and geographical interest. They are all protected by the law, but, unfortunately, the standard methods of state forest inventory and planning do not allow the fixing of rare combinations.

MAIN FACTORS INFLUENCING BIODIVERSITY IN THE SIKHOTE-ALIN FORESTS

Forest biodiversity today is determined in many ways by the cumulative effect of natural and anthropogenic factors. Out of natural factors, a significant effect on forest ecosystems is caused by strong winds that cause windfalls, big floods, and massive damage from pests and diseases. However, the effect of these factors results in relatively short-term local damage in forest ecosystems and a decrease in species BD and, more rarely, cenosis BD. The restoration usually occurs in a natural way during the life span of one or two generations of main forest-forming species—main edificators of forest phytocenoses.

Forest fires cause a greater and longer lasting effect. The only natural cause of forest fires in the Sikhote-Alin is lightning, but this happens quite rarely (about 3 percent of all fires). Even more rare is the recurrence of such naturally caused fires in the same place. Therefore, the negative effect of naturally caused fires is incomparably smaller than those caused by humans. During this decade, the number of fires on the forest territory of the Asian part of Russia has greatly increased, which has caused an increase in the forest area damaged by fires.

But the greatest transforming effect on the forest ecosystems of the Sikhote-Alin is caused by human activities in the forest. The forms of this effect differ, and the most destructive influence is caused by industrial logging operations that embrace significant territories and are called in Russia felling of general use (FGU). The worst consequences are observed in the case of a combination of FGU and fires, especially when they occur many times on the same territory.

In the latter half of the 20th century in the Sikhote-Alin, *Pinus koraiensis* has lost its dominance as a result of **FGU** on almost half of the territories where it once dominated (fig. 2). After the felling of *P. koraiensis,* the predominance status passed to *Tilia mandschurica, Tilia amurensis,* and most of all to *Betula costata*. After industrial felling of *Pinus koraiensis* was prohibited, the volume of FGU significantly increased in the forests with the predominance of *Picea ajanensis*, after which the predominance passes to deciduous species.

As a result of successive combinations of felling and fires in the mixed forests (with *Quercus mongolica*), the area of its predominance has increased sharply, because oak is most resistant to fires. These processes result in a change of dominants in all parts (layers) of forest biocenoses, impoverishment of species and cenosis composition of the forests, convergence of characteristics of species composition and phytocenosis structure, and decrease of their productivity. Such processes to a different degree take place on up to 40-50 percent of the Sikhote-Alin territory.

The greatest transformation of forest ecosystems and the greatest loss of species and cenosis diversity were observed in the southwestern foothills of the Sikhote-Alin. As a result of felling and subsequent numerous fires, coniferous-broad-leaved forests degraded to low bushes consisting of only two layers: tree and shrub layer, where *Quercus, Lespedeza, Corylus*, and some other species grow, and an impoverished grass layer.

At such a degree of degradation, BD losses include 10-15 species of trees, 7-12 species of shrubs, and 40-50 species of grasses. Burning and soil erosion level the conditions of habitats, which in general results in twofold or threefold losses of cenosis BD as compared with the primary one.

MEASURES OF RESTORATION AND CONSERVATION OF BIODIVERSITY IN THE FORESTS OF THE SIKHOTE-ALIN

The influence of unfavorable natural factors on forest ecosystems occurred throughout their evolutionary formation and is one of the conformities of forest-forming processes. Obviously, the measures of restoration and conservation of BD should be adequate to the factors that have a negative transforming influence on forest ecosystems. The possibility of the restoration of BD in the areas where it has been to some degree or other lost depends on the degree of damage of forest ecosystems. The measures of accelerated rehabilitation of windfalls, drying of forests, and other natural damage are known. On the whole, it depends only on the organizational and economical abilities of the human society.

In the parts of the forests of the Sikhote-Alin where, as a result of the felling of coniferous species, deciduous species became dominant, but a sufficient number of coniferous young stand was still preserved, the restoration of the composition and structure of the damaged forest ecosystems occurs, even though very slowly. With the provision of an appropriate protection from fire, it can be expected that more or less full restoration of BD will occur during the life span of one generation of main forest-forming species.

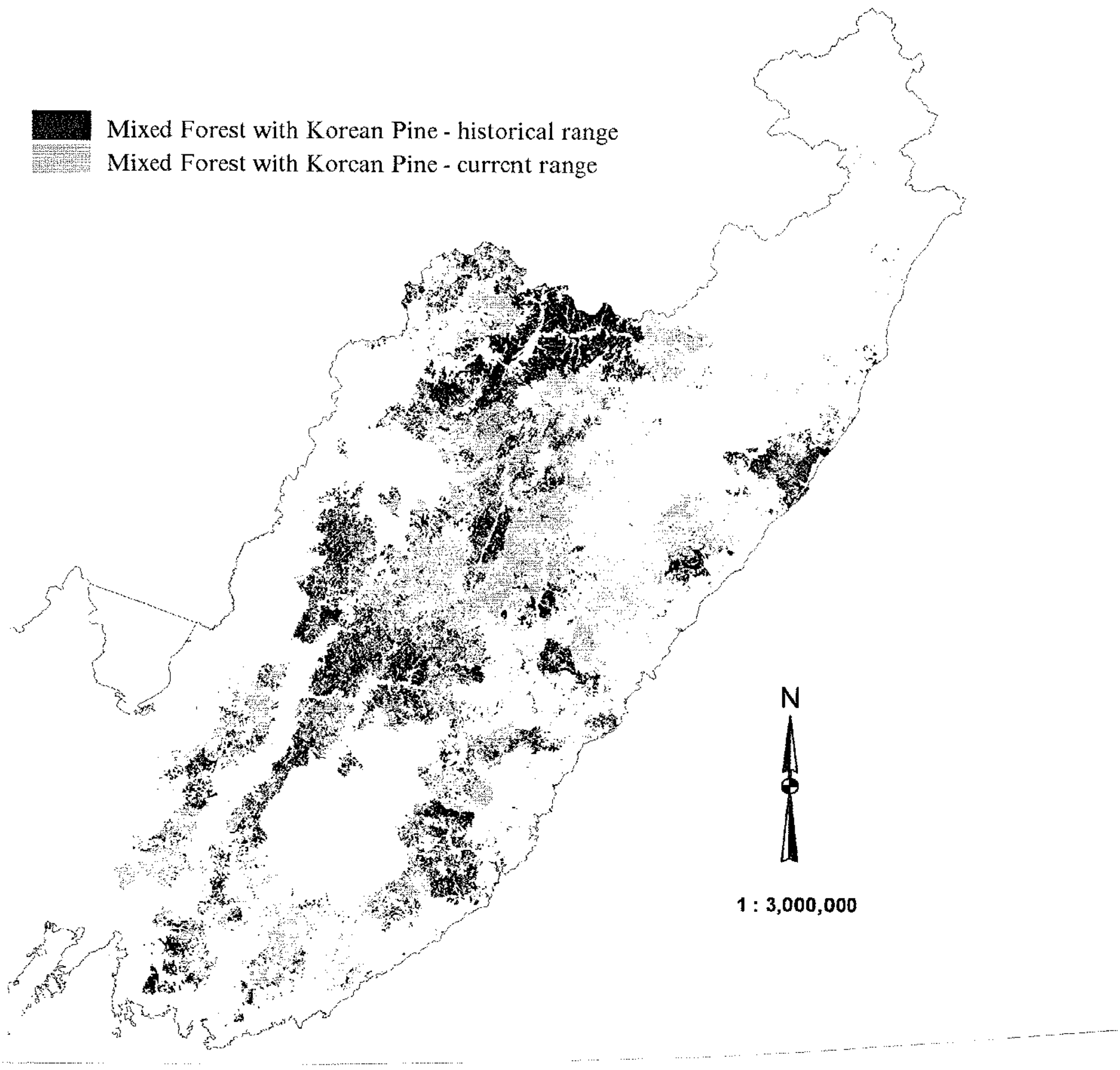

Figure 2.—*Historic and current ranges of the mixed forest with Korean pine (1940-1990).*

In some parts of such areas of young stands, there are no coniferous species or their number is insufficient and a natural source of seed material is lacking. It can hardly be expected that in the near future an artificial planting of coniferous trees will be done there. Therefore, it can be assumed that a number of elements of BD at the species and cenosis levels have been lost for a long time and some of them, probably, forever.

In areas with the greatest degradation of coniferous-broad-leaved forests (to the level of the abovementioned tree and shrub thickets), the full restoration of the former BD in the visible future is practically impossible, because the habitat there has been radically transformed. The necessary and only possible real measure will be the protection of this territory (several hundred thousand hectares in Primorskii krai) from fires, which will help the young stand of *Quercus mongolica* to be restored there.

Considering the already existing negative effects of forest use in the Sikhote-Alin, it is evident measures should be developed promptly for more strict regulation of forest use, which will help conserve BD in the forests that have not been damaged or that have been only slightly damaged by exploitation. This transition to the principles of inexhaustive forest use guarantees a sustainable development of forestry and preservation of the conditions of life sustenance of the aboriginal peoples that live in the Sikhote-Alin and continue to keep their traditional economy.

The forestry status of the forests is of the main importance. In Russia the forests are divided into three groups (categories) in accordance with this characteristic. The first group includes the forests, in which their protective ecological functions are considered to be the main ones (water protection, anti-erosion, health protection, nature conservation, and others, in total over 20 categories of "protection"). The third group includes the forests of the so-called multi-forest areas, in which the industrial (resources) significance of the forests is of the main importance. The forests of the second group occupy an intermediate position. They are considered to be of limited industrial importance. Most commonly they are distinguished in the areas with a scarcity of forests.

Over 70 percent of the forests in the southern part of the Sikhote-Alin and over 80 percent in its northern part belong to the forests of the third group, in which the main method of FGU is clearcutting. However, by the conditions of growing, all forests of the Sikhote-Alin are mountain forests. Use of clearcutting in the mountain conditions contradicts the very essence of their existence, disturbs the local and regional ecological balance, and does not correspond at all to the tasks of the conservation of BD of forest ecosystems at all levels. In such conditions, it is impossible to comply with the main principle of inexhaustive and continuous use of all functions of the forests.

By now in the Sikhote-Alin, there are over 20 confirmed and planned territories of traditional nature management (TTNM) of the indigenous peoples. Clearcutting on TTNM disturbs the conditions of the life sustenance of aboriginal peoples, because it changes to a significant extent the conditions of their living and traditional economy.

We consider these arguments to be sufficient to prohibit clearcutting in the Sikhote-Alin. Practical implementation of such a prohibition is complicated and prolonged, but first and foremost, clearcutting should be prohibited under the following conditions:

- at mountain slopes with a steepness over 15°,
- in all forests of group 1 where they are still permitted,
- in all forests—TTNM of aboriginal peoples,
- in forests of groups 2 and 3 impoverished by previous felling.

It is suggested to also prohibit all kinds of FGU at slopes steeper than 25° and in all the forests at a height of 1,300 m and more above the sea surface, regardless of the form of the landscape and the steepness of the slopes. Therefore, the main kinds of FGU in the Sikhote-Alin should be selective and gradual felling.

It is necessary to permit selective felling under the following conditions:

- at a height up to 750 m above the sea level,
- at plateau-like sites and slopes with a steepness up to 15°—intensity up to 30-35 percent per one felling, with a recurrence in 20 to 30 years,
- at slopes with a steepness over 15°—intensity to 20 percent with the same recurrence,
- at a height over 750 m above the sea level—at all slopes—intensity not more than 20 percent.

Step-by-step felling should be applied mainly in the secondary larch-fir, birch, birch-fir, and birch-larch forests. The duration of step-by-step felling from the first to the last step should be 35-40 years with the main wood species *Picea*, and 20-25 years with the main species *Larix*.

At present, *Pinus koraiensis* and *Abies holophylla* are included in the number of wood species in which FGU is prohibited. But the rules currently in force allow two kinds of felling: "passage" felling that is the final stage of improvement felling before main felling and "sanitation" felling to remove the "sick" trees that supposedly can threaton the "health" of the neighboring trees. The criteria of selecting the trees for these kinds of felling are very uncertain, which allows their subjective interpretation and, as a result, abuse. Previously, before the general prohibition of felling of these wood species for general use, "passage" or "sanitation" felling in the forests was almost never used. Now they are used on a large scale and represent nothing else but disguised prohibited FGU. To preserve BD, it is evident that the notions of "passage" and "sanitation" felling in relation to the species that are especially valuable (*Fraxinus mandshurica*) should be eliminated from use.

A very important thing in the organization of inexhaustive nature management in the broadest sense of this notion is the calculation of permissible annual volume of felling—calculated wood-felling area (CWFA) in case of a clear felling method. As a rule, CWFA that was calculated for large forest management units (forestry unit, state forest enterprise) was used in specific small and medium river basins, for which this felling level was very exhaustive and led to the long-term losses of species and cenosis BD. From now on, until clear felling in the Sikhote-Alin is prohibited, CWFA must be determined for each river basin with an area of not more than 25-30 thousand ha.

As a whole, the discussed measures of the regulation of forest use will make it possible to neutralize gradually the damage that has already been done to BD and to the productivity of the forests of the Sikhote-Alin, and they will prevent the development of some negative tendencies in future forest use. Clearly, in addition to the forest management measures, other measures of BD preservation at all levels are developed and used. They include, for example, the creation of a complex of specially protected territories, the preparation of the materials for the inclusion of a part of the Central Sikhote-Alin in the "Nature World Heritage List," and other actions, but their suggestion and discussion are beyond the framework of this communication.

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