Trends in vegetation cover dynamics in the Russian part of the Amur River basin in relation to the economic development of the territory

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Abstract. This work presents the research results in condition and trends in the vegetation cover of the Amur River basin resulting from economic activities. The economic activity impact is assessed both directly and indirectly. Vulnerability of the vegetation cover in the Amur Region is determined according various factors: ecotone position, unstable living environment; relict nature of plant taxa and communities and low degree of adaptation; insularity of relics, endemic taxa and communities. Risk factors for the plant cover of the Amur Region include large-scale fires, continuous plowing of lands, forest cuttings, construction of hydraulic facilities (hydropower stations and reservoirs), expansion of road infrastructure, mining of non-ferrous metals, etc. The effects of development on the Amur Region territory include discontinuity of the habitats of many relict and endemic species, increase of the pattern structure of their spatial distribution and formation of isolated, unstable populations, decrease in the floral and regional ecological diversity of biogeocenoses, synantropization, unification of the vegetation cover, transformation and destruction of historically established ecosystems, habitats and increasing environmental risks. Four types of ecological state are identified: catastrophic, critical, stressed and satisfactory. The identified zones of catastrophic and critical ecological states of the vegetation cover are confined to the most developed southern parts of the Amur Region and urban agglomerations. Most of the Amur River basin features stressed and satisfactory ecological states, the preservation of which is facilitated by the inaccessibility of these territories.

1. Introduction
The basin of the Amur River has great potential: it contains minerals and lands suitable for agricultural development, hydropower and other resources. Its favorable location allows the greatest economic effect with the minimum labor costs, which can be considered as one of the main factors in the economic development of the territory. A specific feature of nature management of the region is its unsustainable nature, development on the basis of involvement in economic turnover of new natural objects located in poorly developed or undeveloped areas, without investing in further growth of developed territories [1]. Moreover, the existing culture and management methods, powerful onslaught of techniques and technologies not adapted to natural environment, have already led to inevitable changes in the environment.

Complex natural and climatic conditions make the situation even more difficult. The Amur River basin is located on the eastern edge of Asia within the zone of active interaction between the mainland and the Pacific Ocean. This determines the high contrast range between natural and climatic conditions,
the combination of natural boundaries of plant formations of different phratries and their vulnerability to the economic impact.

As the main structural and functional component of ecosystems and vegetation cover is acutely responsive to changes in natural environment. Identifying the trends in its dynamics, assessing the impact of anthropogenic factors on the vegetation cover in modern conditions constitute the basis for planning nature use, taking into account the objectives of conservation of biological diversity and ecological functions of the vegetation cover, and identifying mechanisms of phytogenic landscape stability.

2. Objects, data and methods
The purpose of this research was to study the state of the Amur Region vegetation cover and to identify trends in its development in connection with anthropogenic development. Scientific research works in this field cover a period of more than 20 years.

Detailed route field monitoring surveys were carried out in selected parts of the Amur River basin with varying degrees of involvement in economic activities, which can be considered as model test sites. Methodological developments were used to assess the indicator properties of plants at different levels and in different types of landscapes. The main quantitative and qualitative aspects of indicator species and community populations were used as criteria [2, 3].

Both direct and indirect economic impacts on the vegetation cover were assessed [4]. The direct impact is associated with partial disruption or complete destruction of the original type of vegetation cover. The restoration of vegetation cover in this case is determined by the intensity and consistency of the measures taken, degree of vegetation cover disturbance and the course of successional vegetation changes. The indirect impact is associated with changes in natural and technological factors (humidification, dust pollution, admitting light, chemical pollution, etc.). This occurs mainly in the territories adjacent to the economic sites and located in the area of their influence. Biogeocenoses of these regions are in the state of successional alterations under changing environmental conditions. The reaction of plant populations to environmental changes is determined by their ecological valence. The more sensitive the species are to specific environmental conditions, the more drastic would be the changes in these conditions for their populations.

3. Results and discussion
The nature and intensity of the vegetation cover changes determine the level of impact on vegetation cover (from organismic to biocenotic).

Vulnerability of the Amur Region vegetation cover is determined by various factors: ecotone position and, consequently, unstable living environment; relict nature of plant taxa and communities, their unsuitability to modern natural and climatic conditions, low degree of their adaptation; insularity of the relict, endemic taxa and communities.

Risk factors for the plant cover of the Amur Region include (table 1):
- large-scale fires,
- continuous plowing of the Zeya-Bureya and the Middle Amur Lowlands, in the upper reaches of the Amur River;
- forest cuttings;
- construction of hydraulic facilities (hydro-electric stations and reservoirs);
- expansion of road infrastructure, mining of non-ferrous metals, etc.

Development of the Amur Region has resulted in the following problems:
- discontinuity of the areas of relict distribution, endemic species, increasing the pattern structure of their spatial distribution and the formation of isolated unstable populations;
- decrease in the floral and regional ecological diversity of biogeocenoses;
- synanthropization, unification of the vegetation cover;
- transformation and destruction of historically established ecosystems and habitats;
- increasing environmental risks.
increasing, assessing the transformation level of vegetation

The critical level of the ecological situation manifests in certain areas of the central and southern regions of the Amur Region, local areas on the slopes of the mountain systems Sikhote-Alin, Badzhalsky, Dusse-Alin, etc. The deterioration of the ecological situation is caused by logging, agricultural land use and fires, which differ in the degree of impact on vegetation cover.

Table 1. Description of the leading risk factors for vegetation cover.

| Description of the risk factors | Primorsky Territory [5] | Khabarovsk Territory [6, 7] | Jewish Autonomous Region [8] | Amur Region [9] | Trans-Baikal Territory [10, 11] |
|---------------------------------|-------------------------|----------------------------|----------------------------|----------------|-----------------------------|
| a. Agricultural sector          |                         |                            |                            |                |                             |
| The area of agricultural land   | 1399.10                 | 665.60                     | 537.30                     | 2733.50        | 7645.60                     |
| (thou ha), including:           |                         |                            |                            |                |                             |
| - tilled fields (thou ha)       | 703.70                  | 98.60                      | 94.70                      | 1595.70        | 484.00                      |
| - laylands (% of the land area) | 29.10                   | 3.70                       | 13.10                      | 8.30           | 12.40                       |
| b. Forestry sector (according to data for 2019) |           |                            |                            |                |                             |
| Controlled felling area, mln m³ | 6.20                    | 27.90                      | 1.13                       | 13.60          | 16.32                       |
| Volume of timber harvested, mln m³ | 4.13                    | 7.62                       | 0.23                       | 3.67           | 1.73                        |
| Number of fires, pcs            | 574.00                  | 479.00                     | 109.00                     | 455.00         | 807.00                      |
| Total area swept by fires, thou ha | 63.32                  | 314.90                     | 104.65                     | 291.40         | 367.70                      |
| Forest restoration, thou ha     | 12.82                   | 66.62                      | 2.11                       | 3.36           | 2.63                        |

A disproportionate pressure on ecosystems disrupts inter-ecosystem connections and increases the contrast range of the environment, making plant communities more fragmented. The number and diversity of new ecotones and emerging young ecotonic ecosystems is increasing, as well as the ecotization of vegetation cover.

Four ecological states have been identified after assessing the transformation level of vegetation cover in the Amur River basin based on the complex criteria developed by B.A. Voronov, Z.G. Mirzekhanova and S.D. Schlotgauer [4]: catastrophic, critical, stressed and satisfactory (figure 1).

The environmental situation in the areas of cities and their suburbs, major centers of the mining industry (Luchegorsk, Raichikhinsk, Solnechny, Mnogovershinny, etc.), local sections of mountain territories that have been repeatedly affected by catastrophic fires over the past decades, is highlighted as catastrophic. The complex of existing problems is connected with intensive industrialization and lands use of the territory without taking into account its natural capability and preventive nature protection measures. The catastrophic situation is aggravated by pollution and lack of minor river resources, especially near industrial centers, loss of soil fertility, forest fires and logging, absence or insufficient number of sanitary and discharge zones.

The ecosystems have been completely transformed and the indigenous vegetation cover is completely destroyed and its restoration in a natural way is not possible. The structure, biological turnover and other features of the vegetation cover are almost completely regulated by a human being. Directed restoration of vegetation cover in the form of forest plantations, reclamation activities on dumps, quarries, landscaping in localities, etc. are carried out.

The critical level of the ecological situation manifests in certain areas of the central and southern regions of the Amur Region, local areas on the slopes of the mountain systems Sikhote-Alin, Badzhalsky, Dusse-Alin, etc. The deterioration of the ecological situation is caused by logging, agricultural land use and fires, which differ in the degree of impact on vegetation cover.
Figure 1. Territorial zoning by ecological states of the vegetation cover: case study - the Lower Amur Region.

The development is ongoing and increasing in its intensity; as a result the vegetation cover is greatly transformed and the most adaptive species, such as Betula platyphylla, Populus tremula, Larix cajanderi, Alnus hirsuta, Populus suaveolens, Salix schwerini, S. bebbiana, Sorbaria sorbifolia, Betula fruticosa, B. ovalifolia, Calamagrostis langsdorffii, Artemisia rubripes, A. annua, A. commutata and others, which form white birch, larch, aspen and mixed derivatives of forests and sparse woods, crowberry and willow shrub thickets, reedgrass, mixed reedgrass, mixed sagebrush groups, etc., are preserved. The restorative functions of the phyto gene bank are disrupted so that the vegetative and seed renewal cannot ensure the reproduction of cenopulations; additional measures are required.

The hotspots of tension are delineated within some areas of the central and southern parts of the Amur Region. The complex of existing problems is comparable to the above-mentioned, but their apparent impact on ecosystems is somewhat lower. The vegetation cover is not subjected to severe
transformation – particularly vulnerable rare and endangered species and those at the northern areal limit fall out of plant communities. In some areas, an increase in species diversity is observed due to an increase in the indices of flora synanthropization. Vegetation communities retain the ability to self-regulate their organization. Derived communities feature a simplified structure and reduced species composition. As a result of almost annual fires, the vital activity of some species’ populations has been severely undermined. A “northering” factor, as well as the decrease of vegetative and seed regeneration can be observed; about 70% of floral forms experienced a drop in their population. Species of taiga origin, which can withstand a minimum level of anthropogenic impact, strengthen their positions instead.

We have identified a satisfactory ecological situation associated with poor development of the territory in the northern, central and partly southern regions. These are a kind of “reserve zones” of development, which should remain so in the future. Their ecosystems are stable, but in some areas they suffer from grazing, recreational loads, etc. As a result, the recovery and functioning of the populations of sufficiently adaptive species are proceeding favorably, while those of rare species such as Panax ginseng, Coleanthus subtilis, Cypripedium calceolus, Peonia lactiflora, Coniogramme intermedia, and Lilium pumila are not satisfactory. In ecosystems where the affected areas are small, the transformation is compensated by species of autochthonous communities, development and functioning of which have not been disrupted. They are known for fluctuations and short-term cyclic processes, which serve as thermal stages for successions of development and restoration, adaptive reconstructions of their structure in response to fluctuations in various components of the environment.

Preserved forest, meadow and swamp communities that perform important environmental, water conservation, and biotic functions, with unique relict and endemic plant species included in their vegetation cover, form the core of the Amur Region’s conservation complex [12].

Endemic species are under pressure of anthropogenic factors, and their populations are already adversely affected by mining operations, hydrotechnical activities in river floodplains, land improvement works and recreational impact. Expansion of mining zones is expected to reduce the range and destroy a number of cenopopulations of local endemic species of mountain systems: Saxifraga korshinskii, Aster woroschilowii, Saussurea tomentosa, S. splendida, Spiraea schlothgauerae and others. As a result of regulating the Amur River due to the construction of hydropower plants and reservoirs, it is expected that there will be a concomitant change in the flood regime of rivers and changes in the biological regimes of bottomland plant communities, and the disappearance of endemic species of ephemeral wetland vegetation of the Amur River: Symphyllocarpus exilis, Chenopodium amurense, Potentilla amurensis, Alopecurus longiaristatus and others. This is due to the fact that endemic species are narrowly specialized and adapted to grow only under specific conditions. At present, only very small populations of them can be found in this area. The change or destruction of their habitats will lead to the extinction of such species and the vacated ecological niches will be occupied by synanthropic species with a more extensive distribution and of wide ecological range.

Unidirectional selection aiming at homogeneity of the plant world, simplification of the species diversity, unification of the biotic component is inevitably accompanied by a decrease in the resistance of terrestrial and aquatic ecosystems to various impacts, limiting the ability of plants to adapt to rapidly changing environmental conditions. Populations weakened as a result of anthropogenic impact do not have sufficient adaptive capacity and resistance. A tendency towards a decrease in the floristic regional ecological diversity of biogeocenoses was also noted. The disproportionately strong impact on ecosystems of ecotones disrupts interecosystem connections and increases the contrast of the environment, making plant communities more subdivided and fragile. The number and diversity of new ecotones and emerging young ecotone ecosystems is increasing, and the ecotomization of the vegetation cover is increasing. The current pace of development of the region, ways of exploiting natural resources and production technologies cause degradation of vegetation cover as a result of direct and indirect anthropogenic impact, which is becoming more noticeable and sometimes irreversible.
4. Conclusion
The anthropogenic transformation of the vegetation cover in the Amur basin is manifested in the expansion of areas with completely destroyed or disturbed natural vegetation, fragmentation of habitats, a decrease in the number, occurrence and activity of populations of native species of flora, and an increase in the processes of synanthropization of the vegetation cover. The identified zones of catastrophic and critical ecological state of the vegetation cover are confined to the most developed southern parts of the Amur Region and urban agglomerations. The condition of ecosystems in areas of significant size is determined by agricultural and forestry nature management, as well as by mining and processing activities on local sites. Most of the Amur Basin features stressed and satisfactory ecological states, the preservation of which is facilitated by the inaccessibility of these territories. Risk factors for vegetation cover include forest cuttings and fires that accompany such activities.

With the increase in economic activity in the lower reaches of the Amur River, and with the preservation of the remaining principles in the field of scientific support, development and implementation of measures for the sustainable development of the territory with the preservation of landscape and biological diversity, a significant deterioration in the ecological state of ecosystems is likely to occur in the coming decades. First of all, this will affect the additional violation of the integrity of the range of many species. Population fragmentation and growing isolation between them will deplete genetic resources and disrupt the relationship between the fragmented northern and southern populations, which in turn will limit the ability of the plants of these populations to adapt to dramatically changed microclimatic conditions. Species on the northern border of distribution will be the first to become endangered. These are mainly species whose center of habitation is located in the south of East Asia: Taxus cuspidata, Nelumbo nucifera, Brasenia schreberi, Asplenium tenuicaule, Dennstaedtia wilfordii, Phyllitis japonica, Platanthera ophrydioides, Smilax maximowiczii and others.

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