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GENERAL BIOLOGY

Ecological Modeling of Yamal Tundra Ecosystems: Traditional Nature Use as a Factor of Instability

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This paper represents the results of a comprehensive study on the consistent patterns of the functioning (dynamics) of the shrub and northern tundra ecosystems of the Yamal Peninsula that have been subjected to long-term anthropogenic impact connected with the traditional reindeer breeding and are now subjected to some new influences connected with the development of the oil and gas industry. The study is based on the integration of data accumulated during several decades of investigation of Yamal ecosystems in which we have participated.

The main approach to solving this task was the use of system analysis, which implies the development of modeling (computer) models describing interactions between the key components of the northern and shrub tundra ecosystems of the Yamal Peninsula and verification and analysis of these models. Shwartz [1] considered that such a model can be developed only on the basis of actual data on the structure and dynamics of basic components ("blocks"), composing the "core" of tundra biocenoses and including plants, small mammals, reindeer (mainly domestic), predatory mammals (mainly Arctic foxes), and birds of pray. The above-mentioned components are functionally related with one another; as a rule, these relations are complex (nonlinear), which complicates the prediction of the ecosystem dynamics [2]. Tundra ecosystems of the Yamal Peninsula are considered to be a constellation of two overlapping subsystems, natural (biogeocenosis) and anthropogenic (anthropogeocenosis), which surrounds humans and "works" for them [3]. A simplified diagram of such a system is shown in Fig. 1.

In this paper, we describe only the results of our analysis of the influence of deer breeding (the main type of the traditional nature use in terrestrial Yamal ecosystems) on the vegetation; we did not take into account hunting, because it is less important for both economics of the aboriginal population and vegetation

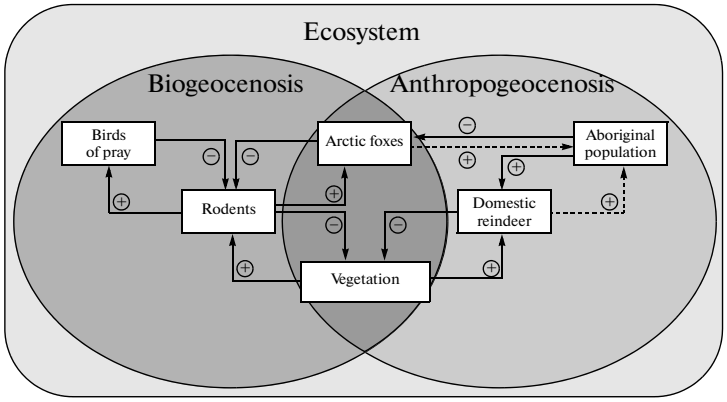

Fig. 1. The schematic diagram of the Yamal tundra ecosystem serving as the basis for modeling. Dashed lines indicate the influences related to advantages from nature use. Solid lines indicate the direct influences and interactions. The plus and minus signs indicate positive and negative relations, respectively.

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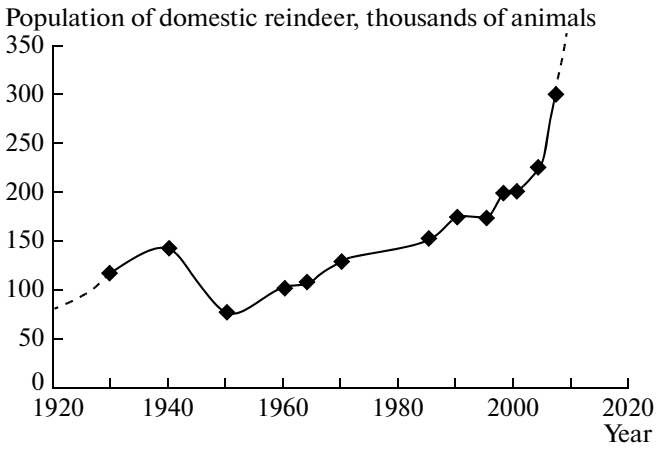

Fig. 2. Dynamics of the reindeer population of the Yamal Peninsula in the 20th and early 21st centuries according to the data of the Department of the Development of the Agroindustrial Complex of the Yamal–Nenets Autonomous Area.

dynamics. The model was developed and analyzed using the AnyLogic 6 University software.

The Yamal Peninsula is a unique transpolar region of Russia. In contrast to most of other similar regions with traditional reindeer breeding, the number of domestic reindeer in this region has not decreased during the past decades; moreover, a significant growth of their population has been observed (mainly due to private herds; Fig. 2).

At the same time, among aboriginal northern ethnic groups, the population growth was the maximum in Nenets, who are the main reindeer breeders of the region; this fact evidences that, during the period of reforms, extensive development of the traditional nature use was significantly stimulated. For example, the average annual increase in the Nenets, Khanty, and Chukchi populations during 1997–2000 was 1.6, 0.85, and 0.8%, respectively, whereas for other northern ethnic groups this value was about zero or even negative [4].

Russian sources on northern reindeer breeding usually consider lichens to be predominantly winter forage, whereas grass and shrubs constitute summer forage. The comparison of the current state of tundra vegetation with Andreev's [5] data on the 1930s showed that the forage plant reserves of the Yamal peninsula significantly decreased (Fig. 3).

This information was used to verify our model. During the modeling, a domestic reindeer stock (and its dynamics) was considered as an independent variable (Fig. 1), and the initial conditions were specified

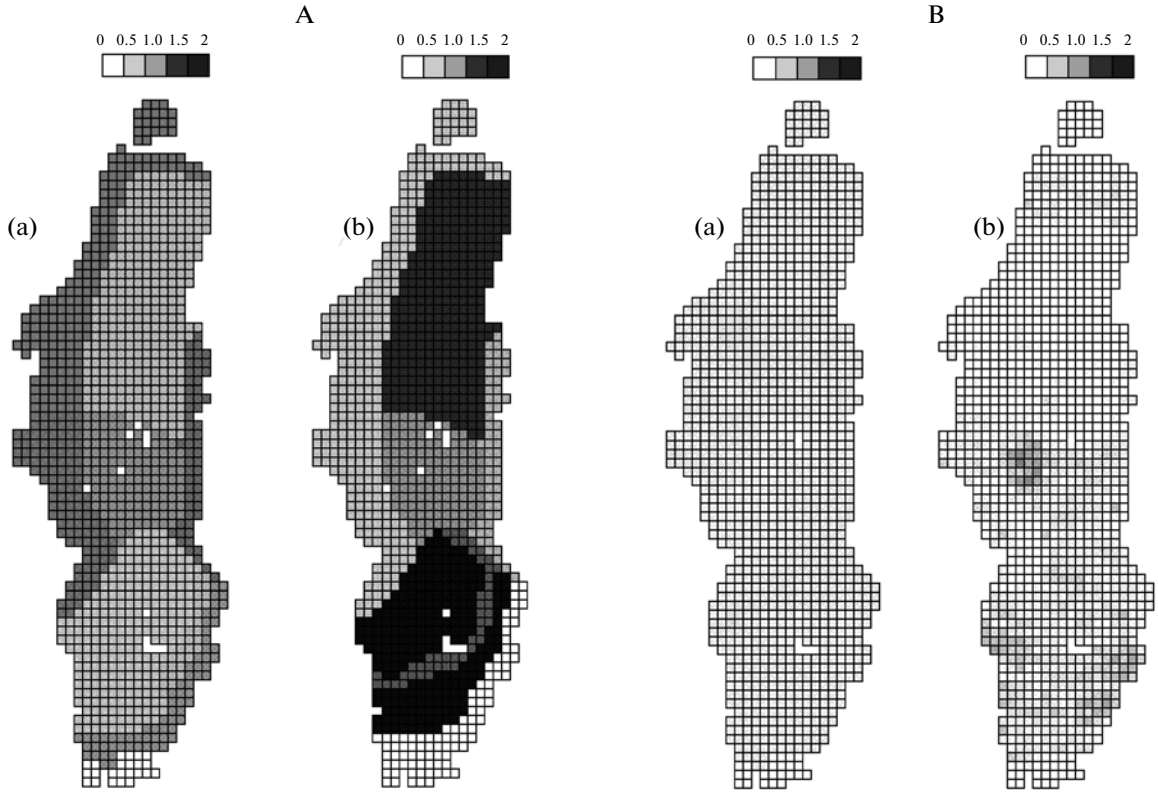

Fig. 3. Decrease in the forage plant stock of the Yamal Peninsula during the period from the 1930s to the end of the 20th century. The area of one square is 10 km^2. (a) Green (summer) forage; (b) lichen (winter) forage. A, forage plant stock in the 1930s, t/ha [5]; B, forage plant stock in 1995 according to the official cartographic data, t/ha [6].

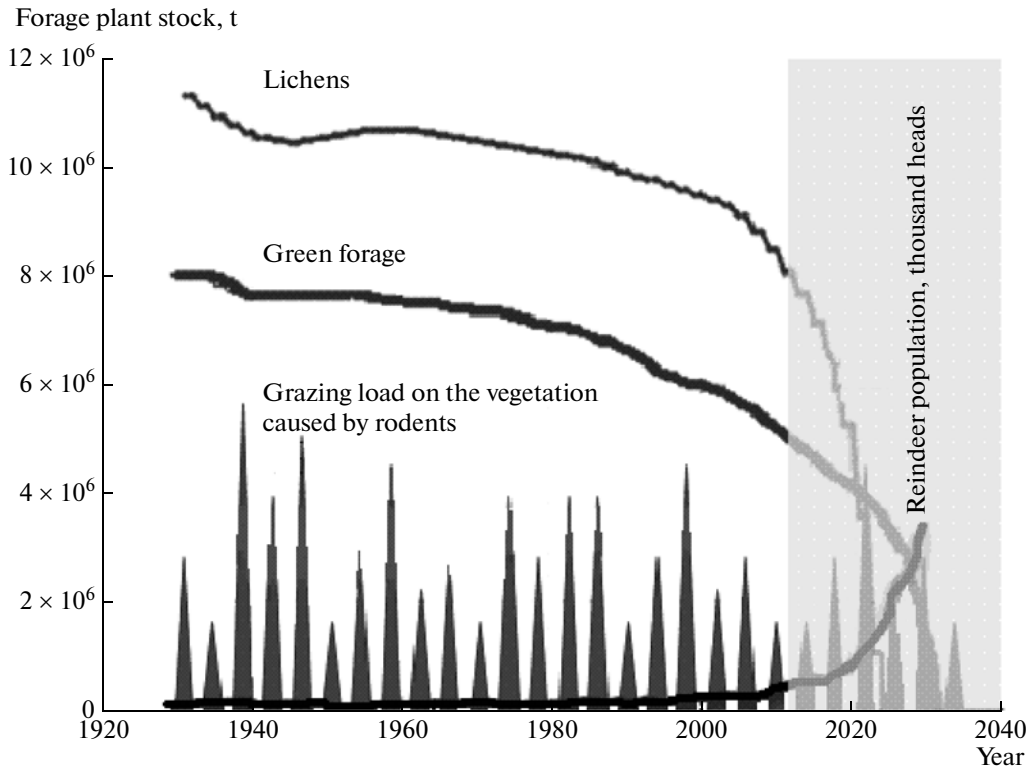

Fig. 4. The simulated dynamics of the forage plant stock of the Yamal Peninsula. The marked area (after 2010) presents a forecast made for the hypothetic case of a continuing tendency of the exponential growth of the domestic reindeer population (which is impossible using only natural forage resources).

according to [5]. We simulated the dynamics of the vegetation for the analyzed period, taking into account both direct grazing load and indirect pasturing influence, especially the mechanical effect (trampling) damaging both aboveground and underground parts of plants. The vegetation recovery rate was calculated on the basis of empirical annual growth data and the dependences described in [7–10]. In addition, we took into account the increase in the populations of small rodents (mainly Siberian and Arctic lemmings), which are also important vegetation consumers in tundra ecosystems. The increase in their populations occurring every three or four years and having a varying amplitude (which corresponds to the results of long-term observations on the Yamal Peninsula) may cause single synergistic effects and significantly enhance the negative influence of the pasturing of domestic reindeer. The results of the modeling allowed us to reconstruct the forage plant stock dynamics in the case of the observed growth of the reindeer population. The trajectory of the dynamic curve, which started from the point determined by the state of the vegetation during the 1930s, ended at the point corresponding to the current state (which was not specified in the modeling procedure); this fact confirms the acceptability of the functional dependences used for the development the model and the modeling (Fig. 4).

In general, the results obtained at the first stage of the Yamal ecosystem modeling do not suggest the necessity to use any other factors (climatic changes, industrial development of gas and oil fields, etc.), except the extensively developing large-scale reindeer breeding, to explain the rapid degradation of the Yamal tundra vegetation in the past decades. This clearly indicates that the rapid growth of the reindeer population is the most important factor of the continuing degradation of the Yamal vegetation, which may become catastrophic in the future. Despite the existing stereotype, the traditional nature use, which is not controlled because of the absence of a science-based ethnic cultural policy, is far from an example of a harmonic coexistence of humans and natural cenoses; on the contrary, the extensive growth of the reindeer population presents a more serious threat for the Yamal ecosystems than, e.g., the development of gas and oil industry.

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