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*CHARACTERISTICS OF LONG-TERM DYNAMICS OF THE BOVANENKOVO GAS FIELD VEGETATION (the Yamal Peninsula)**

SUMMARY. According to the field studies and remote sensing data, structural and dynamic changes of the plant cover on the Bovanenkovo gas field on the Yamal Peninsula for a 20-year period of observations have been analyzed in the article. Analysis of materials of aerial, photographic and satellite surveying in different periods of the development of the field (from the end of the 1980s) have identified tendencies of successions caused by anthropogenic factors. On the sites of anthropogenic impact, vegetation forms several ecological and anthropogenic dynamic rows, the properties of which depend on the types of impact, features of the biotope, and indigenous plant communities. The most active recovery is observed in moss and grass-shrub-moss boggy tundra areas and grass-hypnum communities in gullies. Revegetation of drained lakes ("khasyreys") along with formation of gigrophytic grass-sedge-hypnum communities is commonly observed. Active growth of shrub communities typical of southern subarctic tundra areas is revealed, which corresponds to the ideas about the impact of warming on arctic ecosystems.

KEY WORDS. The Yamal Peninsula, the Bovanenko gas field, tundra vegetation, succession.

The forecast of environmental implications of commercial exploitation of the Yamal Peninsula needs structural-dynamic peculiarities of vegetation to be researched. Vegetation is a vital element of polar geosystems, which keeps the thermal regime and stability of permafrost formations. That is why phytobiota preservation is significant for geosystems integrity and engineering constructions' stability.

According to O.V. Rebristaya, the Yamal flora consists of 406 higher tracheophyte species, and it is taxonomically poor [1]. Although, the lack of vegetation diversity is compensated by the rich variety of biotopes, tansformed by exogenic geomorphological processes. Vegetation dynamics and constant stress factor influence caused many syntaxonomic units to appear [2]. The plant cover of the Yamal Peninsula is evolutionally

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young and therefore unstable, thus anthropogenic influence can change its structure and dynamics. Despite the poor biodiversity of the Yamal flora, some species are considered rare, endangered, and many phytocenoses are vulnerable to technogenic influence. Therefore, field development on the Yamal Peninsula raises the question of the conservation of certain populations, as well as vegetation as a whole.

The conservation and restoration of biological diversity should consider zonal specifics of anthropogenic succession [3]. Successional vegetation changes on the sites of disruption dispersion in tundra zone have been repeatedly described [4–9]. But long-term observations are quite rare, as they are difficult to conduct. It is still unclear which parameters of tundra ecotopes of the central Yamal have most influence on exogenous succession; the order of successions and the set of cultures and community parameters that can indicate such processes are also unknown [10].

In 1987–90, the IPDN of Siberian Branch of Academy of Sciences of the USSR employees actively studied the vegetation cover of the Yamal Peninsula. At that time they conducted a complex estimation of vegetation structure at the Bovanenskovo and Kharasavey gas fields, studied dynamic successions on depleted sites, developed methods of estimation of tundra geosystem stability, and performed a large-scale phytoecological mapping [8, 11, 12]. The field work required a lot of route observations with vegetation description and aerial photointerpretation; they have made a set of ecological profiles, covering valley divide and lacustrine divide types of landscape linking. Besides, anthropogenic dynamics were studied at 15 sample areas, planted in 1987–1989, which included a wide range of landscape-ecological conditions.

Since then, a lot has changed: gas fields' infrastructure, environmental legislation, and the nature and intensity of man-induced impact on plant cover. The question of global warming influence, marked in arctic and subarctic zones, became urgent. This is the reason to compare the 1980s data with the current condition of plant cover. The evaluation of the changes of the past 20 years can determine long-term trends of vegetation and geosystem changes, induced by exogenous and endogenous factors.

This article presents the results of retrospective analysis of plant cover structure of the Bovanenkovo gas field since 1980s. Apart from traditional geobotanic research methods (the description of plant cover of sample sites), cartographic and geo-information methods have been used. One of the most efficient ways to research vegetation dynamics is the analysis of remotely-sensed data – aerial and satellite photographs. Multidimensional use of satellite imagery is the most efficient method of environmental monitoring. Remote sensing is widely used to analyze geo-ecological conditions of the north of West Siberia nowadays. According to remote sensing data, we have evaluated geo-ecological risks at the gas fields of the Yamal Peninsula [14–16] and assayed the landscape transformations of the Taz Peninsula in the area of gas recovery impact [17].

To analyze the changes of plant cover structure, we have used archival large-scale (1:15000) aerial photographs of 1988 and 1990 and modern space images available on the Internet: Quick Bird (spatial resolution: 2.5 m, Google Earth) and WorldView-2.

Using the photographs, we have created large-scale plant cover maps, estimated the coverage of technogenic vegetation depletion and the length of linear depletion (off-road vehicle tracks); after that, we have compared the vegetation conditions of two stages of field development.

The research site is situated in the south of the Bovanenkovo gas field (northern part of the subzone of typical subarctic tundra zones) [18]. During the geobotanic research and large-scale vegetation mapping, we have determined, in total, 32 units of plant associations, detailed description of which can be found in earlier works [8, 19]. The characteristics of the plant cover of the Bovanenkovo gas field differ considerably from the ones of the central and eastern parts of the Yamal Peninsula in the same subzones [8]. Tussocky shrub-moss and shrub-moss-lichen tundras, typical of the zone, occupy small portions of dividing ridge prominences. At present, as well as in the times of early gas field development, low angle wavy loamy divides are dominated by poorly shrubbed moss tundras with prevalence of willows (Salix glauca, S. lanata) and less frequent occurrence of dwarf birches. The dominant species of grass-shrub layer are carex (Carex. arctisibirica) and gramens (Arctagrostis latifolia, Poa alpigena). Motly grasses (Saxifraga punctata, Pedicularis sudetica, Ranunculus borealis, Valeriana capitata) are less abundant here. The moss-lichen layer is stocked closed, with predominance of Cladonia deformis, Cl. coccifera, Cladina mitis, Cl. rangiferina, Cetraria cuculata, Alectoria nigricans. Divide slopes down to flood-plains and wide cluffs are populated by willow-shrub and grass-moss communities with Equisetum arvense, Veratrum lobelianum, Dicranum elongatum, and Hylocomium splendens predominant in the ground cover. Swamp tundras are quite rare, as divides are well drained in the area. The prevailing types of plants are low shrubs (with dwarf birches in predominance), cottongrass-gramen-carex-moss vegetation with sphagnum, and tussocky tudras, occasionally combined with cottongrass-sphagnum associations.

The slopes of terraces above flood-plains are mostly populated with willow-grass-horsetail-moss communities, changing into hygrophobic or occasionally flooded communities (gramen-carex-cottongrass, marsh cinquefoil-cottongrass-sphagnum) in lows. The vegetation of flood-plains consists of grass-carex, willow-shrub and carex-sphagnum communities. Well drained areas of the lower ecologic layer are covered with grass-carex (Carex stans,C. aquatilis, Ranunculus acer, Pedicularis verticillata, Chrysosplenium alternifolium) and grass-gramen (Arctagrostis latifolia, Poaalpigena, Alopecurus borealis, Saxifraga punctata) communities. At a higher level, they change into willow-shrub (Salix lanata, S. phylicifolia, S. glauca) and grass meadows, which have a well-developed ground cover of green moss (Aulacomnium turgidum, Hulocomium splendens var. alaskanum, Tomenthypnum nitens, Dicranum congestum).

The technogenic impact on the ecosystem of the Bovanenkovo gas field for the given period of time is mostly caused by the development of gas recovery and transportation infrastructure. Groups of wells, field bases and camps, and building services have been created in the area of the gas field. According to the results of space images interpretation, exogenous and endogenous factors of technogenesis caused the structure of plant complexes to change since the 1980s.

The exogenous dynamics are influenced by the development of engineering construction and transportation infrastructures, cryogenic processes, and drainage disruption. As a result of engineering construction development, the area of technogenically transformed biotopes has increased. In particular, active construction works have taken place in the south of the gas field, in the valley of the Seyakha River. In the late 1980s, the most influenced areas were flat and low-inclined surfaces of dividing ridges with shrub and grass-moss tundras, but nowadays, vegetation depletion can also be found in flood-plains with shrub-meadow-marsh plant complexes and terraces above flood-plains with grass-shrub-moss tundras. As a result of the depletion, thermokarst, thermoerosion, solifluction, and soil expansion take place, although the main cause of biotope changes is the increase of soil hydromorphism due to ground water runoff disruption (Fig. 1). Open plant communities, the composition of which is mostly defined by the default cenosis and ambiance, grow on underflooded lands. The plant communities of watered grounds commonly consist of hydrophytic carex, sphagnum, hypnum moss, and cottongrass.

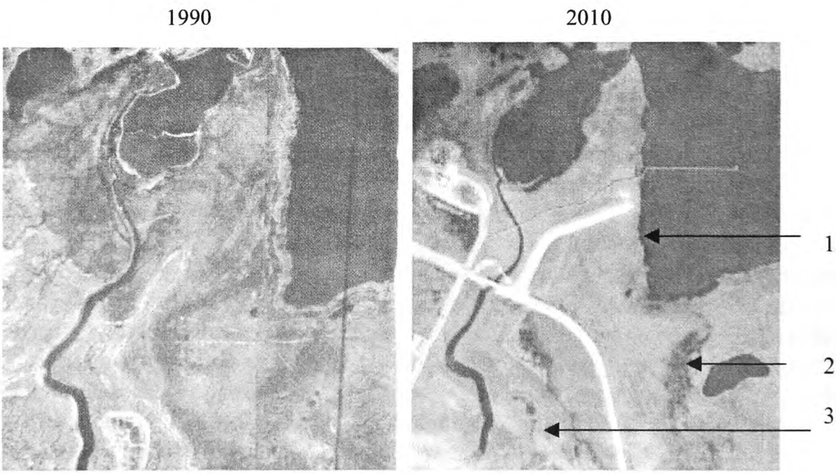

Fig. 1. Biotope changes at technogenesis sites (the south of Bovanenkovo field): extension of the lake area as a consequence of thermal abrasion (1), formation of flooding plots as a result of thermal subsidence of water flow disruption (2), drained-off lake overgrowing (3)

As off-road transportation has considerably reduced since the 1980s in the area, vegetation began to restore on the old vehicle tracks. Depending on the degree of depletion, two variants of restoration succession are possible. If the degree is low, default phytocenoses tend to restore. Intense depletion (when peat horizon is disrupted and the coverage of default cenoses is lower than 20%) leads to the formation of gramen communities. The total length of linear depletion, caused by off-road transportation, reduced, as the vegetation has begun to restore due to the absence of disruption load (Fig. 2).

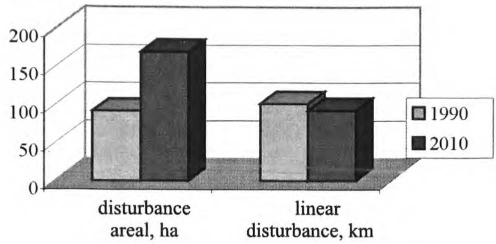

Fig. 2. Changes of the technologically-transformed biotopes area at Bovanenkovo field index plot

The sites with restored plant cover are not vulnerable to exogenous processes, which defines the stabilization of ground thermal regime. The degree of depletion, expressed in terms of relation of the length of linear depletion to phytocenosis area (Fig. 3), reduced in grass-moss marshy tundras on divides (IV), shrub-moss tundras on terraces above flood-plains (VIII), and in cloughs with grass-hypnum moss communities (VI) during the 20 years of observation. This fact confirms the earlier conclusion that the rate of vegetation restoration is higher in hydromorphic and semi-hydromorphic biotopes. The initial stage of anthropogenic dynamics of these biocenoses is characterized by the formation of cottongrass, gramen-cottongrass, and carex-cottongrass communities along with motley grasses.

Several stages are observable in the areas of solifluction ground creep, which appear due to ground thermal regime changes in warm years. The first (hygrophytic) stage is characterized by the formation of pendant grass and cottongrass communities on the depleted substrate; local overwatered depressions are populated with carex (Carex stans). Grounds gradually desiccate and ground creep areas get populated by horsetail (Equisetum arvense) and motly grasses (Tripleurospermum hookeri, Stellaria crassifolia, Cerastium jenisejense), which are gradually replaced by gramens (bluegrass, turfy hair grass). The gramen stage remains for long, but sometimes willow-shrub communities appear, especially if they are spread around the place.

At the Bovanenkovo gas field, one can commonly observe drained-off lakes to be colonized by hygrophytic grass-carex-hypnum moss communities with the predominance of various cottongrasses, carexes, and motley grasses. 9 drained-off lakes (1.5% of the total research site area) are found to get colonized.

We have also detected willow-shrub community (with Salix glauca dominating) areas expanding on dividing ridges and flood-plains. The willow-shrub expansion is found not only in the cases of solifluction, resulting in extra mineral nutrition for shrub communities [20], but also when the biotope functions normally, without direct man-made impact. An example of willow-shrub community formation in the flood-bed of the Seyakha River can be viewed on Fig. 4. The expansion of the area of willow shrub (which is more common for the southern part of subarctic tundra) confirms the gradual shift of latitudinal vegetation zones caused by the warming. The spread of willow-shrub communities is one of the major autochtonous processes of the dynamics of the Bovanenkovo gas field vegetation.

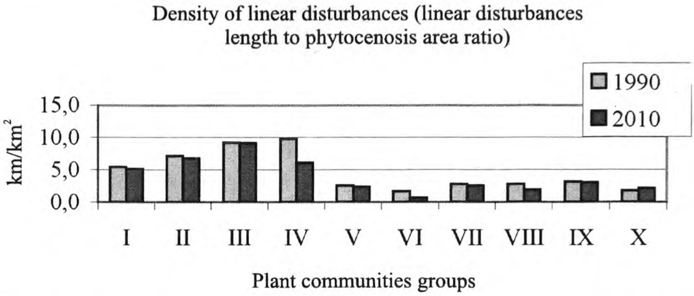

Fig. 3. The level of the area disturbance by transport impact (Bovanenkovo field)
I) shrub-lichen-moss hummocked tundras of watershed ridges; II) bushes and willow grass-shrub-moss (green moss) tundras of low-inclined watershed ridges; III) high bushy (willow-shrub) grass-moss communities of slopes and wide drained hollows; IV) grass-moss marshy tundras of flat slightly drained watershed ridges; V) grass-lichen moss communities of flat-hummocked marshes; VI) grass-hypnum and grass-shrub-moss communities of cloughs; VII) grass-shrub-moss willow and bushes hummocked tundras of terraces above the flood-plain; VIII) grass-moss marshy tundras and grass-hypnum bogs of terraces above the flood-plain; IX) grass-shrub-moss rolling-polygonal bogs of terraces above the flood-plain; X) shrub-meadow-marsh series of communities in floodplains

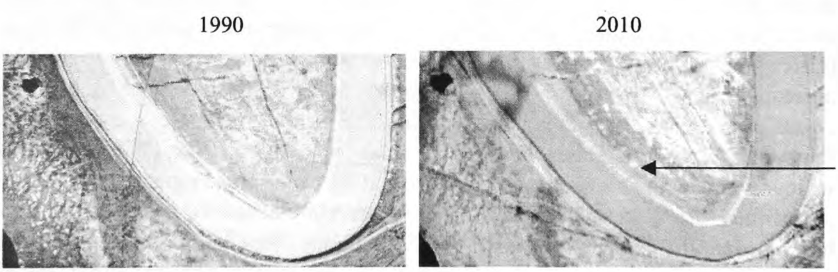

Fig. 4. Extension of shrub communities area (indicated by an arrow) in the Seyakha river, Bovanenkovo gas field

We can also observe the development of exogenous processes – thermokarst, thermoerosion, underflooding, caused by the transportation infrastructure development. In some places, we find the disruption of ground water runoff, which creates watered ground areas with carex-hypnum moss communities. Shrub-meadow-marsh phytocenoses of the flood-plain of the Seyakha River and grass-shrub-moss tundras of terraces above flood-plains have been transformed the most.

At the same time, vegetation restores on the sites, depleted by off-road transportation in the 1980s. At the technogenically transformed sites, we can see the formation of several ecologic stages of plant cover restoration, the properties of which depend on the character of impact and the characteristics of biotope and default phytocenosis. The most active restoration has been found in the watered biotopes: grass-moss swampy tundras of dividing ridges, shrub-moss tundras of terraces above flood-plains, and in cloughs with grass-hypnum moss communities. Although the plant cover restoration on drained dividing ridges did not get any further than the grass-gramen stage. As a result of exogenous and endogenous dynamics, the area of high shrub communities, typical for the southern subzone, has increased.

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