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CHANGES IN VEGETATION AND GEOCRYOLOGICAL CONDITIONS OF THE TAZOVSKY PENINSULA (EASTERN PART) FOR THE PERIOD OF 1988–2016

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Based on field geobotanical descriptions, remote sensing data and analysis of tree-ring chronologies, the dynamics of vegetation in the eastern part of the Tazovsky Peninsula has been studied. The dynamics of vegetation has been shown to be caused by climate changes, and the radial growth of larch, as well as drainage of thermokarst lakes, increases under the influence of climate warming. Reduction in the area of lakes proved to be 20 %, corresponding to the maximal parameters in Western Siberia, suggesting activation of thermoerosion processes. Radial growth of larch has increased at the watershed more than in the floodplain of the Mongayurbey River, indicating an increase in the thickness of the active layer and levelling of the temperature field in various landscape conditions. Anthropogenic succession of vegetation was caused by disturbances during development of the Yurkharovskoye gas field. The sedge-cotton grass and grassy-herb communities of drained lakes ("khasyreys") are restored most rapidly (within 3–4 years) after anthropogenic disturbances. However, the process of formation of dwarf birch-shrub-lichen-moss communities in their place, accompanied by a decrease in the depth of seasonal thawing, takes more than 30 years. The off-road vehicle tracks and other linear disturbances can be traced for 12–20, in rare cases for 25 years on satellite images. Calculation of the normalized difference vegetation index (NDVI) has demonstrated its dependence on air temperatures in the summer and the amount of precipitation of the preceding period, starting from the date of snow cover formation.

Tundras, Tazovsky Peninsula, dynamics of vegetation, climate changes, tree-ring width chronologies, cryogenic processes

INTRODUCTION

Development of hydrocarbon fields in the Arctic regions of Western Siberia makes the study of the vegetation growth dynamics extremely relevant, including its causes, forms of manifestation and the related changes in the geocryological situation. The area of transformed geosystems on the Tazovsky Peninsula constitutes about 10 thousand km^2, or 13.9 % of the territory [*Kornienko, 2011*]. The damage of the vegetation cover results in deepening of the active layer, in a rise in the temperature of permafrost soils, and in activation of the exogenous processes [*Meltser, 1994; Moskalenko, 1999, 2006, 2009*]. The anthropogenic impact results in the formation of plant communities which serve as indicators of changes in the thermophysical properties of soil. For example, formation of a cotton grass-sphagnum bog replacing disturbed flat-topped peat mounds resulted in reduction of the top of permafrost to 2–3 m [*Moskalenko, 2012*]. On frost mounds, the thickness of the active layer doubled after the vegetation was disturbed [*Melnikov, 2012*]. The width of the rings of trees growing in the permafrost zone serves as an indicator of the active layer parameters, as it is associated with the background and local climatic characteristics of different seasons [*Nikolaev and Skachkov, 2011, 2012*].

Climate changes raise the hazard of activation of cryogenic processes. The observations made at the turn of the 21st century showed a trend for the growth of the frozen soil temperatures in the north of Western Siberia [*Pavlov and Malkova, 2010*]. The highest increment of the mean annual air temperature in Russia has been recorded on the coast of the Arctic Ocean, especially in its Asian part [*Report..., 2016*]. It is noteworthy that the changes in the vegetation cover related to climate warming often enhance destabilization of the temperature regime of the permafrost – emergence of trees and growth of shrubs on peatland contribute to snow accumulation and make soil freezing more difficult, while reduction in the abundance of *Cladina* lichens results in the decrease of the albedo [*Ponomareva et al., 2015*].

The goal of the study consisted in identifying the major forms of vegetation transformation related to the anthropogenic impact and current climatic changes and in evaluating the change in the geocryological conditions of the southern tundras of Western Siberia.

THE AREA AND THE METHODS OF STUDIES

The area of the study (Fig. 1) is in the eastern part of the Tazovsky Peninsula, in the basin of the Mongayurbey River and includes the territory of the Yurkharovsky oil and gas condensate field. According to the geobotanical zoning map, it is referred to the subzone of sub-Arctic southern tundras [*Vorobyev and Belov, 1985*]. In the course of the study, a unique geobotanical object was described – extrazonal scarce larch forest in the flood plain of the Mongayurbey River, which is the most northern habitat of the larch (*Larix sibirica*) on the Tazovsky Peninsula [*Valeeva and Moskovchenko, 2008*]. In accordance with the cryolithological map of Western Siberia, the area under study is situated in the trans-Polar zone of continuous permafrost and is referred to the Yamal-Gydan subzone of the Eastern Tazovsky region, in which ice-rich soils prevail, with layer or net cryostructures [*Ershov, 1989*]. Among the permafrost forms of the relief, frosty polygons of thermal contraction cracks, frost heaving and thermokarst phenomena are observed.

The Yurkharovsky oil and gas condensate field, put into operation in 2003, is the main gas production asset of Novatek Company and one of the unique gas condensate fields for the amount of gas extracted [*Medvedev et al., 2014*]. The anthropogenic impact on the field is related to drilling works, laying communication corridors, construction and operation of the complex plants for gas preparation, recycling of drilling mud returns, and methanol production.

To ensure achievement of the goal set, various methods of investigations were applied. As the response of the permafrost zone to climate changes depends on the landscape conditions [*Pavlov and Malkova, 2010*], the prevailing landscape-territorial structures – types of natural boundaries – were identified in accordance with the characteristics of their geomorphology, soil and vegetation cover. The geobotanical descriptions [*Lavrenko, 1960*] were made both for spontaneously developing geosystems and for the anthropogenic impact areas. They were accompanied by description of the soil profiles, primarily of the thickness of peat horizons, by measuring the thickness of the active layer and by recording the exogenous processes. The dynamics of the vegetation cover affected by anthropogenic and natural factors was evaluated using Landsat satellite images [http://www.landsatlook.usgs.gov]. We downloaded all the available Landsat images for the period of 1988–2016 from the Landsat TM, ETM+ and OLI sensors. The images were processed first by the ArcGis and ENVI software and included classification of vegetation, vectorization, and making a geobotanical map. For the mapped units of the vegetation cover, the prevailing exogenous processes and the self-recovery rate were assessed based on remote sensing data (RSD) and materials of filed observations. The dynamics of the landscape-typological complexes and of the corresponding geocryological conditions was assessed by the change in the areas of the thermokarst lakes and khasyreys, of the areas not covered with vegetation (the alluvium of floodplains, eroded sandy hills), and of the areas of anthropogenic impact. The values of NDVI (normalized difference vegetation index) were calculated, allowing assessment of the mass of vegetation and its dynamics, including that caused by the modern climate changes [*Walker et al., 2012*].

To assess the climatic conditions affecting the vegetation, the observation data from the nearest Novy Port and Tazovsky meteorological stations, provided by the federal government organization All-Russia Hydrometeorological Information Institute – World Data Center [http://www.meteo.ru], were analyzed. The local features of the climatic conditions have been investigated based on the tree ring width data measurements of the larch growing under different landscape conditions (floodplain, watershed) [*Cook and Kairiukstis, 1990*]. The response of the tree ring width series to climatic factors has been computed with the software program STATISTICA 10 (multiple regression).

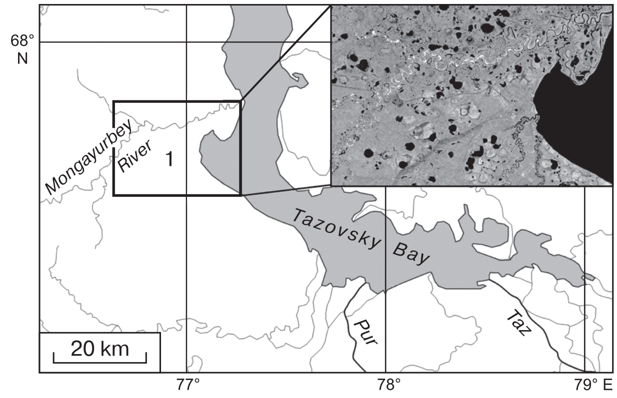

Fig. 1. A schematic map of the region under study (1).

CLIMATIC AND GEOCRYOLOGICAL CONDITIONS

According to the observation data from the nearest Novy Port and Tazovsky meteorological stations, the mean summer air temperature (June–August) rose by 2 °C (by 0.04 °C/year on average) in the period of 1970–2015. Beginning with 1990s, increase in the amount of precipitation in the winter period and in the snow cover thickness (Fig. 2) has been observed, indicating decrease in the winter freezing of the upper soil stratum (the amount of precipitation at

Tazovsky station has been growing on average by 1 mm/year since 1990). The growth of air temperature and of the snow cover thickness results in a rise of permafrost temperature; however, the thermal regime of the soils compared to the atmosphere has been more inert. The change of the mean annual soil temperature associated with the increase in the mean annual air temperature by 1 °C is 0.10–0.25 °C in the tundra zone and by 0.1–0.8 °C in the forest tundra zone [*Vasiliev et al., 2008*].

It was possible to judge about the thermal regime of the soils in the area under study based on the data collected in the nearest site (30–40 km to the south), where distinct growth of the permafrost temperature was recorded: while in 1974 the values of $t = -1.7...-5.9$ °C were observed, in 2008 the following values of $t = -0.8...-3.8$ °C were recorded, with minimum temperatures recorded in hillocky and hummocky tundras, while the maximum temperatures were recorded on the slope of the southern aspect with shrub communities growing [*Drozdov et al., 2010*].

The current dynamics of the thermal regime of air and soils in the territory under study, starting with the middle of the 19th century was studied using tree-ring width chronologies. The study of the cores of larches growing both in the watershed and in the floodplain of the Mongayurbey River showed increase in bio production, proportional with the increase in the vegetation period temperatures, which can be well seen from the linear trends of the radial growth (Fig. 3). Multiple correlation of the radial growth with the air temperature of three summer months reaches 0.61 with the significance level $p < 0.001$. The radial tree growth in the permafrost zone is associated not only with the increase of the summer air temperatures but also with the increase in the snow cover depth [*Nikolaev and Skachkov, 2011, 2012*], essentially determining the temperature regime of frozen soils [*Nekrasov, 1981*]. Multiple correlation of the tree growth with the amounts of precipitation and the air temperatures of the three preceding winter months reached +0.69, with $p = 0.003$, whereas its partial correlation with the amount of precipitation in February was +0.57, with $p = 0.001$. It is to be noted that in the trees growing in the watershed (Fig. 3, *a*), the positive response to the climate was much more expressed that in the trees growing on the floodplain (Fig. 3, *b*). In the past century, the radial growth trend in the watershed was 0.39 mm, with the growth being 2.3 times, whereas during the same time the trend for the floodplain of the Mongayurbey River was 0.12 mm, with the growth being 1.4 times. Thus, the thermal regime of the larch biotope under plakor (mesic upland) conditions became more favorable and approached that of a river floodplain. This provides grounds for the following assumptions regarding: 1) increase in the depth of seasonal thawing in the watershed, which expands the root area [*Nikolaev and Skachkov, 2011, 2012*]; 2) levelling of the temperature field of the permafrost soils in the forest tundra of Western Siberia during climate warming – a phenomenon noted by *D.S. Drozdov et al.* [*2010*].

Dependence of the permafrost thickness on the composition and structure of the tundra phytocenoces has been shown by many authors [*Tyrtikov, 1969; Meltser, 1994; Moskalenko, 1999*]. It is to be emphasized that not only the thawing depth but also its current climatogenic dynamics depends on the type of vegetation growing. It has been noted [*Moskalenko, 2006*] that the trends for the cryogenic processes for peatlands and bogs are different: in the bogs, maximum increase of the permafrost thickness was recorded and the minimum values of the mean annual permafrost temperatures; on peatlands, on the contrary, seasonal thawing changed to a minimum extent, while the soil temperatures grew considerably.

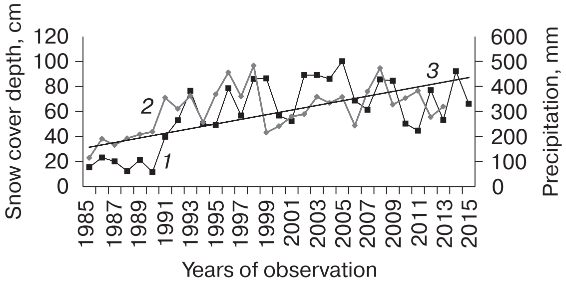

Fig. 2. Changes in the meteorological data at the Tazovsky meteorological station.

1 – snow cover depth at the end of the winter period (April); *2* – total precipitation in the winter period (October–April); *3* – the linear trend of the snow cover depth.

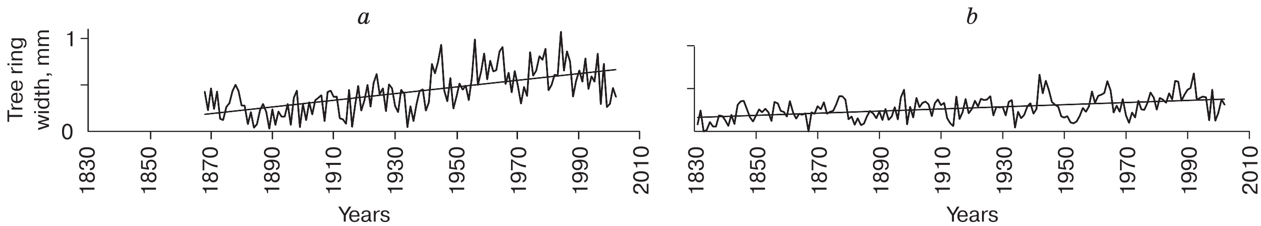

Fig. 3. Radial growth (mm) of the larch in the eastern part of the Tazovsky Peninsula and linear trends:

a – mesic upland tundra of the right-bank area of the Mongayurbey River; *b* – the floodplain of the Mongayurbey River.

The vegetative cover of the hillocky tundra in question is characterized by widely spread dwarf birch and dwarf birch-willow-shrub-moss communities. As the observations have shown, the thickness of the peat layer in these phytocenoses is 5–15 cm, which accounts for its good heat insulating capacity. The depth of the active layer varies within 0.6–0.8 m on the mounds and 0.5–0.7 m in micro depressions. Where drainage deteriorates, cotton-grass-dwarf-shrub-moss-lichen-sphagnum boggy tundras prevail, in which, due to a thicker (15–25 cm) peat layer, small permafrost thickness is observed – 0.4–0.6 m.

Table 1. **Geobotanical indicators of cryogenic processes and of the active layer thickness (the authors' data)**

No.	Plant communities	Active layer thickness, m	Exogenous processes	Self-recovery of vegetation after damage
		Vegetation on watersheds		
1	Low shrub-dwarf willow-dwarf birch-lichen-loss moundy tundras of rained watershed	0.6–0.8 on mounds, 0.5–0.7 micro depressions	Soil heaving, bogging in depressions	Recovery of continuous vegetation cover within 4–6 years, in rare cases, formation of flooded thermal subsidence; damage stops being visible on RSD in 12–20 years
2	Dwarf-shrub-lichen tundras of elevated watersheds	0.7–0.8	Deflation	Recovery of continuous vegetation cover is slow (>10 years), with replacement of dominating plant species; damage is visible for more than 25 years
3	Dwarf willow-grass-moss communities and dwarf shrub-motley grass-moss communities of wide depressions	0.6–0.7	Soliflucton, erosion, nivation	Formation of continuous vegetation cover within 5–7 years; damage is visible for 15–20 years
4	Dwarf birch-dwarf willow-knotberry-ledum-cotton grass-L. polytrichum moss bogged tundras	0.5–0.6	Bogging	Recovery of continuous vegetation cover within 4–6 years, rarely formation of thermal depressions
5	Cotton grass-sphagnum-green moss with willows and dwarf birches bogged hummocky tundras	0.4–0.6	Bogging, seasonal frost heaving	The same
6	Shrub-moss-lichen communities on raised edges, sedge-sphagnum communities in cracks and hollows, crevassed polygonal bogs	0.35–0.60	Bogging, frost cracking, seasonal frost heaving	Recovery of continuous vegetation cover within 8–10 years, formation of flooded thermal depressions; damage is visible for a period from 7 to 25 years
7	Sedge-dwarf shrub-lichen-moss communities on mounds, sedge-cotton grass-sphagnum-hypnum flat-topped hummocky bogs	0.35–0.50 on mounds, 0.6–0.8 in hollows	Seasonal frost heaving, thermal subsidence	In case of minor damage, recovery of continuous vegetation cover within 4–5 years, in case of severe damage – formation of flooded thermal depressions and recovery within 25 years
8	Grass-sedge-sphagnum-hypnum flooded bogs (marshes)	0.55–0.80	Bogging	Recovery of continuous vegetation cover within 2–4 years; damage is visible for 6–12 years
9	Cotton grass-sedge, grass-sedge-hypnum, tall graminoid and shrub-grass-moss series of communities at the place of drained lakes	0.7–1.0 and more	Thermal erosion, deluvial processes, seasonal frost heaving	Recovery of continuous vegetation cover within 3 years; damage is visible for a period from 3 to 15 years
		Vegetation of river valleys and flood plains		
10	Series of open groups of plants on primary alluvium	0.9–1.0 and more	Deflation, river bed evolution	No formation of continuous vegetation cover
11	Larch moss-lichen dwarf shrub light and open forests	0.8–1.0	Deflation in near-river bed areas	No recovery of the tree tier within 12 years has been recorded
12	Shrubs (willow, alder) grass-sedge-graminoid communities	0.8–1.0 and more	Bogging	Recovery of continuous vegetation cover within 4–6 years
13	Motley-grass-graminoid meadows in combination with sedge-hypnum swell-polygonal bogs	0.7–1.0	Bogging	The same
14	A series of motley-grass-graminoid, sedge-cotton grass, shrub-grass-moss communities in the floodplains of small rivers	0.7–1.0	Erosion, deluvial processes, nivation	Recovery of continuous vegetation cover within 3–5 years
15	Graminoid-sedge bogged meadows of the coast of the Tazovsky Bay	0.8–1.0	Bogging	Recovery of continuous vegetation cover within 3–4 years

Large areas are covered with sedge-moss-lichen flat-topped polygonal peatland, spread both on flat watersheds and in riverine depressions. Here frozen peat lies at the depth of 35–50 cm. In the areas of swamps and khasyreys, the permafrost thickness varies from 0.7 to 1 m and more.

The general characteristic of the indicated phytocenoses, the associated geocryological conditions and the observed exogenous processes are shown in the table. It is to be emphasized that most widely spread are the low-shrub (dwarf birch and dwarf willow) shrub-moss communities with a peat layer of medium thickness, which has good heat insulating properties but gets easily damaged when exposed to the anthropogenic impact. Lichen tundras and flat-topped peat mounds, which are most sensitive to mechanical damage, are not commonly found.

THE CURRENT DYNAMICS OF THE VEGETATION COVER

Transformation of the tundra vegetation in changing the air temperature and soil temperature regimes is caused by two main factors: the shift of the latitudinal optima of different plant species and transformation of biotopes caused by activation of the cryogenic processes.

The northward shift of the near-tundra woodlands is an indicator of climate warming [*Shiyatov, 2009*]. On the Tazovsky Peninsula, in the interfluve of the Khadutta and Tabyakha Rivers, northward movement of larches up to 3 m tall has been noted. Over the recent thirty years, the borderline of woodland has shifted northwards by 10–30 km [*Drozdov et al., 2010*]. The increase of the radial growth of the larch trees revealed by us in the floodplain of the Mongayurbey River (Fig. 3) and the appearance of the younger generation of the larch (from 1930s) generally correspond to this trend. However, we did not record massive movement of the larch trees beyond the floodplain of the Mongayurbey River, which is likely to be related to the exclusively isolated location of this enclave inside the tundra zone.

The growth of the air and soil temperatures results in boosting of the cryogenic processes initiating secondary successions of vegetation. The field studies and the analysis of the remote sensing data (RSD) resulted in identification of different types of land surface changes, which caused transformations in the vegetative cover: disappearance of thermokarst lakes, abrasion of lake shores, erosion processes on the slopes of lacustrine depressions and river floodplains, and river bed evolution processes taking place in the Mongayurbey River, with subsequent revegetation of the alluvium, formation of eroded sandy hills.

The process of thermokarst lake drainage and of formation of khasyreys on their site is an indicator of climatogenic changes in the geocryological conditions [*Polishchuk and Tokareva, 2006; Bryksina et al., 2007*]. The wide spread of khasyreys in the southern part of the Tazovsky Peninsula allowed a special type of landscape to be identified there, named 'khasyrey' [*Melnikov et al., 1983*]. The cause of reduction in the area of lakes under conditions of climate warming is increased erosion and drainage due to permafrost thawing [*Dneprovskaya et al., 2009*]. Dependence of this process on zonal geocryological conditions was noted: the most of the disappeared lakes were recorded in the zone of discontinuous permafrost, while in the continuous permafrost zone, on the contrary, the number and the area of the lakes increased [*Smith et al., 2005*]. Similar results, which revealed reduction in the area of lakes in southern tundra and in forest tundra, were obtained in later studies [*Bryksina and Kirpotin, 2012*].

Analysis of the satellite images of the territory of the Yurkharovskoye gas field showed that lake drainage occurred very intensely there. As an example, we will demonstrate a series of satellite images of the right bank territory of the Mongayurbey River in its lower reaches (Fig. 4). Altogether in the period of 1988–2016, 48 lakes disappeared due to drainage, with their area varying from 0.01 to 3.1 km^2, and the total area of the water surface got reduced from 130 to 103 km^2. Reduction of the area of lakes totaled

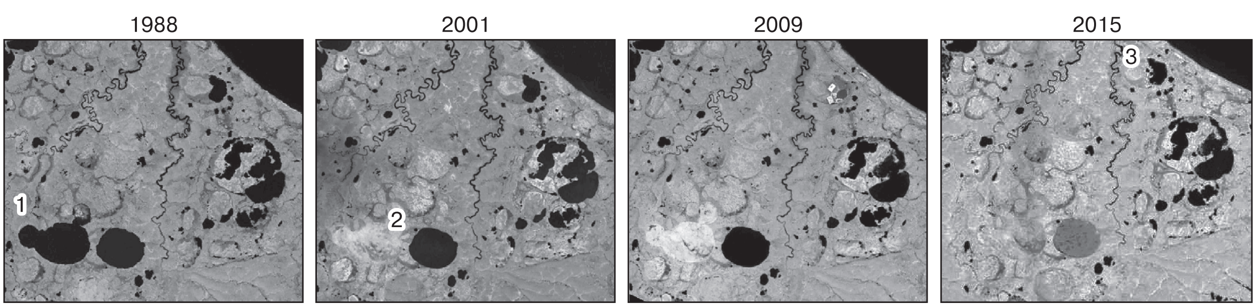

Fig. 4. Changes in the thermokarst lakes in the right-bank area of the Mongayurbey River [http://www.landsatlook.usgs.gov].

1 – a lake in 1988, a khasyrey in 2001–2015; 2 – a lake in 1988–2009, a khasyrey in 2015; 3 – a lake in 1988, 2001, 2015, a khasyrey in 2009.

20 %, which corresponds to the maximum values of this parameter in the discontinuous permafrost zone of Western Siberia, which are 19.0–20.5 % [*Dneprovskaya et al., 2009*]. Intense drainage of lakes indicates boosting of the erosion processes, indirectly confirming the fact of the rise of the permafrost temperature and of the increase in the active layer thickness.

Vegetation growth in the hollows of drained lakes, contributing to stabilization of the thermal regime of soils, passes the stage of domination of cotton grass-sedge and forb-graminoid communities. 15 years after lake drainage, vegetation was represented on the khasyrey studied by a series of low-level sedge-hypnum moss communities, medium-level sedge-cotton grass communities, high-level graminoid-forb communities and shrub (mostly willow) communities growing on the slopes of the lacustrine terraces, which form continuous ribbon communities. The thawing depth under a khasyrey exceeds one meter. As RSD analysis has shown, revegetation of the depressions of drained lakes takes 3–4 years. Further change in the vegetation proceeds in the direction of forming dwarf birch-shrub-lichen-moss communities, the active layer thickness of which constitutes 0.5–0.7 m. It takes more than 30 years for such communities to be formed, initiating decrease in the active layer thickness and stabilization of geocryological conditions. Judging by the series of satellite images, the homogeneous cotton grass-sedge bogs on the bottoms of the khasyreys which emerged after drainage of thermokarst lakes in the 1980s remained nearly unchanged in the 2010s.

Different kinds of anthropogenic impacts constitute a significant threat for the stability of the temperature regime of permafrost. Cases were recorded when under peatland damaged by gas pipeline lining the permafrost table decreased to the depth of 10 m [*Ponomareva and Skvortsov, 2006*]. Foundations of engineering structures cause abrupt rise in the mean annual temperature of the permafrost in the adjacent areas [*Drozdov et al., 2010*].

In the territory considered, the area of the sites completely devoid of vegetation (floodplains of rivers with alluvial sands, the depressions of the newly formed khasyreys, engineering facilities) constituted 0.3 % in 1988 and 1.4 % in 2016. Formation of derivative communities was noted on the sites of anthropogenic damage, clearly seen on the satellite images due to thermal subsidence and flooding. Such damages, caused by off-road truck traffic, lining pipelines and communications corridors affected in different periods 1.3–3.2 % of the territory and reached maximum figures in 2003–2004. As flooding increases and cotton grass-sedge communities emerge on the sites of the thermal subsidence, the change of the geocryological situation proceeds in the direction of the increase in the active layer thickness and a rise in the soil temperatures, with recovery of the temperature regime in many aspects being determined by the vegetation succession rates.

The most active recovery of vegetation after anthropogenic damage occurs on khasyreys, as a large amount of water and mineral nutrients preserved in the soil contribute to recovery. Duration of the vegetation recovery in khasyrey areas coincides with the duration of formation of continuous vegetation cover in primary successions and lasts 3–4 years. The high resilience of khasyreys to mechanical damage was noted before for the tundras of the Yamal Peninsula [*Meltser, 1994*]. In the dwarf birch-dwarf shrub-lichen-moss tundras, widely present on the watersheds, preservation of organogenic soil horizons is the primary condition. Recovery of continuous vegetation cover, when the land is exposed to minor damage with the peat horizon of soils partially preserved, takes from 4 to 6 years, but the floristic composition of the derivative phytocenoses differs from that of the original communities. Normally after mechanical damage, soil subsidence and flooding occur; therefore, at the initial succession stage, sedge-cotton grass communities are formed, which are gradually replaced by knotberry-sedge-sphagnum communities. Analysis of the high-resolution satellite images has shown that under mesic upland conditions, traces left after off-road vehicles' traffic and laying linear structures can be seen during 12–20 years (Fig. 5). Only communities of flat-topped peat mounds are noted for lengthy recovery of vegetation, which takes more than 25 years.

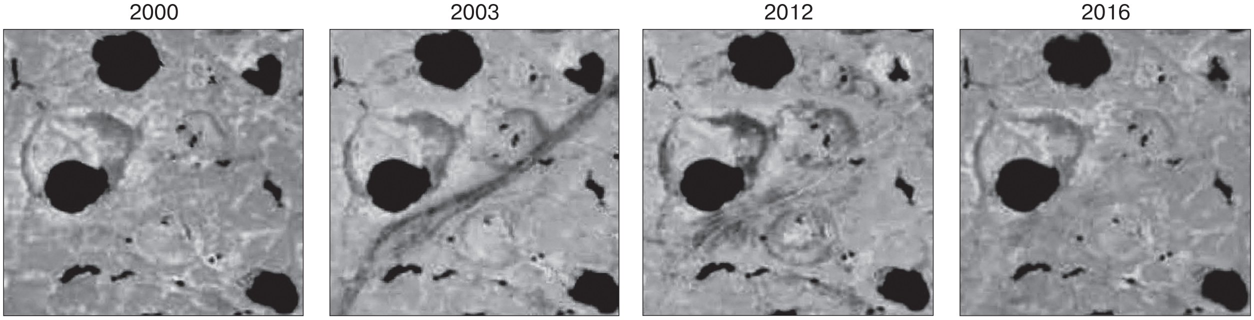

Fig. 5. Revegetation of linear damage in the right-bank area of the Mongayurbey River [http://www.landsatlook.usgs.gov].

It has been noted that the average term of recovery of the vegetation cover and of the natural regime of seasonal thawing after mechanical damage in wet tundra is 20–25 years [*Moskalenko, 2006*]. In the typical tundras of Central Yamal, examination of the corridors of off-road vehicles' traffic has shown that in the case of light damage, complete recovery of the original phytocenoses takes place during a 20-years' period [*Khomutov and Khitun, 2014*]. Thus, the recovery rates of the vegetation communities on the Yurkharovsky oil and gas condensate field are close to those of the neighboring districts. Normally, there is no irreversible degradation of the cryogenic landscapes due to formation of vast flooded thermal depressions, existing for a prolonged period of time (longer than 20 years). Successful self-recovery of vegetation suggests high resilience of the cryogenic landscapes in the territory studied. Vegetation appears as a recovery regulator, due to a system of feedbacks limiting the effects of anthropogenic impact and climate change. For example, earlier vegetation related to the rise of air temperature at the beginning of summer is a factor limiting the growth of the permafrost temperature and the depth of the active layer.

To learn more about the relationship between the vegetation growth and the climatic parameters, we determined the normalized difference vegetation index NDVI, characterizing the amount of phytomass, which, along with the thickness of the organic horizon of soils, affects the rates and depth of seasonal thawing of soils [*Drozdov et al., 2010*]. Year-to-year climate-caused variability of the phytomass exerts non-inertial impact on the permafrost [*Anisimov and Sherstiukov, 2016*]. Due to the climate change, a trend for the NDVI growth in the tundra zone has been observed, which allows scientists to talk about greening of the Arctic [*Walker et al., 2009, 2012*]. The growth of NDVI was recorded in different geographical regions of the Russian North [*Walker et al., 2009; Lavrinenko, 2011; Varlamova and Solovyev, 2014*].

Computation of NDVI in the period of the vegetation growth (the first decade of July) has shown that the values of the index vary from 0.05 to 0.25 and depend on the temperature of the preceding month (Fig. 6). The growth of the air temperature leads to the growth of phytomass and to extension of the vegetation period, thus preventing penetration of heat into the soil strata and becoming a factor of stabilization of the thermal regime of soils.

In the period of maximum vegetation, the average for the area NDVI values varied from 0.28 to 0.36 in different years. It follows from comparison of NDVI with meteorological parameters that the maximum values of the vegetation index are directly dependent on the total precipitation of the previous period, beginning with November of the previous year, when stable deep snow cover is formed (Fig. 7). Increase of vegetation as the total precipitation is increased seems to be related to the following factors: 1) the greater depth of the snow cover prevents freezing of the soil in the winter period, contributes to the rise of the soil temperature and to the active layer thickness; 2) increase in the water content favors the growth of annual plants – sedge, cotton grass, motley-grass hygrophytes, increasing the total phytomass. The current trend for the growth of the total precipitation favors the growth of phytomass and contributes to stabilization of the geocryological conditions.

Given the year-to-year variability of the parameter and having made only a small series of observations, it is impossible to talk about the existing trend for the NDVI growth in the southern tundras of the Tazovsky Peninsula, caused by the global climate change. Numerous as the evidence of the NDVI is for the other regions of the Arctic, this situation is not unique. For example, for the Yugorsky Peninsula in the period of 2000–2011, the NDVI growth was recorded on 53 % of the area, while on 40.4 % of the territory, the changes were insignificant [*Elsakov and*

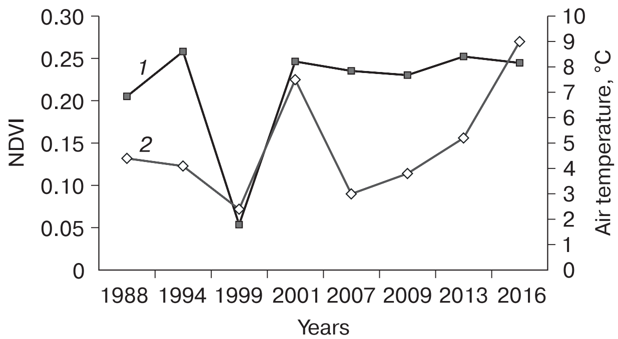

Fig. 6. Change in the average value of NDVI (*1*) for the site in the vegetation growth period (the first ten days of July) and in the average air temperature (*2*) in the preceding month (June).

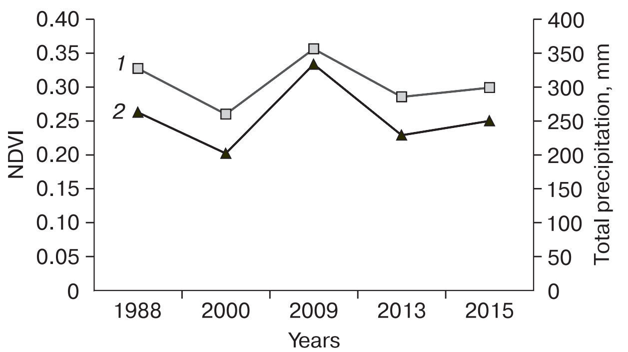

Fig. 7. Change in the average value of NDVI (*1*) for the site in the period of maximum vegetation and in the total precipitation (*2*) in the preceding 9 months (November–July).

Kulyugina, 2014]. It is evident that the dependence of NDVI on climatic parameters is mainly determined by the structure of the floristic composition of the phytocenoses. It has been noted that in the tundras where mosses and lichens dominate, the air temperature growth does not cause any essential increase in the phytomass, unlike in the tundras, where sedges and graminoid plants dominate [*Walker et al., 2009*]. In the hillocky willow-dwarf birch-lichen-moss tundras, widely spread in the territory observed, a rise in air temperatures causes extension of the vegetation period but does not result in the growth of the maximum amount of phytomass. The growth of the index values is observed in the depressions of drained lakes as the vegetation growth continues in them, which makes the territory of the Tazovsky Peninsula different from the territories of the Canadian Arctic and Alaska, where greening is related to the melting of glaciers and growth of vegetation on rocky substrates [*Walker et al., 2009*]. NDVI reduction takes place on the sites under engineering structures. The maximum values of the index (0.7–0.9), corresponding to the category of 'dense vegetation' [*Cherepanov and Druzhinina, 2009*], have been found in the floodplain of the Mongayurbey River and its tributaries, where scarce larch forests are spread, as well as tall willow shrubs. The area of the sites with NDVI > 0.7 has increased over the period in question from 1.1 to 1.9 % of the territory.

CONCLUSIONS

The dynamics of the vegetation growth and of the geocryological conditions in the eastern part of the Tazovsky Peninsula is related to the climate change and the anthropogenic impact. The mean air temperature growth rates over the recent three decades were 0.04 °C per year, while increase in the total precipitation was 1 mm/year on average. The climate change contributed to the radial tree ring growth, especially in watersheds, indicating warming of the soil strata and levelling of the temperature field of the permafrost.

Vegetation growth on the depressions of drained lakes is the main form of the natural dynamics of the local vegetation. In the period of 1988–2016, of the lakes number of decreased by 20 % due to lake drainage, which is close to the maximum figures in Western Siberia and testifies to enhancement of the erosion processes. This is corroborated by the rise in the permafrost temperatures and increase in the active layer thickness. In khasyreys, gradual reduction of the active layer thickness occurs, from more than 1 m to 0.7 m, while duration of the khasyrey successions, the end stage of which is formed by dwarf birch-dwarf shrub-lichen-mass tundras, is more than 30 years.

Damage related to pipelining, communications corridors, and arrangement of filled-up grounds for engineering structures was inflicted in different times to 1.2–3.2 % of the territory and reached maximum values in 2003–2004. It takes 6–8 years for prevailing plant communities to recover from unessential anthropogenic impact, and 12–20 years to do that after significant anthropogenic impact. Normally, there is no irreversible degradation of the cryogenic landscapes due to formation of vast flooded thermal depressions, existing for a prolonged period of time. The results suggest high resilience of phytocenoses, which is related to limited participation of tender lichen tundras in the structure of the vegetation cover and to climate changes favorable for the vegetation (temperature growth and increase of total precipitation). Computation of the normalized difference vegetation index NDVI has demonstrated dependence of its maximum annual values and hence of the total phytomass on the total precipitation of the preceding 9-month period, beginning with formation of the snow cover.

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