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FEATURES OF REVEGETATION OF SAND BLOOUT SITES IN THE NORTHERN TAIGA SUBZONE OF WESTERN SIBERIA

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Despite the presence of large drift sand sites, the northern taiga areas of Western Siberia are currently experiencing a decrease in deflation processes and increase in self-regeneration of the vegetation cover. This paper discusses the drivers of the formation of sand arenas and analyzes the nature of changes in climatic conditions in the Nadym River downstream area. The results of interpretation of space images made at different times and field observations data allowed to assess the vegetation cover and dune microrelief dynamics within the bounds of natural deflation basins widely developed in the study area. The particular characteristics and mechanisms of revegetation are demonstrated by the example of a model deflation basin.

Western Siberia, climate, aeolian processes, vegetation, freeze-thaw action

INTRODUCTION

The concept of "all-over", or ubiquitous development of aeolian relief-forming processes [*Chichagov, 2004*] can be ascertained by diversity of forms of modern and ancient aeolian reliefs in the northern taiga subzone of Western Siberia. Extensive sand blowouts as distinctive and essential element of cryogenic landscapes have justifiably become an object of interest and study to many researchers over the past one hundred years [*Ivanoskii, 1939; Zemtsov, 1976; Velichko and Timireva, 2005; Soromotin and Sizov, 2007; Sizov, 2015*]. Climatic changes and soil disturbances caused by the active economic development of the territory can be named among key factors controlling the deflation processes dynamics in the last decades.

The objective of the study is to identify characteristic features of revegetation within the blowout areas in the northern taiga subzone of Western Siberia.

OBJECTS AND METHODS OF RESEARCH

This study concerns with the numerous and diverse aeolian landforms, with some of them being well represented in the middle reaches of the Nadym river alongside with areas of disturbed soil and anthropogenic relief forms resulted from construction and operations of major trunk gas pipelines (Nadym–Punga, Urengoy–Uzhgorod, Yamburg–Tula, etc.).

Morphologically, aeolian relief is best exposed in the deflation basins, as the accumulation formations (bars, mounds, dune chains, sand drift, etc.) are common both along their surface and at the periphery. Technogenic relief is presented primarily by dry-excavated mines, sidecast road embankments, pipelines and industrial sites, as well as areas used as driveways for heavy machines. From methodological point of view, the study area is divided into two sites (Fig. 1):

I – a more extensive area comprising the Nadym middle reaches and watershed area of the Khetta river (coverage: 17,500 km^2). All the diversity of modern aeolian reliefs is exhibited in this environment of northern taiga;

II – a local site including the right bank of the Kheygiyakha river (Longyugan) river, in its lower reaches – the Nadym observation station of the Institute of the Earth's Cryosphere (ECI) SB RAS, with an area of 240 km^2 – where the objects of detailed

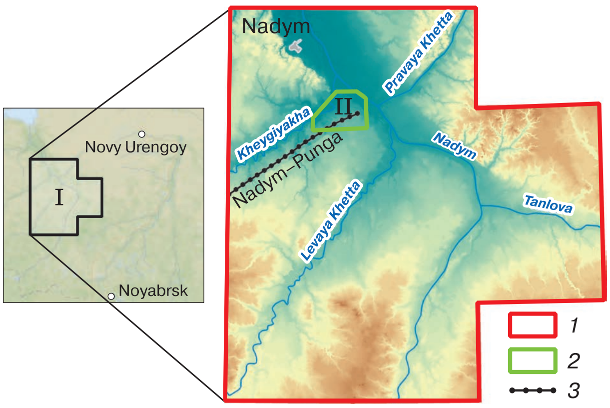

Fig. 1. Overview map of the study area.

1 – site boundary I; *2* – site boundary II; *3* – Nadym–Punga gas pipeline.

studies are situated: a large model deflation basin, disturbed areas along the trunk pipeline, and sand quarries.

The retrospective analysis of the state of drift sand sites followed by their general and detailed mapping involved remote sensing time-series data of the medium and ultra-high resolution aerial and satellite images from openly published sources. The original status of the territory prior to laying the natural transit gas pipelines is shown in the images dated August, 21 1968 made by KH-4B 1104 satellite (US imaging reconnaissance program Corona, NSSDC ID 1968-065A) (http://nssdc.gsfc.nasa.gov). After georeferencing and radiometric correction, the panchromatic data corresponded to the 2.0–2.5 m/pixel spatial resolution in level of imagery detail. The overview mapping of sites with drift sands and regional natural impacts analysis (emergence of burnt areas, water bodies dynamics) were carried out on the basis of digital, multi-spectral imagery from Landsat-5/7, dated July 2, 1987; July 5, 1988; August 3, 2001, and July 25, 2013 (http://earthexplorer.usgs.gov). The detailed mapping of key-sites was carried out on the basis of high resolution images (0.5–0.7 m/pixel) from the WorldView-2 and Pleades-1 satellites

Fig. 2. Position of reference stakes (*1*), profile within the deflation basin (*2*) and geobotanical site (*3*).

(https://maps.here.com). High brightness and geometric characteristics of the data permitted to use them as a spatial foundation for integration of field work results and detailed mapping of the microrelief of deflation basins. We used the expert visual interpretation methods including interpretive guidelines and reference values for wind-blown sands and those partially fixed by vegetation, which estimates were based on the result of multiple field surveys and analytical processing of aerial photography in the 1960–1970s [*Protasieva, 1967; Bogomolov, 1976*].

The field works dedicated to the study of processes of revegetation on the sites subjected to anthropogenic disturbance were initiated by *Moskalenko* [*1999*] in 1972 after implementation of the Nadym–Punga trunk gas pipeline construction project. It has been established that small-scaled sand blowouts emerged on the summits of mineral pingos along the branched pipeline right-of-way. Some sites sized 100 m^2 each were laid within the blowout areas, where the ECI SB RAS staff carried out annual descriptions of vegetation, measured thickness of the active layer and ground temperature in the 10-m deep wells [*Moskalenko et al., 2006*]. Since 2009, the ECI SB RAS extended team has expanded the scope of activities and conducted also comprehensive studies of Quaternary deposits, micro-relief, soil and vegetation within the model deflation basin, located in the vicinity of the Kheygiyakha river mouth. The authors joined the research works in 2012. The 2013–2014 field works resulted in setting up three geobotanical sites, and laying two geobotanical profiles. Site and two profiles were positioned in a deflation basin in the vicinity of the Kheigiyakha river mouth, while two other sites stretched along the Nadym–Punga pipeline. Both the profiles and sites were described, and variations in the components of geosystems documented with regard to: vegetation (determining abundance, occurrence, coverage, height of plant species on 100 registered sites (0.1 m^2 each), with the structures sketched on a 1 m by 1 m grid), measuring the active layer thickness and moisture content, and soil temperature at the surface and at a depth of 1.5 m. In the course of the desktop studies, large-scale vegetation maps and temperature control schemes were generated. To refine the microrelief morphometric parameters, a detailed geodetic survey of type areas of the deflation basin was conducted in August 2013, and the required reference stakes were set up for estimation of local transport of sand material (Fig. 2).

The analysis of climate variations was based on the continuous record of daily weather observations, made available with minor intermittences from 1966 to 2013 at the Nadym observation station through the Automated Information regime information processing system (AISORI) (http://aisori.meteo.ru/ClimateR).

RESULTS

1. Spatial distribution of aeolian relief

The study area, comprising the middle reaches of the Nadym river and the basins of its major tributaries (Tanlova, Kheygiyakha Pravaya Khetta and Levaya Khetta), is characterized by diversity and remarkable distribution of the modern eolian relief in the northern West Siberia. Given that faces of sand sheets are contrasting well against the background of typical tundra-taiga landscapes, the automatic classification methods with subsequent visual adjustment were used for their differentiation. Two Landsat-7 scenes of August 3, 2001 were selected as input data (http://earthexplorer.usgs.gov). Reflection areas with similar spectrum corresponding to areas of permanent and temporary settlements, meander bars, beaches and areas covered with moss were excluded from the interpretation results. Minimum area of the interpreted object is limited to 0.225 hectares.

The distinctive features of the aeolian relief distributions are summarized below:

– total area of drift sands is 235.06 km^2 (1.34 % of the territory), of which 86.93 % account for aeolian relief of natural origin;

– most of the modern aeolian relief (88.3 %) is localized at the altitude range from 19 to 65 meters, with the main area of distribution found to be drained terraces in the middle reaches of the Nadym river; the cumulative area of blowout sites is 134.4 km^2 (65.77 % of the total area);

– the ubiquitous development of aeolian forms is marked in the valleys of almost all the tributaries of the Nadym – Pravaya Khetta and Levaya Khetta, Tanlova, Bolshaya Khukhu, Kheygiyakha – with predominance of small (up to 0.5–0.6 km^2 in area) deflation depressions and basins, elongated in the form of a chain along the valleys. A decrease in the basins' size may be associated with reduced wind speeds and an increase in the groundwater level;

– the largest site affected by natural deflation has an area of 37.21 km^2 and is located on the right bank of the Nadym river, 94 km south-east from the city of Nadym. It represents by itself a chain of deflation basins closed due to the wind erosion. Cumulatively, five largest deflation basins cover the area of 77.66 km^2 (38 %);

– smaller-sized plots of drift sands (10.27 %) were discovered in high watershed areas between the Nadym and Purpe, and Nadym and Levaya Khetta rivers. The absolute elevation limits of the aeolian formations vary there from 66 to 95.5 m, with differences in relative elevations ranging from 40 to 65 m;

– the area of disturbed sands affected by anthropogenic and natural-anthropogenic impacts cover 30.72 km^2 (13.07 %). Basically, the disturbances are localized near the objects of natural gas transportation infrastructure, along the roads and railways, and on the periphery of settlements.

2. Analysis of climatic changes

The availability of the input data from meteorological observations through AISORI system (http://aisori.meteo.ru/ClimateR) allow for expanded analysis of climate changes, in particular, air temperature, amount of precipitation and average annual wind speed.

Analysis of the mean monthly air temperature over the warm period of the year shows a warming trend over the past 50 years, with the sum of the mean air temperatures (May–October) increased on average by 17 °C (Fig. 3, *a*); at this, average temperature beginning from May 1988 showed positive values for most years of observations. The average October temperature has also significantly warmed up (from −6 to −2 °C).

The average annual amount of precipitation, despite the high-amplitude values, increased by about 50 mm (Fig. 3, *b*), with the growth being remarkable for winter, while the amount of precipitation hardly changed in the period from May through October. The precipitation mode has exhibited significant interannual variations, though.

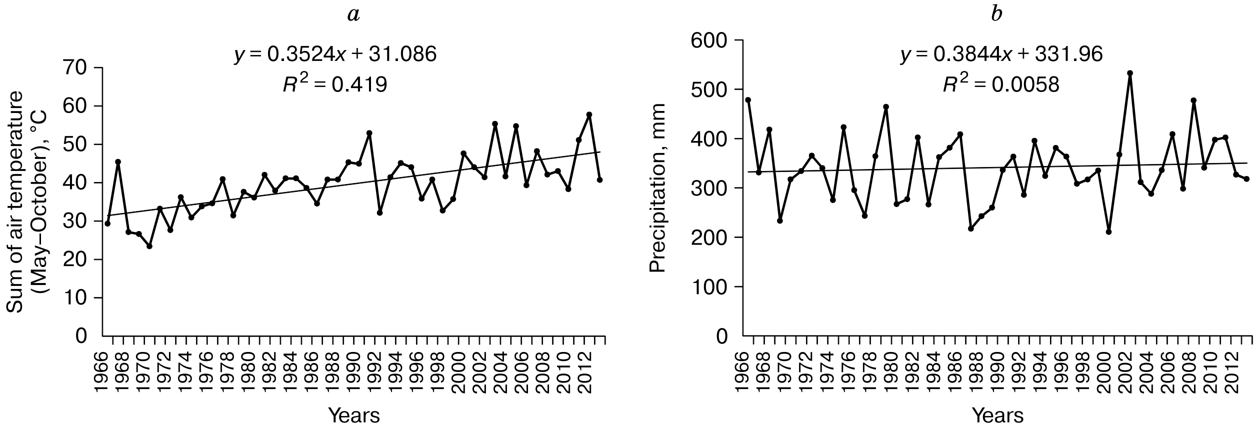

Fig. 3. Sum of air temperatures in the period from May through October (*a*) and annual amount of precipitation (*b*) from the Nadym weather station data.

The average wind speed values increased from approximately 3.5 m/s in 1966 to 4 m/s in 2010, with observed stabilization of indicators in 1984 and a minor trend towards their reduction.

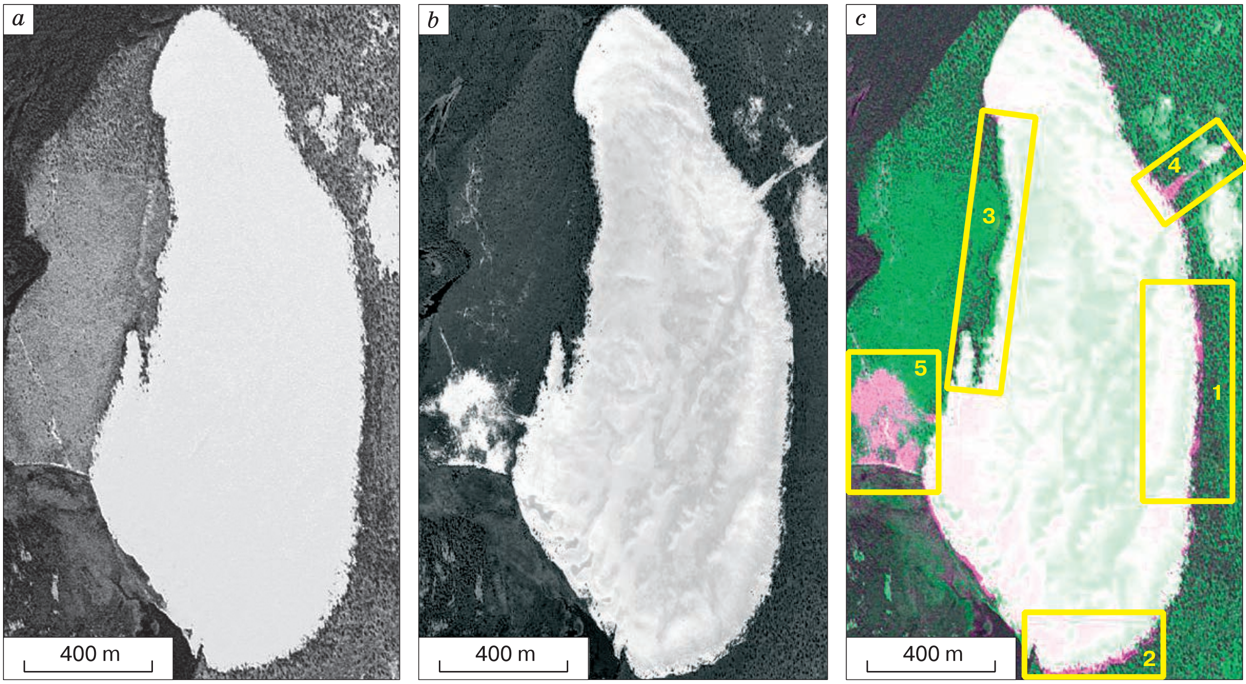

Fig. 4. Changes in the deflation basin:

a – KH-4B satellite imagery, 1968 (http://earthexplorer.usgs.gov); *b* – WorldView-2 satellite imagery, 2012 (https://maps.here.com); *c* – composite images from different time periods; 1 – east (E), 2 – south (S), 3 – west (W), 4 – north-east (NE), 5 –geophysical expedition base.

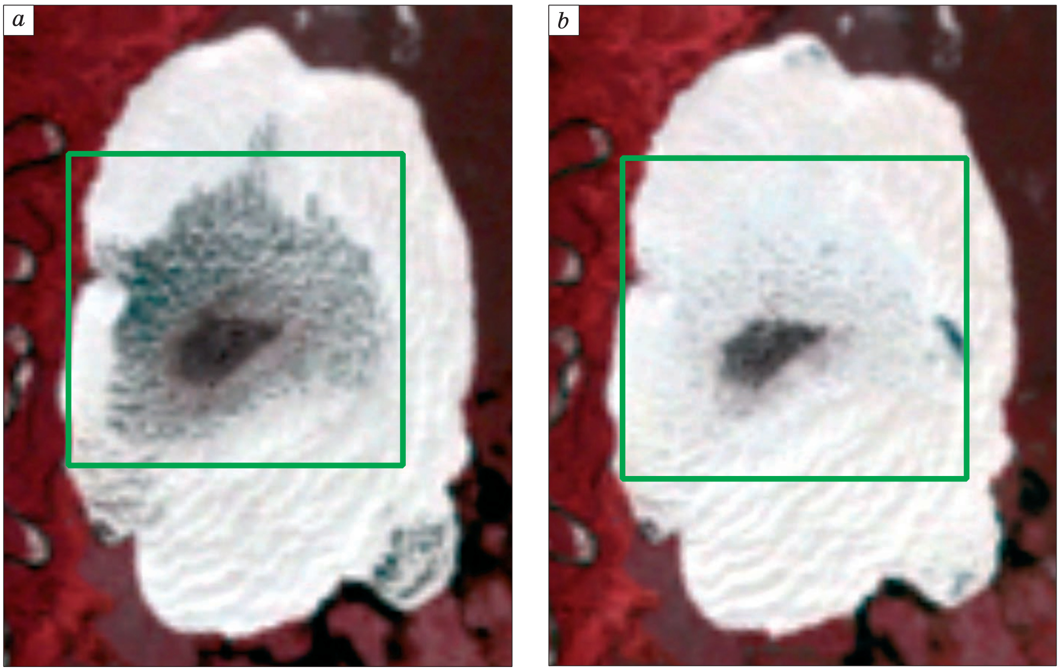

Fig. 5. Seasonal raise of water table in the deflation basin, from the Landsat-5 satellite imagery:

a – July 2, 1987; *b* – July 5, 1988 (http://earthexplorer.usgs.gov).

3. Analysis of satellite imagery from different time periods

Satellite imagery analysis over a relatively long period of 1968–2014 allows to identify major aeolian relief formation processes within the study area, such as changes (positive and negative) in the area of deflation basins, systematic flooding in some areas driven by variations in groundwater levels and related processes of natural revegetation.

Variations in the coverage area can be illustrated by the example of a relatively large (S = 1.15 km^2) basin, located 5 kilometers south of the Yed-yakha river mouth, the Nadym right tributary. Comparison of high resolution images, also by means of synthesizing composite images for different times has shown a slight expansion of the boundaries eastwardly (1) and southwardly (2) (Fig. 4) over a span of 44 years.

This is consistent with the prevailing wind patterns. An accumulation sand bar moved to a distance of 30 m (1, 2), and at the same time, the area of drift sands shrunk (Fig. 4) from the western side (3). The width of the established stable vegetation strip is 20–30 m. Local variations in the basin area are associated with anthropogenic impact, such as temporary roads for vehicles in the north-eastern part (4) and soil disturbances during temporary stay of a geophysical expedition (5) (Fig. 4). The study area abounds with small artificial deflation arenas developed thereby.

Large deflation basins along the Nadym river are located in the zone with a variable level of groundwater. Lack of moisture, on the one hand, impedes the processes of water logging and growth of vegetation; on the other hand, in low-water years for the Nadym river, moisture-deficiency conditions tend to developed on their surface, which in turn favors deflation. The situation of periodic moistening can be illustrated by a large blowout area (S = 5.7 km^2), located 7 km south of the mouth of the Tanlova, the right tributary of the Nadym river (Fig. 5). The satellite image from 1987 distinctly exhibits the raised water table in the central and south-eastern parts, while in the year to follow (1988) there was a decline in the level of groundwater, with the wind-blown sands occupying the entire blowout area, except for a small patch of vegetation in its middle (Fig. 5). Probably, it is the level of groundwater and drainage conditions that ultimately control the processes of deflation basins expansion/reduction.

The flattened portions of the Nadym above flood-plain terraces 1 and 2 covered by pine-lichen thin forests are characterized by great abundance of thermokarst lakes. Satellite imagery analysis shows that these represent drained lakes, resulting in the formation of sand basins, potentially prone to wind erosion. Nevertheless, the revegetation was ubiquitous in the areas of drained lakes during the monitoring period. The initially formed continuous lichen cover promoted accumulation of moisture, which was followed by intensively developing after-growth of pine. The process of revegitation can be illustrated by a small basin in the drained thermokarst lake found near the Nadym weather station (Fig. 6). As of 1968, lichen cover was spread virtually all over the basin surface, with only two sandy sites identifiable in the central part. By 2014, the entire basin had been covered by lichens, along with remarkable natural overgrowing by pine forests, distinctly identifiable in high resolution imagery.

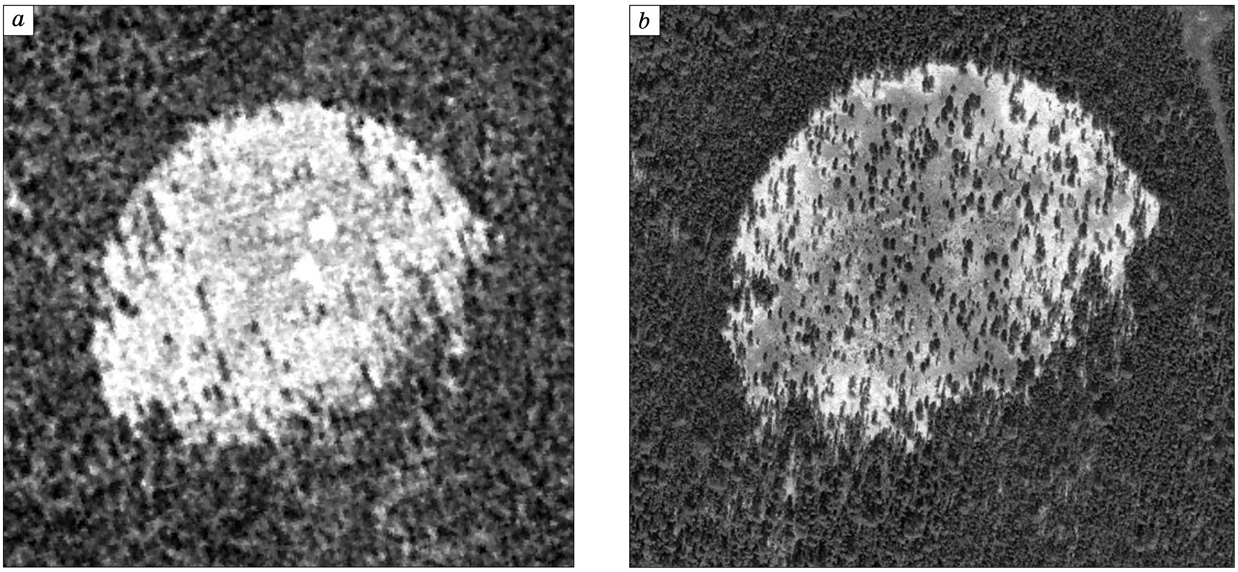

Fig. 6. Drained thermokarst lake basin becoming overgrown with vegetation:

a – KH-4B satellite imagery, 1968 (http://earthexplorer.usgs.gov); *b* – WorldView-2 satellite imagery, 2014 (https://maps.here.com).

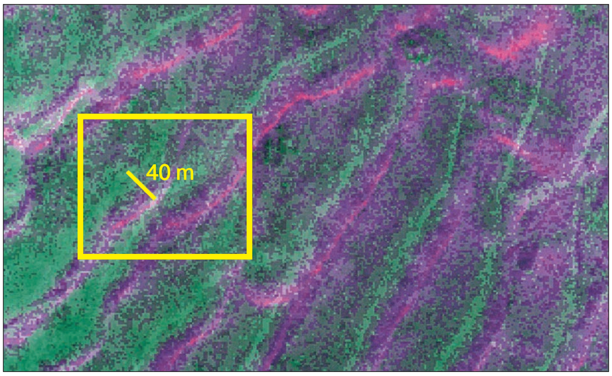

Fig. 7. Movement of elongate dunes along the deflation basin surface on the composite satellite imagery KH-4B, 1968 and WorldView-2, 2012 from different time periods.

Moreover, extensive forest areas affected by fires are highlighted within the study area in the Landsat imagery. Despite the resulting partial destruction of the woody vegetation, there has been no observable deflation in burnt areas, though. Nevertheless, the revegetation processes within burnt areas require special consideration and is beyond the scope of this paper.

4. Analysis of vegetation

A detailed analysis of vegetation growth dynamics was carried out for a model deflation basins, located near the mouth of the Kheygiyakha river. The basin, elongated N–S, covers the area of 193.7 hectares, and has a perimeter of 6450 m. Accumulation sand bars with height from 4 to 12 m are rimming the basin from the north, west and south. The sand bars are the highest on the southern side. On the eastern side, sandy deposits overlie the Nadym terrace 1. The minimum distance as far as the river is 2.4 km.

Lengthy sandy ridges, in structure appearing similar to classic dunes, formed on the basin surface. The height of the ridges average 1.5–2.0 m, reaching their maximum of more than 4 m in the south. The dune ridges move over the surface composed of dense alluvium and complicated by ancient ice wedge polygons and traces of frost-heaving. The dunes faces direction attests to their formation driven by northerly and north-westerly winds. The basin accommodates a currently operating sand quarry in its southern part,

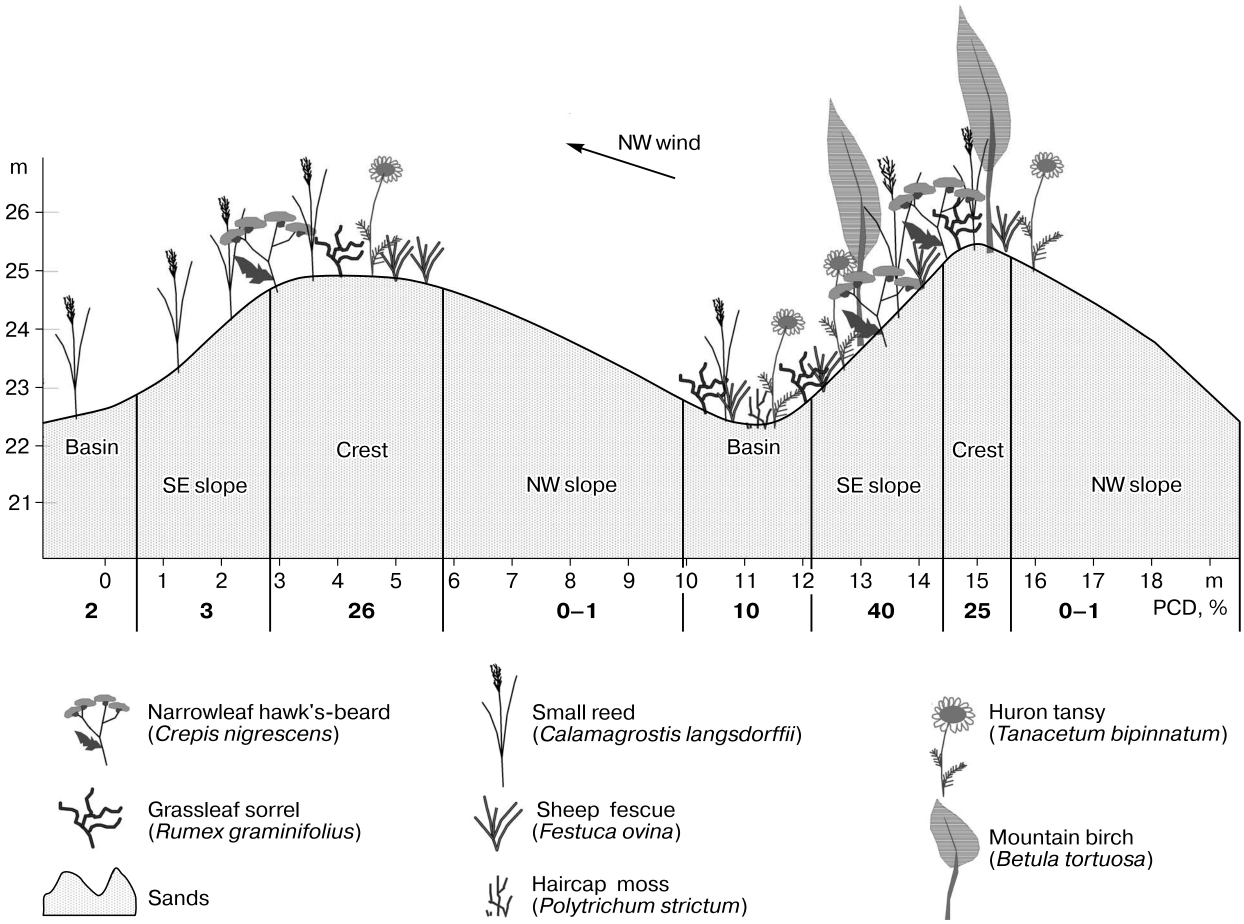

Fig. 8. Geobotanical profile within the bounds of model deflation basin.

Table 1. **Characteristic features of relief, number of plant species and projective cover degree (PCD) of dunes in 2013–2014**

Localization of sites within dune	Number of species	PCD, %
Basin	5	2–10
Crest	6	25
Windward slope	1	0–1
Leeward slope	6	40

and an industrial water intake site in the north-western part.

Comparison of the vegetation cover descriptions made in 2009, 2012, 2013 and 2014, allowed to allocate several zones with different conditions and to estimate the degree of revegetation. An active movement of sand material occurred in the basin middle portion, where dunes moved to a distance of up to 40 m (Fig. 7) in the period of 1968–2012. Therefore, projective cover degree (PCD) proves to be the lowest (10–20 %) there.

A geobotanical profile (Fig. 8) was laid to monitor the revegetation process in the central part.

The studies have revealed that the bottom of the basin with the bedrock outcrops is colonized by primarily haircap moss (*Polytrichum strictum*), then small reed (*Calamagrostis langsdorffii*) and sheep fescue (*Festuca ovina*), followed by Huron tansy (*Tanacetum bipinnatum*) and grassleaf sorrel (*Rumex graminifolius*). The windward slopes have no vegetation, albeit on the leeward slopes, first, small reed (*Calamagrostis langsdorffii*) established itself, then sheep fescue (*Festuca ovina*), Huron tansy (*Tanacetum bipinnatum*), grassleaf sorrel (*Rumex graminifolius*), narrowleaf hawk's-beard (*Crepis nigrescens*), with mountain birch (*Betula tortuosa*) and Scotch pine (*Pinus sylvestris*) rarely encountering amongst them.

The crests of dunes tend to be occupied by the plant species similar to those growing on leeward slopes, but their PCD is higher and trees are more common (Table 1). The eastern part, stretching along the border with the Nadym floodplain tend to be waterlogged with the floodplain vegetation developing on sands, and as many as ten plant species were identified there (Table 2). The western part of the basin is being progressively colonized by the mountain birch (*Betula tortuosa*) and Scotch pine (*Pinus sylvestris*), Siberian larch (*Lárix sibírica*) and Siberian cedar (*Pínus sibírica*). At the crest of the accumulation sand bar, common juniper (*Juníperus commúnis*) may encounter along the forest border. This test site provides home to totally nine species of plants.

Along the northern boundary, active accumulation of sandy material is taking place, with individual trees being progressively buried. In some places, due to sand transport the remnants of vegetation pile up, fixed by the Siberian cedar (*Pínus sibírica*) root system. There have been identified altogether eight plant species. Sand mining works are currently underway in the southern portion of the basin, with the abandoned sections of the quarry being actively colonized by the regrowth of Scotch pine (*Pinus sylvestris*), Siberian larch (*Lárix sibírica*), mountain birch (*Betula tortuosa*). In total, this test site counts five plant species. The processes of sand accumulation with individual trees gradually buried in under were observed in the south-eastern part on the periphery. The height of accumulation sand bars reaches 8–10 m. The accumulation rate can be illustrated by the benchmark point, mounted on one of the trees. During the first year of observation (2013/14) the benchmark was found to be up to 23 cm covered by sand (Fig. 9). However, there has been hardly any sand material transport outside the basin.

Two accumulation sand bars with the established vegetation were allocated to the north-west of the basin. The sandy levees are overgrown with lichen, reindeer moss (*Cladonia alpestris*), bearing the evidence of barren sands revegetation. Some typical forest communities are also present there.

Table 2. **Listing of plant species and projective cover degree observed on the test sites**

Species	Test sites and their localization within deflation basin			
	No. 1, S	No. 2, N	No. 3, W	No. 4, E
Small reed (*Calamagrostis langsdorffii*)		+	+	+
Sheep fescue (*Festuca ovina*)	+	+	+	+
Huron tansy (*Tanacetum bipinnatum*)		+	+	+
Narrow-leaf hawk's-beard (*Crepis nigrescens*)		+	+	+
Scotch pine (*Pinus sylvestris*)	+	+	+	
Siberian cedar (*Pínus sibírica*)		+	+	
Mountain birch (*Betula tortuosa*)	+	+	+	+
Siberian larch (*Lárix sibírica*)	+		+	
Hair moss (*Polytrichum strictum*)	+			+
Juniper (*Juníperus commúnis*)			+	
Sorrel graminifolious (*Rumex graminifolius*)		+		+
Marsh cinquefoil (*Cómarum palústre*)				+
Sphagnum (*Sphágnum*)				+
Arrowhead (*Sagittária*)				+
Total	5	8	9	10
Projective cover degree, %	60	15	40	20–30

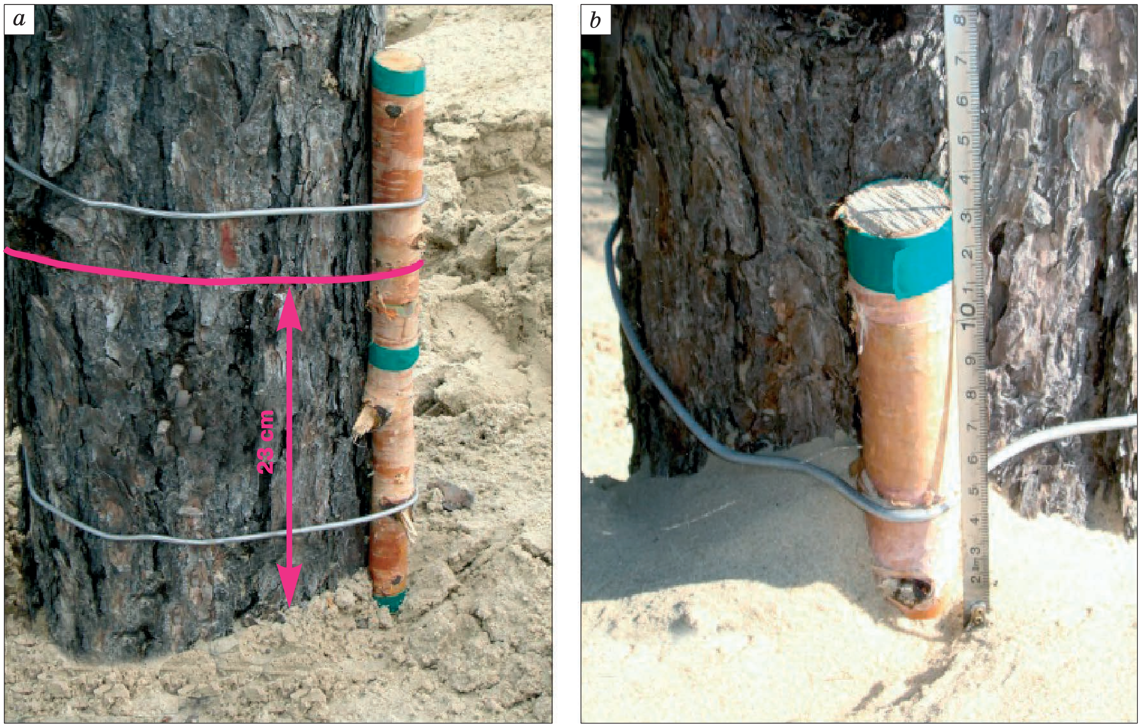

Fig. 9. Sand accumulation in the southern portion of the model deflation basin.
a – 2013; *b* – 2014 (Photograph by S.A. Lobotrosova).

The crest of the sand bar is overgrown with such tree species as betula tortuosa (*Betula tortuosa*) and Scotch pine (*Pinus sylvestris*), Siberian larch (*Lárix sibírica*), Siberian cedar (*Pínus sibírica*). Among the above-surface plant species, apart from alpine bearberry (*Arctostaphylos alpina*), there also present cowberry *(Vaccínium vítis-idaéa)*, crowberry (*Émpetrum*). The slopes are predominated by Scotch pine (*Pinus sylvestris*), Siberian cedar (*Pínus sibírica*), cow-berry (*Vaccínium vítis-idaéa*), hair moss (*Polytrichum strictum*). The basin portion between the levees has provided suitable habitat for swamp ledum (*Lédum palústre*), bilberry (*Vaccínium myrtíllus*), bog bilberry (*Vaccínium uliginósum*), cow-berry (*Vaccínium vítis-idaéa*), and for regrowth of Scotch pine (*Pinus sylvestris*), Siberian larch (*Lárix sibírica*), Siberian cedar (*Pínus sibírica*), Siberian spruce (*Pícea obováta*). Also, a small area of burnt forest becoming intensively overgrown by a great variety of plant species was allocated to the north of the basin.

DISCUSSION OF RESULTS

Disturbances of land cover resulting in the formation of sand arenas are currently associated primarily with anthropogenic activities. The processes of natural revegetation on the exposed surfaces of sand quarries are best studied in the central and northern West Siberian taiga [*Shilova, 1977; Koronatova, 2003; Korkina, 2005*]. Under similar conditions, they can be regarded as artificial analogs of primary deflation basins.

It takes, on average, between 5 and 18 years for sand quarries to become overgrown by vegetation. *Shilova* [*1977*] has identified four stages of this process:

1. Years 1–2: pioneering sporadic herbaceous plants, with occurrences of seedlings of pine, birch and ecotopic grouping;
2. Years 3–4: development of open-type phytocenoses;
3. Years 5–8: development of closed-type phytocenoses;
4. Years 9–12: development of zonal phytocenoses.

Revegetation of quarries by vegetation always begins on greater moistened soils. Thus, wetter interdune depressions tend to be the first overgrown portion of deflation basins. Hair moss (*Polytrichum strictum*), sheep fescue (*Festuca ovina*) and Langsdorf reed grass (*Calamagrostis langsdorffii*) are the commonly recognized hygrophilous species.

Subsequently, sparse herbaceous vegetation develops on the thereby protected slopes of the quarry, which impedes the advancement of deflation. Windward slopes tend to be barren, whereas leeward slopes gradually become overgrown with sheep fescue (*Fes-*

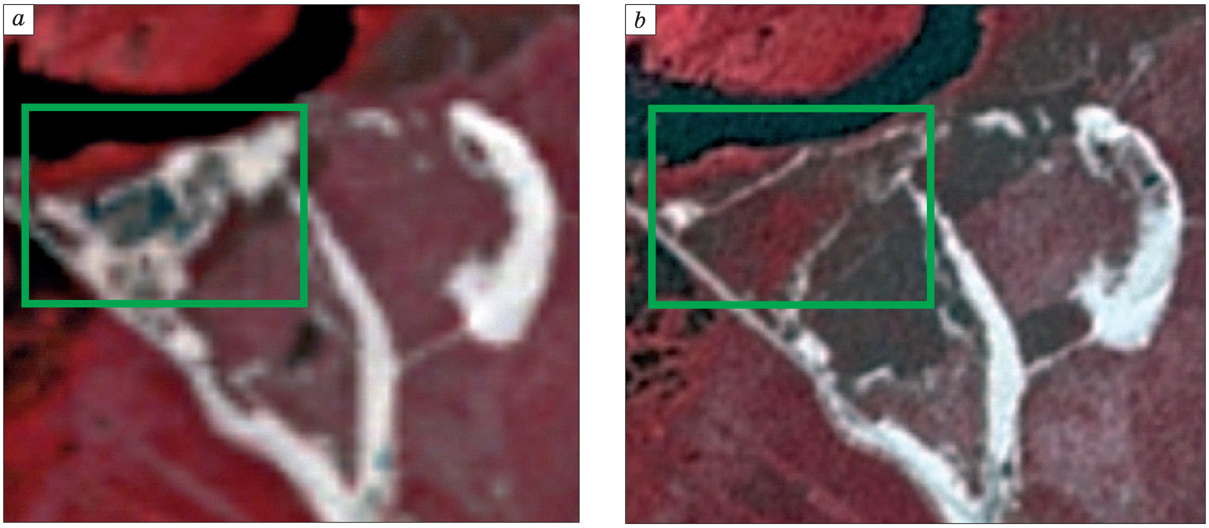

Fig. 10. Sand quarry becoming overgrown with vegetation after satellite imagery:
a – Landsat-5 dated July 5, 1988; *b* – Landsat-7 dated August 3, 2001 (http://earthexplorer.usgs.gov).

tuca ovina) and small reed (*Calamagrostis langsdorffii*), admixed with Huron tansy tansy (*Tanacetum bipinnatum*), mountain birch (*Betula tortuosa*).

Koronatova [*2003*] ascertained that shallow occurrence of groundwater within close proximity to quarries appears to be a key factor controlling their colonization by herbaceous vegetation. A deeper occurrence of the groundwater is more favorable for the development of forest communities, with silts providing a suitable habitat for birch-trees, and sands for pine-trees. A successful revegetation is generally favored by fine-textured young soil, enriched with nutrients, a smaller slope angle of the quarry and by the growth of moss, which is capable of fixing sand. The remote sensing data and the example of the model deflation basin dynamics revealed that the quarry located 1 km to the west which was operating in 1988 became completely overgrown already in 2001 (Fig. 10). The ongoing revegetation of the abandoned surfaces of the quarry by plants is currently observed in the southern portion of the basin.

At the same time, the research conducted by *Moskalenko* [*1999*] in the area along the Nadym–Punga pipeline revealed that over the period spanning 17 years, the area of disturbances on the sites increased from 2 % (at the commencement of construction) to 30 % in various pickets due to the processes, involving aeolian transportation, thermokarst and deflation (along with erosion in the hilly areas and in the near-edge parts of terraces). Remarkably, the destruction of vegetation cover on the flat and gently undulating parts of the drained plains composed of sand, favors the development of aeolian deflation. At this, a 20 cm sand layer hinders the revegetation in the shrub-lichen mound-spotted (or polygonal spotted) tundra. In general, the observations indicate a longer term for plant communities regeneration in the disturbed areas, even under favorable conditions.

The comparative analysis, when expanded geographically, showed that many northern and mid-latitudes regions are currently marked by decreasing trends in the area of wind-blown (aeolian) sands. Thus, natural colonization of tukulans (barren sands) is also progressively advancing in Yakutia where climate changes manifested primarily by the growing warming and humidity are considered to be a key factor contributing to this phenomenon [*Zhirkova et al., 2012*].

The areas of sands tend to be shrinking in the Trans-Baikal region, where *Dulepova* [*2014*] identified the following stages of their revegetation, as they arise:

1) barren sands;
2) predominance of annual plants;
3) predominance of long-rooted plantss;
4) predominance of taprooted perennial plants and low shrubs;
5) hemipsammophytic vegetation steppe, shrub thickets and elm thin forests.

General comparison of stages of revegetation of barren sands in different natural zones revealed some similarities of this process. However, in order to estimate the revegetation degree in any area it is important to take into account such site-specific factors as moisture conditions, relief features, types of the surrounding vegetation, outcrop sizes, soil texture, soils mobility and snow retention conditions [*Shilova, 1977; Sumina, 1997; Mironova, 2000*].

CONCLUSIONS

The results of the research allowed the following conclusions:

1. The modern aeolian relief is fairly well represented in the study area. Morphologically, aeolian landforms are expressed as deflation basins, which can be complicated by elongated dunes on the surface, and accumulation sand bars at the periphery.

2. Climatic conditions, generally, do not promote deflationary processes. The results of the meteorological data analysis have shown a rising trend since 1966 in average temperatures, with the peaks most pronouncedly expressed in mid-seasons (most temperature values in the period from May through October have been positive since 2002). The amount of precipitations showed a slight increase, whereas average wind speeds has decreased.

3. Among the naturally developed areas with potential for the formation of primary blowout arenas, there are markedly identifiable basins of drained thermokarst lakes and areas affected by forest fires. The analysis of multi-temporal satellite images made in 1968 has shown that the drained lake basins are characterized by the development of lichen cover and regrowth of pine and cedar species. The areas affected by forest fire bear evidence of neither newly formed blowouts nor the expansion of the existing ones, inasmuch as revegetation in most of the studied burnt areas proceeded through natural reforestation.

4. Some large deflation basins are characterized by the formation and movement of elongated dunes (about 1 m/year), as well as the accumulation of sand on the periphery of the northern, eastern and southern sides (more than 20 cm/year). Moreover, the variable moisture regime of deflation basins ranges from raised water table to complete drying. Apparently, these conditions (constant transport of sand material and variable moisture conditions) have thus far prevented the basins from complete overgrowing by plants.

5. Mechanism of revegetation of deflation basin is in many ways similar to the processes of revegetation along the dry-excavated quarries located in the identical environments. Given the level of groundwater increases, the grass cover is renewed, whereas natural regeneration of forest communities gradually proceeds at shallow occurrence of groundwaters. Primarily, local depressions become overgrown with vegetation and, subsequently, the inclined relief forms (e.g. quarry walls and basin slopes) known to have worse potential for growth of plants that might stabilize them.

It is noteworthy that, generally, the northern taiga subzone of Western Siberia is currently characterized by the decaying deflationary processes and by predominant trend towards natural revegetation. However, the existence of large deflation basins indicates to a relatively recent change in the trends. Therefore, monitoring and control of disturbed areas are highlighted herewith as necessary for the regions of active anthropogenic impact, and biological recultivation for fixing barren sands by vegetation as compulsory for industrial facilities during their shutdown (e.g. abandoned quarries).

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