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Composition of Plant Communities in Natural and Technogenically Disturbed Ecotopes on Watersheds of the Yamal Peninsula: Floristic Diversity

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Abstract—Specific features in the overgrowing of technogenically disturbed areas with completely destroyed soil and plant cover (a sand pit, a causeway, and an off-road vehicle trail) have been studied in the environs of the Bovanenkovo Oil–Gas Condensate Field. It is shown that the vegetation of natural ecotopes and ecotopes disturbed approximately 20 years ago is characterized by a relatively high similarity in the composition of vascular plants. The total species composition of plant communities (including mosses and lichens) and their structure show a considerable loss of floristic and phytocenotic diversity.

Keywords: ecotopes, plant communities (associations), vascular plants, flora, floristic similarity.

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The species composition and structure of vegetation in anthropogenically disturbed habitats are known to depend on the type and degree of disturbance, moisture supply, topographic position, regeneration period, features of underlying substrates, resources of the local flora, migration of viable plant diaspores from surrounding areas, and a number of other factors. It is considered that an active part in vegetation regeneration is played by species growing on slightly sodded substrates confined exclusively to anthropogenic ecotopes or remaining from previous communities. It has also been found that tundra vegetation regenerates much more slowly than intrazonal vegetation.

To reveal specific features of overgrowing in an area disturbed about 20 years ago, field studies during the growing season of 2006 were performed in the region of the Bovanenkovo Oil–Gas Condensate Field with the purpose of comparative analysis of natural vegetation and vegetation regenerated in areas where the soil–plant cover was completely destroyed.

MATERIAL AND METHODS

The study area lies in the northern part of the subarctic tundra subzone, in the typical tundra belt of the Yamal Peninsula (Aleksandrova, 1977). The climate of the area is cold and excessively humid (Shiyatov and Mazepa, 1995). Vegetation is formed under permafrost conditions in a low hilly plain (9–35 m a.s.l.) with a well-developed network of rivers and lakes. The moisture regime is a major environmental factors determining the species composition, structure, and succession of plant communities in space. General characteristics of vegetation and brief descriptions of the present-day structure of certain communities are given in our previous publications (Andreyashkina, 2008; Andreyashkina and Peshkova, 1995).

In natural habitats, the following communities (associations) were chosen for the study:

(1) Dwarf shrub–moss–lichen polygonal tundras.

(2) Herb–dwarf-shrub associations with patches of mosses and lichens, widely represented in parts of watersheds disturbed by regular reindeer grazing but initially covered by dwarf shrub–moss–lichen spotted hillocky tundras (currently totally destroyed) and polygonal tundras. These associations are formed by species of the local flora.

(2a) Herb–dwarf-shrub associations on solifluction slopes.

(3) Dwarf shrub–lichen–moss spotted hillocky tundras with willows and dwarf birch.

4. Dwarf birch herb–dwarf-shrub–moss spotted hillocky tundras (anthropogenic variant of dwarf-shrub–lichen–moss tundras).

(5) Herb–moss hillocky tundras with willows and dwarf birch.

(6) Willow–dwarf-birch dwarf shrub–herb–moss hillocky and tussocky–hillocky tundras.

7. Herb–moss willow stand.

8. Herb–moss bog.

The first four types of communities and willow stand occur mainly on sandy and sandy loam soils;

Table 1. Ecological spectra of vascular plants, %

Ecological group*	Natural habitats and number of community type									Disturbed habitats		
	periodically dry			mesic		moist			overmoistened	Sand pit	Road	
	1	2	2a	3	4	5	6	7	8		causeway	off-road vehicle trail
Eu	22	14	22	25	21	33	28	32	20	15	17	17
mX + xM	39	43	36	20	34	0	5	0	–	14	12	6
M	25	27	25	28	21	22	29	37	–	29	34	37
hM + mH + H	14	16	17	27	24	45	38	31	76	42	37	40
Number of species	28	44	36	40	29	27	21	35	26	48	35	35
	48			48		44						

* Eu, eurytopic species; mX, mesoxerophytes; xM, xeromesophytes; M, mesophytes; hM, hygromesophytes; mH, mesohygrophytes; H, hygrophytes.

other types, also including willow stand, occupy loamy and clayey substrates.

The regeneration of vegetation in technogenically disturbed areas was monitored in two parts of sand pit no. 3 abandoned 15–20 years ago (100–150 m in diameter and 5–7 m deep); a causeway leading to this pit, constructed of local earth in the area covered by dwarf shrub tundra, willow stand, and herb–hypnum bog; and two segments of an abandoned off-road vehicle trail (sandy loam and loam) in the environs of the former SU-33 settlement.

Geobotanical descriptions were made by the standard method. In areas with natural vegetation, 10 × 10-m test plots were established to visually estimate plant coverage, total (TC) and by layers (C) (three replications for each association), and determine the abundance of dominant vascular plants, moss, and lichen species on the Drude scale. For the same purpose, at least 30 test plots (3 × 3 m) were established in each part of the sand pit and by three plots (10 × 5 m) on the causeway and off-road vehicle trail.

The nomenclature of vascular plants is given according to Cherepanov (1995). The attribution of species to ecological and latitudinal geographic groups was made using the monographs by Sekretareva (2004) for vascular plants and Zheleznova (1994) for mosses. Ecobiomorphs were analyzed according to the system proposed by Polozova (1978). The degree of floristic similarity was estimated using the Sørensen coefficient (C_S, %).

RESULTS AND DISCUSSION

The total checklist of vascular plants found in areas with natural vegetation includes 101 species of 26 families, which amounts to 40% of the number of species recorded in the northern part of the subzone (Rebristaya, 2006). The leading families are Poaceae (21 species); Cyperaceae, Salicaceae, Caryophyllaceae, Asteraceae (8 species each); Juncaceae (6 species), and Scrophulariaceae (5 species). Half of the families are represented by one or two species.

All communities include or are dominated by eurytopic species represented mostly by hypoarctic shrubs and dwarf shrubs: *Betula nana, Salix glauca, Ledum decumbens*, and *Vaccinium vitis-idaea* subsp. *minus.* They also contain large proportions of mesophytes, both vascular plants (*Poa alpigena, P. arctica, Carex arctisibirica, Pyrola grandiflora, Equisetum arvense*) and mosses (*Dicranum acutifolium, Pleurozium schreberi, Hylocomium splendens*). Drought-resistant xeromesophile species (*Salix nummularia, Empetrum subholarcticum, Hierochloe alpina, Calamagrostis lapponica, Racomitrium lanuginosum, Polytrichum hyperboreum*) are well represented, and the same is true of moisture-loving hygromesophiles (*Salix polaris, Aulacomnium turgidum, Polytrichum strictum*), mesohygrophiles (*Arctagrostis latifolia, Calamagrostis holmii, C. neglecta*), and hygrophiles (*Carex concolor, C. rariflora, Eriophorum angustifolium, Rubus chamaemorus, Sphagnum* spp., *Dicranum angustum, Aulacomnium palustre, Calliergon* spp., *Sanionia uncinata*).

The composition of the main cenosis-forming species allows us to distinguish four habitat types, with transition from relatively dry to overmoistened ecotopes being accompanied by distinct changes in the structure of the flora (Table 1). Thus, xeromesophile and mesophile vascular plant species (61–70%) prevail in communities of periodically dry ecotopes, including associations on solifluction slopes. The same ecological groups in combination with mesohygrophytes (75–79%) are dominant in communities of mesic ecotopes. In communities of moist ecotopes, different groups of moisture-loving species and mesophytes are abundant (67–72%); overmoistened ecotopes are dominated by hygrophytes (76%).

Almost equal numbers of vascular plant species (44–48) and families (18–19) have been recorded in periodically dry, mesic, and moist ecotopes, with the floristic composition in each ecotope being relatively even: C_S = 72, 64, 58–67%, respectively (Table 2). Considerable differences revealed in pairwise comparisons between particular communities confirm their individuality. In

Table 2. Values of the Sørensen coefficient (C_S, %) at the level of natural communities

Number of community type	2	3	4	5	6	7	8
1	72	50	60	33	29	35	15
2	–	55	60	28	29	35	12
3	–	–	64	54	49	50	25
4	–	–	–	49	48	40	22
5	–	–	–	–	58	67	27
6	–	–	–	–	–	60	35
7	–	–	–	–	–	–	33

addition, differences between the floras are distinctly manifested at the level of ecotope types (Table 3).

Communities of periodically dry ecotopes are dominated by arctic and arctoalpine species (64–66%). Hypoarctic species are represented ubiquitously (20–43%), and species of the boreal group make up only 8–16% (Table 4). Their proportions in the whole flora (arctic and arctoalpine species, 60%; hypoarctic species, 29%; boreal species, 11%) are very close to those in the flora of the northern Yamal subarctic tundras: 50, 31.2, and 18.8%, respectively (Rebristaya, 2006, p. 64).

In technogenically disturbed areas, herbaceous associations of heterogeneous species composition are ubiquitously found. In the two parts of the sand pit, they occupy 30 to 50% of the area, depending probably on the time when each part was abandoned. Slopes of the pit are occupied mainly by herb–grass associations with patches of *Equisetum arvense*; TC varies from 5 to 80%. In the zone of roads constructed on the bottom of the pit, large patches of *Deschampsia borealis* and *Artemisia tilesii* with an admixture of other species have formed (TC = 30–50%). Waterlogged depressions on the bottom are overgrown by cotton grass and *Arctophila*. Patches of mosses (*Bryum* sp., *Pohlia nutans, Polytrichum hyperboreum*) occur more frequently in the part of the pit abandoned earlier (about 20 years ago).

On the causeway leading to the pit, the slope of the sandy embankment in the segment passing over dwarf-birch tundra is occupied by a horsetail–grass association (TC = 10–20%), and the part of the road passing over willow stand is occupied by a grass–horsetail association (TC = 50–70%). The role of substrate moisture is more evident at the slope base, where mainly sedge (*Carex arctisibirica*)–cotton grass–grass associations have formed in the former segment, compared to horsetail–sedge(*Carex concolor*)–cotton grass association in the latter (TC = 30–50%). The slope of the causeway embankment passing over the herbaceous–hypnum bog is covered with patches of one of tree dominant grass species: *Festuca rubra, Alopecurus alpinus*, or *Deschampsia borealis.* In the segment bordering indigenous vegetation, there is a pool of water with sedge–cotton grass–*Arctophila* beds.

On the flat hilltop with sandy loams where the soil–plant cover was completely destroyed by motor vehicles, only single plants of some herbaceous species (*Deschampsia borealis, Puccinellia angustata, Tripleurospermum hookeri*) occurred in 1990. Since then, a herb–sedge–cotton grass–grass association represented by a patchwork of consisting of a few species (TC = 20%) has formed there (by 2006). The most abundant of them are the cotton grass *Eriophorum angustifolium* and grasses (*Deschampsia borealis, Alopecurus alpinus, Festuca rubra, Calamagrostis holmii*); ruts are overgrown by *Arctophila*; in some areas, patches of mosses (*Bryum* sp., *Calliergon* sp.) occur.

On the southern slope of this hill, fragments of organogenic soil (loam) horizons were partly preserved in about one-third of its area, where small meadows with a rich floristic composition (27 species) and fairly high coverage (up to 50%) formed as early as 1990. In the growing season of 2006, the slope was overgrown by a herb–grass–cotton grass–moss association. In formerly bare and strongly compacted areas, vascular plant coverage varied from 50 to 20%. Most of the slope surface was covered with a thin layer of mosses (*Aulacomnium palustre, Polytrichum commune, Sanionia uncinata, Pohlia nutans*) weakly attached to the underlying substrate. Waterlogged ruts were overgrown by cotton grass (*Eriophorum angustifolium*) and sphagnum.

In technogenic (ruts, dumps, drilling sites, pits, etc.) and naturally disturbed areas (steep banks, landslide sites on loamy slopes, etc.) in the environs of settlement SU-33 and Lake Ngaranato, a total of 82 vascular plant species were recorded (Khitun and Rebristaya, 1997). In the disturbed area examined by this author, 58 species of 17 families have been found. The most abundant families were Poaceae (17 species in

Table 3. Values of the Sørensen coefficient (C_S, %) at the level of ecotopes

Ecotope type	Mesic	Moist	Overmoistened
periodically dry	68	39	14
mesic	–	55	25
moist	–	–	40

Table 4. Geographic spectra of vascular plants, %

Geographic group, %	Natural habitats and number of community type									Disturbed habitats		
	periodically dry			mesic		moist			overmoist-ened	Sand pit	Road	
	1	2	2a	3	4	5	6	7	8		cause-way	off-road vehicle trail
Arctic	28	36	22	22	31	26	19	34	40	46	37	49
Arctoalpine	36	30	31	28	27	18	24	23	8	19	29	17
Hypoarctic	25	20	39	40	28	41	43	32	36	19	20	23
Boreal	11	14	8	10	14	15	14	11	16	16	14	11
Number of species	28	44	36	40	29	27	21	35	26	48	35	35

the sand pit and on the causeway, 11 species on the off-road vehicle in the segment with sandy loam, and 11 more species in the segment with loam), Cyperaceae (6, 4, and 4 species), and Asteraceae (6 and 3–4 species, respectively).

The flora included much fewer drought-resistant species (6–14%), compared to mesophiles and hygrophiles: 6–14 vs. 71–77% (Table 1). The geographic structure of the flora was dominated by arctic and arctoalpine species (Table 4). All recorded species belong to the local flora, except the boreal *Poa compressa* found on the causeway, which is absent from the lists of seed material used for biological recultivation in the study area (Andreeva and Turubanova, 1991; Rozhdestvenskii, 1991; Tyurin, 1991).

The flora of the technogenically disturbed areas includes the following ecobiomorphs: shrubs and dwarf shrubs (*Salix glauca, S. reptans, S. polaris*); dwarf semishrubs (*Rubus arcticus, R. chamaemorus*); herbaceous plants: longi- and brevirhizomatous (**Equisetum arvense, E. palustre,* **Alopecurus alpinus,* **Arctagrostis latifolia, Arctophila fulva,* **Calamagrostis holmii, C. langsdorffii, C. lapponica,* **C. neglecta, Poa alpigena,* **P. arctica, P. compressa, P. pratensis,* **Carex concolor,* **Eriophorum angustifolium, E. medium, E. scheuchzeri, Astragalus subpolaris, Artemisia tilesii, Petasites frigidus, Tanacetum bipinnatum, Valeriana capitata, Carex arctisibirica,* **Festuca rubra, Juncus biglumis, Luzula parviflora, L. wahlenbergii, Cardamine pratensis, Chrysosplenium alternifolium, Bistorta major, B. vivipara, Myosotis asiatica, Polemonium acutiflorum, Saxifraga foliolosa, Ranunculus borealis, Rumex arcticus, Tephroseris atropurpurea*); firm-bunch (**Festuca ovina, Hierochloe alpina,* **Phippsia concinna, Puccinellia angustata, Eriophorum vaginatum, Luzula confusa*); tap-rooted (*Armeria scabra, Draba hirta, Gastrolychnis apetata, Stellaria peduncularis*); creeping-rooted (*Ranunculus hyperboreus*); stolon-forming (*Saxifraga cernua*); annual or biennial (*Cochlearia arctica, Tephroseris palustris, Tripleurospermum hookeri*). This list shows that the flora is dominated by perennial rhizomatous herbaceous plants (37 species), and only some of them (marked with an asterisk) are relatively abundant.

The highest floristic richness (48 species) is characteristic of sand pit areas, which is due mainly to the input of viable diaspores with surface runoff. Compared the initial stage of herbaceous vegetation formation (Rebristaya et al., 1993), the number of species in these areas increased twofold. The smallest number of species (22) is characteristic of the off-road vehicle trail on top of a flat sandy loam hill (where the input of diaspores is hindered).

The slopes of the causeway and areas at their bases are usually colonized by plant species from communities adjacent to this road. Floristic similarity between plant associations on the road and surrounding communities is high in the segment passing over willow stand ($C_S = 58\%$) and decreases to a minimum in the segment passing over the bog ($C_S = 28\%$). Similarity between associations formed in different segments of the causeway is also fairly high ($C_S = 50–55\%$). Only six species (*Equisetum arvense, Alopecurus alpinus, Deschampsia borealis, Festuca rubra, Carex concolor*, and *Eriophorum angustifolium*) are common to all these associations, indicating individuality of their species compositions. The possibility of introduction of viable diaspores with grounds excavated from the pit also cannot be excluded in view of a high coefficient of similarity between the associations of the causeway and the initial communities on sandy watersheds ($C_S =$ 46%. The highest similarity ($C_S = 69\%$) is observed between associations formed in different segments (with sandy loam or loam) of the off-road vehicle trail, as well as between these associations and those of the sand pit and the causeway.

CONCLUSION

The example of the Bovanenkovo Oil-Gas Condensate Field illustrates general trends in anthropogenic transformation of vegetation in the Far North (Matveeva, 1989). Thus, the overgrowing of disturbed tundra areas where soil and vegetation were completely destroyed is an extremely slow process: by the end of the second decade, only 20–50% of the area examined in this study was covered with vegetation.

Total destruction of soil and vegetation in tundra areas on watersheds leads to considerable losses of floristic and phytocenotic diversity. Lichens have not been found in the examined area; bryophytes play only a minor role. Herbaceous associations are ubiquitously present (a total of 58 species); the most prominent among them are rhizomatous annual plants and in some places with Equisetum arvense. Shrubs and dwarf shrubs are represented only by single willow shoots of seed origin and small patches of *Salix polaris* introduced from the surrounding area. But since the proportion of shrubs and dwarf shrubs in the species compositions of the initial communities is small (15%), natural ecotopes and ecotopes technogenically disturbed about 20 years ago show a relatively high degree of floral similarity ($C_S = 60\%$).

The effect of underlying substrates on the process of soil and vegetation regeneration has also been revealed: areas with sandy substrates are dominated by grasses with a considerable proportion of *Equisetum arvense*; sandy loam substrates, by cotton grass–grass communities; loam substrates, by grass–cotton grass communities. At the same time, the floristic similarity between associations of different areas is considerable (C_S = 46–69%). Herbaceous associations are formed by species included in the initial communities (only one alien species, *Poa compressa*, has been found). Pioneering species such as *Deschampsia borealis, Phippsia concinna, Puccinellia angustata, Tripleurospermum hookeri*, and *Tephroseris palustris* occur only in disturbed ecotopes, and their role in the formation of vegetation is relatively small (except for the first two species)

Comparison between ecotopes with respect to the composition of vascular plants in their vegetation deserves special attention. It has been shown that the flora of disturbed areas as well as that of natural periodically drying ecotopes is dominated by arctic and arctoalpine species, indicating a similarity of environmental conditions. The ecological spectrum of the flora is dominated by hygrophile and mesophile species, which is characteristic of natural vegetation in moist ecotopes. Therefore, the retarded process of vegetation formation in disturbed areas is due not so much to the moisture regime of ecotopes as to the harsh climate conditions, low nutrient contents in the substrates, and other factors. The moisture regime is a major factor only in periodically drying ecotopes on flat tops and slopes of watersheds, where soils periodically dry up, with consequent to weathering and eventual destruction of the sod.

Destruction of soil and vegetation, as well as regular reindeer grazing on plakor watershed areas, markedly accelerate the process of so-called herbification of tundra lands. Technogenically disturbed areas are ubiquitously occupied by herbaceous associations, whereas overgrazing leads to the spread of herb–dwarf-shrub associations with patches of mosses and lichens. Regeneration of indigenous vegetation is especially probable in the area of the off-road vehicle trail with loam substrates, but it will require many decades to be completed. The results obtained in different habitats can be used for the study of dynamic processes in the vegetation of the Yamal Peninsula.

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