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Physiological Barriers for Adventitious Species Invasion in Oligotroph Ecosystems of the Middle Ob Area

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Abstract

The comparative assessment of four groups of plant species adaptability to conditions of raised oligotrophic bogs of the Middle Ob area has been made. Researches were conducted in oil extraction zone located between 60-62 degrees north latitude and 75-80 degrees east longitude. Oil extraction has been carried out for more than 40 years. At present, numerous observations on disturbed ecosystems restoration have been made. Dominant groups of local flora species such as *Ericaceae, Pinaceae Cyperacea* were compared with species used in revegetation of boggy ecosystems. On level of adaptation to bogs these species are arranged in the following consequence "*Ericaceae*> *Pinophyta*> *Carex*> adventitious species". Tolerance of species has been compared according to their ecological scales locations, biological efficiency, activity in evergreen conditions, and formation of mycorhiza as well as steady plant communities. In natural ecosystems invasive species can't form steady communities owing to numerous physiological barriers to their development. Boggy ecosystems restore at the expense of plant species of local flora after minor disturbances during oil extraction.

Keywords

Oligotroph; Ecosystems; Oil; Mycorrhiza

Introduction

Intensive development of the Middle Ob area for oil extraction purposes inevitably impacts natural ecosystems of the region in various ways [1-3]. In particular, local natural communities are being invaded by different species not typical for the environment through different channels. The main channels of adventitious species invasion are sowing of such species during revegetation of disturbed territories and accidental introduction [4]. These territories have been developed for more than 40 years [1]. For this reason, big data on dynamics of ecosystems during revegetation have been stored. There are at least two major views on the nature of interaction of natural communities and adventitious species. The first opinion states that natural communities are rather vulnerable and can be destroyed during development [5-7]. The other point of view claims that the conditions of the Middle Ob raised bogs are very specific and that the adventitious species do not posses enough strategies for adaptation to survive in such conditions. The overall aim of this article is to present a comparative analysis of adaptiveness of four ecological groups of plants to the conditions of the Middle Ob raised bogs.

Methods of Plant Research in Raised Bogs

Wetlands and ecosystems close to them in their composition in the Middle Ob area are raised bogs. Plant ecosystems function in the conditions of low nitrogen levels and low content of nutritional element in the root layer. Moreover, low temperatures are accompanied by low availability of oxygen as a result of high water content in bog soils. Total growing degrees above +10, total solar radiation and the length of freeze-free period are much lower than those on Moscow latitude (1900-2400 and 1300-1400; 3400 MJ/м^2 and 4100 MJ/м^2; 90-110 and 120-140 days corresponding). This means that environmental niches of raised bogs incorporate several limiting factors for plant development [8]. Notably, these limiting factors primarily target various functional and physiological plant units.

RGR – relative growth rate – the rate at which biomass grows compared to the original weight W_1 - W_2 / W_1, where W_1 - W_2 represents growth within a specific time frame compared to the original weight.

Photosynthetic and breathing rate was studied with gasometric method with the help of the infrared gas analyzer Infralit III (Germany) with a scale of 0-0.1%, determining the speed of CO_2 gas exchange of plant leaves [9].

Total respiration R is composed of two components: breathing of growth and breathing of sustentation.

It has been demonstrated previously that plants in normal conditions spend approximately 40% of products of gross photosynthesis (Pg) on breathing (R), in other words R/Pg = 40% [10].

Spectrophotometric method and equipment SPECORD 30 (Analytik jena – Germany) was used to assess quantity of pigments. Concentration of chlorophylls (C_a, C_b) and caratinoids (C_{car}) was calculated with the Roebbelen equation [9]. Assessment of root and mycorrhiza development was performed on cross sections of adventitious roots cut with a microtome. Root size, size of the central cylinder, cark size and amount of layers of cells in it were recorded. Type of mycorrhiza and mycorrhiza fungi in the cells of root mesoderm was determined as [11,12,13]. From two to five separate roots were analyzed for each unit. Limits of ecological tolerance are established with the help of Tsyganov scale [14]. The scale measures the following criteria: "moistening" (scale from 1 to 21, ranging from deserts to aquatic ecosystems); "richness – salinification" (scale from 1 to 17, ranging from complete absence of mineral constituents to saline soil where plants do not survive); "nitrogen requirement" (scale from 1 to 10, ranging from lack of accessible nitrogen to ruderal animal farms); "pH" (scale from 1-15, ranging from acid soil to alkaline soil).

Statistical data analysis was performed with the help of "Statistica" software.

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Results

Production processes in plants

Biomass accumulation on the bogs is not big; it ranges from 2,500 to 3000 tn/km². It is 2 - 5 times less than in the forests of the central part of the country [1]. Relative growth rate (RGR) increases in the sequence "ericaceae-conifers-carex-wild grasses" [3,15]. Low level of biomass accumulation is determined by deficit of nearly all resources necessary for life.

Respiration and resource costs of adaptation

Deficit of resources increases levels of energy required by different systems to adapt to such lack of resources. It has been demonstrated previously that in regular conditions plants spend approximately 40% of gross photosynthesis (P_g) products on breathing (R), which implies R/P_g = 40% [10]. When conditions worsen, breathing of sustentation increases, which leads to the increase of R/P_g up to 60-90%. According to the data presented [3], R/P_g in ericaceae ranges from 62% to 80%. It becomes obvious that these plant species cannot use their resources to produce large amounts of biomass. Data for R/P_g correlation on other plants is controversial and requires further studies.

Ever greening dominants of boggy ecosystems

The fact that ericaceae and conifers are evergreen plants allows them to save a lot of photosynthesis products to produce biomass and perform biosynthesis of photosynthesis elements. Lifespan of needles and leaves of ericaceae can reach 3-6 years whereas photosynthetic instrument of carex and invasive species dies every winter.

Ability to withstand sever cold typical of Siberian region is manifested differently in conifers and ericaceae. Figure 1 demonstrates specters of ethanolic extracts of the leaves of three ericaceae and pine-tree. Pine-tree that shifts into winter period demonstrates and even decrease in the whole spectrum of pigments. Ericaceae show a decrease of pigments in the range of 360-490 nm, and chlorophylls (620-700 nm). Levels of carotenoids barely changes, which gives ericaceae their bright-red color in the spring when the snow melts and the plants become visible.

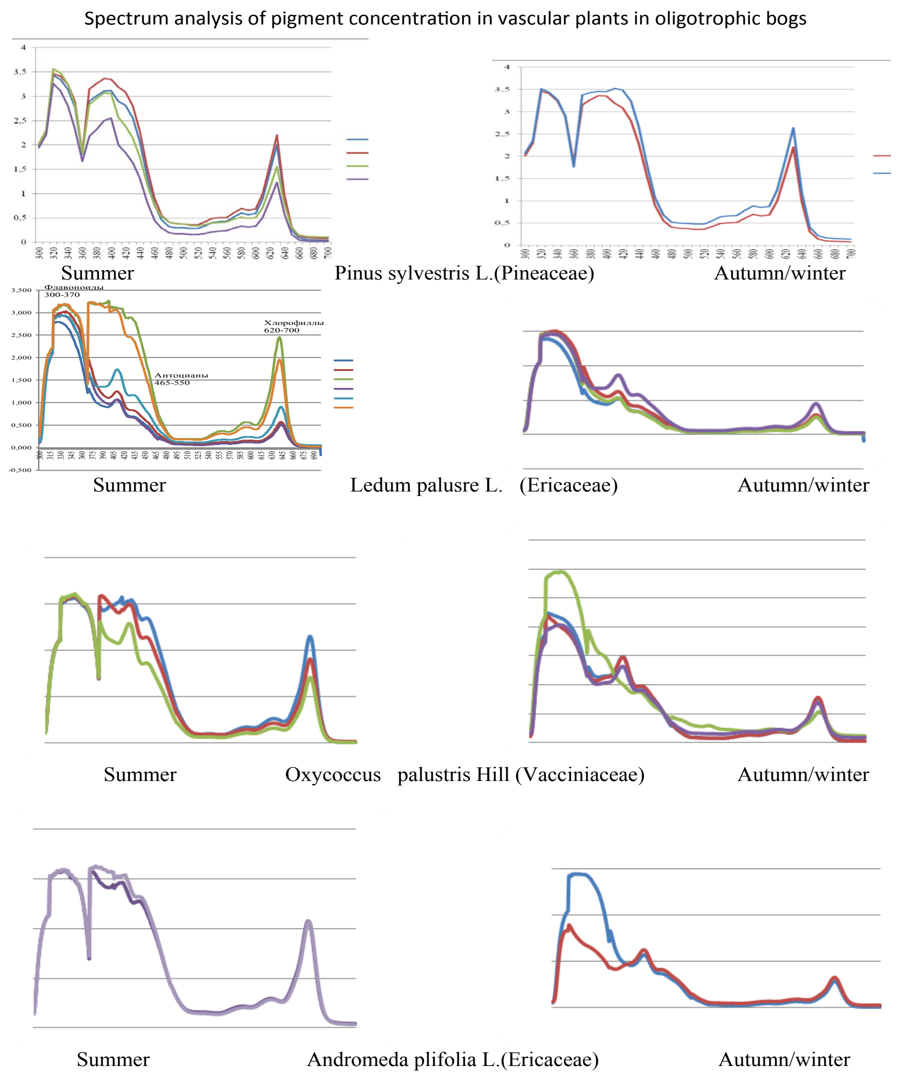

Figure 1: Spectrum analysis of pigment concentration in vascular plants in oligotrophic bogs.

Extraction of nutrients from upper layers of peat and mycorrhiza

Destructive processes are quite mild in raised bogs. Correlation between leaf litter and amount of leaf waste is relatively big and ranges from 15 to 50-60. It implies that undecomposed biomass is being accumulated and its weight is15-60 times higher than amount of leaves falling over the year on average. As a result, average depth of peat layers may reach 2-3 and more meters [3]. On the whole in conditions of low productivity and low rates of decomposing of leaf litter, raised bogs accumulate organic biomass in a form of peat if seen from the perspective of productive and destructive processes [6]. Mycorrhiza facilitates extraction of inaccessible nutritious elements. Groups that are being considered in this research have different types of links with fungi that form mycorrhiza. Ericaceous type of mycorrhiza is representative of Ericaceae family. For a very long time only one fungi type was considered to be able to form ericaceous type of mycorrhiza - *Pezizella ericae* [11-13]. Current research demonstrates that there are many different types of fungi that form ericaceous type of mycorrhiza, including anamorphs of *Oidiodendron* genus and their telemorphs of *Myxotrichum* and *Byssoascus* genus and other unspecified strains.

Ericaceous types of mycorrhiza develop on barren soils and facilitate extraction of phosphates and different types of nitrogen [12,13]. Our studies have shown that ericaceae have mycorrhiza of 2,5-1,5 points and amount of mycorhizza decrease as the amount of peat in the soil increases [11-13].

Another type of mycorrhiza is ectendotrophic mycorrhiza. It is found in only two gymnosperms – pine-tree and larch. Ectendotrophic mycorrhiza is one of types of mycorrhiza that combines features of ectomycorrhiza and endomycorrhiza. It has a lot in common with ectomycorrhiza. In the process of development of symbiotic relations, both create a hypha cover and Hartig net. However, after Hartig net is fully developed, hyphae penetrate epidermis and plant bark cells. The benefits of fungi with ectendotrophic mycorrhiza for plants are still under research. Pine-tree has mycorrhiza of 2.5-1.5 points [11,12,13,14-17].

Plants of Carex genus have almost no mycorrhiza.

Ericaceae and conifers have advantage of extracting inaccessible mineral constituents from peat soil if compared to carex and invasive species. Ericaceous type of mycorrhiza adapts better to barren soils [17,18].

Groups of plants with different adaptiveness to the conditions of oligotrophic bogs

A number of studies of raised bogs [3,6] recognize a common trend where plants change from evergreen ericaceae shrubs through conifers to herbaceous perennial plants and deciduous shrubs as limits weaken and accessible elements of minerals rise. Analysis of some of the species growing in the Middle Ob area in accordance [17-20] with Tsyganov's scale [14] demonstrates that ericaceae adjust better to the limitations of the raised bogs than other vascular plants (Table 1). Ericaceae cope equally well with severe lack of saline elements, lack of nitrogen, and acidic soils. At the same time, they do not cope well with deficit of moisture; for this very reason they live well on wetlands. Although conifers possess almost similar requirements to the environment, there are still certain differences. Conifers require less moisture than ericaceae and live better in soils with higher concentration of nitrogen. Carex can survive in the environment with more moisture, even when their roots and lower leaves are submerged under water (ref. "moistening" scale). Invasive species of different taxonomies prefer dry habitat, meanwhile they require greater concentration of salt and nitrogen. Next, the article dwells on some of the physiological mechanisms that allow plants to adapt to the conditions of raised bogs. The plant groups described here differ in tolerance according to some of the parameters.

Table 1: Limits of ecological tolerance of dominant species in raised bogs.

Limits of ecological tolerance are established with the help of Tsyganov scale [14]. The scale measures the following criteria: "moistening" (scale from 1 to 21, ranging from deserts to aquatic ecosystems); "richness – salinification" (scale from 1 to 17, ranging from complete absence of mineral constituents to saline soil where plants do not survive); "nitrogen requirement" (scale from 1 to 10, ranging from lack of accessible nitrogen to ruderal animal farms); "pH" (scale from 1-15, ranging from acid soil to alkaline soil).

Species	ECOLOGICAL SCALE			
	Moistening	Richness – salinification	Nitrogen	pH
ERICACEAE				
Andromeda polifolia L.	9-14	1-9	3-7	7-11
Oxycoccus palustris Pers.	13-19	1-6	1-4	1-11
Chamaedaphne calyculata (L.) Moench	12-19	1-7	1-5	1-7
Ledum palustre L.	11-19	1-7	1-5	1-5
PINACEAE				
Pinus sylvestris L.	8-20	1-8	1-9	1-13
Pinus sibirica Du Tour	10-19	1-9	3-9	3-9
CYPERACEAE				
Eriophorum vaginatum L.	14-20	1-7	1-5	3-7
Carex limosa L.	13-21	1-7	1-6	1-6
Carex vesicaria L.	12-21	1-11	3-9	5-9
INVASIVE SPECIES (incl. REVEGETATION)				
Bromopsis inermis (Leyss.) Holub	3-19	5-17	3-9	7-13
Dactylis glomerata L.	5-16	3-11	4-10	1-11
Phleum pratense L.	7-19	3-13	5-9	1-11
Tryfolium pratense L.	5-17	1-15	1-10	1-13
Ranunculus repens L.	11-19	3-15	1-9	1-13
Carex acuta L.	11-21	5-13	3-9	7-13

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Dynamics of plants on raised bogs in the areas of oil extraction

Raised bogs and forests constitute the major part of the oilfields in the Middle Ob area. Primarily they are low shrub sphagnous high bogs and mesotrophic bogs, and marshy heathlands that belong to the class of *Oxycocco-Sphagnetea* Br.-Bl. et R. Tx. ex Westhoff et al., 1946 and Pinacae and low shrubs of raised bogs that belong to the class of *Vaccinietalia Uliginosi* Tx. 1955 [2,6].

Apparently, small differences between ericaceae and conifers together with similar levels of tolerance of carex (Table 1) allow dominating vegetation to coexist successfully. Two typically occurring habitus can be observed.

Areas with complete domination of ericaceae: This domination is especially noticeable in the late autumn and early spring – wetlands turn burgundy because of low levels of chlorophylls and increased levels of carotinoids and anthocyans in the red part of the spectrum. In summer season, when the climate changes, the color of raised bogs leans to the green side of the spectrum (Figure 1). Increase in concentration of chlorophylls leads to accumulation of ericaceous biomass. It results in slightly raised areas on the surface of highland raised bogs [17,18]. Raised surface leads to drawdown in areas of raised bogs. It allows for growth of conifers, first off, pine-trees. Pine-trees occupy territories with drier surface. Pine-trees get more oxygen and it becomes possible to change ericaceous mycorrhiza to mycorrhiza of gymnosperms. Apparently, this moisture regime lets pine-trees to take over the whole area of raised surface. This assumption is supported by the way pine-trees grow in groups and are surrounded by wetlands. These groups of pine-trees suppress ericaceae, and conifers greatly contribute to the growth of biomass. Leaf litter of ericaceae decomposes and it leads to drawdown. All this considerably lessens comfort levels for conifers and forms third habitus.

Conifers: Conifers die and overstorey layer forms tend into standing trees while on the ground layer ericaceae dominate again. It starts new cycle of biomass growth in riam area.

These tendencies show a cycle of mutual exclusion. Dry environment and increased levels of nitrogen allow conifers to dominate while change of the environment to dampness and decrease in nitrogen levels allow carex to drive out conifers. It appears that this is how groups of conifers of the same age form: as these groups grow, climate changes take place and conifers die. They are replaced by ericaceae that accumulate biomass and create favorable conditions for next groups of conifers. Carex are present in all environments but they only start to dominate in much damper areas or in areas with peat soils rich in nitrogen and mineral constituents.

Consequently, in our studies, we observe complex dynamic changes in raised bogs, initiated by multifactor fluctuations of environmental conditions: nitrogen content [21], water factor [22], nutritions [23,24] and other environmental factors [25-28]. However, plant communities dominated by *Ericaceae, Pinaceae, Cyperacea* successfully fill natural ecological niches due to environmental conditions.

Adventitious Species in Natural Ecosystems

These species do not have tolerance levels high enough to survive in acid soils with severe lack of nitrogen and mineral constituents.

For a short period of time (maximum 1-3 years) amount of plant species that are used in artificial revegetation is relatively small both in terms of productivity (participation in biological productivity of cenosis) and foliage cover.

No cases have been recorded when plants used in soil revegetation became dominant. Moreover, these species do not survive in restored communities.

Communities for Invasive Species

Communities of invasive species grow steadily in small communities on artificial surfaces: road beds and embankments created for oil extraction purposes.

Construction of oil production infrastructure on wetlands surface requires relocation of big amounts of substrates. It results in establishment of artificial structures that have favorable ground features - plain and linear ground fills, thus establishing man-made mineral formations [5,19,29,30]. Diverse hydrological regime and nutrition conditions, etc. provide invasive species survival in these conditions.

Conclusion

Approximately 95-98% of environmental damage done during oil extraction can be considered medium or low [7]. Massive damages resulting from major accidents are extremely rare. [4]. In general, pollutants that reach ecosystems are not considered very toxic. Oil is composed of hydrocarbons and is not toxic; plants are suppressed by the water repellent film that is formed by oil spread on the surface. Oil is easily dissolved by microorganisms and algae [17,18], and is absorbed later by plants. Waters used in the process of oil extraction contain freely soluble salts (NaCl etc.) and do not include highly priced antibiotics [19]. Therefore, in the conditions of medium and low pollution parameters of environmental niches remain close to intact with a slight raise in the levels of water body trophicity.

This leads to the conclusion that light and moderate pollution of oligotrophic ecosystems activates processes of biomass accumulation (growth processes) and biomass destruction (activation of destructive fungi). Microfluxion of pollutants (about a hundred meters) leads to their even distribution and dilution to biologically safe level. It takes about 1-3 months in warm seasons [19,20]. All studied cases demonstrate that self-regenerating processes in ecosystems depend on the way aboriginal types of algae, fungi, herbaceous plants and land plants behave. In natural ecosystems invasive species can't form steady communities owing to numerous physiological barriers to their development.

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