Changes in Floristic Composition of Meadow Phytocenoses on the Anthropogenically Eroded Slope

S S Smelova¹, M S Zverkov¹,²
¹Kolomna Institute of Moscow Polytechnic University, 408 Oktyabrskoj revolucii st., Kolomna, 140405, Russia
²All-Russian scientific research Institute «Raduga», 38 Raduzhnyj, Kolomna, 140483, Russia

E-mail: rad_sc@bk.ru

Abstract. It is noted that the solution of geoecological problems largely depends on the availability of reliable and comprehensive information about the state of the geosystem and its development trends. The paper presents ecological-dynamic series reflecting changes in the floristic composition of meadow phytocenoses on the anthropogenically eroded slope under conditions of a developing landslide in 2000–2019. The data obtained make it possible to assess the degree of disturbance of the geosystem and can be used to plan economic and environmental protection measures. The article notes to reduce the anthropogenic load on such easily vulnerable biogeosystems as floodplain meadows located on a landslide slope near the built-up area, first of all it is necessary to identify the boundaries of the water protection zone and the coastal protective zone in the site of landslide process, to provide soil consolidation and to restore the vegetation cover, to organize groundwater discharge points on slope, to catch and to organize and surface runoff treatment. It is important to carry out engineering measures for monitoring the landslide development in order to prevent the adverse consequences.

Keywords. Successional process, erosion, geobotanical description, biodiversity, geosystem.

1. Introduction
The role of biodiversity in plant communities is extremely high, because it determines the stability of natural biogeosystems. A decrease in the number of plant species in phytocenoses has a negative effect on functional connections in biogeosystems, this leads to irreversible changes in the spatial structure of communities and even to their destruction. As a rule, anthropogenic impact on biogeosystems is accompanied by the loss of specialized plant species with narrow ecological spectrum. First of all, when the habitat conditions change, rare species disappear [1, 2]. The decrease in the number and loss of rare species begins already at the first stages of degradation of biogeosystems, when the changes are reversible.

Many works have been devoted to the study of the influence of vegetation on the stability of eroded slopes. Vegetation performs bioprotective and bioconstructive functions [3]. Due to the presence of vegetation on the slope, the cohesion of the soil increases [4]. In some studies [5–7] it is noted that the root system of plants helps to an increase in soil shear strength. The vegetation cover protects the soil from erosion by reducing the intensity of surface runoff [8–10]. However, as a result of various anthropogenic impacts, changes in the floristic composition of phytocenoses can take place on the
coastal slopes. This can cause unpredictable geological consequences. Therefore, it is important to regularly assess the condition of the green spaces on the slope.

The purpose of the work was to analyze the changes in the geobotanical and geotechnical environment of an eroded slope with landslide activity. This was needed to design a program of protective measures. Human impact on the landscape is related to the management of natural processes, as a result of which a certain state of the natural-territorial complex is maintained. This state ensures the stability of the ecosystem, as well as the most efficient mode of operation and implementation of the control function.

2. Materials and methods
The eroded coastal slope of the Oka River considered in this work is located at the junction of the Meshcherskaya lowland, plains of Zaoksky and Moscow-Oka interfluve. The latter in the area of Kolomna-city from the side of the Oka River is a slope with a height difference of 150...100 m. The relief is gently ridged, with moraine eroded hillslopes [11, 12]. The coastal slope has a steepness from 15...25° to 45...60 ° (main scarp), overgrown ravines (gullies) are found on the terraces above the floodplain.

The procedure for a standard geobotanical description of a vegetative cover for the territory of this eroded coastal slope were provided and as a result the primary geobotanical profile was drawn in 2000 [13]. The change in vegetation cover on this profile was monitored for 20 years (2000–2019) [14], which made it possible to get a complete picture of the course of the exogenous successional process.

High density housing development of the left bank of the Oka River within the water protection zone, together with geological prerequisites, caused landslides [15].

The landscape-dynamic approach is usually used to study the vegetation cover of river valleys [16, 17]. The valleys are characterized by a regular alternation of plant communities along the transverse profile of slope. In this regard, we based the study of meadow vegetation on the methods of geobotanical profiling and ecological-dynamic series, reflecting the relationship of meadow communities with the main natural (abiotic and biotic) and anthropogenic factors [18]. The morphological structure of the transverse profile of slope is described by identification of facies on the slope. Satellite imagery were obtained using ©GoogleEarth (version 7.3.2).

3. Results
As a result of a landslide under the conditions of an increasing anthropogenic load on the natural geosystems, the process of degradation of vegetation began on this slope [13]. This complicates the dynamics of the landslide process, because infiltration flows are disturbed on soil without vegetation and soils exposed by landslides, and local sites of surface erosion are observed.

Figure 1 shows the dynamics of changes in the floristic composition of phytocenoses on a landslide slope in 2000–2019. The length of the transverse and geobotanical profile from the water’s edge to the high coast is on average 115...145 meters. In this part of the river valley there are (T1), (T2), (T3) and (T4) terraces above the floodplain (slump blocks) on the geobotanical profile [13]. There are no all geomorphological elements typical for the floodplain in the relief of the valley. The transeluvial, transaccumulative and super aquatic facies are sequentially located on the surface of the slump blocks T3, T3, and T4 respectively, T1 – mainly transeluvial facies. The studied landslide is an example of a block-type landslide, stepwise with elements of extrusion and sliding. The landslide steps (slump blocks) have slope mainly towards the water edge. Such a landslide is characterized by a long, slow and intermittent movement, which usually ends with a rapid displacement of a large volume of bedrock [19]. There is a relative integrity of the soil masses separated from the slope. The sudden changes in the structure and condition of the soil are observed in the displacement zone. In the geological structure of slope there are three groundwater mirrors (the Oka-Dnepr, Podolsk-Myachkovo and Kashira aquifer horizons) which come out onto the surface of slope, flow down and accumulate in low places (depressions) on landslide steps. The landslide steps are mainly composed of Jurassic clays.
Thus waterlogged places (super aquatic facies) with hydrophilic plant community (reed, cattail, sedge) are formed in the depressions [20].

Comparing changes in floristic composition on the geobotanical profiles since 2000 to 2019 years, we observe the degradation of vegetation cover in the river valley. During this period (20 years) due to the disturbance in the structure of the soil cover there have been very significant changes in the vegetation cover: a simplification of the structure of communities is observed; there is the active process of introducing weed species into meadow phytocenoses; new secondary communities are formed with the domination of reproductively active species distinguished by pronounced phytocenotic aggression. In meadow communities, biological diversity has dramatically decreased.

The active growth of the landslide was observed in 2004–2009 (the satellite image of 2010 in Figure 2B shows the displacement of woody vegetation in the upper part of the slope as a result of the

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**Figure 1.** Vegetation on slope: A, B, C – in 2000, 2008, 2019 years respectively; I, 2, 3 – groundwater level of Oka-Dnepr, Podolsk-Myachkovo, Kashira aquifer horizons respectively; T₁, T₂, T₃, T₄ – floodplain (slump blocks) terraces; ᵗ – Carex acuminata; ᵇ – Urtica dioica; ᵕ – Artemisia absintium; ᵗ – Echinops sphaerocephalus; ᴵ – Convolvulus arvensis; ᵇ – Geranium collinum; ᵗ – Arctium tomentosum; ᴿ, ᴸ – Salix triandra; ᵕ – Typha latifolia; ᵗ – Companula glomerata; ᵗ – Tanacetum vulgare; ᴷ – Achillea millefolium; ᵇ – Trifolium pratense; ᵗ – Phragmites australis; ᵗ – Angelica sylvestris; ᵗ – Sonchus arvensis; ᵗ – Calamagrostis epigeios.
movement of ground masses), and in 2012–2013 (Figure 2C shows the active phase of the formation of the super aquatic facies in the places where the Podolsk-Myachkovo aquifer horizon come out onto the surface of slope with water accumulation in the depression on the landslide terrace $T_3$). In 2014 (Figure 2D), the reclamation was carried out on the slope: a drainage tray for catching surface runoff and a gabion retaining wall were built, tree and shrub vegetation was planted along the edge of slope.

The comparative analysis showed that the restoration of floristic composition of natural meadow vegetation is very slow and is accompanied by obvious changes in the floristic composition and structure of meadow phytocenoses. In this case, there are irreversible consequences of anthropogenic changes in the vegetation cover of the territory. In the period from 2014 to 2019 slow restoration of the integrity of the vegetation cover of the study area began. The floristic composition is noticeably depleted in comparison with the profile of 2000. Intensive development of the landslide was observed in 2010–2013. (Figure 3A). The single local sites of landslide process caused the movement of ground masses in 2000. Currently, the total area of the landslide slope is about 62000 square meters (Figure 3B) including potentially hazardous local sites of landslide process and their zones of influence. Morphological studies clearly confirm the incompleteness of the landslide process.

Figure 2. Satellite imagery (©GoogleEarth) of landslide process: A, B, C, D – in 2004, 2010, 2013, 2014 years respectively; – local sites of landslide process; – the displacement of woody vegetation; – the formation of the super aquatic facies on slump block $T_3$; – landslide boundaries; – drainage tray and the direction of movement of water; – gabion retaining wall.

Figure 3. Landslide slope in 2010 year (A) and satellite image (©GoogleEarth) in 2019 year (B).
Landslide monitoring also allowed us to identify some regularities associated with the formation of initial plant groups on the soils of slump blocks. At the beginning *Tussilago farfara* settles on the exposed sandy soils of the landslide. Bare plots on loose meadow soils of the landslide are the first to be colonized by *Atriplex alba*, *Atriplex sp.*, *Fumaria officinalis* and *Erodium cicutarium*. These plants are classified as spring annuals. Their development is limited to one growing season with the formation of a large number of seeds. An important role in the process of overgrowth belongs to perennials with taproot system and rhizome. These are two species of wormwood (*Artemisia vulgare*, *A. absintium*), thistle (*Carduus acanthoides*), burdock (*Arctium tomentosum*), chicory (*Cichorium intibus*), sow thistle (*Sonchus arvensis*), etc. The seeds of these plants are characterized by a high degree of germination, and the seedlings are highly competitive ability.

At the first stage of landslide overgrowth, these species are of great importance, because they contribute to the initial stage of consolidation of eroded soils. But in the future, they are undesirable in natural meadow ecosystems. These species cannot form stability vegetation communities and interfere with the restoration of the natural cover on meadow soils, displacing typically meadow species. Most of the meadow species cannot compete with the weedy species of the local flora, as a result of which stable climax phytocenoses cannot form in this territory. The changes in vegetation naturally go in the direction from unstable to sustainable communities. The latter property of ecosystems is largely provided by great biological diversity. A reduction in the number of plant species in phytocenoses adversely affects functional connections in geosystems and leads to irreversible changes in communities and even their destruction.

4. Conclusions
The successions of the vegetation cover of territories are the main indicators of changes in the landscape structure of geosystems. Anthropogenic activity in especially vulnerable natural landscapes leads to their transformation and, in the end, to the degradation of natural biogeosystems, the signs of which are a decrease in the biological diversity of species, a simplification of the tier structure in biogeosystems, a violation of the processes of natural self-regulation, which are responsible for the number of species and composition in biogeosystems. The natural overgrowing of the slope is very slow, taking into account the increasing anthropogenic impact on meadow ecosystems. Restoration of vegetation in the previous floristic composition is impossible.

To reduce the anthropogenic load on such easily vulnerable biogeosystems as floodplain meadows located on a landslide slope near the built-up area, first of all it is necessary to identify the boundaries of the water protection zone and the coastal protective zone in the site of landslide process, to provide soil consolidation and to restore the vegetation cover, to organize groundwater discharge points on slope, to catch and to organize and surface runoff treatment. It is important to carry out engineering measures for monitoring the landslide development in order to prevent the adverse consequences.

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