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Population dynamics of forest-forming tree species on landslide-scree slopes of the right bank of the Kuibyshev reservoir (Tatarstan)

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Population dynamics of forest-forming tree species on landslide-scree slopes of the right bank of the Kuibyshev reservoir (Tatarstan)

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Abstract. The dynamics of forest-forming tree populations under conditions of landslide slopes makes it possible to assess the impact and the anthropogenic regulation of the Kuibyshev reservoir on the forest vegetation state. The Shannon index characterizes the phanerophytes diversity in the structure of forests by landslide elements. The integral signs of the activity/stability of landslide processes on the slopes are the trees functional parameters – the trunks height, the dynamics of cross-sectional areas and wood volumes, reflecting not only the different trees populations state and productivity according to the landslide elements, but also the stage of phytocenoses reforestation of along the right bank of the Kuibyshev reservoir.

1. Introduction

The creation of reservoirs leads to a fundamental restructuring of natural systems. As a result, not only the water runoff and the river regime are transformed, but also bank landscapes. As a result, the rates of hazardous exogenous processes increase by orders. Especially dangerous is the complex of abrasion-landslide processes, as the most significant in terms of damage area and intensity. Reservoir bank transformation often leads to emergency situations associated with threat of buildings, structures and communications destruction, removal of shore areas from the land use, and reservoir ecological state deterioration [1]. In this regard, it is necessary to develop effective methods for hazardous processes monitoring, since knowledge of their spatiotemporal activity is crucial for determining the risk of landslides movement, their impact on natural and anthropogenic complexes and their development modeling.

There are several main trends in landslide processes studies. Firstly, it is a landslide's location inventory [2], assessment of slope stability and zoning of territories according to the degree of landslides risk [3-5], which are key tools for land use planning. Equally important is the monitoring and early warning of landslides processes, which play a fundamental role in landslides mechanism understanding [6-8]. In this case, they are used as traditional methods based on studying the properties of rocks and soils, monitoring of groundwater level in specially equipped wells, reference benchmarks measurements, topographic surveys, and remote sensing methods. With the development of technology in recent years, modern instrumental methods of field observations are widely used – terrestrial and aerial laser scanning (TLS and ALS), unmanned aerial vehicles (UAV), global navigation satellite system (GNSS) [9-12].

Works devoted to the analysis of slope processes influence on vegetation and to phytoindication methods development deserve special attention [13-15]. When applying these methods, the indicator features of various plant species, their floristic, ecological, phytocenotic, biomorphological and other characteristics, composition and structure of the plant community are used. These parameters reflect the position of plants in the successional series, which, according to our assumptions, depends on the landslide age, mobility or stability of its morphological elements [16]. Thus, the widespread use of phytoindication methods could be one of the solutions to optimize the landslide processes monitoring.

The monitoring of landslide-scree processes on the right bank of the Volga River has been carried out by the authors of the article for more than 20 years and makes it possible to assess the state of plant communities under the conditions of gravitational mobility of the soil of the banks, due to both the natural action of the river and anthropogenic regulation of the Kuibyshev reservoir level.

The result of landslide-scree processes is the degradation of broad-leaved forests. The condition of forest communities on landslide slopes additionally depends on the area and condition of the primary sections of the slope, which are often subjected to intensive plowing, built up with dachas and road network [17]. In the absence of anthropogenic impacts on the primary slope and its additional strengthening by artificial planting, there is still hope for partial slope stabilization, reforestation and forest communities' preservation. Dynamics of populations of forest-forming tree species by slope elements reflects the degree of forest disturbance or regeneration. The successional dynamics of landslide slopes vegetation can be traced by comparing of recent and conditionally stable landslides, where the processes of community restoration have already begun or ending.

The main forest-forming species of Volga region nominally indigenous communities are: *Quercus robur* L., *Tilia cordata* Mill., *Acer platonoides* L., *Ulmus glabra* Hubs., *U. laevis* Pall.; rarely co-dominants become *Pinus sylvestris* L., *Populus nigra* L., *P. tremula* L. Indigenous communities along the slopes of northern exposures are represented by moist oak forests with linden and dominance in the grass canopy of *Aegopodium podagraria* L., *Mercurialis perennis* L., *Galium odorata* (L.) Scop., *Carex pilosa* Scop. On the slopes of southern exposures, drier oak forests with maple predominate, less often with pine and dominance of *Asarum europareum* L., *Galium tinctorium*(L.) Scop., *Laser trilobum* (L.) Borkh. The aim of the study is to assess the productivity of forest-forming tree species populations on landslide slopes.

2. Materials and methods

Study area. The Kuibyshev reservoir is located in the central part of the Middle Volga basin at the intersection of the forest and forest-steppe landscape zones of the Volga Upland and the Lower Volga [18] (figure 1). The studies were carried out within the Volga Upland along the right steep bank of the reservoir. Absolute heights are 175–215 m in the north and 250–270 m in the south. The reservoir was formed on October 31, 1955 as a result of the blocking of the Volga River by the Kuibyshev hydroelectric complex and reached its full reservoir level (FRL) of 53 m above sea level during the flood of 1957. Its total capacity is 57.3 km^3, the water surface area is 6150 km^2, the total length along the Volga - 510 km, along the Kama - 280 km. Its width ranges from 2 to 27 km, with a maximum width of 38 km at the Kamskoye Ustye. The average water depth is 9.4 m, the maximum is 41 m. The length of the coastline is 2604 km. The annual amplitude of level fluctuations is about 6 m. The reservoir serves several sectors of the economy: energy, water transport, agriculture and fisheries, industrial and municipal water supply.

The research was carried out 5.5 km southwest of the Syukeyevo v., on the right bank of the Volga River, where landslide processes are actively taking place as a result of the Kuibyshev reservoir creation. This fragment of the coastline is interesting in that it presents both a temporarily inactive section of the landslide slope, where the landslide occurred in 1974 (figure 1, I), and a relatively new landslide that occurred in 2001 (figure 1, II).

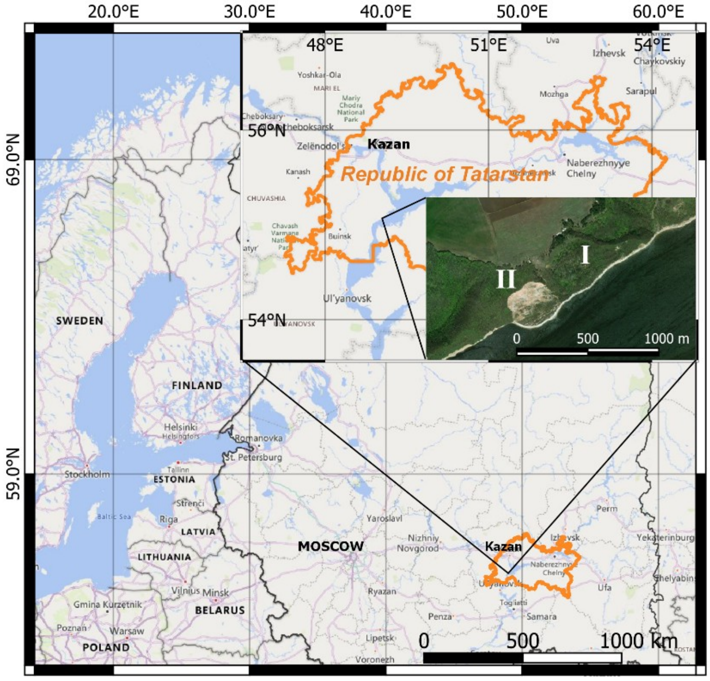

Figure 1. Location of the studied section of the Kuibyshev reservoir bank.

Figure 2 shows that the slope at the second section is "live", a further significant displacement of landslide masses occurred in 2002 and 2017. The presence in the immediate vicinity of landslides of different stages of development makes it possible to compare the state of the vegetation cover (forest stand) on stable and active landslide slopes.

Figure 2. Landslide II development in the 2000-2017 period (Google Earth Timelapse).

On the landslide slope, geomorphological elements of the landslide were determined: the root slope, the crest of the landslide slope, the slope above the landslide, the landslide step, the intra-landslide slopes and the landslide mounds. Geobotanical descriptions were carried out in landslide elements phytocenoses [19-20]. A discount area of 200-400 m² was formed within each element to analyze the state of forest-forming trees populations. All trees were mapped with height and trunk diameter indication according to ontogenetic groups. The information was organized into a database for constructing maps of trees spatial distribution on the landslide, their population structure and productivity assessment.

As functional features of trees, stem height is used as a sign of competitiveness for light [21] and the cross-sectional area of trunks, reflecting productivity. Similar studies were carried out in the upland forests of California on the dynamics and assessment of the state of *Pinus balfouriana* [22]. The Shannon index was taken into account to assess the functional diversity of trees, as well the trunks average cross-sectional area and the tree wood volumes, the stand formula and the undergrowth species composition. The functional diversity of phanerophytes was also determined on various landslide. All phanerophytes are divided into 3 groups: trees of the 1st size 15-30 m (listed above) – mesophanerophytes; trees of the 2nd size 5-10m – *Malus sylvestris* Mill., *Sorbus aucuparia* L., *Padus* *avium* Mill., *Salix caprea* L. – microphanerophytes; shrubs – *Corylus avellana* L.*, Loniceras xylosteum* L.*, Euonymus verrucosa* Scop.*, Viburnum opulus* L., *Cerasus fruticosa* Pall., *Rubus caesius* L. – nanophanerophytes.

To assess the similarity or difference in the species composition of landslide elements phytocenoses of each profile, the Sørensen-Dice similarity coefficient (SDSC) was used, which takes into account the fact of the one or another species presence in the studied phytocenoses. The value of SDSC varies from 0 to 1, the larger it is, the more identical the flora. For our tasks, it is important how the coefficient of similarity between the community of the primary, stable slope phanerophytes and individual phytocenoses of landslide elements will change in case when the primary slope community itself does not undergo strong changes. A significant difference in the SDSC between the elements of the landslide indicates significant differences in habitat conditions.

3. Results

Two profiles (figure 3) near Syukeyevo village (Tatarstan) were studied in this work:

Profile 1, pine planting – a temporarily stable landslide, where a pine plantation about 40 years old grows on the primary slope. Age was determined based on dendrological analysis of wood *P. sylvestris* [23]. The edge is fissured; due to the significant steepness of the slope, the overgrowth of the slope is slow. Along the landslide body at the 1st stage and at the bottom of the landslide scarp, *A. platonoides* with *Q. robur* and *U. laevis*, at the 2nd stage – *T. cordata* and *Q. robur* rarely. Landslide processes are activated along the reservoir banks, as evidenced by a new landslide to the south-west of profile 1.

Figure 3. Profile's location on the studied landslide slopes.

Profile 2, oak forest – the primary slope is represented by a natural broad-leaved forest. The landslide occurred in 2001, the landslide scarp is still unvegetated.

The Shannon index characterizes the diversity of phanerophytes and their number in the community structure. The more species in the community and the fewer differences in their number, the higher the index values. Comparing the Shannon index for phanerophytes of 2 slopes with different degrees of activity, the indices of the temporarily stable slope elements are higher than on the active one (table 1). The low Shannon index of phanerophytes indicates the occurrence of active landslide processes on profile 2.

Table 1. Characteristics of forest phytocenoses by landslide elements.

Landslide element/profile	Stand Formula		Shannon index	
	Temporarily stable	Active	Temporarily stable	Active
Original ground surface	8P2Q + A	4Q4T2A + U	1.17	0.90
Crown	8P2Q	3Q5T2A	1.04	1.16
Main scarp	7A2Q1P	-	1.21	
1st stage	5A 4U1Q + Pn	-	1.40	
2d stage	6T2Q2A + U	6Q3S1Pt	1.38	0.67

Successions of phytocenoses reflect the degressive-demutation stages of ecosystems resulting from the activity or temporary stop of landslide processes. It should be noted that for the "main scarp" and "1 step" of the active slope, the calculation of the Shannon index was impossible due to the absence of trees on these elements. This fact additionally indicates a high level of influence of landslide processes on the unstable slope areas community's development. The mobility of the substrate does not allow phanerophyte seedlings to take root and quickly reach significant sizes. Comparison of the SDSC of the phanerophytes composition in the landslide mobile elements phytocenoses with the bedrock slope, considered as a sample phytocenosis, is shown in figure 4.

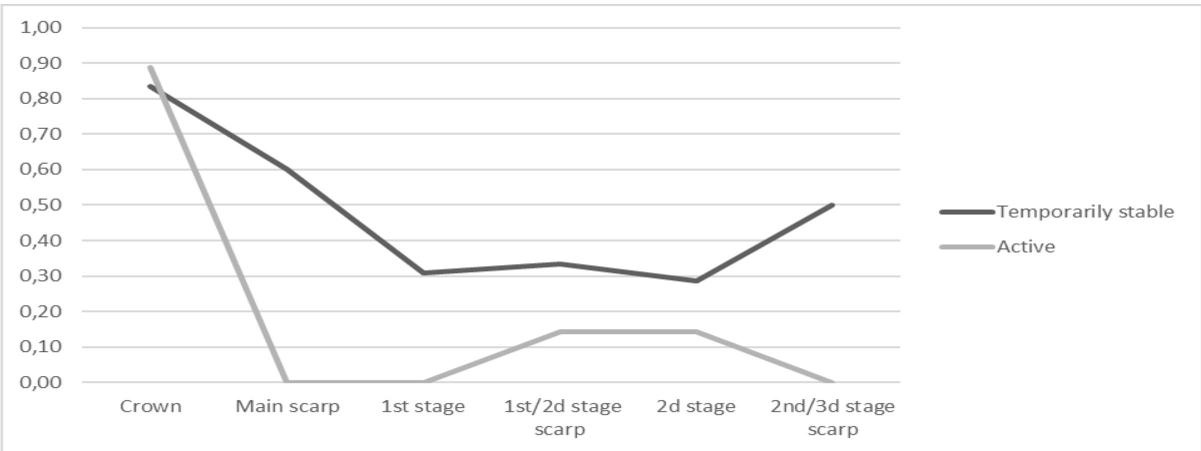

Figure 4. Dynamics of the similarity coefficient of phanerophytes on profiles 1 and 2.

The SDSC of a temporarily stable slope ranges from 0.83 for the "primary slope – crest" to 0.29 for the "primary slope – stage 2". The differences are quite significant, but at the same time, there are common types of trees in the samples, which may indicate the beginning of reforestation.

The SDSC of the active slope varies from 0.89 for the "root slope – brow" pair to 0 for the pairs "base slope – landslide slope", "base slope –1 step", "base slope – internal landslide slope between 2 and 3 steps". The low level of similarity directly indicates the cardinal differences between the communities of destroyed habitats and the biotope of the primary slope. The absence of common species in the sample may indicate a significant impact of landslide movements on the phanerophytes species composition. The displacement of landslide elements entails a change in habitat conditions.

4. Discussion

The wood cross-sectional areas and volumes of different species reflect the forest community productivity and the stages of phytocenoses reforestation by landslide elements. On an active landslide (profile 2), the largest average cross-sectional areas of generative specimens of *Q. robur* (0.22 m²) are observed on the root section of the forest and on the edge of the slope (figure 5).

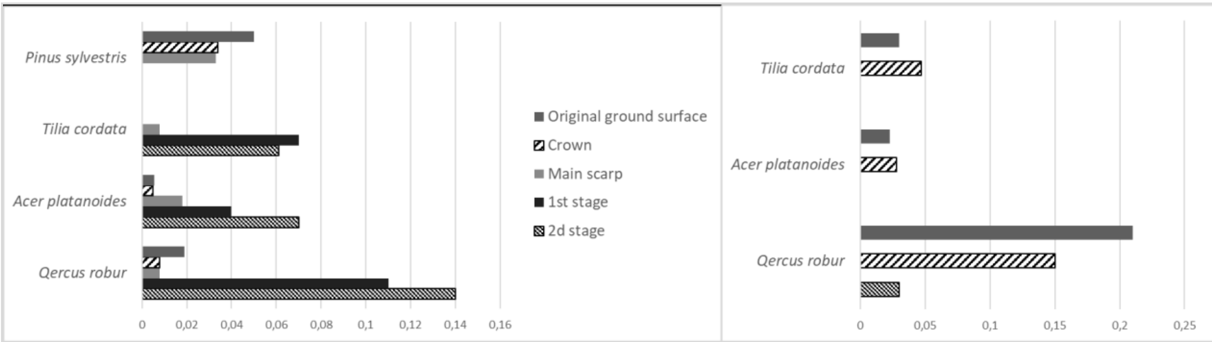

Figure 5. Cross-sectional area, m^2 (left) and wood volume, m^3 (right) of forest-forming trees on the 2nd profile.

In general, on profile 2, the phanerophytes main proportion, both in terms of number and wood volume, falls only on the primary slope and edge. At the 2nd stage, thin forest formed, regenerating oak forests – immature and virginal specimens of Q. robur are noted, so the cross-sectional area is only 0.035 m². Reafforestation of Q. robur could have begun due to the seed bank preserved in the substratum of the slumped part of the primary slope; perhaps, some of the young individuals survived the slumping and took root.

On a temporarily stable slope, the largest average cross-sectional areas and volumes of Q. robur wood are observed at steps 1 and 2 (figure 6). Plantation of P. sylvestris and Q. robur on the primary slope is about 40 years old, so the average trunk diameter varies 0.08-0.12m. The average cross-sectional areas of Q. robur on the primary slopes of active and temporarily stable landslides differ significantly. On an active slope, the average trunk cross-sectional area reaches 0.21 m², while on a temporarily stable landslide, planted by young Q. robur is 0.019 m². On the contrary, on the 1st and 2nd steps of profile 1, the cross-sectional area of Q. robur is 0.11 and 0.14 m² (figure 3). The trunk diameters of young generative Q. robur on profile 1 are 0.2-0.32 m, while those of mature Q. robur on the primary slope of profile 2 are 0.42-0.58 m. Probably, Q. robur specimens growing on the first and second steps of the temporarily stable slope survived the landslide and continued their growth and development. In general, both vegetative sprout and seeds remain on the landslide steps, and the vegetation of the primary slope is partially preserved, so the restoration of forest phytocenoses is better here.

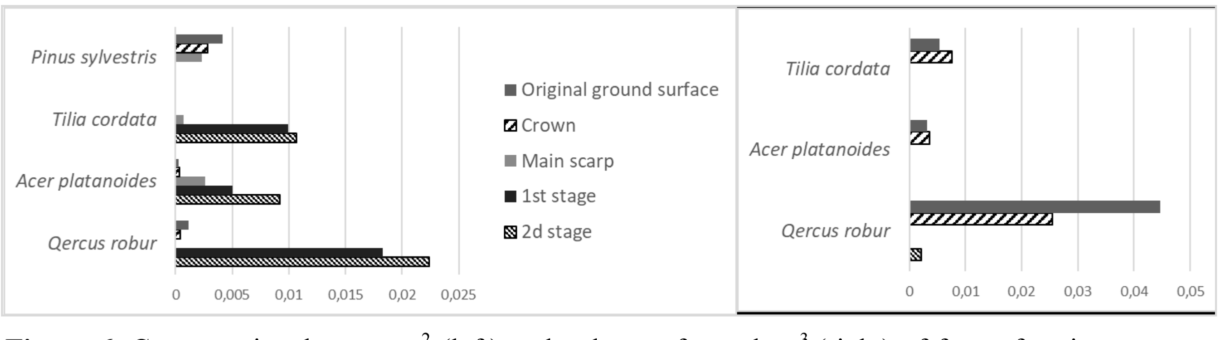

Figure 6. Cross-sectional areas, m^2 (left) and volume of wood, m^3 (right) of forest-forming trees on profile 1.

Reforestation in the lower part of the slope occurs due to the active overgrowth of steps by vegetatively mobile species - T. cordata, P. nigra and fast-growing trees - A. platonoides. For A. platanoides and T. cordata, a good development of generative individuals along the landslide elements is noticeable, which increases the productivity of phytocenoses at certain stages of reforestation down the slope (figure 6).

The restoration of broad-leaved forests on the landslide body elements of a temporarily stable slope is due to the formation of maple-linden communities. A comparative analysis revealed that the number of Q. robur significantly decreases on landslide elements and the structure of its populations is disturbed. On the contrary, the number of T. cordata and A. platonoides, which form secondary forest phytocenoses, increases. A gradual transition to the formation of natural indigenous oak forests is possible in the new landslides' absence.

5. Conclusion

According to the similarility coefficient value and the Shannon index of phanerophytes of two slopes different elements, we can conclude that reforestation has begun on conditionally stable profile 1. On the contrary, actively continuing landslide-scree processes in the upper part of profile 2 prevent the formation of even weed-field vegetation; only *Tussilago farfara L.* and *R. caesius* are rarely recorded. The dynamics of the number and productivity of different tree species along landslide slopes of varying degrees of stability/activity is an important characteristic for assessing forest vegetation and its restoration along the banks of the river. Volga. The lack of forest restoration by landslide elements for 10-20 years is an integral indicator of actively continuing landslide processes.

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