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TÍTULO: La aplicación práctica de diferentes métodos de fitoindicación para estimar deslizamientos de tierra.

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RESUMEN: Sobre la base de 400 descripciones geobotánicas de fitocenosis por elementos de las pendientes de deslizamiento de la orilla derecha del río Volga, se consideraron métodos de fitoindicación. Se propuso el algoritmo general de estudio de pendientes de deslizamientos, teniendo en cuenta el análisis ecológico, fitocenótico, biomorfológico, florístico y poblacional. Para laderas de deslizamientos cubiertos por bosques, el foco principal de la investigación fue la evaluación de la estructura de la población de especies arbóreas que forman bosques, teniendo en cuenta la dinámica de las reservas de madera. Para evaluar las similitudes o diferencias en la composición de especies de las fitocenosis de elementos de deslizamientos de tierra, se utilizó el Coeficiente de Similitud de Dados (CSD).

PALABRAS CLAVES: procesos de deslizamiento de tierras, Fitoindicación, dinámica de las reservas de madera, Escalas Ecológicas, Coeficiente de Generalidad.

TITLE: The practical application of different Phytoindication methods to estimate landslide displacements.

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ABSTRACT: Based on 400 geobotanical descriptions of phytocenoses by elements of the landslide slopes of the right bank of Volga River, various methods of phytoindication were considered. It was proposed the general algorithm of landslide slope study, taking into account ecological, phytocenotic, biomorphological, floristic and population analysis. For forest-covered landslide slopes, the main focus of research is the evaluation of forest-forming tree species population structure, taking into account the dynamics of wood stocks. According to different elements of landslides, demutation-degrading processes of forest phytocenoses depend on anthropogenic influence typology. In order to assess the similarities or the differences in the species composition of landslide element phytocenoses, the dice similarity coefficient (DSC) was used.

KEY WORDS: landslide processes, phytoindication, dynamics of wood stocks, ecological scales, generality coefficient.

INTRODUCTION.

Landslide factors in the Republic of Tatarstan (RT) are very diverse. The intensity of the gravitational mobility of soil on the slopes of large river banks is conditioned by a number of reasons - the low afforestation of the root slopes, the nature of slope steepness and height and the constant washing of banks.

Serious changes in the existence of slopes on the territory of the Republic of Tatarstan occurred during the creation of the Kuibyshev and Nizhnekamsk reservoirs; as floodplains were flooded, the destructive power of the waters increased, the groundwater level rose, which activated abrasion processes.

The emergence of new landslides and the revival of old ones are often caused by the intensification of anthropogenic impacts — road construction, the production using various vibrating mechanisms, the concentration of surface runoff, soil excavation, the use of territory for house building and land plowing. Often, under the influence of various factors, the coast of water bodies is eroded, which leads to the shift of the coastal strip towards socially significant objects or land plots.

Monitoring observations of landslide processes are based, for the most part, on instrumental methods of measurement and require significant resource and time-human costs. One of the solutions which allows to optimize and reduce costs during the setting up of exogenous geological process monitoring could be the introduction into practice of various methods of bioindication that use the functional and ecological properties of plants. These include biomorphological, phytocenotic, and ecological characteristics of plants; they estimate the populations of edificatory, dominant species of populations and the succession dynamics of phytocenoses forming natural complexes along the slopes and river banks.

The study of landslide processes is of great importance for the prevention, the reduction of landslide risk occurrence and the minimization of natural disaster consequences. In this regard, the number of studies related to the study of landslide process dynamics has the noticeable tendency to increase and develop in the following areas during the last two decades:

1. The inventory of landslide phenomenon location, the assessment of slope stability, the zoning of territories by the degree of landslide phenomenon risk occurrence, which are the key tools for land use planning and management [The Water Code of the Russian Federation N 74-FZ issued on June 3, 2006; Varnes D.J (1984); Fell R, Corominas J, Bonnard C, Cascini L, Leroi E, Savage WZ

(2008); Van Westen CJ, van Asch TWJ, Soeters R, (2006); Petschko H, Brenning A, Bell R, Goetz J, Glade T (2014)].

2. The monitoring of landslide processes based on remote sensing methods and GIS [Jones L.D. 2006; Pradhan B (2010); Casagli N, Catani F, Del Ventisette C, Luzi G (2010); Maugeri M., Motta E., Raciti E., (2006); Knizhnikov Yu.F., V.I. Kravtsova, O.V. Tutubalina, 2004].

3. The estimation of landslide phenomenon occurrence probability and the prevention of landslide occurrence on the basis their occurrence mechanism study to solve the applied and the fundamental issues of exogenous catastrophe prevention [Thiebes B, Bell R, Glade T, Jäger S, Mayer J, Anderson M, Holcombe L (2014); Palladino M.R., Turconi L, Luino F., Brunetti M.T., Peruccacci S., Guzzetti F., (2015); O.D. Smiletsev, A.V. Ivanov, N.V. Hayuk, K.A. Kravtsova, A.G., 2007; Mikhailov O.V., Golubev E.A., Smolyaninova E.I., 2013; Corominas J, van Westen C, Frattini P, Cascini L, Malet JP, Fotopoulou S, Catani F, Van Den Eeckhaut M, Mavrouli O, Agliardi F, Pitilakis K, Winter MG, Pastor M, Ferlisi S, Tofani V, Hervás J, Smith JT (2014); Sousa RL, Karam K, Einstein HH, 2014].

4. The analysis of landslide process impact on the dynamics of vegetation and the assessment of the plant component response to various exogenous effects. Recently, such works has been revitalized [Sykora L. 1961;Turmanina V.I. 1964; Alestalo, J., 1971; Stefanini, M.C., 2004; Guida, D., Pelfini, M., Santilli, M., 2008; Ermokhina K.A. 2009; Klimes J. Yepes J., Becerril L, Kusak M, Galindo I., 2016].

The studies have shown the possibility of bioindication method use based on the analysis of individual plant species response or phytocenoses in general to determine the state of landslide displacements, their approximate age and the degree of their stability [Kozhevnikova M.V., Fardeeva M.B., Mugliev B.I., 2010; Kuteeva V.S., Fardeeva M.B., 2010; Fardeeva M.B., Mrakova A.V., 2013]. Such monitoring methods are called phytoindication. Timely warning of landslide displacement occurrence allows you to prevent a negative impact on socially significant objects, to identify the most active areas on a landslide body and to make recommendations for their

consolidation. These materials can serve as a starting point for the targeted research of socially significant objects located along the right bank of the r. Volga, where there is the activity of landslide processes under the influence of the Kuibyshev reservoir.

Methods.

The main field research method is geobotanical description. The following main geomorphological elements of the landslide were identified on the landslide slope: the root slope, the ridge above the landslide slope, the above landslide slope, the landslide step, the intra-landslide slopes and the landslide hillocks.

The geobotanical profile was laid through all geomorphological elements, an accounting trial area from 100 to 400 m², or 10–20 trial plots of 1 m2 were inside each element. To analyze the state of forest-forming species populations, the areas of 200-400 m² (depending on the size of the landslide elements) were laid and mapped. All trees were plotted on the map, taking into account the height and the diameter of the trunk, they determined the specific composition of the phanerophytes, the dynamics of wood volumes and the age structure of forest-forming trees by the landslide elements of the slope. Geobotanical descriptions were carried out according to generally accepted phytocenotic methods with the identification of dominant and sodomine species in the community [Voronov A.G. Geobotany, 1973; Braun-Blanquet J., 1964; Drude O., 1913]. In order to assess the state of forest-forming species populations, we used the generally accepted population-based methods.

The objects of study are landslide slopes of the indigenous bank of the Volga River, grouped into 14 sections: Volga sublime-flat region of RT - “Dachnaya”, “Tetyushi”, “Gora Lobach”, “Dolgaya Polyana”, “Kamskoe Ustye”, “Zaton Kuybysheva”, “Labyshki”; Volzhsko-Vyatsky upland plain region of RT - “Troitsky Forest”, “Semiozerka”, “Ishtugan”; Vyatka-Kama lowland region - "Aktanysh", "Koschakovo", "Quiet Mountains"; East Zakamsky elevated plain area of RT - “Podgornye Baylyary”.

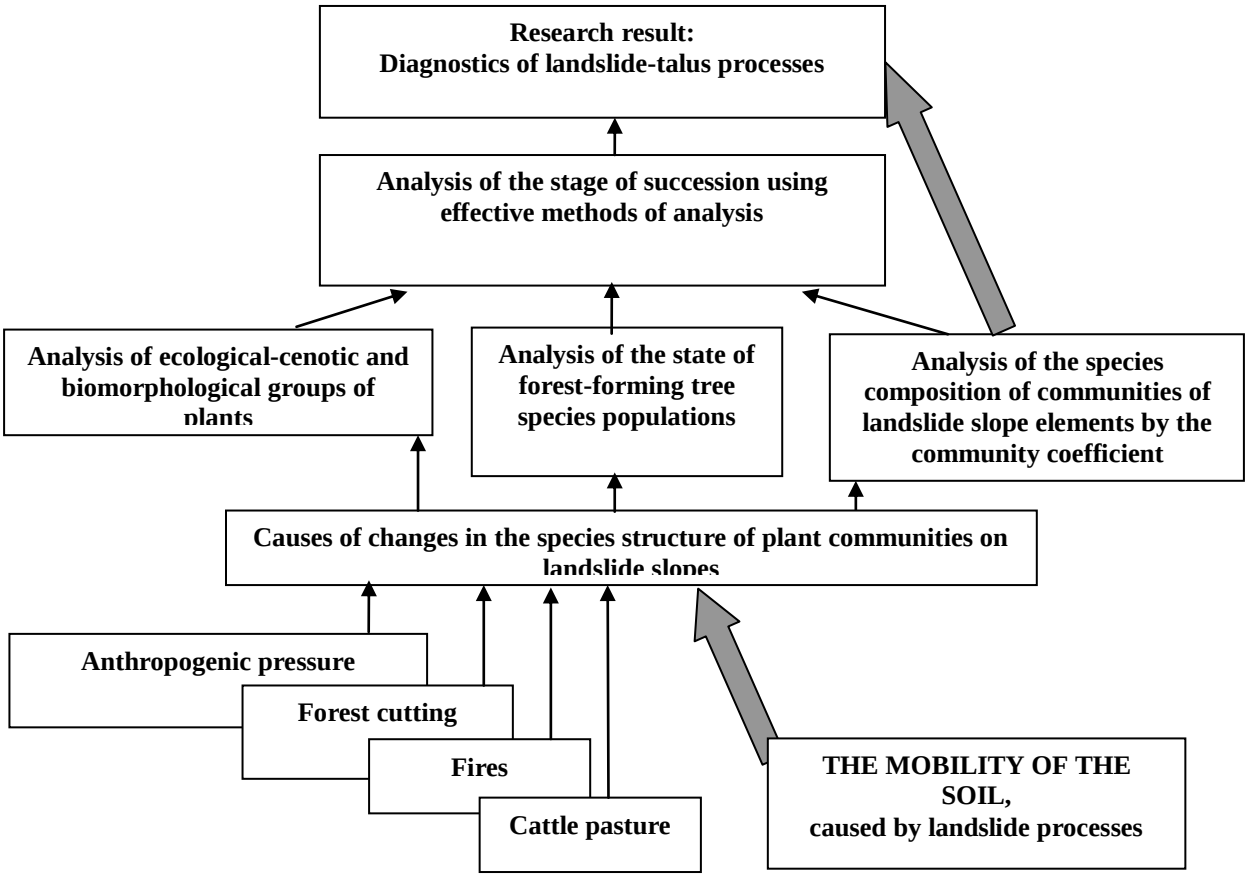
403 descriptions were collected, made in different areas during the period from 1999 to 2017 and listed in the "Flora" information base of the of General Ecology Department at the Institute of Ecology and Nature Management [Rogova T.V., Prokhorov V.E., Shaikhutdinova G.A., Shagiev B.R., 2010]. The data were systematized in the table indicating the area, the year and the author of the descriptions and the morphological element of the landslide body, to which the description could be attributed.

To assess the similarities or differences in the species composition of landslide element phytocenoses of each profile, the dice similarity coefficient (DSC) was used. To continue the use of phytoindication methods to study the landslide displacements and refine more effective analysis to assess their condition, prevent new or activate old landslides, the attempt was made to analyze and summarize the accumulated material during the 17-year period, collected in different regions of Tatarstan (RT). The main goal of the work was to determine the effective methods of landslide displacement phytoindication and to evaluate the accumulated geobotanical descriptions of landslide slopes to develop the mathematical models of plant community response to abrupt changes in the environment.

Results and Discussion.

In previous works, we studied the possibility of phytoindication method use during landslide process monitoring in meadow-steppe and forested slopes along the right bank of the Volga River. To do this, they analyzed the effectiveness of the following types of analysis: floristic analysis (systematic affiliation of species and the ratio of families); biomorphological (the definition of life forms that take into account the root systems, their thickness, length and the ability to hold the soil); ecological-coenotic analysis, and the ratio of ecological-coenotic groups (ECG) of species in the communities formed on different elements of a landslide. Thus, a general research algorithm was developed (Fig. 1).

Fig. 1. The description of the research process



On forest-covered slopes, in addition to the assessments of phytocenosis species composition similarity and the general ecological analysis, the assessment of the state and the dynamics of forest-forming tree species described within each plot by various elements of the landslide turned out to be significant. For this they determined the number, the stocks and the dynamics of wood volumes, the age and the spatial structure of different tree species forming forest communities on the indigenous slope and on landslide elements.

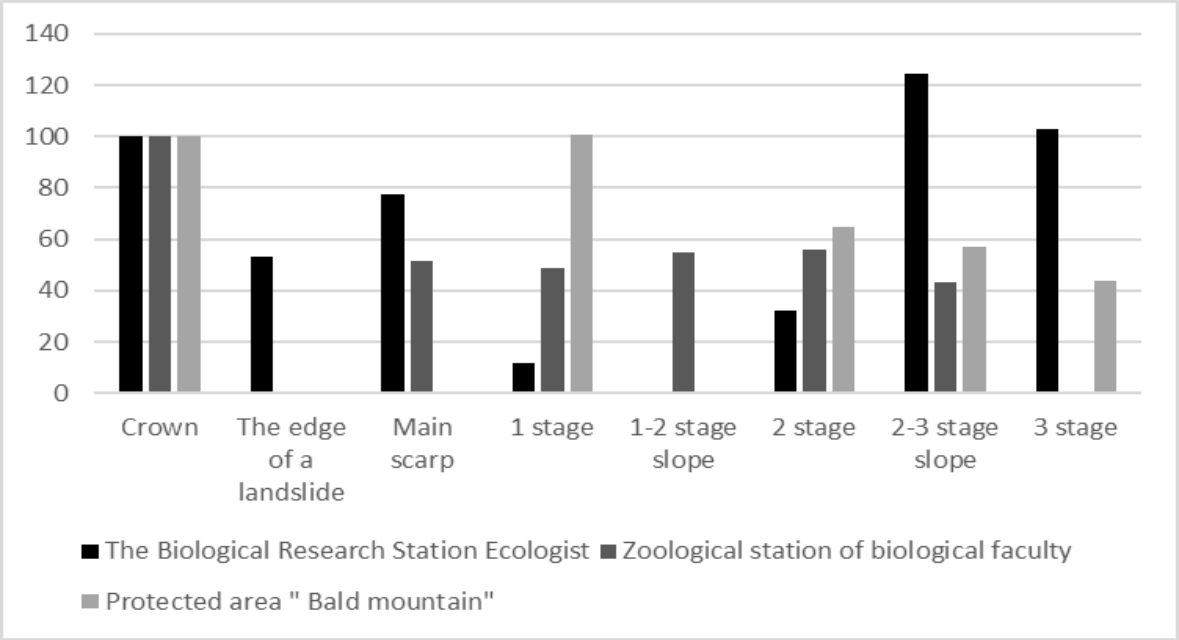
The comparative analysis revealed that the number of Quercus robur is significantly reduced on landslide elements and the structure of its co-populations is violated. On the contrary, the number of Tilia cordata and Acer platonoides increases by landslide elements, which form the derived forest phytocenoses.

With some stabilization of landslide slopes (or individual slope elements), the stocks of wood of long-term lindens will correspond to the stocks of oak wood with the linden and the maple of indigenous phytocenosis. It is assumed that on the slopes, where the process of reforestation is

successful and landslide processes are reduced, the age structure of forest-forming trees should be complete, and the wood reserves for the landslide elements should correspond to the similar characteristics of tree populations confined to the phytocenoses of the primary slope (Fig. 2).

As an example, we cite the data on landslide slopes of the northern and northwestern exposures (Verkhneuslonsky district of the Republic of Tatarstan) located along the native bank of the Volga River.

Fig. 2 The percentage of timber resources of all forest tree species on the elements of the landslide in comparison to the timber resources of the indigenous slop.



Taking the root slope as the reference area, the timber reserves on it were determined as 100%. In general, it can be noted that for different elements of landslides, reforestation processes take place in different ways, which is conditioned by the typology of anthropogenic influences. So, there is no forest restoration on the areas of constant mowing and partial cutting (intra-landslide slope between I-II levels, the IInd level is on the landslide "Biological station - Ecologist") or an intensive recreation site (intra-landslide slope between I-II levels on SPNA "Lysaya Gora").

In the conditions of the slope stabilization and the minimization of anthropogenic impacts on landslide elements, the restoration of forest vegetation is observed, which contributes to a significant accumulation of wood volumes.

Wood stocks of forest-forming tree species are phytoindicative population parameters. The most stable landslide areas (aboriginal slopes or landslide stable elements) are characterized by the largest reserves of wood, which are provided by the presence of oak forests or long-lasting lime trees.

In general, the population dynamics of forest-forming tree species confirms the succession dynamics of phytocenoses on the landslide slope. During the exogenous succession, they change the species composition, the composition of dominates, the set of higher plant biomorphs, the indicators of community species diversity, and accordingly, the type of plant association.

The process indicators are ecological-dynamic or succession series of vegetation; at that, the succession series of phytocenoses are distinguished not only on the basis of floristic, biomorphological, ecological and phytocenotic spectra comparison concerning the species of the studied phytocenoses, but also on the basis of dominant species population structure, in particular forest-forming trees. The identification of plant associations that arise as the succession series of indigenous oak-linden forests helps to determine the stability or the mobility of landslide elements, the stages of overgrowing or restoration of forest on landslides.

To continue the use of phytoindication methods, they performed the evaluation analysis of the accumulated geobotanical descriptions of landslide slopes for a 17-year period. To determine the response of plant communities to the abrupt changes in the environment, they used the method mathematical model development.

In order to assess the similarities or the differences in the species composition of landslide element phytocenoses of each profile, the dice similarity coefficient (DSC) was used, taking into account the presence of one or another species in the coenoses. The value of DSC varies from 0 to 1, the closer the indicator to one, the closer communities are to each other by the composition of flora. It is assumed that the more time has elapsed since the last movement of the substrate, the less vegetation cover was disturbed, since restorative succession occurred, the smaller the differences in species composition between the root slope and the landslide elements under study.

Only 3 model landslide elements were selected for further studies: a root slope, an over landslide slope and 1 step. One of the main hypotheses of this work was the connection of the dice similarity coefficient value for individual elements of landslides with the root slope and the age of their occurrence. It was important for us to understand whether there is a statistically significant dependence, and what regression equation could describe it. DSCs were calculated for 46 landslides between the root/supra-landslide step and between the root slope/step 1. Also the relative age was given for these profiles.

It was assumed that if the similarity coefficients of plant species lists between the selected elements will be closer to one, then the landslide will be conditionally stable and fairly old. In order to identify this dependence, the correlation method was used.

In general, it can be noted that for most of the landslides under study, the dice similarity coefficients between the selected phytocenoses of model landslide elements vary from 0 to 0.4 - the similarity of the species composition is insignificant (Fig. 3). Only at 9 landslide sites, the DSC between the phytocenoses of the model elements was high and varied from 0.6 to 1. These areas were represented mostly by forest-covered slopes.

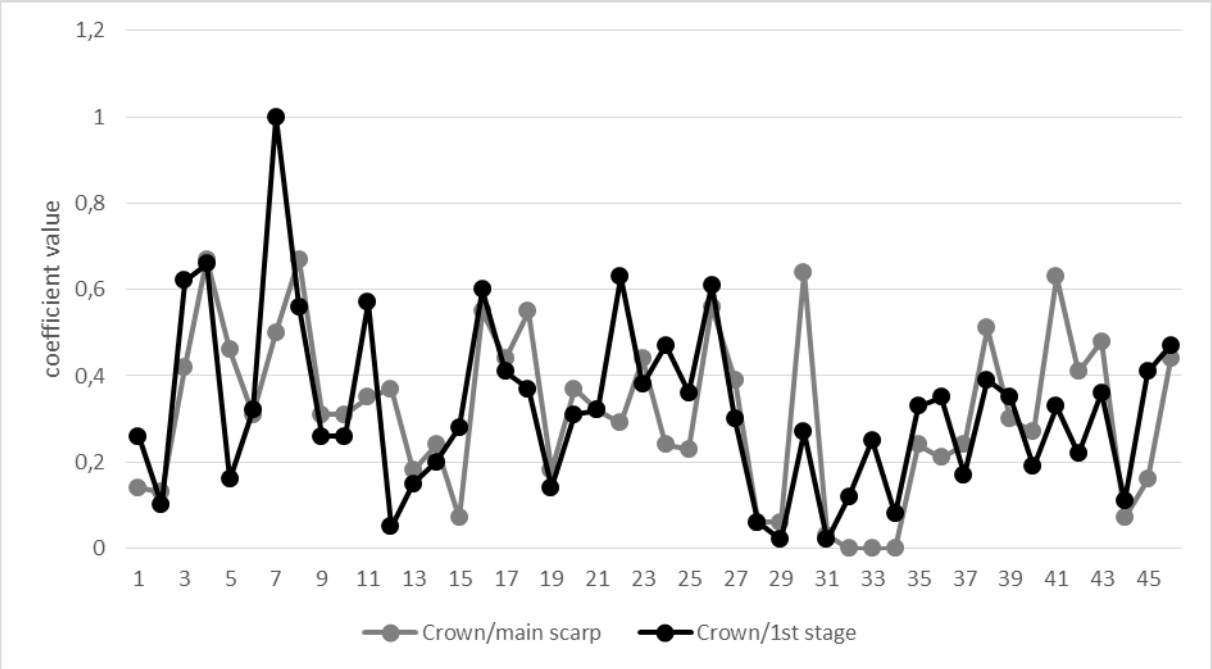
Further, they calculated the square of the distance between the coefficients (DSC) of phytocenoses:

1. Between the root slope and the above-landslide step.

2. Between the root slope and step 1.

The supposedly large value of the generality coefficient and the minimal difference of squares between the elements indicates a certain stabilization of the landslide slope. It turned out that such a pattern is characteristic mainly for 7 landslide slopes covered with forest vegetation. Here, long-lasting lime trees or the lime trees with spruce and pine are similar by their species composition and population structure of forest-forming tree species to the forest communities of the indigenous slopes.

Fig. 3 The dynamics of dice similarity coefficient of at various landslides.



On the contrary, the combination of low DSC values and the minimum difference of squares between the elements reflects apparently the active nature of landslide processes. The DSC value of 0 indicates a recent landslide. There are 3 such sections. However, the correlation dependences are low: 0.22 between the base slope and the over landslide slope, and 0.16 between the base slope and the step. Perhaps this is due to the large number of geobotanical descriptions of young and active landslides.

The changes in the species composition of phytocenoses on the slopes are the result of catastrophic factors (“stressful processes”) - a landslide gathering, when the substrate is completely bare and an over-landslide slope is formed, or by the moderate changing of some abiotic parameters -, for example, humidity, which mainly depends on landslide element slope and the nature of the substrate, in particular, during the formation of the landslide stage. In order to assess such "minor" changes in the environmental conditions on the morphological structures of the landslide, we used the amplitude scales by D.N. Tsyganov [1983].

For model sites of socially significant importance - SPNA "Lobach mountain" and the pier of the Kama Ustye district center (of Kama-Ustyinsky district of the RT) -, the environmental conditions were assessed based on the method of crossing of most intervals by 8 factors: thermoclimatic, continental, cryoclimatic, humidity, nitrogen provision, salt wealth, acidity and light.

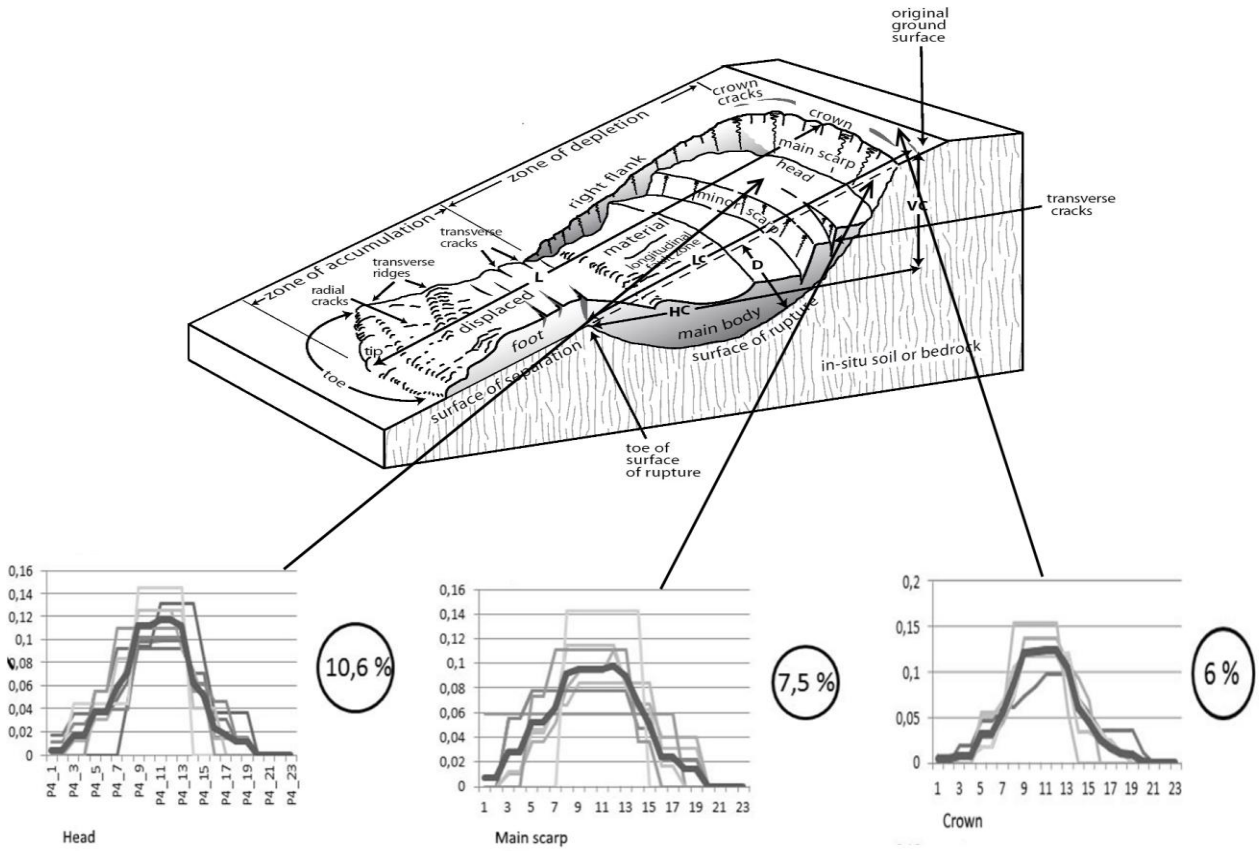
Two tables were used for calculations: ecological amplitudes and the scale of factors. Using this method, the ranges of score values of all plant species are reviewed and the segment is found that contains the largest number of considered species ranges. Thus, three values were determined - the left border, the right border and the middle of ecological scale amplitude overlap interval of most plant species. A similar analysis was carried out for the selected 3 model elements of the landslide (root slope, over landslide slope, level I).

They also considered the possibility of D.N. Tsyganov's environmental scale use to simulate the response of plant communities to environmental changes. In ecological scales, parameters are considered as a fixed point. The software was carried out at the Department of Mathematical Modeling of KFU, by prof. A.A. Saveliev.

The main difference of the Bayesian paradigm is that the unknown parameter of the probabilistic model is considered as a random variable. With regard to landslide processes, this means that a priori available information is the histogram of the number of species distribution across the ranges of the ecological scale on the element of the root slope, and the experimentally obtained sample is the distribution of the number of species on the above-landslide slope or on the 1st landslide step.

In order to assess the possibility of the Bayesian model development concerning the response of the plant community to stressful changes in the biotope, they calculated the histograms of D.N. Tsyganov's scale value distribution by humidity for the groups of 15-year-old active landslides by separate morphological elements. Visually, it can be estimated that there are the differences in the distribution of histograms, and the accumulated material allows for modeling (Fig. 4).

Fig. 4 The distribution of plant species according to the scale by D. N. Tsyganov "humidity" for a group of 15-year-old landslides.



CONCLUSIONS.

In summary; in general, one can say that the methods of phytoindication, considered in this work, provide the opportunity to monitor and evaluate quickly the nature of activity or “conditional stability” of both individual landslide elements and landslide slopes, which is especially important to determine the state of such areas on socially significant facilities.

The most rapid and fairly effective method is the method of floristic, biomorphological and ecological-phytocenotic analysis of phytocenoses and the determination of degressive-demutation process nature in the phytocenoses of both individual elements of a landslide and the entire landslide body.

The use of the population method, with the assessment of the edificatory species population status, is most effective in forest-covered landslide sites. The assessment of the state and the changes in the plant cover of individual elements of a landslide in spatial and temporal dynamics based on ecological scales by D.N. Tsyganov can be considered informative and promising for the use by the method.

The development of the Bayesian model to determine the response of the plant community to the stressful changes in the biotope as the result of landslide processes is very promising and will be used in further analysis.

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