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IMPACT OF SLOPE PROCECESS ON THE WILLOW GROWTH IN YAMAL

SUMMARY. The dendrochronological analysis of the impact of cryogenic processes on the shrub vegetation growth within the typical tundra around the Bovanenkovskoe field in Yamal Peninsula is carried out. Due to the lack of tree vegetation around the studied area, the features of the radial increment of willow bushes are examined, sampled from the sites of demonstrating different cryogenic processes. Owing to the existence of annual rings, the shrubs may be good indicators of environment and tundra ecosystems change as a whole. The analysis of the conducted chronologies shows that during the last 50 years the radial increment of willow has the periods of the growth increase and reduction. According to the correlation analysis, the limiting role of July temperature on the radial growth of shrubs, which is the most strongly expressed for the Slope site (R=0.68), is noticeable. The growth of the shrubs at the Landslide site is caused by July (R=0.51) and partially by August air temperature (R=0.39). The results of the dendroindicational analysis confirm its efficiency when dating and researching the dynamics of slope processes in order to detect the regularities of serial facies development and prove the necessity of dendrochronological researches, being carried out on a wider scale for a detailed and comprehensive study of the impact of local conditions and slope processes on the radial increment of shrubs for different areas. The application of the dendroindicational method allows to estimate, if the risk of landslide processes increases or not.

KEY WORDS. Dendrochronology, tree-ring chronology, radial growth, landslide.

For the last decades, an intensive industrial gas field exploration has begun in Yamal. The first formation to have been produced in Yamal is the Bovanenkovskoe field, which is assigned for exploration with the help of the construction of the Obskaya-Bovanenkovo railway road, the Bovanenkovo-Ukhta multiline gas transmission pipeline, gas filed structures, roadways, etc. Typical for Yamal, natural cryogenic processes, alongside with techno-natural ones, which are activated after the beginning of the industrial field development, may essentially complicate the performance of extraction and gas transportation objects. The widespread distribution of natural cryogenic processes is predetermined by the specific features of the composition and formation of seasonal and permafrost rocks, their salt content and the wide distribution of underground ice. One of the hazardous processes is cryogenic flow slides such as the block shift of the seasonally thawed layer (STL) through the boundary line of frozen and thawed rocks [1].

When carrying out the complex investigations in the corridor area of the projected gas transmission pipeline, we have applied the dendrochronological method for the estimation of the impact that cryogenic processes have on the shrub vegetation growth within the typical tundra in the area of the Bovanenkovskoe field. Peculiarities

of the radial increment of willow bushes at the sites demonstrating slope cryogenic processes have been examined. Owing to the existence of annual rings, the shrubs are a reliable indicator of environment and tundra ecosystems changes as a whole. The purpose of this paper is to study the dendroindication of landslide sites on the basis of researching the radial increment of willows and to analyze the impact of climatic variables on these processes.

In Yamal, dendrochronological investigations were carried out basically by the staff from the Ural Institute of Ecology of Plants and Animals, Ural Department, Russian Academy of Science [2-6]. Besides, the works on researching the radial increment of willows in the Yamal region at the *Vas'kiny Dachi* station of the Institute of Earth Cryosphere, Siberian Department, Russian Academy of Science, are well-known [1], [7], [8].

The data and methods of the research. Changes of climatic conditions and the dynamics of cryogenic processes closely connected with them (solifluction, dormant and active stages of landslides) determine the dynamics of the Yamal tundra ecosystems productivity, which has one of the indicators such as (one indicator of which is) the radial increment of the shrub vegetation. Taking into account the fact that the shrub vegetation is an essential factor of tundra resistance, peculiarities of the radial increment of saw cuts samples taken from the stem of willow bushes (*Salix* genus) have been examined during the dendrochronological works.

Samples for studying the willow growth (*Salix Lanata L., Salix Glauca L.*) were taken in early August, 2006) within the typical tundra at the sites of activation of slope processes. Dendroindicational investigations of the features of cryogenic soil creep development were conducted in the area of Lake Tyurin-to with the purpose to obtain information about the dynamics and timing of their occurrence within the typical tundra at the sites of III marine terrace (Fig. 1). The dendroindicational analysis was performed at two sites with willow.

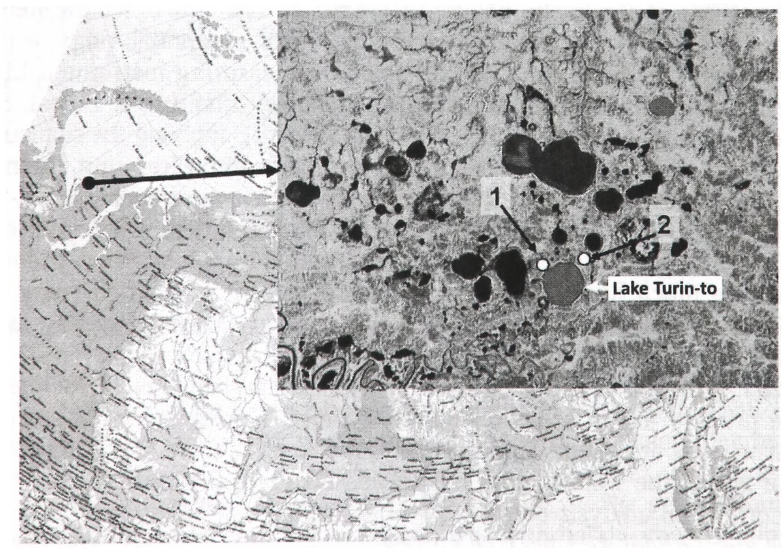

Fig. 1. The area of dendrochronological material gathering.
1 — the *Landslide* site, 2 — the *Slope* site

The *Landslide* site (Fig. 2a) is a fragment of the slope which has morphological features, allowing to classify it as a usual slope facie with a special form of microrelief (obsolescent fragments of lithogeneous foundation of seasonally thawed layer of prime facie and plant associations, characterized for progressive successions after flow landsliding). This site is situated in the area of the north-western part of the Lake Tyurin-to coast, 10-20 m from the brench crest (coordinates: 70°44' N, 67°57' E).

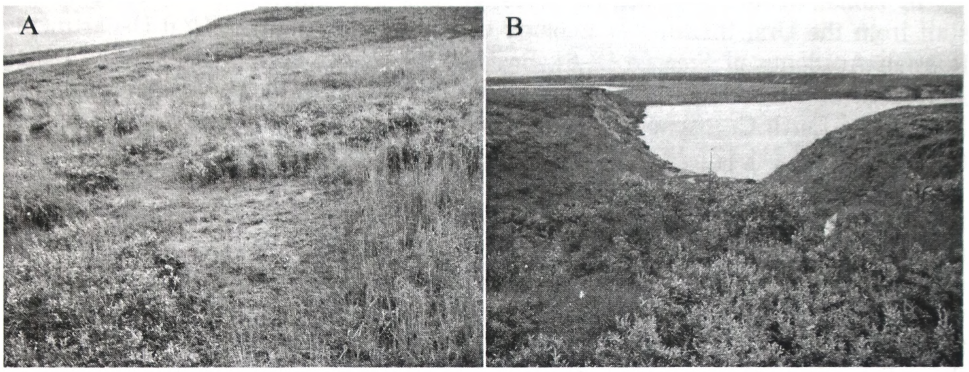

Fig. 2. Survived fragments after landsliding within the *Landslide* (A) and *Slope* (B) sites, where the samples of willow stems were taken

The *Slope* site (Fig. 2b) is a territory with terrace-like patches of sliding sediments along the active gullet slope. The depth of seasonal ground thawing at the top of the gullet on the 11th of August 2006 was 90 cm, but at the bottom of the terrace-like foundation — 94 cm. The gullet is about 1 km distance from the north-eastern part of the coast of Lake Tyurin-to (coordinates: 70°44 N, 67°59 E).

The gathering of the core samples of bushes was carried out on the basis of standard methods of dendrochronology [9-11]. 20-25 saw cuts of willow stems were taken from every site. Measurements of the width of annual rings within the accuracy of 0.01 mm were made by means of the measuring instrument LINTAB-III in the laboratory of dendrochronology of Sukachev Institute of Forest, Siberian Department, Russian Academy of Science (Krasnoyarsk), applying the semiautomatic apparatus LINTAB V-3.0 [12]. When dating and performing tree-ring chronologies, conventional dendrochronological methods with the usage of such special-purpose programmes as COFECHA, ARSTAN, TSAP V3.5 and others, were applied [9-10], [12-13]. The difficulty of this procedure is determined by the fact that willow stems at slopes have much hard streak, the sufficient percent of omitted (very narrow) rings. In this regard, measurements of the stems were made according to several radii. False and omitted rings were detected during this procedure.

Results. 2 tree-ring willow chronologies have been constructed for the studied area. The primary analysis has demonstrated that, among the gathered material, the oldest willows are at the *Slope* (56 years) and *Landslide* (57 years) sites. The maximum age of the willows does not exceed 90 years in the studied area [14].

The correlation analysis between two chronologies, regarding the willows from the *Slope* and *Landslide* sites (the correlation ratio is 0.72), has been carried out. The timing ratio of the radial increment of willow at these sites comprises more than 82%. This fact points to the existence of a similar external factor, affecting

equally both sites. Slope processes characteristic to the studied sites of willow bushes may also be considered as a common factor, along with the climate.

The analysis of the constructed chronologies indicated that during the last 50 years the radial increment of willow had the periods of the growth increase and reduction. The dating has shown that three generations of bushes grow on the *Landslide* site. The germination of the first generation occurred in the early 1950s, the second one occurred in the mid-1970s and the third one occurred in the late 1980s and the early 1990s. The oldest growth bushes occurred at the *Slope* site in the early 1950s-1960s, but the last generation occurred in the late 1970s and in the early 1980s. The tree-ring chronologies indicated that the new generation of bushes appears in the period of the increase of the radial willow increment, i.e. in the most favorable time for the willow bushes growth.

Performing the visual analysis of the width of the radial increment (Fig. 3), discrepancies in the dynamics of the radial willow increment were marked. The most favorable conditions for the willow growth were at the *Slope* site. This fact may be explained by better soil drainage at this site, that is important for the better growth in tundra conditions. Beginning from 1954, both chronologies show the opposite trend in the willow increment. The reduction of the radial increment of bushes was observed at the *Landslide* site. However, in the period of 1967-1974, the reduction of the willow increment for both sites was registered with the harsh growth inhibition in 1967 and 1970. It is expressed for the *Slope* site very clearly.

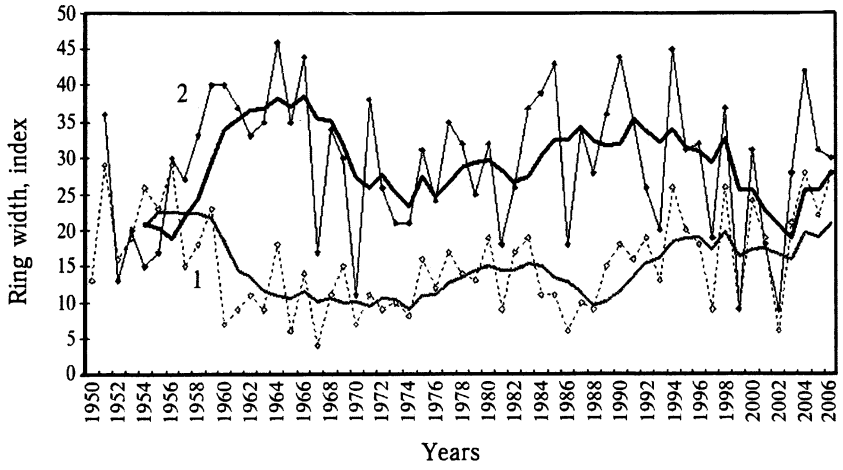

Fig. 3. Willow (Salix) tree-ring chronologies. 1 — the *Landslide* site, 2 — the *Slope* site

Since the mid-1970s the certain increase of the willow increment was registered at the *Slope* site. The maximum covered the periods of 1982-1985, 1988-1991, and 1994-1996. Starting from 1997, the reduction of the radial willow increment was registered, except the last three years. At the *Landslide* site, also since the mid-1970s, the willow increment increased till 1983. Later, in the period from 1984 to 1988, the reduction of the radial willow increment with harsh growth inhibition was registered in 1986. Since 1989 till now, in comparison with the previous site, bushes increment has increased. For the last 35 years, the radial willow increment reduced

at both sites in 1981, 1986, 1993, 1997, 1999, and 2002. The correlation analysis between tree-ring chronologies and the average air temperature change was carried out at the Marre Sale synoptic station (Fig. 4). The correlation of the radial willow increment with the July air temperature for the *Slope* site (R=0.68, where p<0.01) was detected. The growth of bushes at the *Landslide* site is also caused by the July (R=0.51, where p<0.01) and August air temperature (R=0.39, where p<0.01).

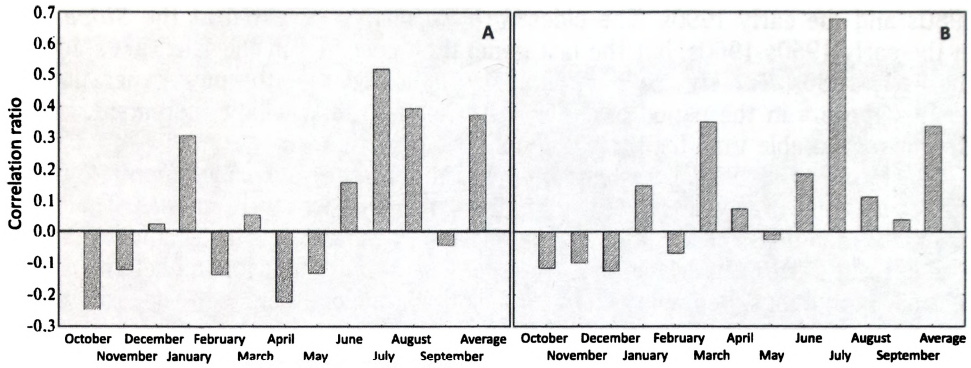

Fig. 4. Correlation ratios of the radial willow increment with the average air temperature according to the Marre Sale synoptic station. A — the *Landslide* site, B — the *Slope* site

The results of the analysis allowed us to compare the graphical data of the average air temperature in July with the radial increment of bushes for the long-term period (1950-2006). The synchronous dependence of the average air temperature in July on the radial increment of bushes was registered (Fig. 5, 6). At the *Landslide* site, both synchronous and asynchronous years between the increment of bushes and the average air temperature in July were registered. The increment reduction in 1960, 1963, 1981, 1997 and 1999 was caused by the cold summer season. However, in 1967, 1974, 1984, 1993, and 2002, the willow increment reduction was not caused by the low air temperatures in July, but, on the contrary, it was caused by the high ones. Perhaps, at this site, soliflual processes were especially active in these years, and the landslide occurred in one of them.

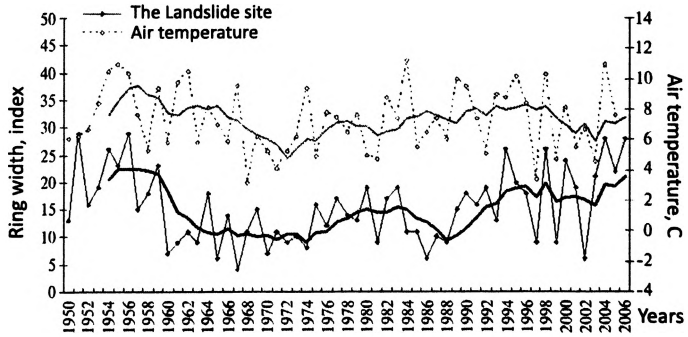

Fig.5. The correlation of the radial increment of willow stems of the *Landslide* site and the air temperature in July according to the Marre Sale synoptic station

The similar picture of the changes in the average air temperature in July and the radial willow increment (Fig.6) was registered. However, considerable discrepancies in general dynamics of the radial increment are noticeable between two sites under study. Thus, the general reduction of the growth occurred at the *Landslide* site in the late 1980s, and the further change of the willow increment up to now does not correlate with the general dependencies of the July temperatures. Moreover, starting with the mid-1990s, the reduction of the radial willow increment was registered at this site, although the decrease of the July air temperatures did not occur in this period.

The impact of some local factors can be assumed. These external factors which are significant for the willow growth at these sites can include the change of the temperature and humidity conditions, as well as the ground movement of the active layer. At the *Landslide* site, the changes in the radial increment which do not correlate with the changes of the average air temperatures in July may be caused by the increase of the temperature of the root layer on willow blocks survived between sliding surfaces, where the depth of seasonal ground thawing increased due to soil denudation. At the *Slope* site, it may be caused by the damage of the root bush system in the process of periodically recurrent displacement of blocks. In this context, we can suppose that the cryogenic slide occurred in 1984 at the *Slope* site. The willow blocks were affected by the soil creep along the ravine slope at the late 1960s, but, starting from the mid-1990s, they were gradually moving down the slope.

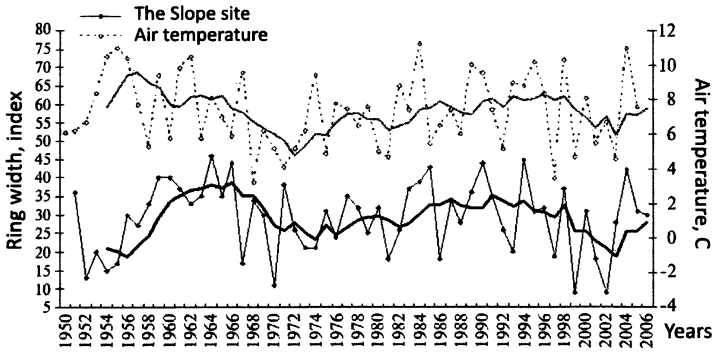

Fig. 6. The correlation of the radial increment of willow stems of the *Slope* site with the air temperature in July according to Marre Sale synoptic station

Besides, the existence of willow communities was registered above the slope edge of the ravine and on the surface of the terrace itself, judging by the number of tree rings added in this period; that gives an evidence of environmental changes which are favorable for the this vegetation type within facies peculiar to typical tundra. Perhaps, it may be explained either by the drainability increase of willow habitats or by the increase in the depth of seasonal soil thawing due to the change of climatic conditions.

The data obtained were compared with the results of the earlier works carried out on the territory of South Yamal [15-16]. The periods of increase and reduction of the radial increment of willow bushes appeared to be generally correlated in the

most cases. In the north growth border, the growth of bushes is closely connected with climatic factors; that determines the similarity of the radial increment at the sites located at a considerable distance from each other. Therefore, the radial increment has the signal characterizing the dynamics of ecosystem condition for the considerable territory.

We should pay attention to the asynchrony of the year-to-year dynamics of the July average air temperature and the radial increment at the *Landslide* and *Slope* sites in 1954, 1960, 1962, 1984, and also to the existence of the long-term similar periods at these sites — 1962-1974 and 1984-1992. We may assume that the process of solifluction was activated at the *Landslide* site in 1962-1974. Later, the rehabilitation of the willow community continued till 1984. The landslide is likely to occur in 1984. The analysis of the radial increment response to the July average air temperature at the *Landslide* site proves the higher probability of this duration of the landslide process activation. The asynchrony of the year-to-year dynamics in the 1960s was registered on the background of the general tendency of the decrease in the average monthly air temperatures in July, but in the mid-1980s it was registered on the background of their increase. The activation of soliflucted-landslide processes at this site occurred during two climatic periods, determined for Yamal earlier (1954-1957, 1959-1962, 1983-1984, and 1989-1990) which favorably affected the development of landslides. We should pay attention to the fact that the beginning of the reduction of the radial increment in the periods of 1967-1970 and 1984-1988 coincides with the two from the four peaks of the standard thawing depth (1938, 1967, 1984, 1989), which were noticed earlier [1] by analyzing the factors affecting the activation of cryogenic landslide processes.

The conclusion. The registered reduction of the radial willow increment, which is asynchronous to the dynamics of the July average air temperature, gives an evidence of the instability in the condition of the lithogeneous foundation of the tundra ecosystems landscape complexes and indicates the possibility of development of hazardous landscape processes at such sites. The detected regularity allows us to reveal the periodicity in soliflucted-landslide processes and to apply these data for estimating the landslide risk at slope sites where willow communities grow. The results of the dendrochronological analysis given in this paper prove its efficiency when dating and researching the dynamics of slope processes, they confirm the necessity for dendrochronological research to be carried out in a wider scale for a detailed and comprehensive study of the impact local conditions have on the development of slope processes in different Arctic areas.

REFERENCES

1. Leybman, M.O., Kizyakov, A.I. Cryogenic Landslides of Yamal and the Yugorskiy Peninsula. Moscow: Institute of the Earth Cryosphere, Russian Academy of Science, 2007. 206 p.

2. Khantemirov, R.M., Shiyatov, S.G. Main Stages of Development of Tree Vegetation in Yamal in Holocoen //Ecology. 1999. No. 3. P. 163-169.

3. Khantemirov, R.M., Shiyatov, S.G. Radiocarbon and Dendrochronological Datings of Subfossil Wood in Yamal and their Application for Researching the Dynamics of Forest Tundra Ecosystems // Biota of the Ural Subarctic in the Late Pleistocene and Holocoen. Ekaterinburg, 1999. P. 3-22.

4. Shiyatov, S.G., Mazepa, V.S., Khantemirov, R.M., Goryachev, V.M. Results and Prospects of Application of the Dendrochronological Method for Dating Archeological, His-

torical, and Ethnographical Monuments on the Territory of Yamal // Scientific Herald of Yamalo-Nenets Autonomous Okrug. 2000. P. 49-56.

5. Shiyatov, S.G., Khantemirov, R.M. Dendrochronological Dating of the Wood of Bushes from Archeological Settlement Yarte VI on Yamal Peninsula // Yamal Ancientry. Issue 1. 2000. P. 112-120.

6. Khantemirov, R.M., Surkov, A.Yu., Gorlanova, L.A. Climatic Change and Formation of Age Generation of Larch on the Polar Forest Boundary in Yamal // Ecology. 2008. No. P. 323-328.

7. Leybman, M.O., Archegova, I.B., Gorlanova, L.A., Kizyakov, A.I. Stages and Demonstration of Cryogenic Landslide Processes according to Researches Data in the Yugorskiy Peninsula and Yamal // Cryosphere of the Earth. 2000. Vol. 4. No. 4. P. 67-75.

8. Gorlanova, L.A. Procedure of Dendrochronological Dating of Landslide Events // Extreme Cryospheric Phenomena: Fundamental and Applied Aspects: (Proc. of International Conference). Pushchino, 2002. Moscow: Scientific Council on Cryology of the Earth, Russian Academy of Science, 2002. P. 148-149.

9. Cook, E., Kairiukstis, L. (eds.) Methods of Dendrochronology: Applications in Environmental Science. Dordrecht-Boston-London: Kluwer Acad. Publ.,1990. 394 p.

10. Vaganov, E.A., Shiyatov, S.G., Mazepa, V.S. Dendroclimatic Investigations in the Ural-Siberian Subarctic. Novosibirsk: Nauka, 1996. 246 p.

11. Shiyatov, S.G. Dendrochronology of the Upper Boundary of Forest in Ural. Moscow: Nauka, 1986. 136 p.

12. Rinn, F. TSAP version 3.5. Reference Manual. Computer Program for Tree Ring Analysis and Presentation. Heidelberg: Frank Rinn, 1996. 264 p.

13. Holmes, R.L. Computer-Assisted Quality Control in Tree-Ring Dating and Measurement // Tree-Ring Bulletin. 1983. 44. P. 69-75.

14. Arefyiev, S.P. Chronological Estimation of Condition of Tundra Bushes of Yamal // Siberian Ecological Journal. 1998. No. 3-4. P. 237-243.

15. Shiyatov, S.G., Mazepa, V.S. Climate // Nature of Yamal. Ekaterinburg: Nauka. Ural Department, 1995. P. 32-68.

16. Tsibul'skiy, V.R., Valeeva, E.I., Arefyiev, S.P. et al. Natural Environment of Yamal. Vol. 1. Tyumen: Institute of North Development Problems, Russian Academy of Science, 1995. 168 p.