Colonization of the young glaciofluvial deposits at the period of the modern climate warming in the North-Chuya glaciation center

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Abstract. We have investigated the early colonization of plants on the highly disturbed glaciofluvial deposits of the Aktru valley. The modern colonization of the deposits are occurs in their middle part. It was impossible until the modern climate changes because of harsh disturbance regime which was prevented any colonization in this area by regular destruction of both plants and habitats. Now the regime is milder. 100 species from 31 family and 64 genera are participating in colonization now. The most of involved species are high-mountain ones and belong to Poaceae, Asteraceae and Salicaceae families. Most common growth forms of these plants are perennial herbs and shrubs. The colonizing Larix trees are exist only as shrub growth form. The formed communities are underdeveloped and may be considered as existing on the pioneer stage of succession. The plant communities development is slow because of harsh disturbance regime thus forming of young forest similar to those in the higher part of the deposits will require a lot of time.

1. Introduction

The importance of monitoring of biodiversity is increasing during the modern climate warming identified across the globe [1]. The plant colonization monitoring is becoming more important as the warming intensifies. The especially important part of these studies are monitoring of biodiversity of plant communities belonging to forming and unstable landscapes and control of new species invasions. The climate of the intermountain basins of the Altai Mountains has changed significantly: mean annual temperature has increased by 3.8°C, but in the Altai high-altitudinal areas it changed only by 1.5°C; annual precipitation of these areas has decreased by 10% [2].

The plant colonization of systematically disturbed landscapes is an especially interesting part of the biodiversity monitoring. Plant communities of such landscapes demonstrate low stability, because they lack aedificator plants with a strong environment-forming influence which typically dominate in fully developed plant communities. We assumed such plant communities are probably more susceptible to climate change than fully formed ones which demonstrate significant stability and resilience. The monitoring of these plant communities has a significant scientific value, both basic and applied. It allows assessing their natural dynamics under the influence of the climate change and studying their adaptation to the ones. We believe the results may be extrapolated to previous periods of climate warming which occurred many times during warming-cooling cycles of the Russian Altai past [3]. Such investigation
are also useful as a part of investigation of climatically determined changes of ecosystem potential related to their biosphere functions and providing human-related goods and services.

The modern floristic complexes of Aktru valley was formed after massive floods caused by glacier melt-water streams which was very intensive after the end of maximal for the last 1000 years climate cooling (first half of the XIX century) which affected many mountain systems of the world [4,5]. These complexes are important source of information which allows making reconstruction of plant colonization peculiarities and development of landscapes of the past, like during interglacial periods of Pleistocene and Holocene when vast glaciofluvial deposits were formed. This information cannot be fetched out by paleobotanical methods so the studies of modern plant communities forming on these deposits are the single source of such information.

A little works in the colonization of the glaciofluvial deposits are exist. The H. Birks [6] who studied the glaciofluvial deposits of Harris Creek at the valley of Clutlan glacier (Canada, Rocky mountains) has identified 35 species of 24 genera, 17 families of vascular plants and mentioned Salicaceae family and Salix genera had a maximal species diversity. Del Moral et al. [7] has investigated glaciofluvial deposits formed by volcanogenic flood in the valley of the Muddy river (St. Helens mountain, USA, Rocky mountains) and has identified 58 species from 46 genera and 19 families; 3 families had a largest species diversity: Asteraceae – 8 species; Poaceae – 8 species; Pinaceae – 8 species. P. Wardle who studies the deposits formed by melt water flow from Franz-Josef and Fox glaciers (New Zealand) has mentioned only 15 most important species [8].

Our long-term studies in the mountain glacier basins of the Central Altai [9] fetched out that between studied basins of Severo-Chuiskiy, Yuzhno-Chuiskiy and Katunskiy glaciation centers the Aktru basin (Severo-Chuiskiy range) is the most suitable for this investigation. The Aktru mountain glacier basin (50°05' N, 87°45' E) has long glaciofluvial deposits and it is well studied in the geomorphological sense so we choose it as a model basin for our studies of plant colonization of glaciofluvial deposits.

2. Study area and data gathering
The Aktru basin is situated in the highest part of the Severo-Chuiskiy range – the mountain-glacial junction Bish-Iirdu. It is very representative as it is typical for the Altai by orographical and landscape characteristics [10]. A severe alpine topography is prevailing here. The Aktru valley which are is in the middle and lower part of basin is through and deeply incised. Slopes of the valley are steep, sometimes almost vertical. The upper part of the basin is occupied by Malyi Aktru, Pravyi Aktru and Levyi Aktru glaciers and their older moraines. The upper part of bottom of the Valley of Aktru river is covered by glaciofluvial deposits of high capacity (up to 6 m) with flat surface [11]. These deposits were formed in place of vast glacier Aktru of Akkem stage which covered bottom of the valley about 4000 years ago as a result of melting of Aktru glaciers during the cycles of the warming and cooling of the climate of the last thousands years. The deposits constitute of stratified sediments of glaciofluvial streams and consist of sand, gravel, pebbles and boulders. Their upper part is limited by terminal moraine rim of Bolshoy Aktru glacier (2300 m a.s.l.) formed in XVII century and their lower part is limited by Akkem stage glacier noraine rim (1950 m a.s.l.) [3, 12]. The single Aktru glacier was divided to Malyi and Bolshoy Aktru glaciers during recession about 2000 years ago. The cooling of the first half of XIX century was strongest for the last 2000 years. The modern warming period was started in the mid XIX century. In the beginning of this period a vegetation which was existed on the glaciofluvial deposits before was destroyed by powerful glaciofluvial flushes flowed down from melting glaciers. It is confirmed by prof. M.V. Tronov [13] observations who in 1936 noticed the vegetation of glaciofluvial deposits of the Aktru valley is almost not exist. Young glaciofluvial deposits have length about 5 km; they are about 40-500 m wide and constitute the extensive zander field covered by gravel, pebble, boulders and small patches of sand and glacier silt. About 2/3 of the field is not covered by vegetation.

Aktru meteorological station data gathered in 1960s–1990s indicate that before the modern global warming was registered in Altai at 1980s [14] the climate of the basin was cold: mean annual temperature was -5.2°C; mean summer temperature was +8.7°C. The precipitation was relatively low
(563 mm/year) [11, 14]. During the modern warming mean annual temperature in the Aktru basin has increased to about -4°C and precipitation is decreased by about 10% [2].

The data for this investigation was gathered during long-term (2002–2017) monitoring of plant colonization and vegetation development which was performed on the glaciofluvial deposits of the Aktru river valley [15]. Data was gathered along the transects made along the river banks and directed from the upper boundary of the glaciofluvial deposits (moraine rim of XVII century) to their lower boundary (moraine rim of Akkem stage glacier).

3. Results and discussion

The young glaciofluvial deposits of the Aktru river valley are situated in the upper part of the mountain forest belt of Severo-Chuisky range, at altitudes of 1950–2170 m a.s.l.

Results of our long-term observations and analysis of high-resolution satellite images made in a different time (1960s, 2018) indicate that the glaciofluvial deposits consist of 3 landscape zones (higher, middle and lower). The higher zone is the upper third of zander field (2170–2140 m a.s.l). Landscape of the zone is represented by elevated areas (young terraces of the Aktru river [12]) where forming of a larch forest has begun about 60 years ago. At the present day these areas are covered by young and dense single-generation larch forests with average tree age about 60 years [16]. River banks of the lower part of the terraces are covered by strips of shrub thickets which start their forming about 40 years ago. Most of these thickets are formed by willows (mostly Salix coesia and S. saposhnikovii) and roundleaf birch (Betula rotundifolia). A dense (about 100% cover) moss storey exists under the thickets [17].

The largest part of the young glaciofluvial deposits (up to 80% of general area) include both middle (2140–2100 m a.s.l) and lower (2100–1960) zones and covered by shallow hollows and small ridges. The surface of its part of the deposits is covered by gravel, pebble and boulders with small patches of sand and glacier silt. They constitute open large gravel-pebble fields with underdeveloped vegetation.

Ecological peculiarities of plant colonization and development of vegetation include complex disturbances; some of disturbances have a catastrophic or subcatastrophic impact on the vegetation. Primary catastrophic disturbance in this area is lateral shifts of the Aktru riverbed on the zander field, which completely destroy both plants and habitats. The most common subcatastrophic disturbance is forming of ground water and surface icings which cause death or significant damage of colonized plants. Usually they destroy above-ground parts of shrubs and trees, but do not damage plant nutrients supply in the ground, seed bank and underground parts of perennial herbs. As a result this disturbance impact significantly limits survival of shrubs and trees in the areas affected by icings but allow survival of perennial herbs.

These disturbances create the most severe impact in the lower part of the glaciofluvial deposits where lateral shifts of the riverbed are most common. The river annually divides to multiple shifting arms here. As a result the water flow annually remove the upper layer of deposits and destroys all plants which settled there together with seeds and soil nutrients necessary for plant colonization. The ground water icings are also most severe in this area of the deposits. The icings occur annually; their thickness may reach 1.5-2 m and they may remain unhawed until mid summer. The deposits of this area are very water-saturated and in the early winter ice for a significant depth merging with a ground icing to monolithic icy layer. The layer is pushing not iced ground water up where it is turni to surface icing [17,18]. These annual disturbances of the lower area are the cause of absence of any vegetation in the lower zone.

During the modern climate change period (since 1980s) the landscape area in the middle part of the zander has become more suitable for plant colonization because of significant degradation of Aktru glaciers [19] and following decrease of thawed water flow. These changes are made disturbance regime here much safer for the plant colonization. A comparison of the high-resolution satellite images of 1960s and 2018 indicates that this part of the zander field is changed since 1960s. The volume of thawed water produced by melting of Aktru glaciers in 1960s was much larger than now and middle part of the glaciofluvial deposits then was covered by multiple arms of Aktru river, just like the lower part of zander field now. As a result both plants and habitats were destroyed annually there just like in the lower
zone now. The gravel-pebble deposits are more stable in the present day and a risk of destruction is greatly reduced, but in the warmest days of summer, when glacier thawing is especially intensive, multiple brooks are channel across the middle part of deposits forming the typical landform with small ridges and hollows. The forming of icings in this area occurs only in rare years. Our observations indicate the icings here were occurred in winters of 2003–2004 and 2017–2018 and caused a significant damage to most plants in this part of the deposits. The strongest damage was caused to the above-ground parts of trees and shrubs but seed bank and underground parts of perennial herbs were not affected.

100 species of vascular plants from 31 family and 64 genera was registered in this part of the zander field during our long-term investigations. Most of the species which colonized the study area are belong to Poaceae (14 species), Asteraceae (13 species) and Salicaceae (12 species) families [20]. The largest species numbers are belong to 2 large genera: Salix genera are represented by 11 species and Poa genera by 7 species. High-mountain species of cold habitats (psychophytes) are dominate in ecological space of the colonized gravel-pebble deposits as 45% of all species are belong to this group. The role of other ecological groups are significantly lower: the share of forest-meadow species (mesophytes) is 22%, stony habitat plants (petrophytes) share is 17%, the plants of very humid habitats (hygrophytes) has 14% and species of steppes and arid habitats (xerophytes) has only 6%. High share of the high-mountain cold-tolerant species indicates a very cold and harsh temperature regime of the deposits. The thermal regime of bottom of the valley is strongly influenced by cooling factors during the entire vegetational period. These factors are cold winters from glaciers, presence of glacier river Actru and glacier melt waters which are channel by deposits in the warmest days. Beyond these factors the cooling influence is also created by an underlying permafrost horizon which exist under the surface of middle part of the glaciofluvial deposits on the depth of about 40 cm.

The plant species of this zone are belonging to 16 growth forms. The most common growth form of pioneer species is perennial herbs (72%), most of them belong to rhizome herbs; the rest (28%) are woody plants (trees, tall shrubs, dwarf shrubs, semi-shrubs).

Our data suggest the most actively colonizing species is not numerous: 35 species have medium occurrence 20% or more; only 14 species have higher occurrence and only 10 species have occurrence above 50%. 9 of them are perennial herbs: Aster alpinus, Campanula rotundifolia, Castilleja pallida, Chamerion latifolium, Crepis karelinii, Elymus transbaicalensis, Gypsophila cephalotes, Hedysarum neglectum, Leontopodium ochroleucum and 1 is shrub Pentaphylloides fruticosa. Only 4 most active species have occurrence 90% or more; it is shrubs Myricaria dahurica, Salix coesia, S. saposhnikovii and tree Larix sibirica. Most species (55%) has low occurrence. The Myricaria dahurica, Salix coesia and S. saposhnikovii are most common and numerous shrubs; the most common herbs are Chamerion latifolium, Crepis karelinii, Castilleja pallida and Gypsophilla cephalotes.

The migration of the propagules and their ecosis on the open gravel-pebble plots are crucial for colonization of this landscape. Our investigations indicate the most of the colonizing plants has light seeds or seeds with adaptations for wind-dispersing. Diversity of winds in the Aktru valley (fens from the steppes, glacier winds, valley wall winds) [14] provide excellent conditions for dispersal of propagules from all surrounding plant communities: post-fire and old-growth forests, forest-tundra ecotone, mountain tundra. The species with seeds which has adaptations for wind dispersal are represented by trees Larix sibirica, Populus laurifolia and Betula alba, numerous shrub species (11 species of Salix genera, Betula rotundifolia, and Myricaria dahurica; one dwarf shrub (Dryas oxydonta) and some species of perennial herbs, (13 species of Asteraceae family, Chamerion latifolium, Ch. angustifolium). 15 species like Castilleja pallida, Gypsophilla cephalotes etc. has a very light seeds which also dispersed by wind. Thus more than 70% of all species are distributed by wind. Species with animal-involved dispersion of seeds are less numerous (about 30% of all species). They are represented by 14 species of cereals, including 7 species of Poa genera, Elymus transbaicalensis, E. sajinensis etc.; two species of each of Juniperus и Lonicera genera.

Forming of the vegetation is most active on flat sites and in the small hollows between rock ridges, but cover of all colonized species (including active) is low. Most pioneer species (about 80%) occurs singularly, as isolated from each other individuals. Cover of 14 most active species may reach 1-2% or
even 3-5% but it happens only in the most auspicious sites. Only 2 species of grasses (Poa alpina and P. altaica) form aggregations. Total cover is very low and most often is about 1-2%, but in some plots may reach 5-7%.

The latest data on the plant colonization and vegetation development on the open gravel-pebble deposits allowed us to make the assumption: vegetation of this part of the glaciofluvial deposits is just started its development and plant communities here is currently on the earliest part of pioneer stage of the primary succession which was started under the impact of modern climate changes.

We believe the monitoring of a larch colonization of the deposits is especially important because it is crucial for prediction of further development of the vegetation. Much probably the local primary succession will end with forming of young larch forest. Our observations of this species colonization indicate the massive appearance of young larch individuals in 2004–2006. The later checks (in 2011, allowed us to fetch out that about 80% of registered seedlings are died. The survived individuals have age 9-12 years, exist in immature ontogenetic state and developing not as small trees but as shrubs because their upper buds are regularly die under the influence of frost. These results allow us to presume the development of a larch forest in the middle part of the glaciofluvial deposits is unlikely under the modern climatic conditions of the glaciofluvial deposits of Actru valley.

4. Conclusion
Data gathered in the high-altitudinal areas of the Severo-Chuiskiy glaciation center allows to make a conclusion that the glaciofluvial deposits were settled by species with diverse ecology during the interglacial periods of Pleistocene and Holocene. Most of these species were cold-resistabt high-mountain species. Predominance of the species of Asteraceae, Poaceae, Salicaceae and genera Salix, Poa on the open pebble areas of modern glaciofluvial deposits allows to presume they are actively participated in colonization and development of vegetation in the Altai during previous geological epochs. Colonization and development of vegetation on the glaciofluvial deposits are occurs only at stable parts of zander field. These processes are slow under the current conditions, as glacier stream shifts still may destroy habitats and icings are severely damaging or destroying plants once per several years. The disturbance regime is especially important as it serves a primary limiting factor influencing forming of vegetation. High-mountain plants (psychophytes) are the most important plant group. The predominant growth form are shrubs and perennial herbs.

The modern climatic change allowed expansion of vegetation on the previously unsettled areas where the succession is still in the earliest pioneer stage, it is also slowed down by disturbances.

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