ABS ACTA BIOLOGICA SIBIRICA
A journal on the biodiversity of Siberia and the adjacent lands

Acta Biologica Sibirica 9: 293–315 (2023)
doi: 10.5281/zenodo.7879848
http://journal.asu.ru

RESEARCH ARTICLE

Soils and vegetation of the riverside floodplain in the hydrological continuum of the southern tundra within the Pur–Taz interfluve (Western Siberia)

Sergey V. Loiko[1], Nina V. Klimova[1], Ivan V. Kritckov[1],
Darya M. Kuzmina[1], Sergey P. Kulizhsky[1]

1 *Tomsk State University, 36 Lenin Ave., Tomsk, 634050, Russia*

Corresponding author: Sergey V. Loiko (s.loyko@yandex.ru)

Academic editor: R. Yakovlev | Received 31 March 2023 | Accepted 24 April 2023 | Published 2 May 2023

http://zoobank.org/0A5E7EF6-A8CB-46FD-935B-51A33AA968AC

Citation: Loiko SV, Klimova NV, Kritckov IV, Kuzmina DM, Kulizhsky (2023) Soils and vegetation of the riverside floodplain in the hydrological continuum of the southern tundra within the Pur–Taz interfluve (Western Siberia). Acta Biologica Sibirica 9: 293–315. https://doi.org/10.5281/zenodo.7879848

Abstract

Climate warming has significantly impacted the ecosystems of the Subarctic and Arctic. It has most strongly affected highly productive ecosystems, including those formed in river floodplains. Due to the initially high (background) values of NDVI, remote monitoring methods are not suitable for detecting changes in the biological productivity of floodplain vegetation. Research for both individual regions and landscapes is needed. However, for the floodplains of many rivers in Western Siberia, there are no primary descriptions of soils and vegetation. We have studied the soils and vegetation of the riverside floodplains in the lower reaches of the Taz River within the Pur–Taz interfluve. The studies were carried out within the hydrological continuum from the stream to the main Taz River. A regular change in soils and vegetation along the hydrological continuum was established, with fluvial processes intensifying. Ecosystems with the greatest diversity of plants, with thick layered soils such as Pantofluvic Fluvisol (Polyarenic, Polysiltic, Humic), are formed in the valleys of the tributaries of the Taz River on the natural riverside levee. The floodplain of the Taz River is distinguished by small differences in the heights of topographic elements, loamy soil texture, waterlogging and permafrost. The soils of the studied hydrological continuum were assigned to two Reference Soil Groups (Gleysol and Fluvisol). To describe the diversity of basic soil properties, six principal qualifiers and nine supplementary qualifiers were used. An assumption was made about the replacement of willow bushes by alder bushes during the warming period with the growth of some species of forbs (*Parasenecio hastatus*). The study made it possible to outline ways of further studying the floodplains of the Subarctic of Western Siberia.

Keywords
Permafrost, Arctic, Subarctic, Fluvisol, Gleysol, natural levee, alluvium

Introduction

Climate warming causes various changes in the soil and vegetation cover of the Arctic, which will only intensify in the future. Climate warming occurs in parallel with an increase in the atmospheric transport of nitrogen compounds and various dust fallouts (Forsius et al. 2010; Krickov et al. 2022), which enrich the biogeochemical cycles of land and affect the fluxes of chemical elements in hydrological networks (Abbott et al. 2015; Bowden et al. 2008). An increase in mean annual air temperatures and precipitation (Vasiliev et al. 2020; Malkova et al. 2022) contributes to an increase in the thickness of the active layer (Kaverin et al. 2021). The near-surface layers of permafrost peat deposits contain a significant pool of nutrients (Lim et al. 2021), so their thawing leads to an increase in the availability of nutrients for plants. Climate warming causes the northward migration of more southern species and an increase in the biological productivity of plants. An integral assessment of the ongoing changes is carried out via the remote monitoring of landscapes, which makes it possible to calculate the Normalized Difference Vegetation Index (NDVI) (Myers-Smith et al. 2020). On the basis of NDVI monitoring, a "greening" of arctic and subarctic landscapes was recorded (Tishkov and Krenke 2015; Berner et al. 2020; Tigeev et al. 2021), which reflects the improvement in conditions for plant vegetation. At the same time, in part of the Arctic, there is a "browning" of landscapes (Frost et al. 2019), often associated with the activation of geomorphological processes. However, for a significant area of the subarctic and arctic regions, the NDVI values do not show a significant trend (Miles and Esau 2016; Miles et al. 2019). Landscapes showing a significant increase in the NDVI are the first to respond to ongoing climate change. They are often represented by non-zonal (intrazonal) vegetation and soils. These are, for example, shrub ecosystems on drained slopes of tundra uplands (Loiko et al. 2022), vegetation of basins of drained thermokarst lakes (Loiko et al. 2020), and ecosystems of urban areas (Koptseva and Abakumov 2021), etc. To predict the future state of ecosystems in the Subarctic and Arctic, it is necessary to describe their species structure, soil characteristics, parameters of biogeochemical processes, and identify mechanisms for increasing or decreasing biological productivity.

The riparian zones and floodplains of rivers and lakes experience the integral impact of the processes occurring in river catchment areas. Additionally, if the processes occurring after the drainage of thermokarst lakes are well studied (Jones et al. 2022), then much less research is devoted to changes in the vegetation and soils of the Arctic and Subarctic river floodplains during climate warming. This is largely due to the fact that floodplains are characterized by the most productive vegetation, and at maximum NDVI values, its trends are not noticeable. For example, when analyzing a map of statistically significant greening and browning trends in the north of Western Siberia, it can be seen (Miles et al. 2016) that the vegetation of the Ob, Nadym, Pur, and Taz floodplains does not have a significant NDVI trend. However, the available recent studies indicate that the floodplain vegetation is also actively changing in the course of climate warming (Frost et al. 2023). To assess changes in the productivity of floodplain vegetation, the NDVI index is insufficient, so other, more detailed approaches are required. Changes in the floodplains are associated not only with the improvement of climatic conditions of growth, but also with the transformation of the hydrological regime (Mann et al. 2010) and the supply of fertile river suspension (Krickov et al. 2018). The vegetation of the riverside floodplain is most susceptible to change. To plan and conduct detailed studies of the dynamics of soils and vegetation in the floodplains of the Arctic rivers, their primary survey is necessary. However, for the floodplains of many rivers in Western Siberia, soils have not yet been studied and vegetation has been poorly studied, especially for the floodplains of small rivers. So, for example, for the largest river Taz, detailed studies were carried out from its upper reaches to the confluence of the Panchatka River (Titov and Potokin 2001). We are not aware of any systematic studies of soils in the Taz floodplain. The floodplain vegetation and soils of the lower reaches of the Taz River, within the southern tundra, have been studied only in the most general form (Likhanov 1972; Pis'markina and Byalt 2016; Glazunov and Nikolaenko 2018). At the same time, we note that it is the floodplain and bog landscapes in Western Siberia that are the places that allow for the discovery of rare or new species in the region (Kosterin et al. 2019; Kapitonova 2020).

To fill this research gap, we carried out studies of vegetation, soils, and the conditions of their formation in the conditions of the riverside floodplain in the south of the tundra zone. The studies were carried out in the left-bank part of the lower reaches of the Taz River (Western Siberia, Russia). The studies were carried out within the framework of the hydrological continuum concept (Doretto et al. 2020). The studies were carried out sequentially from the smallest watercourse to the large river Taz. The aim of the study was to study what soils and plant communities form in the riverside floodplains of the southern tundra hydrological continuum and observe how they change as they move downstream. Our study can be useful for determining the direction of successions as hydrological processes change under conditions of climate warming, as well as for planning work on monitoring the soil and vegetation cover of floodplains.

Materials and methods

In the course of route studies and in the analysis of satellite images, rivers and streams in the catchment area of the lower reaches of the Taz River were selected. Sites for studying soils and vegetation of near-channel floodplains were selected based on the size of the river catchment area upstream. Watersheds with an area of about 1–10^3 km^2 are covered. Figure 1 shows the locations of the studied sites. The list of the studied sites and rivers is given in Table 1. The southernmost studied river, the Sambotayakha, according to the schemes of physical and geographical zoning (Likhanov 1972), flows approximately along the border between the tundra and forest–tundra zones. Accordingly, all the studied points are located in the tundra zone. The studied floodplain ecosystems belong to the left tributaries of the Taz River. When choosing sites for studying soils and vegetation, we were guided by topography and vegetation. The sites were located near the main channel of the river, within the natural levee and its slope (except for streams that do not have a levee). A total of 18 sites were studied. During the field work, soil pits were dug, and the front wall of the soil pit was leveled and photographed. Soil horizons were identified, after which samples were taken from them. For each site, geobotanical descriptions were made (on sites 10x10 m in size or within natural contours, with small sizes of phytocenosis). The description was carried out in tiers. For each species, its abundance was recorded. The abundance of plants in a community was estimated as coverage (percentage of horizontal projection).

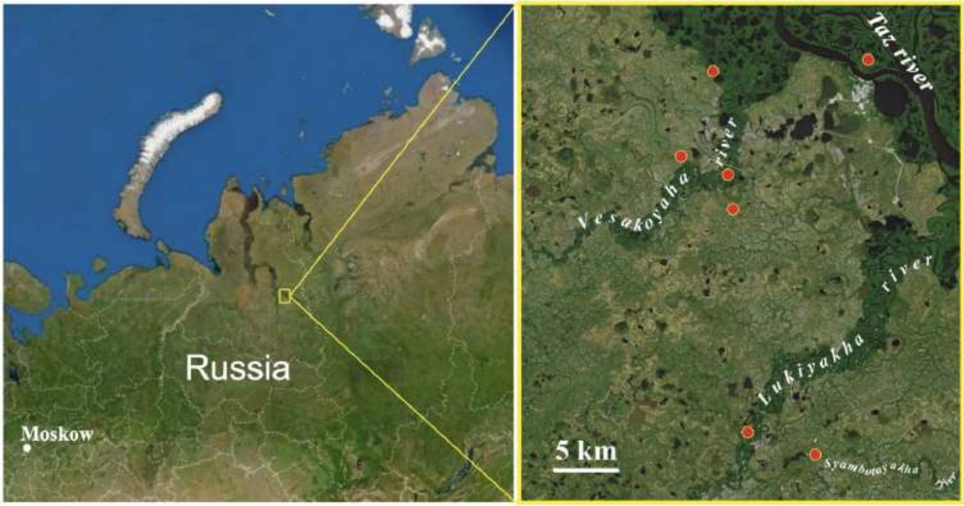

Figure 1. Study area and sites of riverside floodplains (red circles).

In laboratory conditions, bulk monoliths were formed from soil samples, which were used to clarify the morphological features of soil horizons. Classification and diagnosis of soils was carried out using collected samples and descriptions of soils obtained in the field as well as photographs of the front walls of soil pits. For classification, the International soil classification system WRB 2022 was used (Schad 2023; IUSS Working Group WRB 2022). The logical–interpretative processing of the collected photographic materials, descriptions of soils, vegetation, and relief was carried out using the comparative geographical method and the hydrological continuum concept (Doretto et al. 2020). Due to the inaccessibility of the study area and the impossibility of tracing changes in the soils and vegetation of the riverside floodplains using the example of one river from source to mouth, accessible watercourses with different catchment areas were studied. At the same time, it was assumed that these rivers were similar within the landscape under consideration, which is confirmed by previous studies of these rivers (Krickov et al. 2018). To clarify the classification diagnosis of soils of some sites, data on the carbon content in soil samples were needed. The C concentration in soil samples was measured using catalytic combustion with CuO at 900°C, with an uncertainty of ≤0.5% using the Thermo Flash 2000 CN Analyzer at Tomsk State University.

Table 1. Geographical coordinates and topography of the studied sites

River	Sw*, km^2	Site field number	Latitude and longitude	Features of the topography near the studied site
Stream	1.2	Stream1	N67°17'49.9" E78°48'29.0"	The near-channel zone is not topographically expressed and is constantly flooded. The width of the floodplain is between 30–40 m.
Bolshaya Yarneyakha	19	B_Yar21-1	N67°19'35.8" E78°43'49.3"	The channel is deep (up to 3–4 m at low water), has the shape of a rosary in plan, and the walls of the channel are steep. Between the extensions of the channel in the form of ponds there are steps with a fast flow of water. The width of the floodplain is between 30–40 m.
		B_Yar21-2	N67°19'37.2" E78°43'55.0"	
Syambotayaha	75	Samb21-1	N67°09'22.3" E78°57'26.1"	The river bed is wide, winding, with sandy bars of different heights. On the border of the channel and the main surface of the terrace, a levee is developed, rising above the main surface of the riverside floodplain by 0.5 m. The width of the floodplain is between 100–120 m.
		Samb21-2	N67°09'22.6" E78°57'26.2"	
		Samb21-3	N67°09'22.9" E78°57'25.7"	
		Samb21-4	N67°09'22.6" E78°57'24.8"	
Lukiyakha	656	Nyni21-1	N67°10'15.1" E78°49'46.9"	Strongly meandering river, many oxbow lakes. Lots of sandbanks. In low water, the height difference from the water to the top of the riverside levees reaches between 4–5 m. The width of the riverside floodplain reaches several tens of meters. The width of the floodplain is up to 1 km.
		Nyni21-2	N67°10'15.7" E78°49'46.4"	
		Nyni21-3	N67°10'15.8" E78°49'48.2"	
Vesakoyaha	566	Vesa21-1	N67°19'08.9" E78°48'43.4"	A river with large meanders and oxbow lakes. Wide sandy slopes and riverside levees up to 2–3 m high. The eroded shores are sandy/loamy. The shores of oxbow lakes are sloping, loamy. The width of the floodplain is up to 1.5 km.
		Vesa21-2	N67°19'08.8" E78°48'44.2"	
		Vesa21-3	N67°19'08.9" E78°48'42.4"	
		Vesa21-4	N67°19'11.5" E78°48'08.9"	

River	Sw*, km²	Site field number	Latitude and longitude	Features of the topography near the studied site
Taz	150000	TzFl17-1	N67°22'52.7" E78°59'33.5"	A floodplain with a very complex spatial morphology. Elevation differences in low water from the water's edge to near-channel elevations usually do not exceed 2–4 m. There are thermokarst subsidences. Deposits are detrital/loamy. The width of the floodplain is up to 15–24 km.
		TzFl17-2	N67°22'52.5" E78°59'44.1"	
		TzFl17-3	N67°22'54.2" E78°59'34.6"	
		TzFl17-4	N67°22'26.9" E78°46'33.7"	

Result

The obtained data on the soils of the studied sites are given in Table 2. The river network of the considered part of the Pur–Taz interfluve begins with streams. These streams are of two types. Streams of the first type are less common and flow down from permafrost polygonal peat bogs. Streams of the second type flow from thermokarst lakes, which are located among permafrost polygonal peat bogs on flat plains.

The streams of the first type do not have a channel in their upper reaches. For such streams, the riverside floodplain, channel, and floodplain are identical. Their floodplain, 5–20 m wide, is flat and constantly flooded with water. These streams are fed by both bog waters and waters of valley taliks. Films of iron hydroxides accumulate on the surface during low water periods (Fig. 2). The soils are diagnosed as Reductigleyic Histic Gleysol (Loamic). There is a peat horizon of a very low bulk density intertwined with horsetail and cinquefoil roots, no more than 15–25 cm thick. Under the peat horizon lies a totally gley horizon. These floodplains are overgrown with low-growing Salix sp. with an admixture of *Betula nana*. The herbaceous cover is represented by *Carex aquatilis* and *Comarum palustre*, locally with *Calamagrostis langsdorffii* and *Eriophorum* sp. The moss cover is represented by *Sphagnum* sp. and *Bryales* sp.

The second type of streams have a well-cut channel, with pronounced sides. The streams have a fast flow and do not dry up, even in low water during a year with average humidity. The channel looks like a rosary from above—rounded ponds and sections of the channel with a fast current alternate, often with rifts or small waterfalls. The vegetation of the channel slopes is represented by *Salix* sp. with an integument of *Calamagrostis langsdorffii*. By the water, *Carex aquatilis* and *Comarum palustre* are added. The soils of the channel slopes were identified as Stagnic Fluvisols (Polyarenic, Polysiltic). Behind the brow slope of the channel on the terrace, occasionally flooded in the spring, a community of *Betula nana* is formed with the participation of *Salix* sp., *Vaccinium vitis-idaea*, *Vaccinium uliginosum*, *Calamagrostis* sp., and *Carex* sp., with a well-developed moss cover of *Bryales* species (*Aulacomnium turgidum*, etc.) and small participation of lichens. The soils of these terraces are identified as Protogleyic Pantofluvic Fluvisol (Polyarenic, Polysiltic, Folic).

Table 2. Soils and vegetation of the studied riverside floodplain sites

River	Sw*, km²	Site field number	Topographic position / Active layer thickness	Soil name by WRB (2014 with 2015 updates)	Plant community	Plant litter thickness, cm	Thickness of sand interlayers (cm) / thickness of silty interlayers (cm) up to a depth of 50 cm from the mineral soil surface
Stream	1.2	Stream1	Flat bottom, surface water / No	Reductigleyic Histic Gleysol (Loamic)	Ernik and scrubby willow with sedge and marsh cinquefoil	12	Loam soil
Bolshaya Yarneyakha	19	B_Yar21-1	Steep stream bed slopes / No	Stagnic Fluvisol (Polyarenic, Polysiltic)	Reed grass willow with sedge near the water	0	Loam soil
		B_Yar21-2	Flat floodplain terrace in the stream valley / 55	Protogleyic Pantofluvic Fluvisol (Polyarenic, Polysiltic, Folic)	Dwarf willow and birch, reed grass and sedges, mosses	5	32/18
Syambotayaha	75	Samb21-1	Sand bar rising above the water level in low water / No	Pantofluvic Fluvisol (Arenic)	Dwarf willow and herbs with low coverage	0	43/7
		Samb21-2	Top of the riverside levee / No	Pantofluvic Fluvisol (Arenic, Ochric, Nechic)	Birch–larch forest with alder and herbage	6	Not layered
		Samb21-3	Elongated depression at the border of the low and riverside floodplain / No	Gleyic Fluvisol (Arenic, Nechic)	Mossy, grassy meadow	6	Not layered
		Samb21-4	Flat part of the low floodplain / 23	Histic Gleyic Fluvisol (Epiarenic, Polyloamic, Gelic, Nechic)	Grass–dwarf shrub–sphagnum floodplain	24	8/24
Lukiyakha	656	Nyni21-1	Slope riverside levee / No	Pantofluvic Fluvisol (Polyarenic, Polysiltic, Humic)	Horsetail–reed grass willow	0	20/30
		Nyni21-2	Foot of the riverside levee where the stream flows into the river / No	Gleyic Fluvisol (Siltic, Humic)	Meadow of reed grass and sedge	0	10/40
		Nyni21-3	Top riverside levee / No	Pantofluvic Fluvisol (Polyarenic, Polysiltic, Humic)	Alder shrubs dominated by reed grass	2	15/35

River	Sw*, km²	Site field number	Topographic position / Active layer thickness	Soil name by WRB (2014 with 2015 updates)	Plant community	Plant litter thickness, cm	Thickness of sand interlayers (cm) / thickness of silty interlayers (cm) up to a depth of 50 cm from the mineral soil surface
Vesakoyaha	566	Vesa21-1	Wide convex surface of the riverside floodplain / No	Pantofluvic Fluvisol (Arenic, Ochric, Nechic)	Alder forest dominated by reed grass and forbs	5	48/2
		Vesa21-2	Slope riverside levee / No	Stagnic Pantofluvic Fluvisol (Episiltic, Polyarenic, Ochric, Nechic)	Willow–alder reed shrubs	7	17/33
		Vesa21-3	Wide convex surface of the riverside floodplain / No	Pantofluvic Fluvisol (Arenic)	Tall alder with dominance of *Parasenecio hastatus* in the herbaceous layer	3	40/10
		Vesa21-4	Low floodplain washed away by the river at the top of the meander / No	Pantofluvic Fluvisol (Polyarenic, Polysiltic)	Willow with horsetail and reed grass	0	20/30
Taz	150000	TzFl17-1	Elongated depression / No	Gleyic Fluvisol (Siltic, Profundihumic)	Fen with dominance of sedge and marsh cinquefoil	6	Loam soil
		TzFl17-2	Elongated depression / No	Gleyic Histic Fluvisol (Siltic, Profundihumic)	Fen with dominance of sedge and marsh cinquefoil and low-covered willow	16	Loam soil
		TzFl17-3	Top riverside levee / 69	Stagnic Fluvisol (Siltic, Gelic, Profundihumic)	Willow–alder reed grass	8	Loam soil
		TzFl17-4	Flat low floodplain / No	Gleyic Fluvisol (Episiltic, Endoarenic)	Sedge meadow	5	24/26

Figure 2. Colloids of iron (III) hydroxides in the water of a stream with an unexpressed channel.

In the lower reaches of the streams, at the places where they flow into the rivers, the slopes of the stream channels decrease. On moist, loamy sloping soils identified as Gleyic Fluvisol (Siltic, Humic), sedge meadows with a cover of *Carex aquatilis* (60–100%) are formed. There is an admixture of *Calamagrostis langsdorffii* and single occurrences of *Veronica longifolia*, *Equisetum arvense*, and *Galium boreale*. Higher up the slope, a band of *Duschekia fruticosa*, *Salix* sp., *Rosa majalis*, *Ribes* sp. begins.

A topographically pronounced annually flooded floodplain appears near rivers with a catchment area of more than several tens of square kilometers. The near-channel floodplain of such rivers is represented by a natural levee, and the larger the river, the greater the width of the levee. Soils of the riverside levee have a pronounced layering, with favorable thermal and water–air regimes. The riverside floodplain of the Sambotayakha River is not wide, the vegetation is represented by sparse thickets of low-growing willow *Salix* sp., with the participation of *Rosa majalis*. Herbaceous cover is deficient in *Equisetum arvense*, *Chamaenerion angustifolium*, *Tanacetum bipinnatum*, *Solidago* sp., and *Poaceae* sp. There is undergrowth of *Betula pubescens* and *Larix sibirica* (Fig. 3A). The Pantofluvic Fluvisol (Arenic) soil has no loamy layers (Fig. 4A).

A plant community with a large coverage was formed on the riverbank of the Lukiyakha River (Fig. 3B). Within the first tens of meters, the dominant shrub is several species of *Salix*, and the subdominants of the shrub layer are *Lonicera pallasii* and *Rosa majalis*. There is undergrowth of *Betula pubescens* and *Larix sibirica*. The shrub cover is between 40–50%, and the herbaceous layer is between 20–40%. Dominants of the herbaceous layer are *Calamagrostis langsdorffii*, *Equisetum arvense*, and *Parasenecio hastatus*. Less abundant are *Alopecurus pratensis*, *Chamaenerion angustifolium*, *Galium boreale*, *Tanacetum bipinnatum*, *Veronica longifolia*, *Ptarmica impatiens*, *Solidago* sp., *Poa* sp., and *Veratrum lobelianum*. In terms of species saturation, this is the richest plant community. The soil is classified as Pantofluvic Fluvisol (Polyarenic, Polysiltic, Humic) (Fig. 4B). The described community at a distance from the river channel is replaced by alder shrubs (*Duschekia fruticosa*). The herbaceous layer under the alder canopy is dominated by the *Calamagrostis langsdorffii*; *Veratrum lobelianum*, *Equisetum arvense*, *Parasenecio hastatus*, *Senecio nemorensis*, *Chamaenerion angustifolium* are noted as constituents of an admixture.

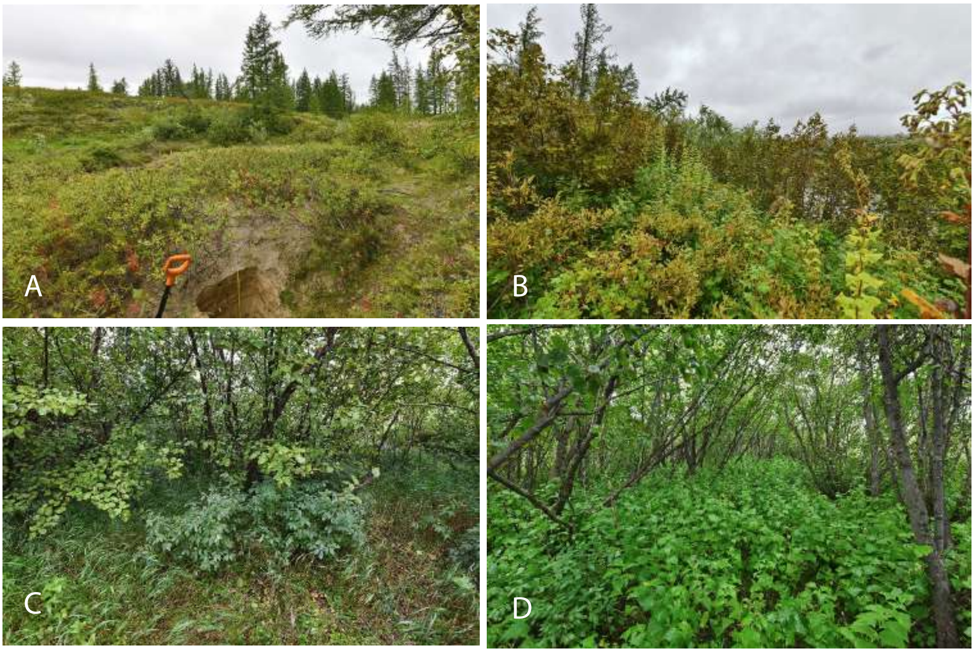

Figure 3. Plant communities of riverside floodplains on layered soils: **A** – sparse pioneer herbaceous willow; **B** – willow with an admixture of wild rose, in herbaceous layer–reed grass; C – forb–reed alder; D – tall alder with a dominance of *Parasenecio hastatus*.

The largest and widest riverside levees are found on the Vesakoyaha River. Soils – Pantofluvic Fluvisol (Arenic, Ochric, Nechic) (Fig. 4C). Communities are diverse. Tall alder shrubs with *Lonicera pallasii* under the canopy are described. *Calamagrostis langsdorffii* dominates in the herbage with the participation of *Rubus arcticus*, *Parasenecio hastatus* (Fig. 3C). Alder schrubs with dominance in the herbaceous layer of *Parasenecio hastatus* with the participation of *Calamagrostis langsorffii* and *Senecio nemorensis* are also described (Fig. 3D). The soils of the slopes of the riverside levee of the Vesakoyakha River were diagnosed as Pantofluvic Fluvisols (Polyarenic, Polysiltic) (Fig. 4D). The plant community on the slopes of the levee is an alder shrub with an admixture of *Salix* sp. with the participation of *Ribes* sp. The herbaceous layer of *Calamagrostis langsdorffii* with an admixture of *Parasenecio hastatus*, *Rubus arcticus*, and *Aconite volubile* is well developed.

The highest convex tops of the riverside levees do not flood in the spring. In the soils of such sites, layering is poorly expressed and the course of post-alluvial soil processes is diagnosed. On the Sambotayakha River, a similar site describes the soil Pantofluvic Fluvisols (Arenic, Ochric, Nechic). A forest community is formed with the dominance of *Betula pubescens* and *Larix sibirica*. The shrub layer contains *Duschekia fruticosa* with low *Lonicera pallasii*, *Rosa majalis*, and *Juniperus* sp. The grass–shrub layer is dominated by *Vaccinium vitis-idaea* with an admixture of *Calamagrostis langsdorffii*, *Equisetum arvense*, and *Carex globularis*. The soil is Pantofluvic Fluvisol (Arenic, Ochric, Nechic), with plant litter up to 6-cm thick (Fig. 5 A). There is wood debris on the surface. Unflooded areas of riverside levees were also found in the floodplain of the main river Taz with Stagnic Fluvisol (Siltic, Gelic, Profundihumic) soils. These soils have permafrost at a depth of less than one meter (Fig. 5B). The first layer of the plant community consists of *Duschekia fruticose*, and *Salix* sp. *Calamagrostis langsdorffii* dominates under the canopy and in gaps, with the participation of *Galium boreale*, *Veronica longifolia*, *Equisetum arvense*, *Rubus arcticus*, and *Lonicera pallasii*.

The features of the transition from the riverside floodplain to the lower floodplain are described with the example of the Sambotayakha River. Changes in soil properties along this transition consist of an increase in gleyic and stagnic properties in soil profiles with distance from the main channel. On the surface, the thickness of organogenic horizons increases, and permafrost appears at a depth of no more than 1 m. Gleyic Fluvisol (Arenic, Nechic) was identified in elongated depressions (Fig. 6A) and Histic Gleyic Fluvisol (Epiarenic, Polyloamic, Gelic, Nechic) was described in adjacent flattened areas of the lower floodplain (Fig. 6B). In the plant communities of elongated depressions, the herbaceous and dwarf shrub layers of *Carex* sp., *Calamagrostis langsdorffii*, *Equisetum arvense*, and *Rubus arcticus* are well expressed, with less participation of *Vaccinium vitis-idaea* and *Comarum palustre*, and with a well-developed moss cover of Bryales (*Calliergon* sp., *Hypnum* sp.). On flat areas of the lower floodplain, Ledum palustre dominates with the participation of *Betula nana*, *Vaccinium vitis-idaea*, *Vaccinium uliginosum*, *Empetrum nigrum*, *Rubus chamaemorus*, and *Carex* sp., with a continuous moss cover of *Sphagnum* sp.

Soils with gley horizons dominate on the riverside floodplain of the Taz River. These horizons are absent only on narrow, elongated natural levees; in other cases, Gleyic Fluvisol (Siltic, Profundihumic) or Gleyic Histic Fluvisol (Siltic, Profundihumic) predominate (Fig. 6C). Gleyic Histic Fluvisol occupies a slightly higher topographic position. The floodplain soils of the lower reaches of the River Taz are fine-textured, even near the main channel. Heavy texture, high moisture and gleization of soils, and prolonged flooding of the floodplain lead to the predominance of plant communities composed of moisture-loving plant species in the floodplains. Small elevations are occupied by *Salix* sp., between which there are meadows of *Carex aquatilis* with *Comarum palustre*, with the participation of *Veronica longifolia*, *Calamagrostis langsdorffii*, and *Equisetum fluviatile* (Fig. 7A). Alder bushes, as mentioned above, are distributed only on the highest manes, directly near the channel of the Taz River.

Figure 4. Soils with well-developed layering and favorable thermal and water–air regimes: **A** – Pantofluvic Fluvisol (Arenic); **B** – Pantofluvic Fluvisol (Polyarenic, Polysiltic, Humic); **C** – Pantofluvic Fluvisol (Arenic, Ochric, Nechic); **D** – Stagnic Pantofluvic Fluvisol (Episiltic, Polyarenic, Ochric, Nechic).

Figure 5. Soils of the most elevated riverside levee without pronounced layering: **A** – Pantofluvic Fluvisol (Arenic, Ochric, Nechic); **B** – Stagnic Fluvisol (Siltic, Gelic, Profundihumic).

The soil profiles of floodplain ridges and interridge depressions (sites TzFl17-1, TzFl17-2) near the main channel of the floodplain of the Taz River do not have clear layering, which makes it impossible to distinguish between Gleysols and Fluvisols morphologically. Therefore, to diagnose fluvic material, it is necessary to apply the diagnostic criterion "b", which requires the determination of the content of organic carbon in soils. According to this criterion, the soil material is diagnosed as fluvic if some layer in the soil profile contains 25% more carbon than the overlying layer (IUSS Working Group WRB 2022). The carbon content data are shown in Figure 8. It can be seen from these data that the 60—70 cm layer in the TzFl17-1 profile and the 65—75 cm layer in the TzFl17-2 profile have a higher carbon content (>25%) relative to the layers that overlap them. Therefore, the soils are diagnosed as Fluvisols. The soils of the riverside levee, characterized by the TzFl17-3 profile, have a very weak layering, but the distribution of carbon in depth gradually decreases.

Sandy layers in the soils of the floodplain of the lower reaches of the Taz River appear only in the near-terrace part, near slopes composed of sandy deposits. In these positions, the texture of floodplain soils is influenced by slope processes and the removal of sandy material by streams. In such a site near a channel of the Taz River, we diagnosed Gleyic Fluvisol (Episiltic, Endoarenic) (Fig. 6D). In this soil, sandy proluvial deposits are overlain by silty loam. The plant community is a sedge meadow (*Carex aquatilis* dominates) (Fig. 7B). Such meadows occupy the lowest floodplain levels and usually adjoin the channels of the Taz River.

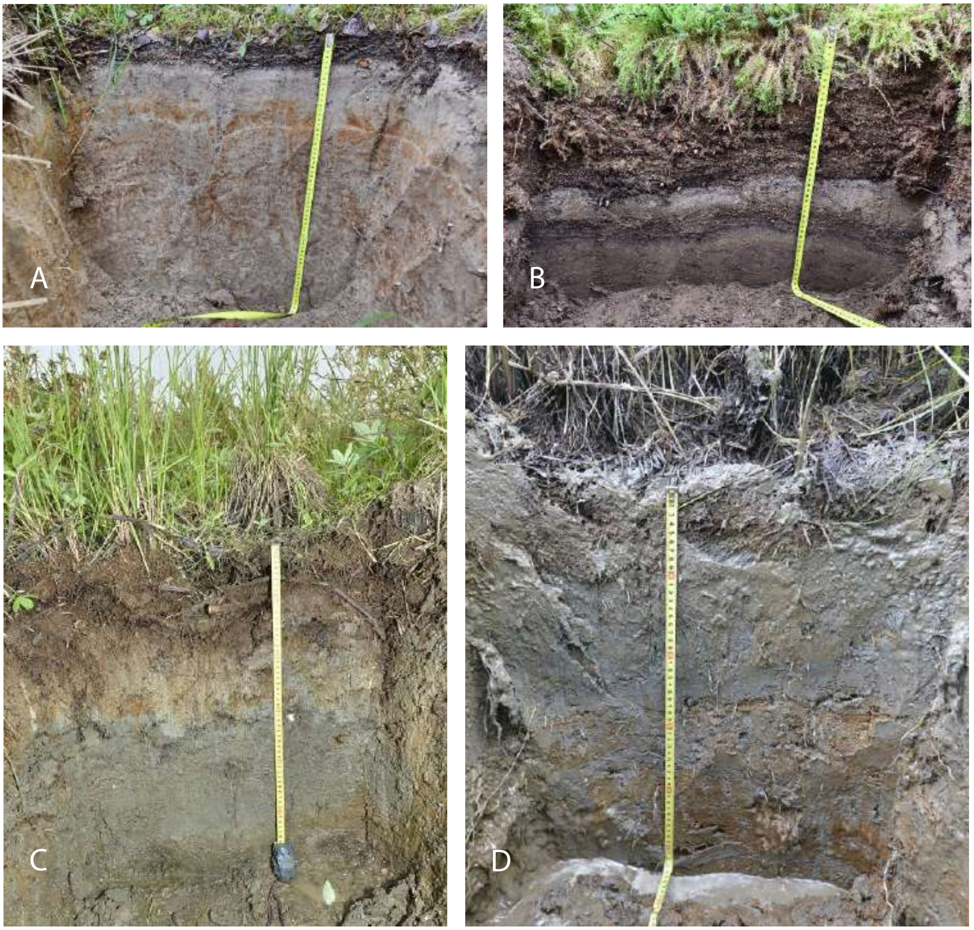

Figure 6. Soils with unfavorable thermal (permafrost) and water–air regime (gley): **A** – Gleyic Fluvisol (Arenic, Nechic); **B** – Histic Gleyic Fluvisol (Epiarenic, Polyloamic, Gelic, Nechic); **C** - Gleyic Histic Fluvisol (Siltic, Profundihumic); **D** – Gleyic Fluvisol (Episiltic, Endoarenic).

Discussion

The soils and plant communities of the riverside floodplains naturally change in the hydrological continuum of the southern tundra as the catchment area of the river increases. In streams and small rivers with a catchment area, the first square km of the riverside floodplain is only slightly wider than the channel. Highly productive herbaceous–shrub ecosystems develop within the flat bottom of the channel and its slopes. Streams with a catchment area of 10–20 km^2 have a flat floodplain surface outside the channel. Such a floodplain is rarely flooded in spring and has a high cover of mosses, ericoid dwarf shrubs, and dwarf birches (Tables 1, 2). Riverside levees appear near channels with a catchment area of several tens of km^2 or more. Such tributaries of the Taz River are characterized by predominantly sandy deposits (Likhanov 1972). Layered soils form on the riverside levees, often with layers of different textures. Such soils have favorable thermal, air, and nutrient soil regimes. It is here that shrub thickets and shrubby meadows are formed with the highest species diversity and plant height. The width of a zone with highly productive vegetation usually does not exceed several tens to a hundred meters, after which the thickness of peat horizons sharply increases; permafrost, mosses and often soil water appear at a depth of no more than a few tens of cm.

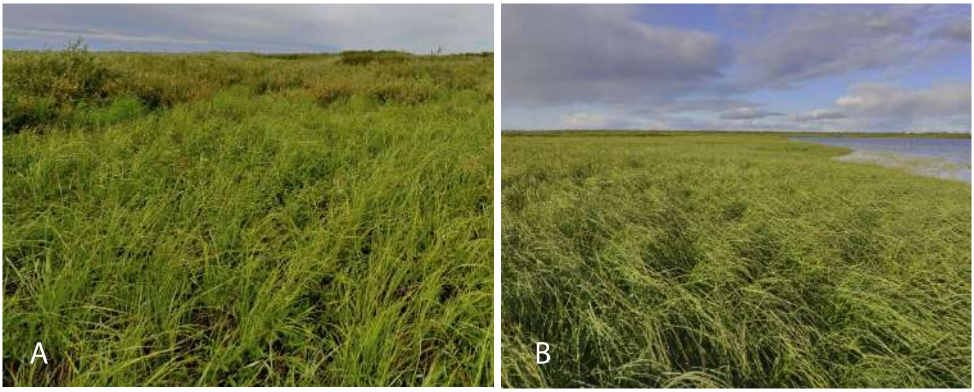

Figure 7. Plant communities on Gleyic Fluvisols: **A** – fen sedge meadow with marsh cinquefoil; **B** – fen sedge meadow.

The vegetation and soils of the floodplain of the lower reaches of the Taz are very different from the floodplain ecosystems of its tributaries. At the study site, the width of the Taz floodplain reaches between 17–23 km; because of this, the energy of the flow drops sharply. During floods, silt and wood are deposited in floodplains (Likhanov 1972). The floodplain here belongs to the firth–delta type (Korotaev 2011); therefore, even on the natural levee, the soils have a heavy loamy texture. Wet sedge and sedge meadow fens with a subdominance of reed grass and marsh cinquefoil are widespread. On higher elevations, they are replaced by shrubby willow meadows and willow shrubs. Monodominant sedge meadows are found where flood spring water removes plant litter. The introduction of reed grass and marsh cinquefoil into the phytocenosis is associated with the accumulation of litter and the formation of a peat horizon. Such conditions arise when the strength of the flow decreases in the spring flood, caused by the displacement of the channels.

In the soils that are formed at the highest levee (near the channels of the Sambotayakha, Vesakoyakha and Taza), the occurrence of soil processes more typical for the taiga zone was diagnosed. The supplementary qualifier Ochric indicates the occurrence of autochthonous humus accumulation, most likely caused by the activity of mesofauna, such as earthworms, noted when digging soil pits. Another process is podzolization, which develops in the upper 5–10 cm, under the plant litter. It consists of two sub-processes — the bleaching of mineral grains and precipitation of iron (hydr-)oxides. The results of the first process in the names of the soils are marked with supplementary qualifier Nechic, which indicates the presence of silty grains bleached from (hydr-)oxide films of iron (III). However, the processes of illuviation of these compounds down the profile are not reflected in the name, since there is no suitable qualifier in the Reference Soil Group Fluvisol. The most suitable qualifier is available in the Arenosol Reference Soil Group; it is the Brunic principal qualifier, indicating a slight browning of the soil material, including due to the processes of illuviation of iron (III) compounds. Another process noted only for the riverside levee of the Taz River (the soil of the TzFl17-3 site), which is composed of loamy deposits, is the appearance of a soil structure. This structure is represented by lumpy aggregates no larger than one cm in size. Lumps break up into rounded aggregates several mm in size.

One of the most unusual phytocenoses is a floodplain shrub on the riverside levee of the Vesakoyaha River (Fig. 3D; Table 2, site Vesa21-3), in which the shrub layer is composed of *Duschekia fruticosa*, and the herbaceous layer consists entirely of *Parasenecio hastatus*. This species has not been noted in previous studies (Likhanov 1972; Tyrtikov 1972). In the more southern forest–tundra and forest sections of the floodplain of the Taz River, this species is usually recorded as an admixture, only occasionally as a co-dominant. In a recent work on the floodplain of the Lukiyakha River, *Parasenecio hastatus* (*Cacalia hastata*) was noted as an occasionally occurring species along the banks of water bodies and streams, in near-channel willow forests (Pis'markina and Byalt 2016). It is possible that willow shrubs have been replaced by alder shrubs in recent decades in response to climate warming. The introduction of alder enriches the soils with nitrogen, which leads to an increase in the cover in the plant communities of the studied floodplains of *Parasenecio hastatus*, which is demanding for warmth and soil fertility.

The first comprehensive studies in the lower reaches of the Taz River were carried out at the end of the 1960s (Likhanov 1972). In the floodplain of the Taz River during those years, a continuous distribution of permafrost rocks was noted, with the exception of areas near a river channel. Our observations have shown that, in moist shrubby meadows, there is no permafrost down to a depth of 1.5 m. However, in riverside levee soils under alder shrubs, the active layer was only 70-cm thick, which corresponds to the zonal tundra on upland. Under the alder shrubs of the upland tundra, the active layer reaches several meters (Loiko et al. 2022), which strongly distinguishes floodplain alder shrubs from upland alder shrubs. Apparently, this is due to the wind redistribution of snow. Due to the general high bushiness of the floodplain and the lower wind strength, snowdrifts do not form within the alder forests. The presence of permafrost subsidence indicates that there is permafrost under wet shrubby meadows. They are diagnosed by wet dead bushes sticking out from under the water (Fig. 9). Most likely, the depth of permafrost is more than

2 m. The wet meadow–shrub landscapes of the Taz floodplain are most similar to the landscapes of khasyreys of the middle successional stage in terms of soils, topography dynamics, and dominant plant species (Loiko et al. 2020). Thermokarst processes are also active in middle-stage khasyreys. The comparison of geocryological conditions allows us to make a cautious conclusion that over the past 50 years, the thickness of the active layer has slightly increased within the lower topographic positions. Additionally, this could lead to an increase in the area of meadow fens and the appearance of wet patches of shrubs.

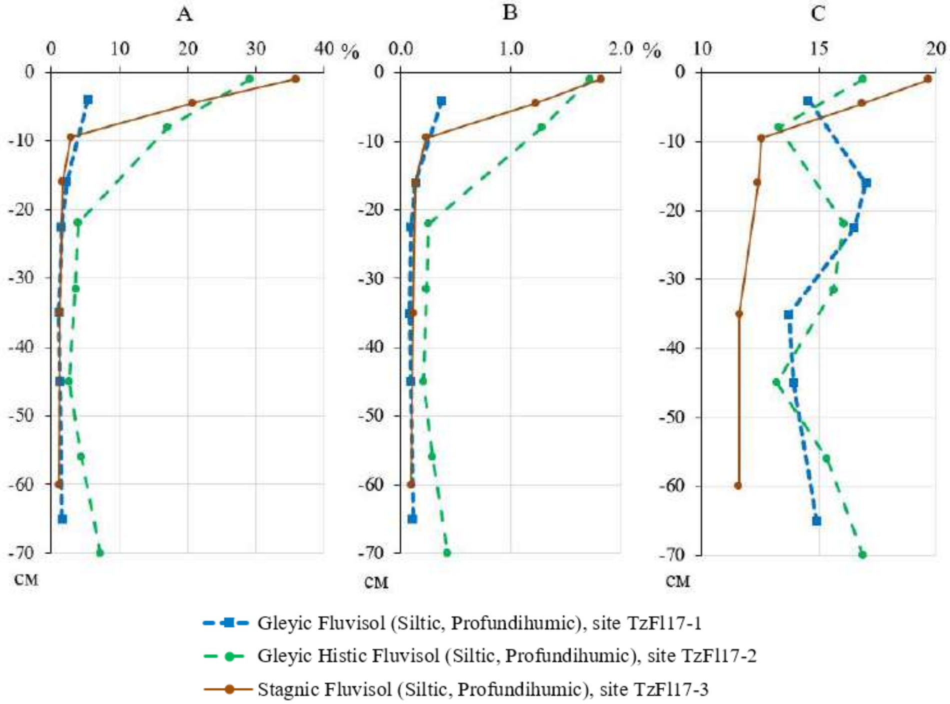

Figure 8. Content of soil carbon (**A**), total nitrogen (**B**), and the ratio of carbon-to-nitrogen (**C**) in riverside soils of the floodplain of the Taz River.

Climate warming also affects the vegetation cover of floodplains. An increase in the cover, stature, and density of vegetation communities of the Alaska River floodplains has been noted in our approximately 30-year sample period (Frost et al. 2023). As noted by many authors, the shrubification of floodplain meadows due to climate change or the abandonment of agricultural land is a common process in the boreal climate (Bork and Burkinshaw 2009; Ivanov et al. 2022). Our studies have shown a high level of vegetation coverage in riverine floodplains, with the exception of river bars. Because of this, it is problematic to assess the climatogenic trends in the development of vegetation in the field. More active shrub growth can be expected in warmer climates. The presence of plant litter in most of the studied sites indicates that, as of late, the rivers can be characterized by a low level of spring floods, as well as a less active transport of river suspensions. Obviously, the lower activity of spring channel processes contributes to the gradual introduction of mosses into the peripheral parts of the riverbeds of the floodplain and the displacement of herbs, and, consequently, leads to a decrease in the primary productivity of vegetation. The conditions for the existence of wet meadows in the floodplain of the Taz River are better, due to the wetting of shrubs. As has been repeatedly noted (Tape et al. 2012), shrubs spread deep into the tundra mainly through floodplains, dendritic corridors of streams, and outcrops. Therefore, another consequence of warming could be the expansion of alder, willows, and herbs along the stream valleys deep into the Pur–Taz interfluve. Further research is needed to identify this process.

Figure 9. Dead willow bushes in the hearth of thermokarst on the shore of a floodplain reservoir.

There are different points regarding the response of floodplain hydrodynamic processes to climate warming. It is shown that summer climate warming and an increase in precipitation increase the transport of river suspension, but this process is strongly inhibited by bogs (Mann et al. 2010). The formation of shrubs on streams leads to a decrease in their summer runoff, since taliks are formed along with this (Liljedahl et al. 2020). It is obvious that the bushes of the riparian zone streams also prevent erosion processes. However, one should not expect their strong influence on the intensity of spring runoff. The high coverage of nitrogen-fixing alder bushes noted in this study can significantly affect the enrichment of waters with nitrogen compounds during spring floods, if the scenario of increased spring floods on rivers is implemented. Alder (*Duschekia fruticosa*) contributes to a significant accumulation of nitrogen in soils (Walker 1989; Van Cleve 1996), from where it can be mobilized by rivers.

Floodplain soils in Western Siberia are widely distributed. This is primarily due to the weak slope of the surface, which contributes to the strong meandering of rivers and the formation of vast floodplains. The formation of floodplain soils is largely associated with the processes of sedimentogenesis, which results in the accumulation of products of soil erosion and coastal abrasion on the surface of floodplain soils, which are further transformed by soil formation processes. Most of the carbon in floodplain soils accumulates autochthonously (Lininger et al. 2018). Thus, floodplain soils can be considered as a place of burial and conservation for chemical compounds, in particular carbon. At the same time, floodplain soils can serve as a source for previously accumulated organic carbon during extreme flood processes, leading to its mobilization. The dynamics of floodplain processes and soil changes will lead to further changes in regional floras and coverage of herbaceous species in ecosystems. It is shown that even in the much more studied Ob-Irtysh basin, new studies in the floodplains contribute to the correction of species lists of regional flora (Popova 2021). Revealing the relationship between the processes of geomorphological soil dynamics and changes in vegetation in a warming climate should be a priority in the course of studying the landscapes of the Subarctic and Arctic.

Conclusions

The soils and plant communities of the floodplains make a significant contribution to the pedodiversity and biodiversity of the Subarctic, respectively. These ecosystems are receivers of geochemical and thermal runoff in landscapes. Due to this, they have the highest productivity of vegetation. In the riverside floodplains, more southern plant species are concentrated, and soils are formed that usually do not have permafrost and features of more southern soil formations. The soils of the studied hydrological continuum are assigned to two Reference Soil Groups (Gleysol and Fluvisol). To describe the diversity of basic soil properties, six principal qualifiers and nine supplementary qualifiers were used. The main changes in soil properties are associated with the presence/absence of layering, gleyic properties, and peat horizon. Although the presence of plant litter does not appear in the names of soils, it is important for floodplain conditions, since it reflects the regime of spring flooding in recent decades. Our study is the first attempt to describe the soil–ecological conditions of vegetation growth in the most dynamic landscapes of the Pur–Taz interfluve riverside floodplains. Until now, little attention has been paid to the study of floodplains and their response to climate warming under Subarctic conditions. However, there is already work pointing to the importance of floodplains as areas of underestimated carbon storage, especially as climate change could alter geomorphological processes in permafrost regions (Lininger et al. 2019). In the future, it is necessary to study the floodplains of the Taz River and its tributaries, not only from the point of view of climatogenic landscape dynamics, but also in order to assess carbon stocks and the lability of its compounds after entering the channel water flow.

Acknowledgements

This work was supported by the Russian Science Foundation (project number 18-77-10045).

References

Abbott BW, Jones JB, Godsey SE, Larouche JR, Bowden WB (2015) Patterns and persistence of hydrologic carbon and nutrient export from collapsing upland permafrost. Biogeosciences 12: 3725–3740. https://doi.org/10.5194/bg-12-3725-2015

Berner LT, Massey R, Jantz P, Forbes BC, Macias-Fauria M, Myers-Smith I, Kumpula T, Gauthier G, Andreu-Hayles L, Gaglioti BV, Burns P, Zetterberg P, D'Arrigo R, Goetz SJ (2020) Summer warming explains widespread but not uniform greening in the Arctic tundra biome. Nature Communications 11: 4621. https://doi.org/10.1038/s41467-020-18479-5

Bork EW, Burkinshaw AM (2009) Cool-Season Floodplain Meadow Responses to Shrub Encroachment in Alberta. Rangeland Ecology & Management 62: 44–52. https://doi.org/10.2111/07-009

Bowden WB, Gooseff MN, Balser A, Green A, Peterson BJ, Bradford J (2008) Sediment and nutrient delivery from thermokarst features in the foothills of the North Slope, Alaska: Potential impacts on headwater stream ecosystems. Journal of Geophysical Research: Biogeosciences 113: G02026. https://doi.org/10.1029/2007JG000470

Doretto A, Piano E, Larson CE (2020) The River Continuum Concept: lessons from the past and perspectives for the future. Canadian Journal of Fisheries and Aquatic Sciences 77: 1853–1864. https://doi.org/10.1139/cjfas-2020-0039

Forsius M, Posch M, Aherne J, Reinds GJ, Christensen J, Hole L (2010) Assessing the Impacts of Long-Range Sulfur and Nitrogen Deposition on Arctic and Sub-Arctic Ecosystems. AMBIO 39: 136–147. https://doi.org/10.1007/s13280-010-0022-7

Frost GV, Bhatt US, Epstein HE, Walker DA, Raynolds MK, Berner LT, Bjerke JW, Breen AL, Forbes BC, Goetz SJ, Iversen CM, Lara MJ, Macander MJ, Phoenix GK, Rocha AV, Salmon VG, Thornton PE, Tømmervik H, and Wullschleger SD (2019) Tundra Greenness. Arctic Report Card 2019. http://www.arctic.noaa.gov/Report-Card

Frost GV, Roland CA, Schmidt JH (2023) Dynamic disequilibrium: Recent widespread increases in vegetation cover on subarctic floodplains of Interior Alaska. Ecosphere 14: e4344. https://doi.org/10.1002/ecs2.4344

Glazunov VA, Nikolaenko SA (2018) Materials on the flora of the vicinity of the settlements of Tazovsky and Gaz-Sale (Yamal-Nenets Autonomous Okrug). In: Man and North: Anthropology, Archaeology, Ecology. Materials of All-Russian Scientific Conference, Tyumen (Russia), April 2018. Tyumen Scientific Center SB RAS Press, 501–504. [In Russian]

IUSS Working Group WRB (2022) World Reference Base for Soil Resources. International soil classification system for naming soils and creating legends for soil maps. 4th edition. International Union of Soil Sciences (IUSS), Vienna, Austria.

Ivanov V, Milyaev I, Konstantinov A, Loiko S (2022) Land-Use Changes on Ob River Floodplain (Western Siberia, Russia) in Context of Natural and Social Changes over Past 200 Years. Land 11: 2258. https://doi.org/10.3390/land11122258

Jones BM, Grosse G, Farquharson LM, Roy-Léveillée P, Veremeeva A, Kanevskiy MZ, Gaglioti BV, Breen AL, Parsekian AD, Ulrich M, Hinkel KM (2022) Lake and drained lake basin systems in lowland permafrost regions. Nature Reviews Earth & Environment 3: 85–98. https://doi.org/10.1038/s43017-021-00238-9

Kapitonova OA (2020) Additions to the vascular flora of the Tyumen region, Western Siberia. Acta Biologica Sibirica 6: 339–355. https://doi.org/10.3897/abs.6.e52696

Kaverin D, Malkova G, Zamolodchikov D, Shiklomanov N, Pastukhov A, Novakovskiy A, Sadurtdinov M, Skvortsov A, Tsarev A, Pochikalov A, Malitsky S, Kraev G (2021) Long-term active layer monitoring at CALM sites in the Russian European North. Polar Geography 44: 203–216. https://doi.org/10.1080/1088937X.2021.1981476

Koptseva EM, Abakumov EV (2021) Peculiarities of vegetation in some populated localities of northern West Siberia. Botanicheskii zhurnal 106 (2): 177–191. https://doi.org/10.31857/S0006813621020058 [In Russian]

Korotaev VN (2011) Golotsenovaya istoriya rechnykh del't arkticheskogo poberezh'ya Sibiri. Geografiya i prirodnyye resursy 3: 13–20. [In Russian]

Kosterin OE, Priydak NV, Shaulo YOD (2019) New findings of rare vascular plants in Novosibirsk. Acta Biologica Sibirica 5 (3): 146–153. https://doi.org/10.14258/abs.v5.i3.6536

Krickov IV, Lim AG, Manasypov RM, Loiko SV, Shirokova LS, Kirpotin SN, Karlsson J, Pokrovsky OS (2018) Riverine particulate C and N generated at the permafrost thaw front: case study of western Siberian rivers across a 1700 km latitudinal transect. Biogeosciences 15: 6867–6884. https://doi.org/10.5194/bg-15-6867-2018

Krickov IV, Lim AG, Vorobyev SN, Shevchenko VP, Pokrovsky OS (2022) Colloidal associations of major and trace elements in the snow pack across a 2800-km south-north gradient of western Siberia. Chemical Geology 610: 121090. https://doi.org/10.1016/j.chemgeo.2022.121090

Likhanov BN (1972) Natural conditions for the development of the Tazovsky oil and gas region. Nauka Publishing House, Moscow. 232 pp. [In Russian]

Liljedahl AK, Timling I, Frost GV, Daanen RP (2020) Arctic riparian shrub expansion indicates a shift from streams gaining water to those that lose flow. Communications Earth & Environment 1: 1–9. https://doi.org/10.1038/s43247-020-00050-1

Lim AG, Loiko SV, Kuzmina DM, Krickov IV, Shirokova LS, Kulizhsky SP, Vorobyev SN, Pokrovsky OS (2021) Dispersed ground ice of permafrost peatlands: Potential unaccounted carbon, nutrient and metal sources. Chemosphere 266: 128953. https://doi.org/10.1016/j.chemosphere.2020.128953

Lininger KB, Wohl E, Rose JR (2018) Geomorphic Controls on Floodplain Soil Organic Carbon in the Yukon Flats, Interior Alaska, From Reach to River Basin Scales. Water Resources Research 54: 1934–1951. https://doi.org/10.1002/2017WR022042

Lininger KB, Wohl E, Rose JR, Leisz SJ (2019) Significant Floodplain Soil Organic Carbon Storage Along a Large High-Latitude River and its Tributaries. Geophysical Research Letters 46: 2121–2129. https://doi.org/10.1029/2018GL080996

Loiko S, Klimova N, Kuzmina D, Pokrovsky O (2020) Lake Drainage in Permafrost Regions Produces Variable Plant Communities of High Biomass and Productivity. Plants 9: 867. https://doi.org/10.3390/plants9070867

Loiko SV, Kuzmina DM, Istigechev GI, Kritskov IV, Lim AG,Klimova NV, Novoselov AA, Konstantinov AO, Novolodskaya EV, Kulizhsky SP (2022) The Transformation of Morphological Properties of Soils Due to the Low Arctic Tundra Shrubification. Bulletin of Tomsk State University. Biology 59: 6–41. http://dx.doi.org/10.17223/19988591/59/1 [In Russian]

Malkova G, Drozdov D, Vasiliev A, Gravis A, Kraev G, Korostelev Y, Nikitin K, Orekhov P, Ponomareva O, Romanovsky V, Sadurtdinov M, Shein A, Skvortsov A, Sudakova M, Tsarev A (2022) Spatial and Temporal Variability of Permafrost in the Western Part of the Russian Arctic. Energies 15: 2311. https://doi.org/10.3390/en15072311

Mann DH, Groves P, Reanier RE, Kunz ML (2010) Floodplains, permafrost, cottonwood trees, and peat: What happened the last time climate warmed suddenly in arctic Alaska? Quaternary Science Reviews 29: 3812–3830. https://doi.org/10.1016/j.quascirev.2010.09.002

Miles MW, Miles VV, Esau I (2019) Varying climate response across the tundra, forest-tundra and boreal forest biomes in northern West Siberia. Environmental Research Letters 14: 075008. https://doi.org/10.1088/1748-9326/ab2364

Miles VV, Esau I (2016) Spatial heterogeneity of greening and browning between and within bioclimatic zones in northern West Siberia. Environmental Research Letters 11: 115002. https://doi.org/10.1088/1748-9326/11/11/115002

Myers-Smith IH, Kerby JT, Phoenix GK, Bjerke JW, Epstein HE, Assmann JJ, John C, Andreu-Hayles L, Angers-Blondin S, Beck PSA, Berner LT, Bhatt US, Bjorkman AD, Blok D, Bryn A, Christiansen CT, Cornelissen JHC, Cunliffe AM, Elmendorf SC, Forbes BC, Goetz SJ, Hollister RD, de Jong R, Loranty MM, Macias-Fauria M, Maseyk K, Normand S, Olofsson J, Parker TC, Parmentier F-JW, Post E, Schaepman-Strub G, Stordal F, Sullivan PF, Thomas HJD, Tømmervik H, Treharne R, Tweedie CE, Walker DA, Wilmking M, Wipf S (2020) Complexity revealed in the greening of the Arctic. Nature Climate Change 10: 106–117. https://doi.org/10.1038/s41558-019-0688-1

Pismarkina EV, Byalt VV (2016) Materials for the study of biodiversity in the Yamalo-Nenets Autonomous District: vascular plants of the Nuny-Yaha River basin. Vestnik of Orenburg State Pedagogical University. Electronic Scientific Journal 1 (17): 49–69. http://www.vestospu.ru/archive/2016/articles/7_17_2016.pdf [In Russian]

Popova EI (2021) Synanthropization and species diversityof floodplain ecosystems of the Ob-Irtysh basin, Russia. Acta Biologica Sibirica 7: 545–558. https://doi.org/10.3897/abs.7.e78477

Schad P (2023) World Reference Base for Soil Resources – Its fourth edition and its history. Journal of Plant Nutrition and Soil Science 186: 151–163. https://doi.org/10.1002/jpln.202200417

Tape KD, Hallinger M, Welker JM, Ruess RW (2012) Landscape Heterogeneity of Shrub Expansion in Arctic Alaska. Ecosystems 15: 711–724. https://doi.org/10.1007/s10021-012-9540-4

Tigeev AA, Moskovchenko DV, Fahretdinov AV (2021) Current trends in natural and anthropogenic vegetation in Western Siberia's sub-tundra forests based on vegetation indices data. Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa 18 (4): 166–177. https://doi.org/10.21046/2070-7401-2021-18-4-166-177 [In Russian]

Tishkov AA, Krenke-Jr AN (2015) "Greening" of the arctic in the twenty-first century as a synergy effect of global warming and economic development. Arktika: ekologiya i ekonomika 4 (20): 28–37. https://elibrary.ru/item.asp?id=25009940 [In Russian]

Titov YuV, Potokin AF (2001) Vegetation of the floodplain of the Taz River. Publishing House of SurGU, Surgut, 140 pp.

Tyrtikov AP (1972) Vegetation dynamics and development of permafrost in the environment. Moscow University Press, Moscow 198 pp. [In Russian]

Van Cleve K, Viereck LA, Dyrness CT (1996) State Factor Control of Soils and Forest Succession along the Tanana River in Interior Alaska, U.S.A. Arctic and Alpine Research 28: 388–400. https://doi.org/10.1080/00040851.1996.12003191

Vasiliev AA, Drozdov DS, Gravis AG, Malkova GV, Nyland KE, Streletskiy DA (2020) Permafrost degradation in the Western Russian Arctic. Environmental Research Letters 15: 045001. https://doi.org/10.1088/1748-9326/ab6f12

Walker LR (1989) Soil Nitrogen Changes During Primary Succession on a Floodplain in Alaska, U.S.A. Arctic and Alpine Research 21: 341–349. https://doi.org/10.1080/00040851.1989.12002748