E3S Web of Conferences **555**, 01002 (2024) https://doi.org/10.1051/e3sconf/202455501002
RIEEM 2024

Studying and mapping natural complexes of the piedmont plain of the Dokuchaev ridge (Kunashir island, Great Kuril ridge)

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Abstract. The article presents the findings of geosystems studies of the piedmont accumulative plain located between the mountain massifs of Dokuchaev ridge and Tyatya volcano on the Kunashir island. The plain is a unique natural object, as denudation prevails in the Kuril Islands and accumulative forms are not widespread here. Field surveys of vegetation, soils and topography were carried out according to standard methods. Ultra-high spatial resolution satellite image, topographic maps and scientific literature were also used as materials. As a result, thematic maps were compiled and features of spatial distribution of geosystems were identified.

1 Introduction

Kunashir Island is one of the largest and southernmost islands of the Great Kuril Ridge. Warm mild climate, transportation accessibility and high development of the island (Kunashir is the most populated among all Kuril Islands) have led to increasing recreational interest to this territory from year to year. The flow of tourists became especially notable since 2022. Recreational sector began to play an important role in the island's economy. Increasing recreational activities having impact on local geosystems determined the necessity to study them.

Geomorphologically, Kunashir is a series of volcanic massifs connected to each other by low-lying isthmuses. In the southern part of the island there are Mendeleev volcano and Golovnina volcano, separated by the Sernovodsky isthmus. It is separated from the northern part by the vast South Kuril Isthmus. The northern part of the island has a more complex structure. It is composed of the Dokuchaev volcanic ridge formed by a linear-nested system of volcanic centers [1] and crowned by the Smirnov and Rurui volcanoes. There is also a massif of the young somma-vesuvium type volcano Tyatya, located close to the Smirnov volcano and partially overlapping it with the base of the cone. In addition, there is an ancient, significantly destroyed massif of the Lovtsova peninsula, separated from the Tyatya volcano massif by the Kruglov isthmus.

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Between the southeastern foothill of the Dokuchaev Ridge and the southwestern foothill of the Tyatya volcano, an accumulative plain was formed, composed of these mountain systems products of destruction. The valley of the Tyatina River, the largest on the island, as well as other relatively large rivers such as Nochka, Saratovskaya, Rogachevka, is associated with this plain. The plain is covered mainly with coniferous forests, partly swampy. It should be noted that accumulative forms in general are not very characteristic of the Kuril Islands, where denudation predominates. This fact makes the geosystems of the described piedmont plain unique not only on Kunashir, but also on the Kuril Islands as a whole.

Geosystems between the Saratovskaya and Rogachevka rivers were studied as a part of the 2023 field surveys. Field surveys included descriptions of vegetation, soils, and landscapes using standard methods. The study area was 10 square kilometers.

2 Materials and methods

Mapping source materials, in addition to the results of field surveys, were topographic maps and Pleiades 1B satellite space image dated September 27, 2019, with a spatial resolution of 0.5 m. A total of 61 complete geobotanical descriptions corresponding to the five profiles were compiled during the study. The number of soil sections is slightly less and comprises 42 pieces.

Before the field survey, materials and publications on individual components of the natural environment and landscapes in general were reviewed [2–7], and maps from the Kuril Islands atlas [8] were analyzed.

2.1 Vegetation mapping

The reference material for geobotanical surveys was provided by scientific publications, including the monograph "Flora of the Kuril Islands" by V.Yu. Barkalova[8], identifier of higher plants of Sakhalin and the Kuril Islands by D.P. Vorobyov [9], "Flora of Kunashir Island" by L.M. Alekseeva [10], as well as geobotanical descriptions of previous years, compiled in the territory adjacent to the mapped area.

In the course of the study we applied methods of processing publications, compiling and analyzing geobotanical descriptions and mapping on the basis of field surveys and space image. Among the field methods of the study the following were applied: conducting route surveys, profiling and compiling complete geobotanical descriptions during the routes according to the standard methodology. The routes covered all habitat types and repeatedly crossed different landforms, as well as all types of contours identified during preliminary laboratory interpretation.

Latin names of plant species in the text are given according to the online database https://powo.science.kew.org, which contains the most recent information on the systematic position of taxonomic units and their legal names. Russian and Latin names are given according to the open online atlas and plant identifier https:/www.plantarium.ru, which contains the most common and well-known names of taxonomic units.

Based on the contours of vegetation communities identified in the course of laboratory interpretation and points of geobotanical descriptions imposed on these contours, vegetation classification was made. The names of plant communities presented in the legend of the final map (Fig. 1) are formulated by summarizing the names of phytocenoses corresponding to each of the geobotanical description points belonging to one contour or group of contours. The color scale of the outlined contours was selected by analogy with the vegetation map of the Amur basin [11] and the vegetation map presented in the Kuril Islands atlas [8]. Shading indicates contours belonging to plant communities that are dynamic states of other communities.

Fig. 1. Fragment of vegetation map of the study area. The width of the upper and lower frames of the map fragment is 2 km. Indices interpretation: 1 – Sasa spruce forests, including menziesia forests (*Picea glehnii*, *Rhododendron pentandrum, Sasa kurilensis, Cornus canadense, Carex spp.*); 2 – Sedge spruce forests, including myrica forests (*Picea glehnii, Myrica gale, Carex spp., Eriophorum vaginatum, Calamagrostis purpurea*); 4 – Fir forests with open grass canopy (*Abies sachalinensis, Cornus canadensis, Vaccinium praestans, Sasa kurilensis*); 5 – Ferny moss fir and spruce/fir old-growth forests with yew, including disturbed by windthrow (*Abies sachalinensis. Picea jezoensis, Taxus cuspidata, Dryopteris expansa, Carex spp.*); 8 – Tallgrass/sasa birch forests with ukurundu maple (*Betula ermanii, Acer ukurunduense, Sasa kurilensis, Petasites japonicus* subsp. *giganteus*); 9 – Tallgrass willow/alder and alder forests (*Alnus hirsuta, Salix udensis, Sambucus sieboldiana, Lysichiton camtschatcensis, Urtica platyphylla, Filipendula camtschatica*); 10 – Wet meadows with alder (*Alnus hirsuta, Calamagrostis purpurea, Carex spp., Hosta sieboldii, Sanguisorba tenuifolia, Iris setosa*); 15 – Tallgrass gramineous/filipendula meadows (*Filipendula camtschatica, Reynoutria sachalinensis, Petasites japonicus* subsp. *giganteus, Urtica platyphylla, Calamagrostis purpurea*); 17 – Rush/sedge meadows, including reed and myrica meadows (*Juncus spp., Carex spp., Phragmites australis, Myrica gale, Calamagrostis purpurea*); 19 – Comarum/sedge back bogs (*Carex spp., Comarum palustre, Vaccinium oxycoccos, Menyanthes trifoliata*); 20 – Woodreed/sasa units, also with tree species, on the site of former military fortifications and other antropogenically disturbed territories (*Sasa kurilensis, Calamagrostis purpurea, Artemisia montana, Abies sachalinensis, Picea glehnii*).

2.2 Soil cover mapping

All soil sections are laid out along catenas which are the contiguous elementary landscapes from the coast to the island interior, and forming profiles. They provide understanding of the spatial structure of the soil cover and the confinement of soil units to landforms, sediments and plant communities. All soil descriptions were carried out according to the same methodology. Diagnosis of genetic horizons was carried out in accordance with the Russian Soil Classification [12].

The soil surveys resulted in a soil map (Fig. 2). Based on the interpretation scheme, topographic map and location of description points, elementary soil areas were identified taking into account the landscape-geobotanical scene of the area. Soil subtypes became the main taxonomic unit on the map. Colors for soil types and subtypes are chosen in accordance with the data of the Unified State Register of Soil Resources of Russia.

Fig. 2. Soil map fragment of the study area. The width of the upper and lower frames of the map fragment is 2 km. Indices interpretation: 1 — Haplic Cambisol; 2 — Brunic Arenosol; 3 — Haplic Arenosol; 4 — Sapric Histosol; 5 — Gleyic Histosol; 6 — Gleyic Fluvisol; 7 — Fluvic Gleysol.

2.3 Landscape mapping

In landscape mapping at the field survey stage, the descriptions were compiled in accordance with the methodology of the Moscow School of Landscape Science [13, 14], i.e. at the level of units and sub-units. It should be specified that sub-units unite elementary hierarchical landscape units (facies) and characterized by their position within one mesorelief element of the same exposure. They are genetically and functionally connected, possess a single lithological variety of surface sediments and plant community (within a sub-unit, dominant species and the proportion of their participation in the phytocenosis may vary) [15]. Landscape units consist of sub-habitats and facies and confined to certain mesoforms of relief [16]. They are characterized by the presence of a single type of soil and phytocenosis. An example of such unit is an offshore bar with gentle slopes, occupied by bamboo forest with a single spruce and fir undergrowth on coarse-humus representative soils. The top and slopes of this hillock are separate examples of sub-units here.

The legend of the compiled large-scale landscape map (Fig. 3) is presented in matrix form, where the morpholithogenic base with relief and sediment characteristics is indicated horizontally, and the land cover is indicated vertically. The mapping method and color palette are based on the methodological instructions of A.A. Vidina [13].

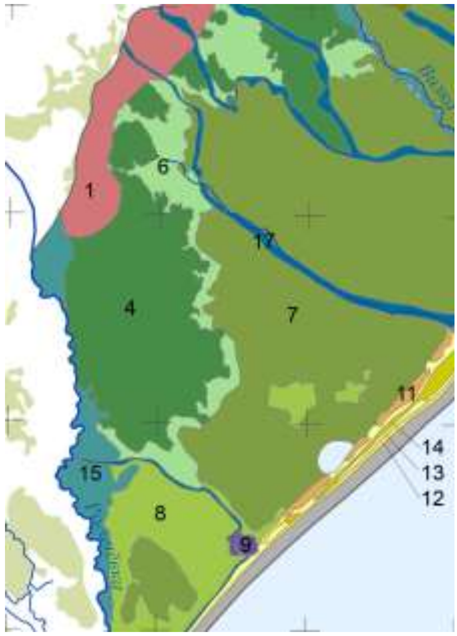

Fig. 3. Landscape map fragment of the study area. The width of the upper and lower frames of the map fragment is 2 km. Indices interpretation:

The lower parts of the ridge's slopes and deluvial shelves, gently sloping (4-6°): 1 - with ferny moss fir and spruce/fir old-growth forests with yew, including disturbed by windthrow on haplic cambisol. Accumulative marine terraces, composed of upper quaternary undifferentiated sediments, subhorizontal (2-3°): 4 - with ferny moss fir and spruce/fir old-growth forests with yew, including disturbed by windthrow on haplic cambisol; 6 - with tallgrass gramineous/filipendula/sasa meadows on haplic cambisol with sapric histosol spots. Accumulative marine terraces, composed of upper quaternary undifferentiated sediments, flat (0-1°): 7 - with sasa spruce forests, including menziesia forests on sapric histosol; 8 - with tallgrass gramineous/filipendula/sasa meadows on sapric histosol; 9 - with comarum/sedge back bogs on sapric histosol. The tops of coastal ramparts composed of polygenic basalt sands: 11 - with sedge spruce forests on haplic arenosol; 12 - with sasa meadows on haplic arenosol. 13 - Slopes of coastal ramparts, subhorizontal and flat (2-8°), with sasa meadows on haplic arenosol; 14 - Depressions between coastal ramparts Rush/sedge meadows, including reed and myrica meadows on sapric histosol. Floodplains of rivers: 15 - with tallgrass willow/alder and alder forests on gleyic fluvisol and fluvic gleysol. 17 - Floodplains of streams with ferny moss spruce/fir forests with gramineous meadows on gleyic fluvisol and fluvic gleysol.

3 Results

3.1 Vegetation structure

The vegetation map identifies 20 association groups belonging to coniferous forests and sparse woodlands, coniferous-deciduous and deciduous forests, grass-shrub communities and meadow communities, swamps and disturbed communities.

Most of the territory is occupied by dark coniferous forests, primarily swamp forests formed by Glen spruce *Picea glehnii* (F.Schmidt) Mast. often depressed. Thus, the most widespread in the mapped area are spruce bamboo forests, including Mencisia, in the shrub layer of which, as a rule, *Rhododendron pentandrum* (Maxim.) Craven dominates. Iin the grass-shrub layer there is abundant *Sasa kurilensis* (Rupr.) Makino & Shibata, *Lysichiton* *camtschatensis* (L.) Schott., *Cornus canadensis* L. and various species of sedges. In the marginal part such forests are often replaced by spruce sedge sparse forests, including waxberry forests. The dominant species in these communities are *Picea glehnii* (F.Schmidt) Mast. in the tree layer. *Myrica gale* L. is dominant in the shrub layer, and sedges and grasses, including *Calamagrostis purpurina* (Trin.) Trin. and *Eriophorum vaginatum* L. are dominant in the grass-shrub layer.

At the foothills of the Dokuchaev Ridge slopes in the northwestern part of the mapped area, old-growth fir and spruce-fir fern green-moss forests disturbed by windthrow are widespread. These forests are formed by *Abies sachalinensis* (F.Schmidt) Mast. and *Picea jezoensis* subsp. *jezoensis*. The grass and shrub layer is dominated by *Dryopteris expansa* (C.Presl) Fraer-Jenk. & Jermy, *Onoclea struthiopteris* (L.) Roth. In the same part of the study area spruce-birch-fir sedge-shield forests are observed, which are close to fir and spruce-fir fern green-moss forests in terms of species composition. In spruce-birch-fir communities, besides *Abies sachalinensis* (F.Schmidt) Mast. and *Picea jezoensis* subsp. *jezoensis*, *Betula ermanii*Cham. also dominates. In the grass-shrub layer of this group of forests it is important to note species of the genus *Carex*, as well as *Dryopteris expansa* (C.Presl) Fraer-Jenk. & Jermy.

Between swampy spruce forests of *Picea glehnii* (F.Schmidt) Mast. and fir and spruce-fir fern forests there are fragmentary wet-grass meadows, dominated by Calamagrostis *purpurina* (Trin.) Trin, *Lobelia sessilifolia* Lamb., *Iris setosa* Pall. ex Link, *Hosta sieboldii* (Paxton) J.W.Ingram and others.

Significant areas along relatively large watercourses are occupied by willow-alder and alder tallgrass forests. The dominants in these associations are *Alnus hirsuta* (Spach) Rupr., *Salix udensis* Trautv. & C.A.Mey., as well as *Sambucus sieboldiana* (Miq.) Graebn. in the tree layer and *Lysichiton camtschatensis* (L.) Schott., *Urtica platyphylla* Wedd., *Filipendula camtschatica* (Pall.) Maxim. in the grass layer.

Meadow communities are primarily represented by tallgrass reedgrass-meadowsweet associations widespread throughout the mapped area, except for its south-eastern part. Such meadows are characterized by polydominance, but the most important elements in them are *Calamagrostis purpurina* (Trin.) Trin. and *Filipendula camtschatica* (Pall.) Maxim. In addition, reedgrass-meadowsweet meadows are characterized by the presence of such species as *Reynoutria sachalinensis* (F.Schmidt) Nakai, *Petasites japonicus* subsp. *giganteus* Kitam, *Urtica platyphylla* Wedd. Among the meadow communities, reedgrass-bamboo associations formed by only two species, *Sasa kurilensis* (Rupr.) Makino & Shibata and *Calamagrostis purpurina* (Trin.) Trin., are prominent. Such meadows stretch in a wide strip at the foothills of the Dokuchaev Ridge slopes in the northern part of the mapped area, and also occur in fragments in the northeast of the study area.

It is worth mentioning the presence of fragments of birch and yellow maple tallgrass-bamboo associations among the above-mentioned tallgrass reedgrass-meadowsweet meadows. As a rule, these are small phytocenoses distinguished under the crowns of *Betula ermanii* Cham. In the shrub layer of such communities *Acer ukurunduense* Trautv. & C.A.Mey., and *Sasa kurilensis* (Rupr.) Makino & Shibata and *Petasites japonicus* subsp. *giganteus* Kitam dominate the grass layer.

The seaside landscape complex generally alternates between offshore bars and lowerings. Offshore bars are occupied predominantly by grass-bamboo meadows, as well as grass-bamboo associations with the presence of hedge-row rose. Thus, communities of offshore bars are characterized by dominance primarily of *Sasa kurilensi*s (Rupr.) Makino & Shibata, and to a lesser extent there is a dominance of *Rosa rugosa* Thunb., *Artemisia montana* (Nakai) Pamp., *Iris setosa* Pall. ex Link and *Sanguisorba tenuifolia* Fisch. ex Link. It should be mentioned that in lowerings between offshore bars there are lakes of lagoon origin (e.g., Lake Natasha), along the shores of which the previously described spruce sedge sparse forests of *Picea glehnii* (F.Schmidt) Mast., sometimes with the presence of *Abies sachalinensis* (F.Schmidt) Mast. are widespread. In the lowerings between offshore bars, small areas occupied by cinquefoil and sedge lowland swamps are also noted, including in the place of overgrown lakes. Such phytocenoses are characterized by dominance of *Comarum palustre* L., species of the genus *Carex, Vaccinium oxycoccos* L., *Menyanthes trifoliata* L..

Sea-facing slopes of the offshore bars are occupied by narrow strips of mixed grass-sedge and wild rye meadows. In these associations, *Leymus mollis* (Trin.) Pilg., *Carex macrocephala* Willd. ex Spreng., *Plantago camtschatica* Link, *Glehnia littoralis* (A.Gray) F.Schmidt ex Miq. dominate.

Plant communities affected by anthropogenic activities were observed in the study area, in particular, reed-bamboo complexes, in some places with the presence of tree species, at the former military fortifications and other anthropogenically disturbed areas. Such communities are typically formed by 5 species that are *Sasa kurilensis* (Rupr.) Makino & Shibata и *Calamagrostis purpurina* (Trin.) Trin., *Artemisia montana* (Nakai) Pamp., а также *Picea glehnii* (F.Schmidt) Mast. and *Abies sachalinensis* (F.Schmidt) Mast..

Extending along the Pacific Ocean, the strip of beach is without any vegetation.

3.2 Soil cover structure

Among the soils described, five soil types and ten soil subtypes were identified.

Haplic Cambisol. This soil type is characteristic of broad-leaved and coniferous-broadleaved forests of moderately warm and humid climate on loamy-clay eluvo-deluvium of sedimentary and igneous rocks. A diagnostic horizon for this type of soils is the middle structural-metaphorical horizon BM, the peculiarity of which is the manifestation of pedogenic transformation of the soil-forming rock.

Two subtypes were identified among brown soils in the study area. First of all, brown soils are typical medium deep or deep, with the deepness of gray humus horizon increasing when approaching the Dokuchaev Ridge foothill. Secondly, humous brown soils differ from typical brown soils by the presence of humus material of oily consistency distributed in the humus horizon.

Brunic Arenosol are widespread in the middle and southern taiga of Central Siberia, as well as in the upper part of the forest belt of the mountain systems of the Urals, southern Siberia, and the Far East. Such soils are formed on rank and sandy-loam eluvo-deluvium of massive-crystalline rocks of predominantly medium-basic composition and polymineral sands. Rusty coarse-humus and humous rusty coarse-humus soils are common in the study area. The latter differ from the first in the presence of humous material in the coarse-humus horizon. All soils of this type were found on polymineral sands associated with the seashore.

Haplic Arenosol belong to the organo-accumulative soils. They form mainly under grass plant communities on unconsolidated substrates. Coarse-humus soils are characterized by coarse-humus horizon gradually replaced by little changed soil-forming rock. There is one subtype identified which is typical coarse-humus soil.

Sapric Histosol are characterized by the presence of surface peat horizon of different composition, the total deepness of which exceeds 50 cm. All peat soils in the territory belong to the peat eutrophic type. Typical peaty eutrophic subtype and peaty eutrophic humous-peat subtype differ in the degree of decomposition of plant residues in the upper horizon. The peat eutrophic quasi-gley subtype differs from the typical subtype by the presence of an olive-colored quasi-gley horizon with small patches of grayish-blue and ochre color near small pores and cracks. The underlying peat mass in all subtypes is represented by layers with varying deepness, consisting of peat with different degrees of decomposition.

Fluvisols belong to the trunk of synlithogenic soil formation. They are formed under conditions of floodplain regime, i.e. regular deposition of fresh river alluvium layers of different mechanical composition on the floodplain surface. The profile usually contains buried horizons and multiple layers of soil-forming rock. Alluvial humus soils are the main soil type in the territory. The alluvial humus gley and alluvial humus gleyey subtype are distinguished, differing in the intensity of gleying.

3.3 Landscape structure

The elevation difference at the site is not more than 40–50 m, which indicates a flat relief character, generally not typical for the territories of Kunashir island. The highest positions are occupied by the foothills of the Dokuchaev Ridge, the lowest are occupied by the Pacific Ocean coast. A series of offshore bars with heights up to 20 m and sharp cliffs facing the coast serve as local elevations. In turn, the interfluve, which is occupied by marine terraces of different levels, has a relatively flat relief with a steepness of up to 3°.

Marine terraces occupying most of the area are composed of marine sands, often overlain by volcanic deposits and deluvial loams, especially closer to the Dokuchaev Ridge foothills. Offshore bars are composed of black-colored polygenic basalt sands.

Thus, prevailing heavy granulometric composition in the dominant part of the territory, increased moisture content, as well as the limitation of the flat plain by a local watershed on the way of decreasing hypsometric level create conditions for the formation of dominant peat soils of the territory, where the Glen spruce (*Picea glehnii*) occupies its ecological niche.

Closer to the slopes of the ridge with increasing steepness dark coniferous forests grow on non-organogenic typical brown soils. These forests are old-growth and therefore these areas are characterized by a large number of windthrows. In the north-east of the territory, characterized by more undulating relief, loamy sediments and better drainage conditions (since the erosion base here – the Saratovskaya River – is not blocked by a local watershed in the form of offshore bars) mixed fir-birch-spruce forests with Phellodendron sachalinense and Acer mayrii grow.

In the interfluve areas, the headwaters of small watercourses have catchment lowerings, which, unlike the adjacent territory, are made of sediments of heavier granulometric composition, overlain by peat and occupied by more hygrophilous plant communities.

Along the seashore there is a series of offshore bars, with decreasing absolute height from southwest to northeast. Here one can observe the alternation of three series of different-aged bars, the oldest of which are occupied by dark coniferous forests, and the youngest are occupied by bamboo forests. The most active exogenous process at the site is also represented here that is called abrasion, which is scouring of the bars by ocean waves. Interval lowerings, which are more humidified, are occupied by waterlogged meadows, often associated with lakes of lagoon origin. In turn, some of these lakes, which have a small area, are gradually overgrown with sphagnum, evolving into transitional swamps.

The valleys of the Saratovskaya and Rogachevka rivers have several levels of floodplains. The high floodplain is predominantly represented by tallgrass meadows, the middle and low floodplains are represented by willow-alder forests on alluvial gley soils. High floodplain levels are fragmented throughout the valleys.

Thus, the territory has a rather homogeneous landscape structure, in which the greatest diversity is characterized by the complex of offshore bars.

4 Conclusions. Brief landscape characteristic

The results of the study revealed that the study area is quite homogeneous in landscape terms. Geosystems such as homogeneous spruce-bamboo forests growing on peaty soils, which are dominant, and also, for example, small complexes of offshore bars, which are rather fragmented in their structure, are widespread.

The dominant units in the study area are flat marine terraces occupied by spruce bamboo forests on peaty eutrophic soils. Closer to the slopes of the ridge, on gentle slopes composed of dealluvial loams, fir and spruce fern green-moss forests grow on typical brown soils. Offshore bars as one of the youngest mesoforms of relief are only partially occupied by forest vegetation, and the dominant communities here are grass-bamboo meadows on coarse-humus typical soils. The valleys of the Saratovskaya and Rogachevka rivers have several levels of floodplains. The high floodplain is predominantly represented by tallgrass meadows, the middle and low floodplains are represented by willow-alder forests on alluvial gley soils.

Unique complexes are transitional sphagnum swamps in the south-west of the site, currently forming from lagoon-type lakes, and forests in the north-east with the presence of broadleaved species not typical of the study area such as Phellodendron sachalinense and Acer mayrii.

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