Forest vegetation mapping in the North of the Koryak Region

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Abstract. The distribution boundaries of light-coniferous and deciduous forests formed by larch (Larix cajanderi Mayr), stone-birch (Betula ermanii Cham.), white birch (Betula platyphylla Sukacz.), poplar (Populus suaveolens Fisch.), chosenia (Chosenia arbutifolia (Pall.) A Skvorts.), alder (Alnus hirsute (Spach) Turcz. ex Rupr.) and willow trees (Salix udensis Trautv. et C.A. Mey., S. schwerinii E.L. Wolf), as well as elfin wood communities formed by Siberian dwarf-pine (Pinus pumila (Pall.) Rgl.), dwarf-alder (Alnus fruticosa Rupr.), and dwarf-birch (Betula middendorfii) have been clarified for the North of the Koryak Region. With the help of this map, the boundaries of the new geobotanical subdivision of the North of Koryak Region will be clarified and the most important phytogeographical boundaries within the Beringian forest-tundra zone will be determined.

1. Introduction
Beringian forest-tundra zone is situated in the North-East Asia. It covers the North of the Koryak Region (the mainland part of the Kamchatka Krai) and the South of the Chukotka Autonomous Region. The terrain is alpine and mid-mountainous, including the Koryak Upland, Penzhinsky Ridge and the adjacent intermountain depressions. The data on the distribution patterns of forests and elfin woodlands in the mainland of the Koryak Region are very few, insufficient and contradictory. According to the aerial observations of the 1950s [1], the scheme showing the borders of main forest-forming species was firstly compiled. But in recent decades the climate change took place and could strongly influence the distributional patterns of forest communities. The goal of our research was to clarify the natural phytogeographical boundaries of the forest-forming tree species.

2. Methods and Materials

2.1. Study area
The field studies of the vegetation cover of the North of the Koryak Region were carried out in 2011–2020 within Olyutorsky and Penzhinsky districts of the Koryak Administrative Territory. The field studies had covered the coasts of the Gulf of Korf and the Olyutorsky Gulf, the Goven Peninsula, the
South-Eastern part of the Koryak Upland, the Parapolsky Dale, the Penzhina River valley, the Vetviesky and Penzhinsky Ridges [2–5].

The vegetation cover of the Southern and Eastern branches of the Koryak Upland is characterized by lower altitude belts. Elfin woods formed by Siberian dwarf-pine (Pinus pumila) and dwarf-alder (Alnus fruticosa) predominate up to 400–500 m above the sea level (a. s. l.). They alternate with thickets of dwarf-birch (Betula middendorffii) and fragments of mountain tundra. At altitudes of 500–600 m, mountain tundra is dominated by lichen-rich and dwarf-shrub communities. At altitudes more than 700–800 m, stone screes and stony placers with a predominance of scale lichens are common. Flood-plain forests of poplar (Populus suaveolens), chozenia (Chosenia arbutifolia) and tree willows (Salix udensis, S. schwerinii) stretch along the rivers by narrow strips.

2.2. Field and aerial studies
A number of key areas were laid out within the 8 model territories, differing in geomorphological features and a set of habitats. The key areas were covered by a network of routes. About 650 sample plots were laid down in typical habitats, in the following sizes: in forests – 400 m² (20×20 m), in elfin wood, shrub, tundra, meadow, and mire communities – 100 m² (10×10 m). At the sample plots, detailed relevés were carried out with a complete determination of species composition of vascular plants, mosses and lichens, with an estimate of the projective coverage (in %) for each layer and each species.

For every sample plot, the altitude above the sea level, the exposition and steepness of the slope, the position in the landscape, the depth of permafrost, the thickness of the organic horizon or peat deposit were determined. The quantitative characteristics of the habitats were used to analyze the distribution of plant communities by gradients of environmental factors.

About 650 relevés were carried out; communities of larch, stone-birch, white-birch and floodplain forests, Siberian dwarf-pine and dwarf-alder elfin woods, dwarf-birch thickets, willow shrubs, meadows, mountain tundra and mires were characterized. The coordinates of the sample plots were determined using Garmin personal navigators with GPS and GLONASS positioning systems. In addition, to determine the coordinates, we used the built-in geolocation functions in Xiaomi and Honor smartphones, running the ANDROID system.

Small-scale bioclimatic maps were compiled and the bioclimatic subdivision of the North of the Koryak Region was developed after the generalization and analysis of long-term meteorological data series using remote sensing data based on the Köppen-Geiger climate types [6], and using the “World Map of the Köppen-Geiger Climate Types” [7, 8]. For a more detailed analysis, we used gridded climate data for the territory of the former USSR from the “Atlas of Agroecological Resources of Russia and Neighboring Countries” [9], as well as the data from the WorldClimPortal [10]. Global information on the distribution of bioclimatic indicators on the WorldClimPortal was first published in 2005 for the period of 1960–1990. In subsequent versions, the calculation period for the bioclimatic indicators listed on the site was extended to the period of 1950–2000 and further, up to 2018.

2.3. Methods for remote sensing data decoding
A complex method for decoding remote images has been developed, based on combining a digital 3D model of the terrain and a series of multi-temporal satellite images that differed by phenology season (spring-summer-autumn), reflecting different phenological states of the vegetation cover. In connection with the periodic improvement of terrain models over the past 20 years (their resolution increased from 1000 to 500 and 250 m /pixel), the results were processed and refined.

At the beginning of the research, the Global Digital Elevation Model (DEM) SRTM-90 (Shuttle Radar Topography Mission) was used. It was created in 2003 (finalized in 2014) on the base of the radar topographic survey of the most part of the Globe conducted in 2000 (except the northernmost (>60° n. l.) and the southernmost (>54° s. l.) latitudes, and the oceans). In the subsequent versions, there were a consistent refinement of the vegetation cover states based on the DEM GMTED-2010 (Global Multi-resolution Terrain Elevation Data), originally developed in 2010. This version of the
DEM was developed by combining the data from various sources of satellite information DTED, SRTM, ICE Sat, and others; this gave a possibility to produce a more accurate version of the altitude matrix.

As the initial data for vegetation mapping, we used the freely available medium-, high- and ultra-high-resolution remote sensing data from the MODIS, Landsat, Sentinel, Quick Bird, GeoEye, WorldView satellites for the survey period from 1974 to 2020. Assessing the availability and the quality of high-resolution remote sensing data (RSD), it was revealed that the combination of the coverage areas of the five main geoservices (Bing, Google, Here, Nokia, Yandex) together forms a complete coverage of the territory of the Kamchatka Krai.

For mapping of habitat types by topographical characteristics we used DEMs of different resolutions: GMTED 2010 (250 m), SRTM (90 and 25 m), ASTER GDEM v2 (16 m). Data processing was carried out using the software packages ArcGIS 10, ERDAS Imagine 2014. Both pixel-based approaches (ISODATA) and object-oriented segmentation (Multiresolution) were used for automated classification of spectral characteristics of the satellite data and the terrain patterns (altitude above sea level (m), exposure, and slope steepness (deg.)). Based on DEM, two-layer bitmap images (DEM-composites) were calculated: sin (α) and cos (α), where α is the angle of the pixel's solar exposure.

Multichannel RSD and DEM composites were subjected to the two-level automatic segmentation with specified levels of spatial detailing. The obtained RSD and DEM segments were combined into a unified layer of base polygons; they were classified using the maximum likelihood method with the tutor samples of reference plots. As the additional information, a digital forest inventory database and vector forest inventory maps showing the boundaries of forest allotments and forest quarters were used; as well as the original vegetation survey field data obtained in 2016–2020.

3. Results and Discussion
Combination of "winter–summer" images made it possible to determine the boundaries of the vegetation cover polygons (forests–elfin woods, elfin woods–tundra, etc.) with a high accuracy and to identify the altitudinal boundaries of the vegetation belts.

In addition, a joint analysis of the vegetation contours obtained from high- and ultra-high-resolution satellite data had revealed a significant overlap between the boundaries of the vegetation classes in the landscape and on the digital topographic map at scale of 1:100 000. This allowed us to clarify the boundaries of the plant community types. This method was successfully used for decoding the satellite images of the mountainous territories of the Kamchatka Peninsula and the South of the Koryak Region [11].

It was also helpful to use the data of the "Globe Land 30" Project (2000–2013), that was completed in the National Geomatic Institute of China in 2014 on the basis of the long-term series of Landsat satellites (resolution 30 m/px) [12]. These data were successfully used to refine the boundaries of plant community types and to distinguish the vegetation cover classes within the previously selected polygons. Using the developed algorithm, vegetation maps of the eight key areas (M 1:200 000; 1:250 000; 1:300 000) were compiled and the legend for them was developed. When compiling vegetation maps and developing the legend, the dominant-determinant approach to the plant communities' classification was used.

The location of the settlements and linear and square infrastructure objects (roads, communication lines and power systems, agricultural lands, etc.) was also updated. For these purposes, the digital data of the "Global Forest Change 2000–2012" Project were additionally used [13]. These data were compiled on the basis of a long-term series of Landsat satellite images (30 m/px resolution). Using these data, a number of boundaries on the map were clarified and the satellite pyro-geographical data were added [14].
4. Conclusion
The remote sensing data, aerial photographs, original relevés and itinerary research data were used for the purpose of small-scale forest vegetation mapping. A map of forests and elfin woods allocation in the mainland part of the Koryak Region was compiled (figure 1).

Distribution boundaries of forest and elfin wood communities formed by larch, Siberian dwarf-pine, dwarf-alder, Stone-birch, White birch, poplar, alder and willow trees were revealed for the North of the Koryak Region. The areas of the forest and woodland formations were clarified.

Larch (Larix cajanderi Mayr) open-forests are met only in the upper- and middle-reaches of the Penzhina River, in the valleys of the Penzhina and its tributaries, as well as on the slopes of Kolyma Highlands.

![Figure 1. The small-scale forest vegetation map of the North of the Koryak Region.](image)

The Stone-birch (Betula ermanii Cham.) groves are found in the areas adjacent to the Bering Sea coast. They occupy Southern and Eastern slopes of the Southern spur of the Koryak Upland; and do not occur North of 61° 30' N L. Betula ermanii communities do not overcome the Parapolsky Dale depression, and do not occur West of 167° 30' E L. White birch (Betula platyphylla Sukacz.) groves are common in the continental districts of the Koryak Region – in the valleys of the rivers Penzhina, Talovka, Belaya, Oklan, Apukvayam, and on the slopes of the Penzhinsky Ridge. They spread much further to the North: White birch groves are met in the valleys of the rivers Main and Anadyr (Chukotka Autonomous Region) [1]. The areal of Betula platyphylla extends to the Northern spur of the Koryak Upland and runs up to the Arctic Circle (66° 33’ N L). The natural phytogeography boundary between the two birch formations runs along South-Eastern spurs of the Koryak Upland.

Flood-plain forests formed by poplar (Populus suaveolens Fisch.), chosenia (Chosenia arbutifolia (Pall.) A Skvorts.), alder (Alnus hirsute (Spach) Turcz. ex Rupr.) and willow trees (Salix udensis Trautv. et C.A. Mey., S. schwerinii E.L. Wolf) are met only in the river valleys. They stretch in a narrow strip (100–200 m wide) along the rivers.
Siberian dwarf-pine (*Pinus pumila* (Pall.) Rgl.) and dwarf-alder (*Alnus fruticosa*Ruopr.) elfin woods form a zonal vegetation type of the Beringian forest-tundra Zone. They occupy the most part of the area. Dwarf-alder thickets are more common for the mountain slopes close to the Bering Sea Coast.

Based on the vegetation maps of the key areas, using the system of coupled analysis and the classification of ground and remote sensing data in the ArcGIS package as well as the vegetation data bank, the North of Koryak Region Actual Vegetation Map (M 1:500 000) compilation has been started. The map will display the patterns of the vegetation cover differentiation of the Region. With the help of the map, the boundaries of the new geobotanical subdivision of the North of Koryak Region [15] will be clarified and the main phytogeography boundaries within the Beringian forest-tundra Zone will be determined.

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