Analysis transformation of forests of the Southern Sakhalin by remote sensing data using geoinformation technologies

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Abstract. The forests in the south of Sakhalin are classified as taiga zone and before the beginning of large-scale use almost completely covered its territory. The reserves of spruce and fir forests often reached 600 m³ per 1 ha. Only in south-western part of Sakhalin broad-leaved forests grows as an admixture in dark coniferous forests. Above the belt of dark coniferous forests were indigenous forest communities of stone birch and thickets of cedar elfin wood. In the floodplains of many rivers, willow-alder and poplar forests grew with the participation of coniferous and some broad-leaved species. The composition, structure and qualitative state of modern forests, due to long-term industrial logging, large-scale fires and other anthropogenic transformations of natural landscapes, significantly differ from their original, natural state. The article evaluates the current state and structure of the forest cover in southern part of Sakhalin according by data obtained from the Landsat-8 spacecraft, soften-up with using geoinformation technologies. Dark coniferous forests have undergone the greatest changes, reducing the occupied area more than 3 times due to their active exploitation over the past century. Currently zonal dark coniferous forests are mostly replaced to derived stone-birch forests, their share have increased significantly in the forest fund.

1. Introduction

Active industrial forest management has led to significant changes in the structure of Sakhalin vegetation in the last century. Elimination of indigenous forests was also occurred as the result of development of human settlements, construction of industrial plants, railways, roads, carrying out reclamation of agricultural lands and the establishment of cultivated land, laying of power lines and pipelines, development of mineral deposits, etc. Significant changes in forest vegetation occurred in the south of the Island.

The assessment of the state of plant communities based on remote sensing data of the Earth’s surface is carried out by determining their spectral reflectivity. Waves of different lengths when reflected from leaves of trees behave differently: some are reflected from the surface of chlorophyll cells, others – mesophyll [1]. The reflectivity of the canopy of various tree species is basis for identification their condition when deciphering aerospace images.

Large phytomass reduces the reflectivity of surface covered with vegetation in the red zone of the electromagnetic spectrum, due to the absorption of solar radiation by chlorophyll (600-700 nm), and leads to a fairly significant increase in near infrared spectrum region (750-1300 nm). The ratio of these indicators makes it possible to distinguish the territories occupied by different plant communities and assess their condition. Currently, more than 200 variants of vegetation indices have been developed [2-
4]. They are selected based on the characteristics of the spectral reflectivity of certain plant formations.

Modern geoinformation technologies have fairly wide range of tools for analyzing spatial data and processing attribute information, which allows them to be used for study changes in the composition and structure of forest cover.

2. Methods and Materials
The available satellite images from the Landsat 8 spacecraft, made in the period from 2017 to 2019, served as materials for the analysis of forest lands [5]. The main criteria for selecting images were the date of orbital survey during the growing season (July-October) and absence of clouds over the researching area.

For the classification of raster images there have been used the variety of methods [6-8]. In the work, the classification procedure "with training" was carried out. The training sample is made up from set of pixels representing image of etalon sites where geobotanical descriptions are performed. Groups of pixels belonging to different physiognomic vegetation types are visualized and converted to vector format. At the final stage, the map model was generalized to minimum allocation area - 0.25 ha.

All plant communities were separated by their spectral characteristics based on survey data in a combination of channels 6-5-4. The results of the research allowed us to make map of the vegetation of the territory in its current state.

3. Results and Discussion

3.1 Composition and structure of indigenous forests
Forests in the south of Sakhalin, as on the entire island as well, are the dominant type of vegetation, are classified as taiga zone and before active colonization and large-scale use of forest resources, almost completely covered its territory. This was primarily due to the favorable natural and climatic conditions for the growth and development of coniferous forests. Moderate thermal conditions not only during the growing season, but also throughout the year, heavy precipitation and high humidity, scattered radiation and low-mountain landscapes with drained and moist soils contributed the formation of very productive forests here, formed mainly by ayan spruce (Picea ajanensis) and sakhalin fir (Abies sachalinensis). Under optimal growing conditions, the reserves of spruce-fir forests often reached 600 m³ per 1 ha [9].

On scheme of geobotanical zoning of Sakhalin, the forests of southern part of the island are assigned to subzone of dark coniferous forests with predominance of fir trees [10]. Only in the south-western part of Sakhalin, broad-leaved species are found admixture in dark coniferous forests: mongolian oak (Quercus mongolica), sakhalincork tree (Phellodendron sachalinense), mayra maple (Acer mayrii), kalopanax septemlobate (Kalopanax septemlobus), japanese elm (Ulmus japonica), manchurian ash (Fraxinus mandshurica), etc.

Of course, at the beginning of last century, dark coniferous forests in the south of island were very widespread, occupying sea-shore and river terraces, the lower and middle parts of the mountain slopes, rising to a height of 600, sometimes up to 700 m above sea level. Above the belt of dark coniferous forests, there were indigenous forest communities of stone-birch (Betula ermanii) and thickets of cedar elfin (Pinus pumila). Willow-alder and poplar forests grown with the participation of coniferous and some broad-leaved species occurred in many river's valleys. Light coniferous forests were formed from larch trees (Larix cajanderi) and their sparse stand on wet and swampy areas with peaty soils, mainly around lakes and lagoons. Thus, natural forest cover of the southern part of Sakhalin, compiled according to expert estimates, as well as archival and stock materials, was consisted of dark coniferous forests reached 80% of the forested area, in particular about 7% - forests were stone-birch forests, 1% – formation brush wood cedar elfin, 3% – floodplain (valley) willow, alder and poplar forests and their various mixed variants, 7% – larch forests and their sparse stand.
3.2 Active development of forest resources

Active development and use of the forest resources of the south of Sakhalin began in 1905, after ending of the Russian-Japanese war and transferring of the southern part of the island under the jurisdiction of Japan. In territory of the Karafuto governorate, established by Japanese government in the south of Sakhalin, 9 cellulose paper mills (CPM) were built in very short period, focused on processing valuable coniferous, mainly spruce and fir. Most territories of CPM had access to the sea, which ultimately ensured uninterrupted and fairly cheap export of finished products to Japan. CPM had a significant impact on the usage of the forest resource base in the entire part of the island occupied by the Japanese, became one of the powerful city-forming factors and contributed to the active land conversion of the south of Sakhalin. Of course, the commissioning of all CPM at full capacity led to a sharp increase in logging, the volume of which to mid 30’s of the last century reached 5-7 million m$^3$ per year. As a result, from 1906 to 1932, the total volume of deforested area in the south of the island was 58.38 million m$^3$. According to the conclusion of the state commission that examined the forests of Karafuto, during these years, in fact, twice as much wood was cut down and harvested. Significant amounts of logging were carried out during illegal logging, the number of which was 4,265 cases at that period [11].

Large volumes and high intensity of logging led to fact that by 1945 all the available and most productive dark coniferous forests of the southern part of Sakhalin were cut down for the main use and, accordingly, especially valuable stands of spruce and fir were completely cut down. Small areas of untouched forests are preserved only in the upper reaches of rivers, on steep slopes and other hard-to-reach areas. During the 40 years of their stay in the south of the island, the Japanese had harvested more than 117 million m$^3$ of wood [12].

The forests of the south of Sakhalin, which had been selectively felled many times by the beginning of the 1950s, after the ending of stage of intensive timber withdrawal, were represented by spruce-fir stands with high completeness. The enterprises of the Sakhalin forest complex, even on the island as whole, could not achieve the volume of "Japanese" logging during the Soviet period from 1946 to 1991. During this time, Sakhalin harvested an average of about 3-3.5 million m$^3$ of wood per year. The decline in forest cover occurred as the result of the transition from selective logging, used by the Japanese, to continuous logging with "mortise logging road", which was carried out by Soviet forestry enterprises since the early 1970s. Large areas of deforested land did not appear in areas of deforestation, but were formed in territories where forest fires took place [13].

3.3 Assessment current state of forests in the south of Sakhalin

The assessment of the current state and structure of the forest cover of the southern part of Sakhalin was carried out using geoinformation technologies. Multi-zone images, as well as their synthesized images, are very informative for vegetationresearches. The basis for the selection of reference areas was the visual interpretation of multi-zone images. Geobotanical sites were laid on these sites, which provided the identification of the spectral characteristics of various types of forest vegetation [14, 15]. The images were processed in the ArcGIS software. To achieve high accuracy of selection, the classification "with training" was performed.

The composition, structure and quality of modern forests differ significantly from their original, natural state, as a result of the impact of long-term industrial logging, large-scale fires and other types of anthropogenic transformation of natural landscapes (figure 1).
Figure 1. Composition and distribution structure of plant communities in modern forests of southern Sakhalin.
The results of the geoinformation analysis of forests are presented in table 1.

Table 1. Modern structure of forest lands in southern part of Sakhalin Island.

| The forest formation                   | Share of occupied area, % |
|----------------------------------------|---------------------------|
|                                        | 1900 | 2020 |
| Dark coniferous forests                | 80   | 24.98|
| Birch forests                          | 7    | 48.22|
| Hemlock forests                        | 7    | 3.62 |
| Forest plantations                     | -    | 2.30 |
| Valley (floodplain) forests            | 3    | 2.28 |
| Formation of brush wood cedar elfin    | 1    | 0.98 |
| Treeless areas (burning, logging, bamboo forests, etc.) | 2  | 17.62 |

Currently, available estimated cutting area for Sakhalin island is about 2 million m³ in total, and logging enterprises of various forms of ownership use it only by 10-20%. According to the data obtained, dark coniferous forests have undergone the greatest changes. The area occupied by them has decreased by more than 3 times due to active exploitation during century. Currently, dark coniferous forests are mostly replaced by derived stone-birch forests, share of which in the forest fund has increased significantly. As result of reforestation, artificial forest plantations have also appeared, mainly from light-coniferous species – pine and larch. At the same time, in the structure of the forest fund of the south of Sakhalin, quite significant areas are steadily occupied by old burns and cuttings overgrown with Kuril bamboo.

4. Conclusion
The research showed that the modern forests of the southern part of the island are radically different from their original, natural state. Undoubtedly, the intensity of logging is significant, but not the only factor in the reduction of forest resources. Wood harvesting in quite significant amounts does not prevent the transition to sustainable development, in case of providing control in the forestry sector, primarily by reducing burning of forests. To large extent, possibility of using wood resources in the south of the Sakhalin island depends on the methods and ways of logging, as well as on the reorientation of the entire forest complex to the integrated use of wood raw materials.

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References
[1] Kronberg P 1985 Fernerkundung der Erde : Grundlagen und Methoden des Remote Sensing in der Geologie (Stuttgart : Enke)p 394
[2] Crippen R E 1990 Calculating the Vegetation Index Faster Remote Sensing of Environment vol 34 p 71-73
[3] Cerepanov A S and Druzhinina E G 2009 Spectral properties of vegetation and vegetation indices Geomatics 3 pp 28-32
[4] Dubinin M Yu Vegetation indices Website Geographic information systems and remote sensing (GIS-Lab URL http://gis-lab.info/qa/vi.html accessed 25.02.2021)
[5] Landsat Science (Website NASA (National Aeronautics and Space Administration) URL https://landsat.gsfc.nasa.gov accessed 25.02.2021)
[6] Richards J A and Jia X 2006 Remote Sensing Digital Image Analysis: An Introduction 4th ed (Berlin Springer) p 439
[7] Borengasser M, Hungate W S and Watkins R 2007 *Hyperspectral Remote Sensing: Principles and Applications* (London: CRC Press) p 128 DOI https://doi.org/10.1201/9781420012606

[8] Shahtahmassebi A, Yang N, Wang K, Moore N and Zhangquan Sh 2013 Review of shadow detection and de-shadowing methods in remote sensing *Chinese Geographical Science* vol 23 4 pp 403-420 DOI https://doi.org/10.1007/s11769-013-0613-x

[9] Ageenko A S and Klintsov A P 1969 *Forests of Sakhalin Island and the Kuril Islands* (Sakhalin region) *Forests of the Far East* ed A S Ageenko (Moscow: Forest Industry) pp 228-263

[10] Tolmachev A I 1955 *Geobotanical zoning of the Sakhalin island* (Moscow-Leningrad: Publ. House Academy Sc USSR) p 80

[11] Lee Ben Dyu 1973 Predatory exploitation of the forest resources of Southern Sakhalin during the Japanese occupation *Materials on the history of the Far East* (Vladivostok: Far Eastern Research Center of the USSR Academy of Sciences) pp 186-188.

[12] Vlasov S T 1959 *Forests of Sakhalin Island. Reference materials* (Yuzhno-Sakhalinsk: Sakhalin Book Publishing House) p 108

[13] Sheingauz A S 2010 *The History of forest management Geosystems of the Russian Far East at the turn of the XX-XXI centuries: in 3 vols.* vol 2. *Natural resources and regional nature management* ed P Ya Baklanov and V P Karakin (Vladivostok: Dalnauka) pp 95-102

[14] Melkiy V A, Verkhoturov A A, Sabirov R N and Bratkov V V 2019 Analysis of the state of forest lands on Sakhalin Island. *VestnikSevero-Vostochnogo federal'nogo univertsiteta im M K Ammosova. Seriya: Nauki o Zemle* No 2 (14) pp 68-73

[15] Bratkov V V, Vorob’ev V A, Melkiy V A and Verkhoturov A A 2020 Mapping of dynamics of plant communities of northern part of the boreal forests of Sakhalin island by remote sensing data *Monitoring. Science & Technologies* vol 45 (3) pp 6-13 DOI: https://doi.org/10.25714/MNT.2020.45.001