Inter-annual variability of the forest area of different types of surface of the Leningrad region

I Martyn, Y Petrov*, S Stepanov, V Abramov and A Sidorenko
Department of applied computer science, Russian State Hydrometeorological University, 79 Voronezhskaya Street, St. Petersburg 192007, Russian Federation

*Corresponding email: yaroslav.petrov025@gmail.com

Abstract. In connection with the vast territories of the Russian Federation, accounting for the area of forests and other objects of the forest sector and their changes becomes problematic. At present, this accounting is best carried out thanks to the methods of remote sensing of the Earth. This article presents an example of analyzing the inter-annual variability of forest land areas in the Leningrad Region for the period 2015-2019, according to remote sensing data, using statistics without the use of complex algorithms. All the data obtained are summarized in a table. The analysis of variability of land areas by methods of mathematical statistics is carried out and the year of disappearance of this type in the territory of the region is determined for the most vulnerable types.

1. Introduction
Forestry plays a significant role in the economy of the Leningrad Region. The relevant committees and departments are active in finding ways of interaction between business and the state, as well as improving the existing potential. Much attention is paid to the issues of preserving and increasing the natural resources of the region. The territory of the region is located in the taiga zone in the middle and southern subzones, a small part of the south of the region, within the Luzhsky district and the Izhora upland – in the zone of mixed forests [1]. Dense coniferous forests and mixed deciduous forests, interspersed with swamps, the area occupied by them reaches 70% of the territory of the region-serve as an important raw material resource of the region and abound in flora and fauna. In the western and southern parts of the region, there are areas of relict broad-leaved forests [2].

In the forests grow medicinal plants berries: lily of the valley, bearberry, blueberry, lingonberry, etc. The territories adjacent to St. Petersburg are occupied for agriculture [3].

2. Methods and Materials
Global Land Cover allows you to quickly get visualization data and data on the percentage of the area occupied by any type of vegetation from the total area of the region, you can also view statistics without performing complex algorithms of actions [2].

Land cover maps represent spatial information on different types (classes) of physical coverage of the Earth's surface, e.g. forests, grasslands, croplands, lakes, wetlands. Dynamic land cover maps include transitions of land cover classes over time and hence captures land cover changes. Land use maps contain spatial information on the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it.
The yearly moderate-resolution land cover maps do primarily target land cover detection and their changes, although it's not so straightforward to put boundaries between definitions of land cover and land use classes [4, 5]. The map is provided together with vegetation continuous field layers that provide proportional estimates of vegetation cover for several land cover types.

In Global Land Cover, the information is obtained using the PROBA-V sensor, temporal coverage – annual, between 2015 and 2019 and spatial information 100m resolution, global.

The obtained data on the share of the occupied area relative to the total area ( % ) for the period 2015-2019 were used in the work. A linear trend was calculated for the most shrinking surface types

\[ X = a_0 t + a_0 \] (1)

Extrapolating the trend, the approximate date of the disappearance of this type of landscape was determined [6, 7].

3. Results and Discussion

Figures 1-6 show maps of the distribution of vegetation type in the Leningrad Region for the period 2015-2019. When comparing the obtained maps, there are no obvious changes in the variability of the area of a particular type of vegetation. It can be seen that the main share of the territory of the Leningrad region is occupied by forests of mixed type, broad-leaved and coniferous. On the site of the settlements of the region are highlighted in red - the development of the territory. Outside of the city, arable land is allocated, the main part of which is concentrated to the south of St. Petersburg. Their equal area is occupied by grassy vegetation. Other selected species are observed on a small area.

| Closed forest | Open forest | Other Land Cover |
|---------------|-------------|-----------------|
| Evergreen needle-leaved | Evergreen needle-leaved | Shrubland |
| Deciduous needle-leaved | Deciduous needle-leaved | Herbaceous vegetation |
| Evergreen broadleaved | Evergreen broadleaved | Herbaceous wetland |
| Deciduous broadleaved | Deciduous broadleaved | Moss & lichen |
| Mixed type | Mixed type | Bare / sparse vegetation |
| Unknown type | Unknown type | Cropland |
|                |              | Built-up |
|                |              | Snow & ice |
|                |              | Permanent water bodies |

**Figure 1. Legend for figures 2-6**

**Figure 2. Vegetation types of the Leningrad Region for 2015.**
Since there are almost no noticeable changes on the above maps, a map of the annual change in the area of forest cover was built (figure 7). Here you can already see the foci of change by year. In the area of St. Petersburg, there is not much variability in the type of vegetation. The most active change occurred in 2017, in the area of the Ivinsky Razliv reservoir and in a large area south of Lake Ladoga, where logging was most likely carried out. Currently, the most active changes are taking place on the southern coast of Lake Ladoga and along the riverbanks, as well as in the area of Kingisepp.
Figure 6. Vegetation types of the Leningrad Region for 2019.

Figure 7. Map of annual changes in vegetation types in the Leningrad region for the period 2015-2019.

From 2015 to 2019, the areas of herbaceous vegetation and forests of unknown species decreased most significantly in the Leningrad Region, and the area of arable land with shrubs decreased less significantly. In the same period, there is a significant increase in wetlands, as well as the area of development and permanent reservoirs (table 1). From this we can conclude that the increase in the area occupied by the city, although not significant, as well as the waterlogging of the territory of the Leningrad region.

Table 1. The share of the occupied area of the vegetation type from the total area of the region (%) in the period 2015-2019.

| Type                  | The share of the occupied area of the total area of the territory (%) |
|-----------------------|---------------------------------------------------------------|
|                       | 2015  | 2016  | 2017  | 2018  | 2019  |
| Shrubland             | 0.13  | 0.12  | 0.11  | 0.1   | 0.1   |
| Herbaceous vegetation | 4.04  | 3.89  | 3.65  | 3.55  | 3.5   |
| Herbaceous wetland    | 0.55  | 0.87  | 1.43  | 1.71  | 1.88  |
| Cropland              | 3.84  | 3.83  | 3.83  | 3.82  | 3.81  |
| Built-up              | 1.51  | 1.52  | 1.52  | 1.52  | 1.53  |
| Permanent water bodies| 13.02 | 13.05 | 13.07 | 13.08 | 13.08 |
| Open forest           |       |       |       |       |       |
| Evergreen needle-leaved| 0.06  | 0.06  | 0.06  | 0.06  | 0.06  |
Statistical estimates of trends in the area share of vegetation types for the period 2015-2019 are given in table 2. In accordance with the Student's criterion, at a significance level of 5%, the approximate critical value is $R^2_{CRIT} \approx 0.66$. When $R > R^2_{CRIT}$ the trend is considered significant.

Table 2 shows that for evergreen needle-leaved, deciduous broadleaved, mixed type (open forest) and deciduous broadleaved (closed forest) there is no trend, all the selected trends are significant. Trend coefficients $a$ are negative for shrubland, herbaceous vegetation, cropland, unknown type (open forest), evergreen needle-leaved (closed forest), mixed type and unknown type (closed forest), the largest negative trend values are marked for unknown type (closed forest), the largest positive trend value is marked for herbaceous wetland.

| Type                                | $R^2$  | $a_1$  |
|-------------------------------------|--------|--------|
| Shrubland                           | 0.94   | -0.008 |
| Herbaceous vegetation               | 0.94   | -0.14  |
| Herbaceous wetland                  | 0.97   | 0.35   |
| Cropland                            | 0.94   | -0.007 |
| Built-up                            | 0.8    | 0.004  |
| Permanent water bodies              | 0.86   | 0.015  |

| Open forest                         |        |        |
|-------------------------------------|--------|--------|
| Evergreen needle-leaved             | -      | -      |
| Deciduous broadleaved               | -      | -      |
| Mixed type                          | -      | -      |
| Unknown type                        | 0.98   | -0.03  |

| Closed forest                       |        |        |
|-------------------------------------|--------|--------|
| Evergreen needle-leaved             | 0.89   | -0.005 |
| Deciduous broadleaved               | -      | -      |
| Mixed type                          | 0.75   | -0.003 |
| Unknown type                        | 0.96   | -0.18  |

Let's consider estimates of the disappearance of vegetation types for which a negative trend is noted based on the trend approach. It is based on the immutability of the conditions for the entire period up to the date of extinction, with any change in the conditions (climatic, legislative and other), the calculated estimates of the disappearance of the vegetation type will be rejected. Figure 8-10 shows the trend with the year of the disappearance of vegetation types. As a result, the disappearance of shrubland will occur in 2031, the type of herbaceous vegetation on the territory of the Leningrad region will disappear by 2043, and the share of the area of Unknown type (closed forest) will decrease to 0 in 2060. Since the proportion of variance described by trends is quite large, the predictive estimates can be considered fairly accurate.
Figure 8. Results of extrapolation of the area fraction shrubland.

Figure 9. Results of extrapolation of the area fraction herbaceous vegetation.

Figure 10. Results of extrapolation of the area fraction Unknown type (closed forest).

4. Conclusions
In this paper, we consider the use of the Copernicus service to study the area of vegetation types in the Leningrad Region for the period 2015-2019, identify trends for these areas and prognostic estimates of the disappearance of vegetation types for which a negative trend is noted. Such applications [8-10] allow for more accurate estimates of various environmental parameters.

The analysis of Global Land Cover revealed changes in the areas of vegetation types, as well as the variability of the location of some types. The growth of urban space due to the reduction of a certain
type of vegetation has been revealed, and the process of waterlogging of the region has been high over the past 4 years.

Estimates of the disappearance of vegetation types with a negative trend for the period 2015-2019 are presented. It is determined that under these conditions, shrub will disappear most quickly in the Leningrad region in 10 years, and herbaceous vegetation will disappear in 20 years. Predictive estimates of the disappearance of vegetation types are obtained under the assumption that their trends are constant over time, i.e., while maintaining the current forest policy, climatic conditions, etc. However, if you change any of the terms of the valuation dates subject to change.

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