INSTITUTE FOR ENVIRONMENTAL SOLUTIONS

Augmented Urbans

Spatial data analysis report for Cesis (Summary)

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Augmented Urbans

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Introduction

Spatial data analysis report for Cesis is prepared within the project "Augmented Urbans" co-funded by EU's Central Baltic Interreg Programme. It consists of the following data products:

1.1.1. Evaluation of vegetation cover within last five years - mapping of vegetation intensity, consistency and changes;
1.1.2. Classification of vegetation in basic classes - permanent grassland, deciduous and coniferous trees, impermanent vegetation;
1.1.3. Mapping of biological value;
1.1.4. Relief model and slope;
1.1.5. Object height model and classification;
1.1.6. High resolution (10 cm/pix) orthophoto from 2020;
1.1.7. Data analysis report in Latvian and summary in English.

The particular document is the summary of the data analysis report. Full description of the methodology could be found in the Latvian version of the report. Spatial data products are delivered to the municipality of Cesis.

1. Evaluation of vegetation cover

Vegetation intensity

Normalized difference vegetation index (NDVI) obtained from airborne and spaceborne spectral data is often used for vegetation intensity assessment. Maximal NDVI values are used over the whole observation period to avoid seasonal influence. High resolution (2 m/pix) vegetation maximal intensity obtained from three airborne spectral datasets (2014-2018) is shown in Figure 1.1. Vegetation intensity could be classified into five classes:

- NDVI > 0,75 - very dense vegetation cover (usually corresponds deciduous forests, agricultural fields as well as fertile grasslands);
- NDVI 0,5...0,75 - dense vegetation cover (usually corresponds coniferous forest or sparse deciduous forests, less fertile agricultural fields or grasslands);
- NDVI 0,25...0,5 - sparse vegetation cover where vegetation isn't the dominant land cover type;
- NDVI 0...0,25 - very sparse vegetation cover where vegetation presence is minimal;
- NDVI < 0 - land cover without vegetation or water.

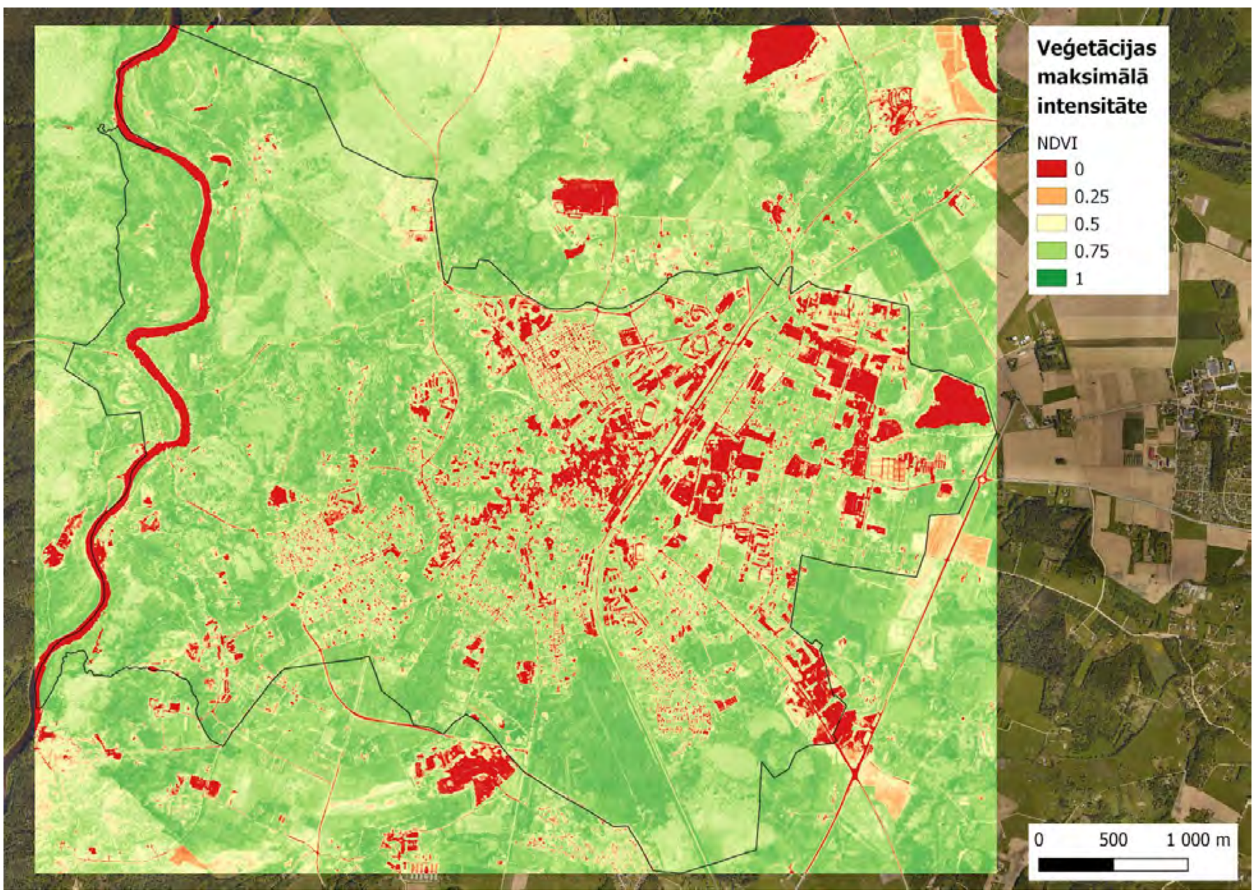


Figure 1.1. Vegetation maximal intensity for Cesis obtained from three airborne (ARSENAL) spectral datasets (2014-2018).

Similar vegetation intensity assessment could be obtained from Sentinel-2 satellite spectral data. In this case, theoretical observation frequency could be once every 5...10 days. However, real cloud-free Sentinel-2 data observation frequency is 1...4 times per month. Vegetation maximal intensity (5 m/pix) obtained from Sentinel-2 data (2016-2020) is shown in Figure 1.2. The digitalization is lower in comparison to the airborne data product because each image pixel represents the vegetation cover in an area of 25 m^2.

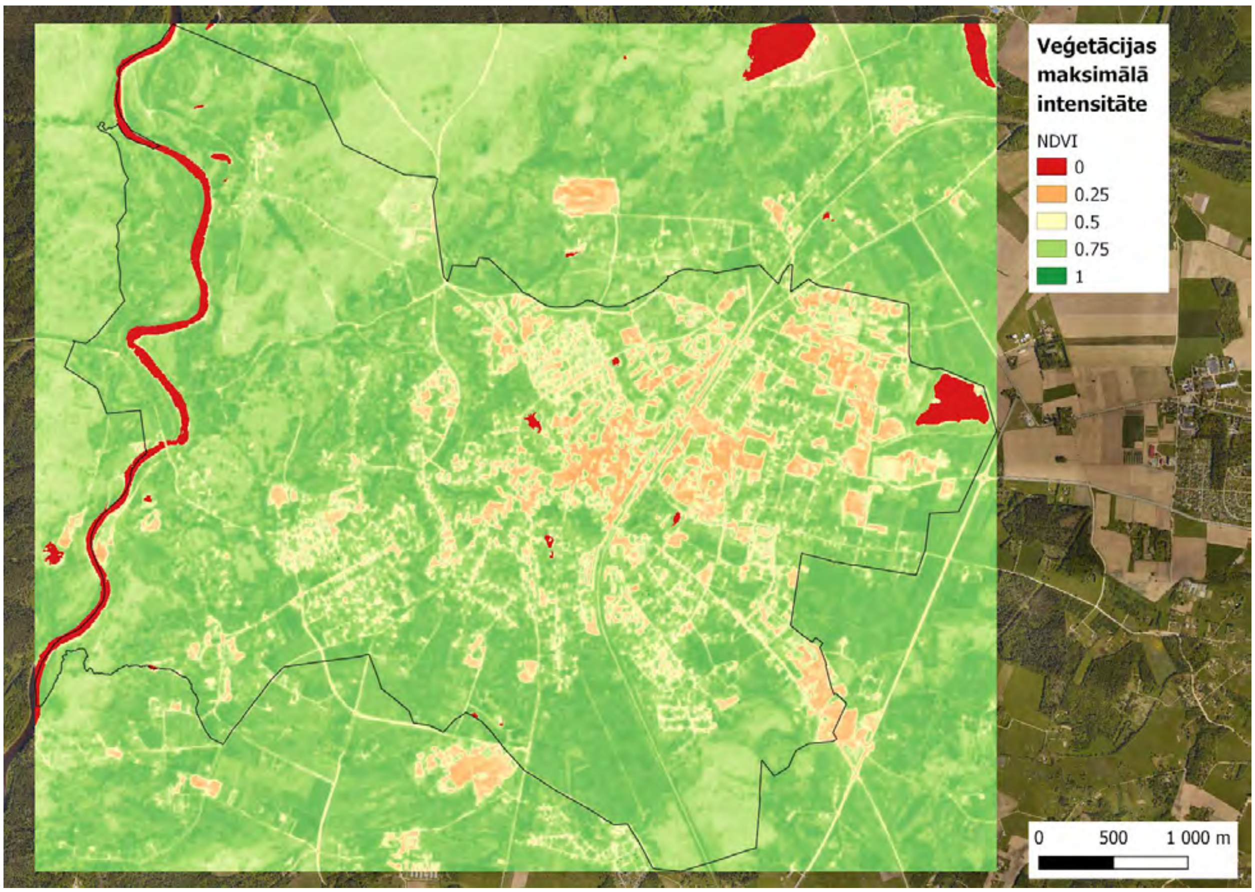


Figure 1.2. Vegetation maximal intensity for Cesis obtained from Sentinel-2 spectral data (2016-2020).

The analysis of vegetation intensity in Cesis for the last five years (2016-2020) shows that 88% of the territory has corresponded to a green area (48% of very dense vegetation and 40% of dense vegetation). Another 10% has corresponded to a sparse or no vegetation and 2% to water bodies.

Vegetation consistency

Minimal NDVI value from yearly maximum NDVI values (2016-2020) is used for the assessment of vegetation consistency. Yearly maximum NDVI value is obtained from all available cloud-free Sentinel-2 data. Vegetation consistency visualizes permanently green areas, see Figure 1.3. It was observed that 79% of Cesis territory corresponds to a permanent green area (24% of very dense vegetation and 55% of dense vegetation). Periodic loss of green area could be caused by economic activity, e.g. construction.

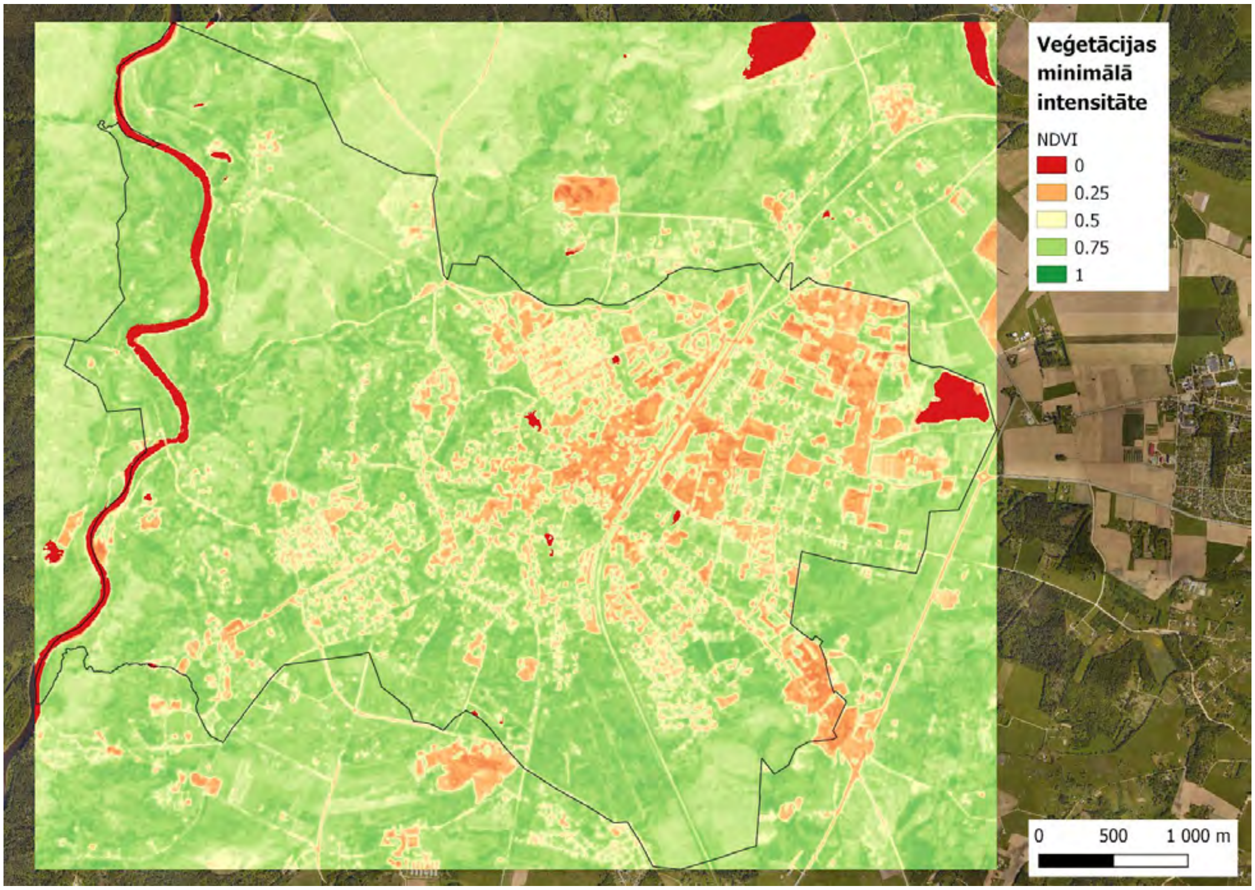


Figure 1.3. Vegetation consistency for Cesis obtained from Sentinel-2 spectral data (2016-2020).

Vegetation changes

Yearly maximum NDVI values obtained from Sentinel-2 spectral data are used for the evaluation of vegetation changes over time. False-colour RGB images could be used for visualisation of vegetation changes over three years, see Figures 1.4a-c. Grayscale colours represent areas with insignificant vegetation changes, in contrast, areas with vegetation loss or gain appear in different colours depending on the year in which they occurred. For example, Cesis stadium appears red in Figure 1.4a due to natural grass cover in 2016 which was lost starting reconstruction in 2017. It appears dark in Figures 1.4b,c because natural grass cover was replaced with artificial grass cover.

Vegetation intensity changes in Cesis over five years are shown in Figure 1.5. Green area percentage varies from 81,5% in 2018 up to 83,5% in 2020 with annual changes of 1...4 percentage points. In contrast, very dense vegetation percentage varies from 33,4% in 2018 up to 38,7% in 2020.

Figure 1.4a. Vegetation changes 2016-2018: R - 2016, G - 2017, B - 2018.

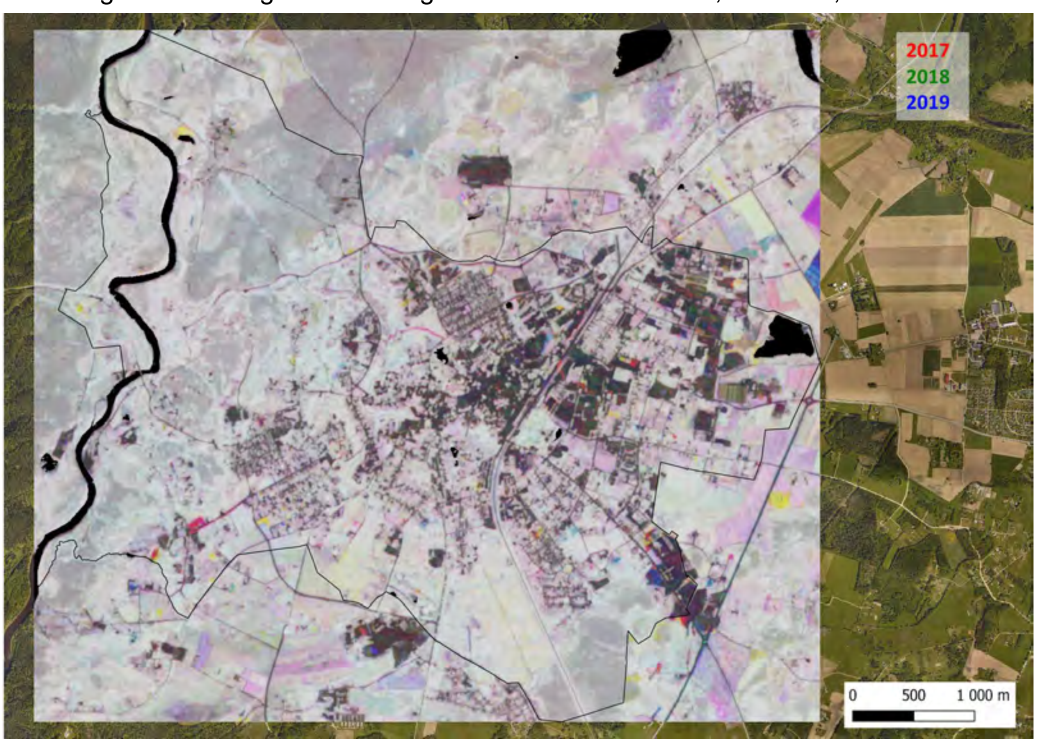


Figure 1.4b. Vegetation changes 2017-2019: R - 2017, G - 2018, B - 2019.

Figure 1.4c. Vegetation changes 2018-2020: R - 2018, G - 2019, B - 2020.

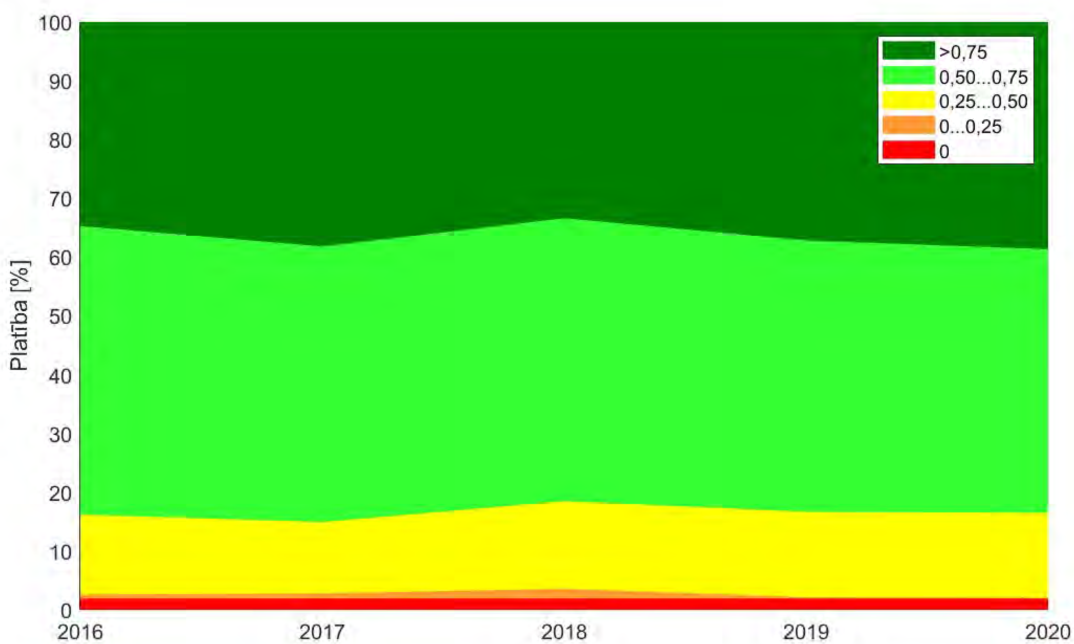


Figure 1.5. Vegetation intensity (NDVI class) changes in Cesis 2016-2020.

Linear regression could be used for the assessment of vegetation trends over a large period of time minimizing artefacts caused by different weather conditions and border pixels. Therefore, temporal yearly maximum NDVI data of each map pixel was used for fitting linear regression model and finding model coefficients *b* and *a*, see Figure 1.6. Vegetation trend is represented with coefficient *b* but actual vegetation intensity with coefficient *a*.

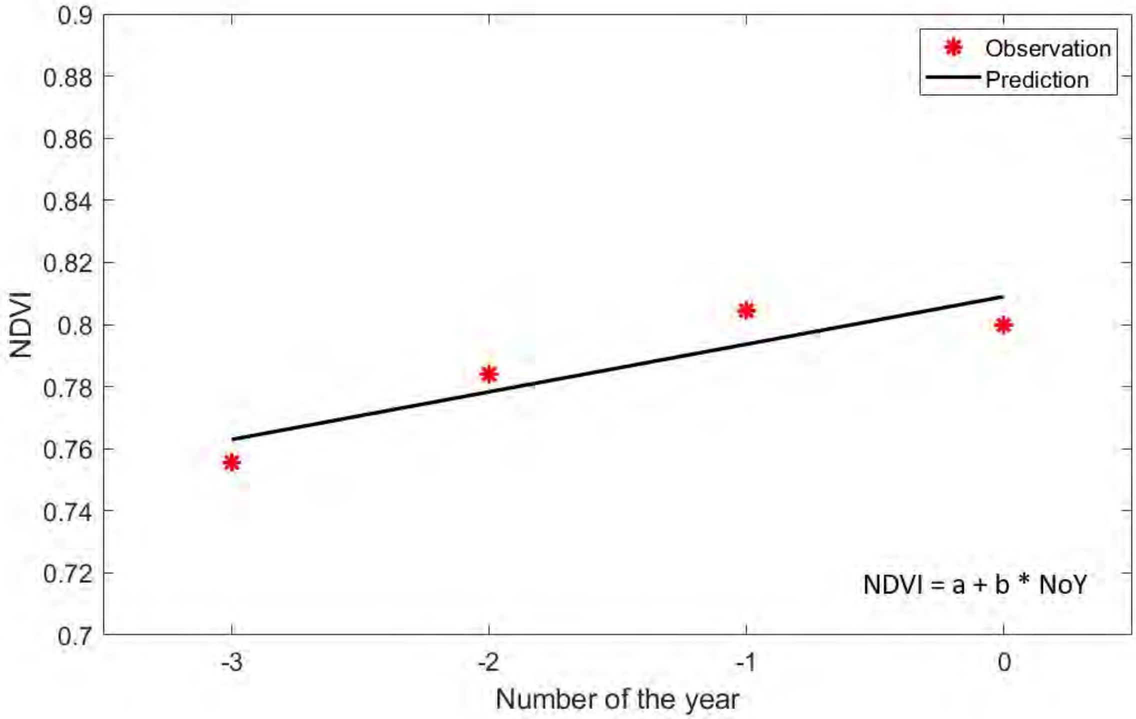


Figure 1.6. Linear regression model for assessment of vegetation trend *b* where *a* is actual vegetation intensity.

Actual vegetation intensity a map is shown in Figure 1.7 and corresponds well with vegetation intensity in the last observation year 2020. Green area percentage is 83% and 38% of the territory is covered with very dense vegetation.

Vegetation trend *b* map is shown in Figure 1.8 where positive *b* values represent vegetation intensity gain but negative *b* values - vegetation intensity loss. Vegetation trend *b* values are in the range between -0,05...0,05. In overall, a positive vegetation trend was observed in 61% of Cesis territory with a median coefficient *b* value of +0,0021. In contrast, a negative vegetation trend was observed in 37% of Cesis territory and 10% of the territory it could be considered significantly negative (<-0,0115 which is median value 0,0021 minus standard deviation value 0,0136). Significantly negative vegetation trends most probably correspond to areas with construction activity. Overall, positive vegetation trends could be observed more in the River Gauja valley (in the Western part of the city) but a negative one in the industrial area of Cesis (in the Eastern part of the city).

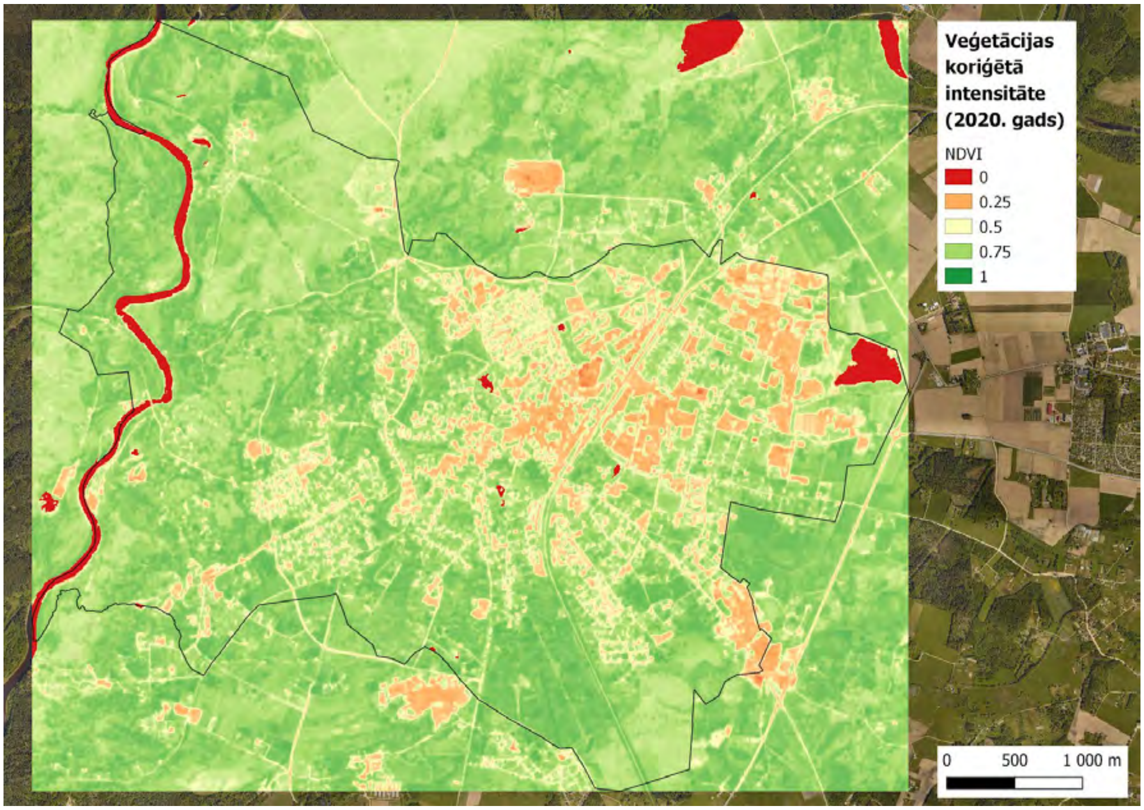


Figure 1.7. Actual vegetation intensity or coefficient *a* map.

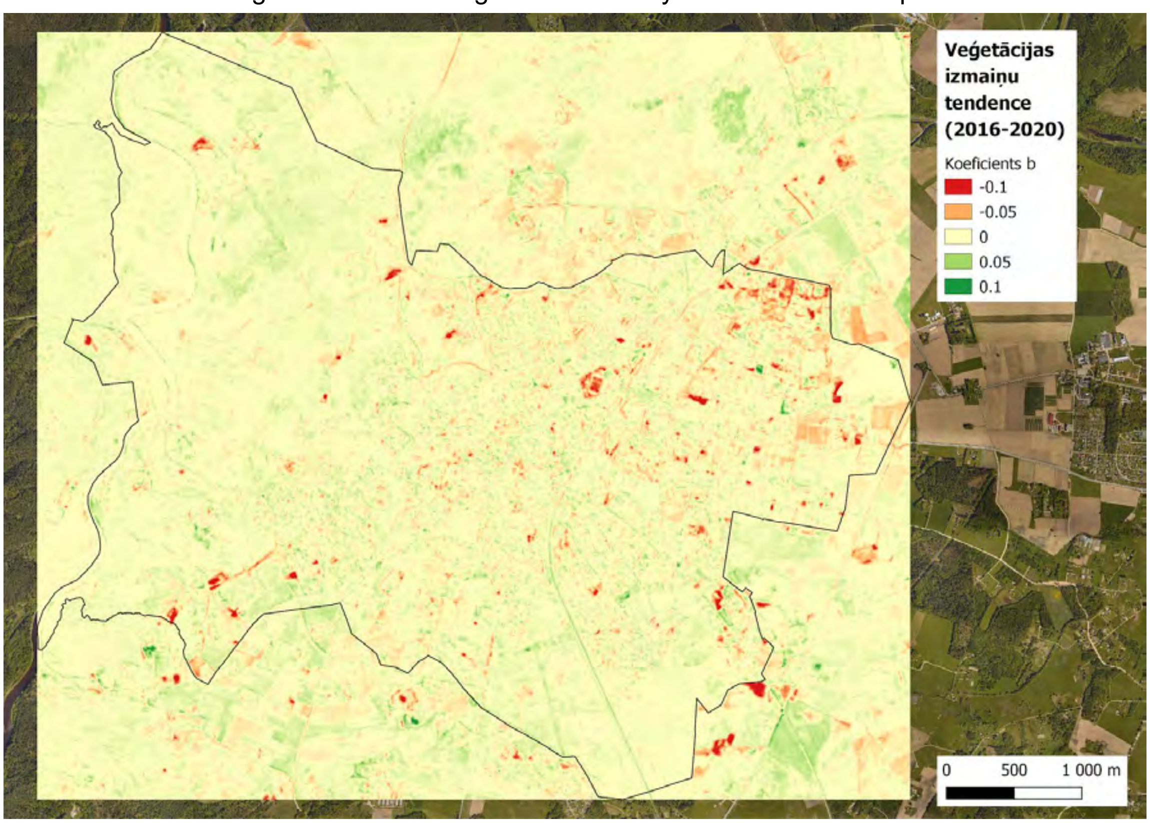


Figure 1.8. Vegetation trend (2016-2020) or coefficient *b* map.

2. Classification of vegetation in basic classes

Land cover classification in basic classes was performed using vegetation intensity 2019 (see Figure 1.7, Section 1) and object height model classification (see Figure 5.2, Section 5) as well as information from OpenStreetMap and the Rural Support Service database. The land cover could be divided into eight basic classes:

1. **Water** - the area covered with permanent water (e.g. rivers, lakes, ponds);
2. **Land without vegetation -** bare land or paved areas;
3. **Grasslands** - grass type vegetation covered area;
4. **Agricultural land** - registered agricultural land;
5. **Shrubland** - the area covered with medium height (0,5...2 m) vegetation;
6. **Deciduous trees** - the area covered with deciduous trees >2 m height;
7. **Coniferous trees** - the area covered with coniferous trees >2 height;
8. **Buildings** - a different type of buildings and constructions.

Land cover classification for Cesis territory is shown in Figure 2.1 but the legend is described in Table 2.1.

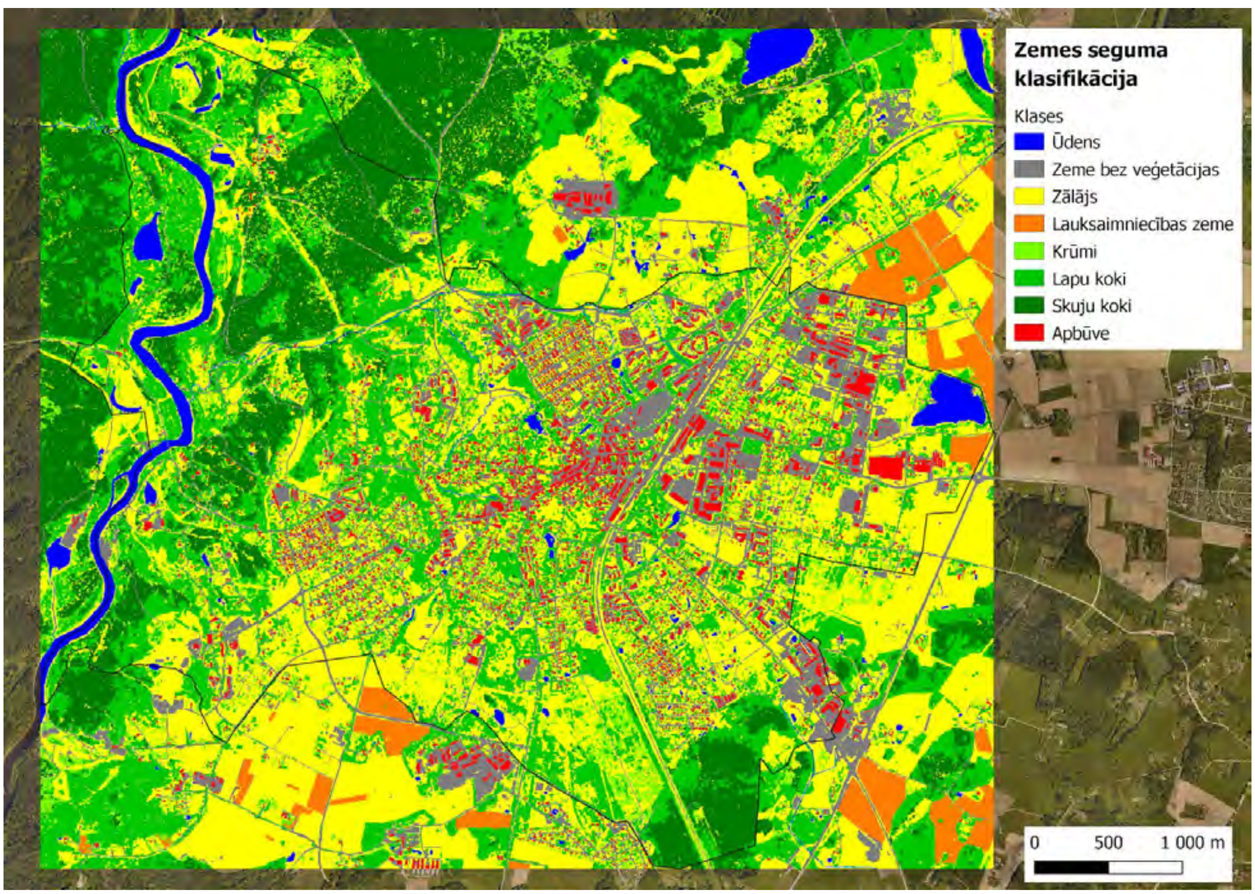


Figure 2.1. Land cover classification for Cesis.

Table 2.1. Land cover classification legend

Colour	Value	Class
	1	Water
	2	Land without vegetation
	3	Grasslands
	4	Agricultural land
	5	Shrubland
	6	Deciduous trees
	7	Coniferous trees
	8	Buildings

Land cover type distribution in Cesis is shown in Figure 2.2. Dominant land cover type is grassland (28%) and deciduous trees (27%). Trees cover 40% of Cesis territory but vegetation - 77%. Land without vegetation (including roads) covers 14% of the territory but buildings - 6%. Water bodies occupy 3% of Cesis territory.

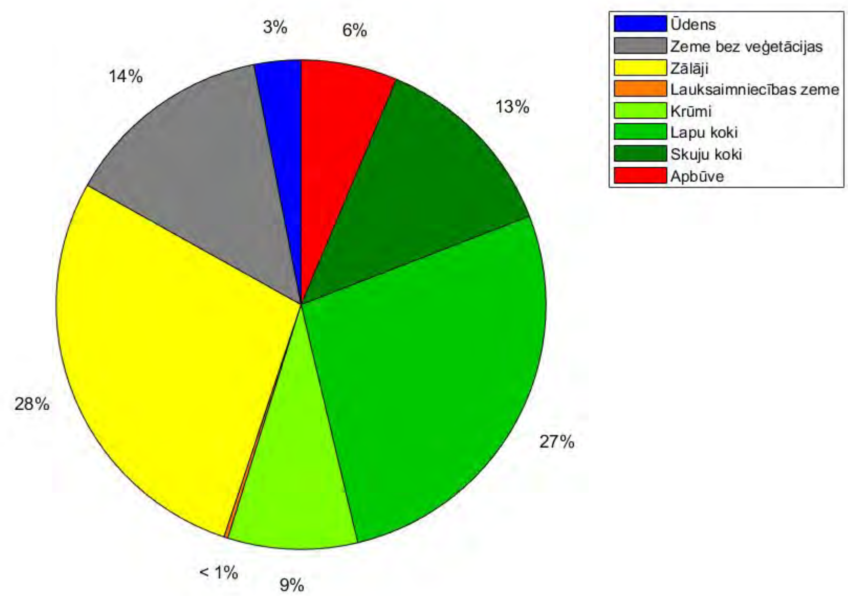


Figure 2.2. Land cover type distribution in Cesis territory.

3. Mapping of biological value

Mapping of biological value is based on the evaluation of different landscape aspects - diversity of ecosystems, their fragmentation and border impact, biotope size and connectivity. The main components used for biological value assessment are:

- Biologically valuable land cover presence and border impact;
- Biologically valuable class polygon size;
- Biologically valuable class polygon connectivity;
- The presence of protected biotopes and species;
- The negative impact of roads and railways.

Biologically valuable land cover classes are:

- Water (water bodies and watercourses);
- Grasslands;
- Agricultural land;
- Shrubland;
- Deciduous trees;
- Coniferous trees.

The impact on the biological value of the presence and border of biologically valuable classes is shown in Figure 3.1. The presence of a biologically valuable class ensures a basic value of 100. Null value land cover classes are buildings and land without vegetation cover (including roads and railways). Border impact was calculated for each biologically valuable polygon of size >0,1 ha as a descending gradient from 100 to 0 in the 50 m buffer zone.

Each biologically valuable polygon is a habitat for different species - the larger the polygon, the more species it corresponds to as a habitat. The biological value component of 100 was attributed to all polygons with the size of 30 ha and larger. The value linearly decreased from 100 to 0 for polygon sizes from 30 ha to 0,1 ha. The impact on the biological value of the polygon size is shown in Figure 3.2. It was observed that larger polygons are usually located in suburbs or outside the Cesis.

Connectivity of same class polygons is essential for migration of species as well as provide additional living space. Connectivity impact was calculated for each biologically valuable polygon of size >0,1 ha as a descending gradient from 100 to 0 in the 1 km buffer zone. It was observed that most of the polygons are well connected and their connectivity value was >90, see Figure 3.3. Lower connectivity was observed in the case of distant water bodies or agricultural fields.

The presence of protected biotopes and species is an important aspect of the assessment of the biological value. Each protected biotope received an additional biological value of 100 with a descending gradient in the 10 m buffer zone. The impact of protected species was a descending gradient from 100 to 0 in the buffer zone that corresponds to the biotope size of particular species. The impact on the biological value of the presence of the biotope is shown in Figure 3.4.

Figure 3.1. The presence of biologically valuable land cover class and border impact.

Figure 3.2. The size of a biologically valuable class polygon.

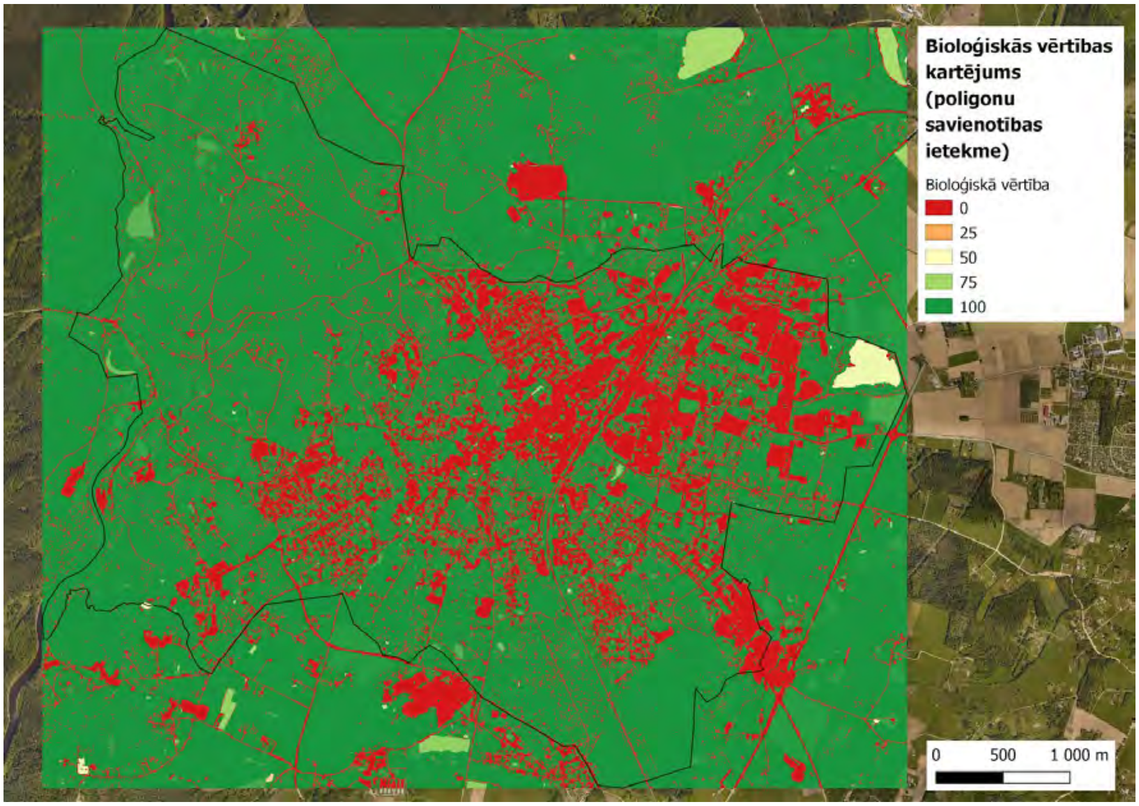
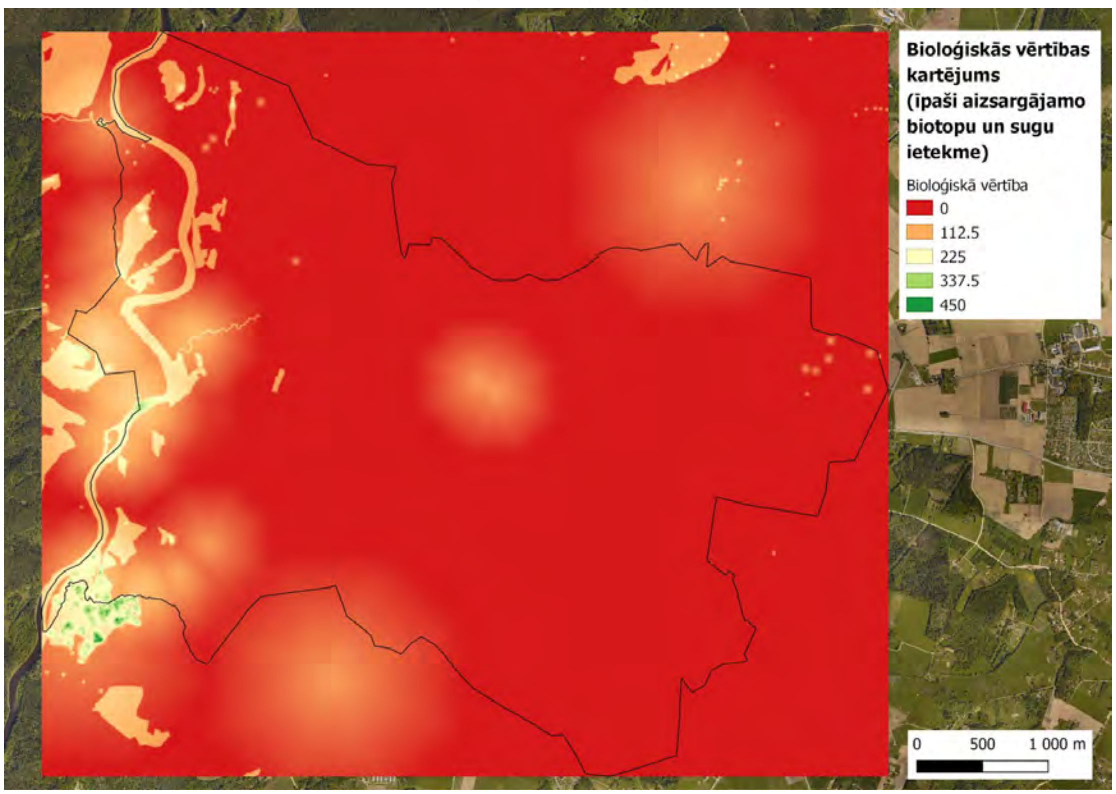


Figure 3.3. The connectivity of biologically valuable class polygons.



Attēls 3.4. The presence of protected biotopes and species.

Roads and railways negatively impact the biological value in the buffer zone of 50 m. Therefore, the negative impact of roads and railways was calculated as a descending gradient from -100 to 0 in the 50 m buffer zone, see Figure 3.5. In the case of roads, negative border impact was calculated only for main roads according to the OpenStreetMap information.

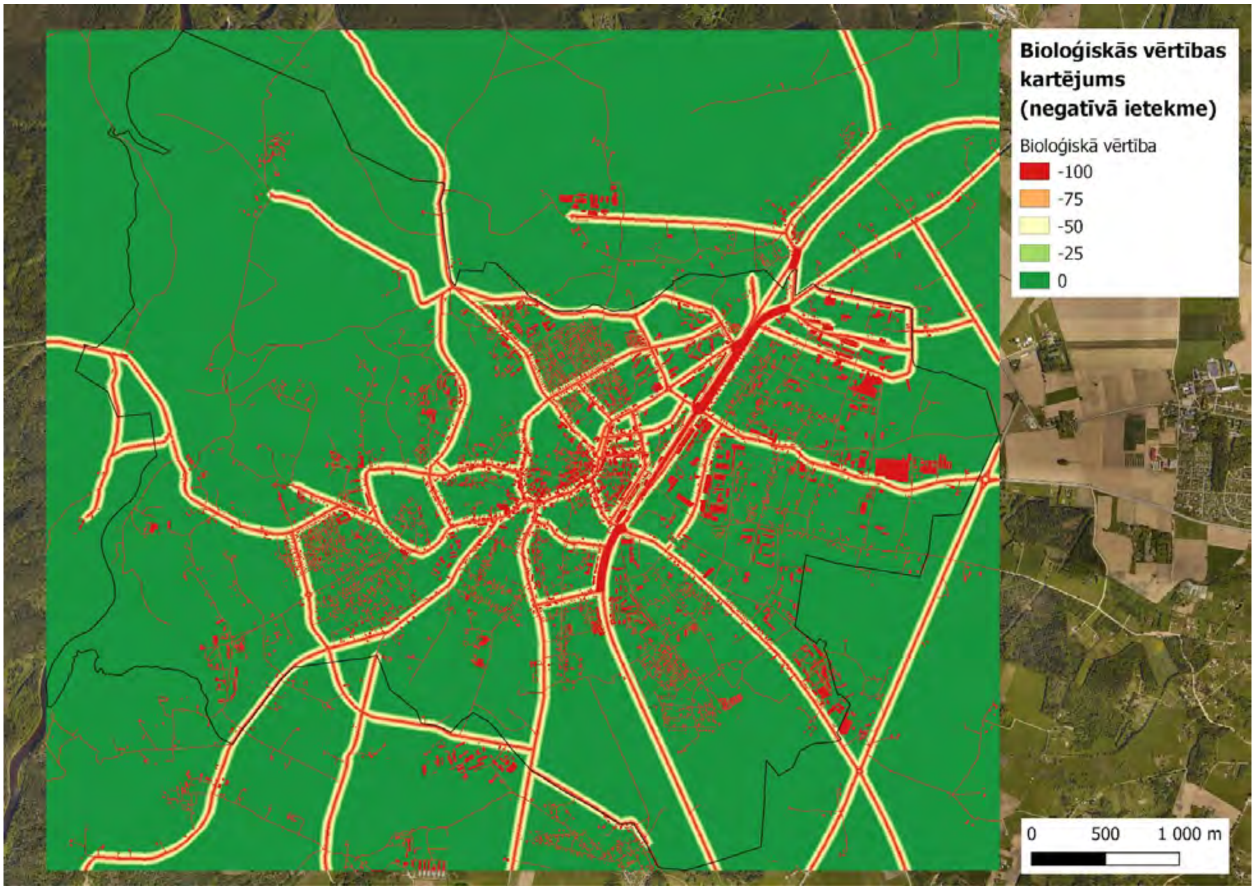


Figure 3.5. Mapping of negative impact on biological value.

Total biological value assessment is produced by summing all previously described components and is shown in Figure 3.6. The areas with the highest biological value are mostly located in the River Gauja valley due to relatively large and well-connected polygons of different biologically valuable classes as well as the presence of protected biotopes and species. The castle park is highlighted as a biological value hotspot in the centre of Cesis.

It should be noted that biological value mapping depends on the chosen components and their weight coefficients which can be specified under the guidance of a biodiversity expert. The prepared result can be used to compare biodiversity in different parts of the pilot's territory or territorial units.

Figure 3.6. Biological value map for Cesis.

4. Relief model and slope

Relief model

Digital relief model was produced from laser scanning data using ground points, see the result in Figure 4.1. The multimodal distribution of height above the sea level in Cesis is shown in Figure 4.2 where two peaks could be observed at 24 and 120 m. Relief height varies between 23,4 and 131,0 m with median value 92,8 m.

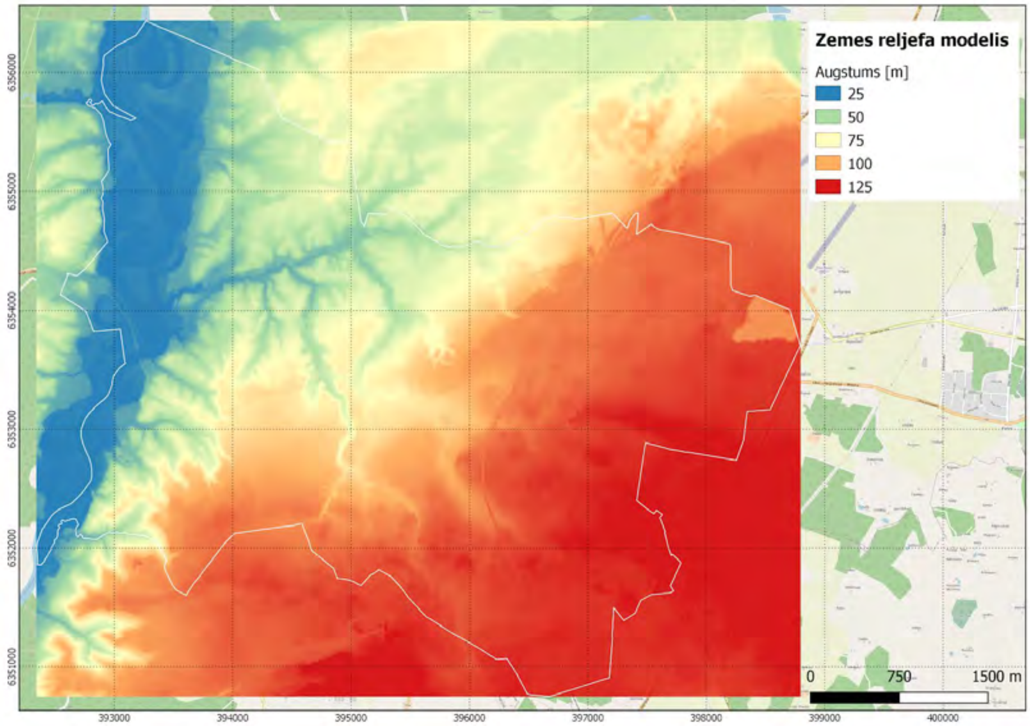


Figure 4.1. Relief model (1m/pix) for Cesis.

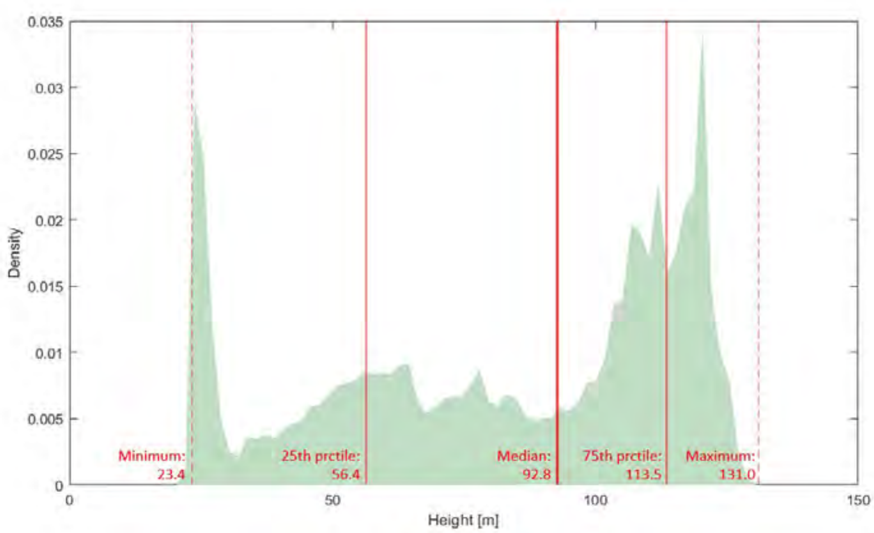


Figure 4.2. The distribution of height above the sea level in Cesis.

Relief slope model

Relief slope was calculated from the relief model using the Horn algorithm, see the result in Figure 4.3. The distribution of relief slope in Cesis is shown in Figure 4.4. Relief slope is <3.3° in most cases. Higher slope concentration could be observed in the River Gaujas valley. The relief slope is in the range of 0...78.9° with a median value of 3.3°.

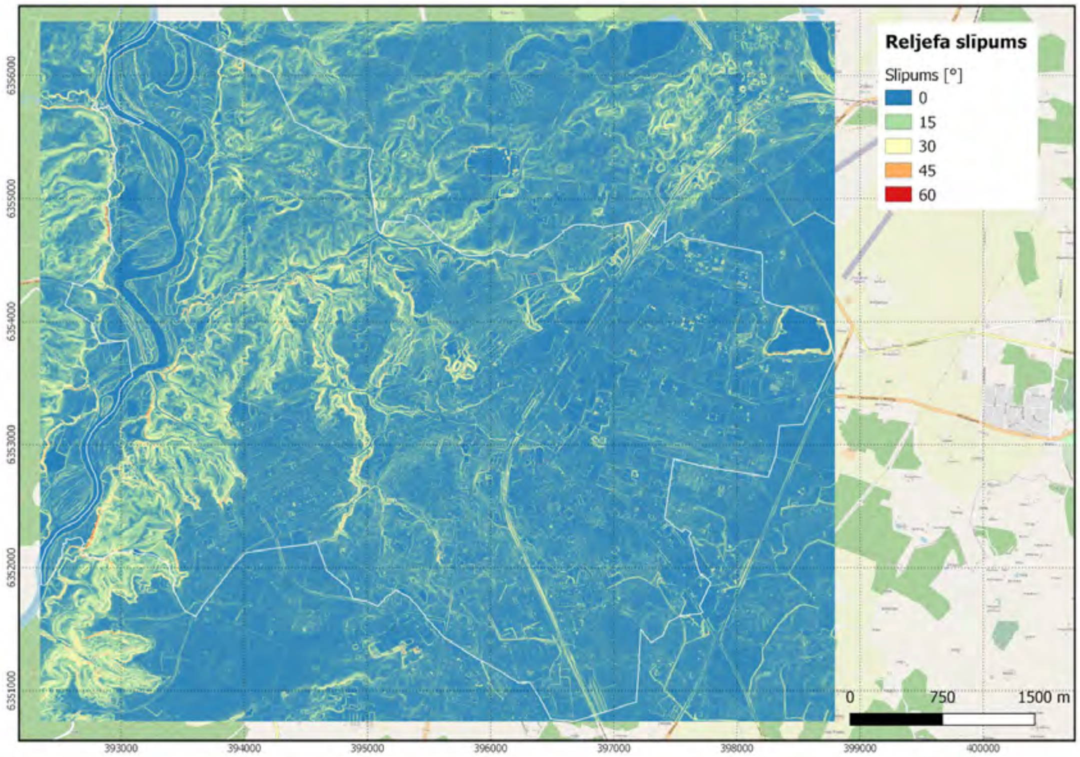
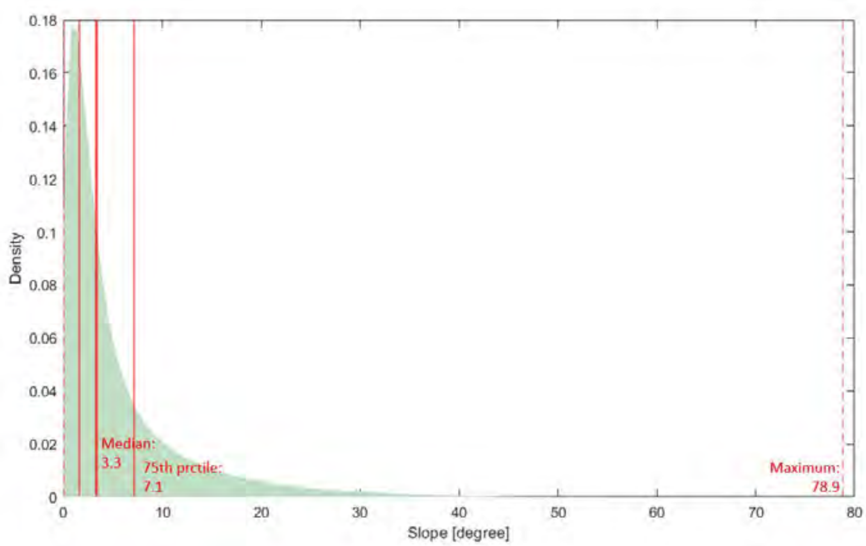


Figure 4.3. Relief slope model for Cesis with 15° step.



Attēls 4.4. Cēsu pilsētas reljefa sadalījums pēc slīpuma.

Local relief model

Local relief was calculated using mean relief value in 100 m radius as a reference, see the result in Figure 4.5. Positive values correspond to local hills but negative values to local valleys. Local relief model is useful for mapping of small watercourses in the territory.

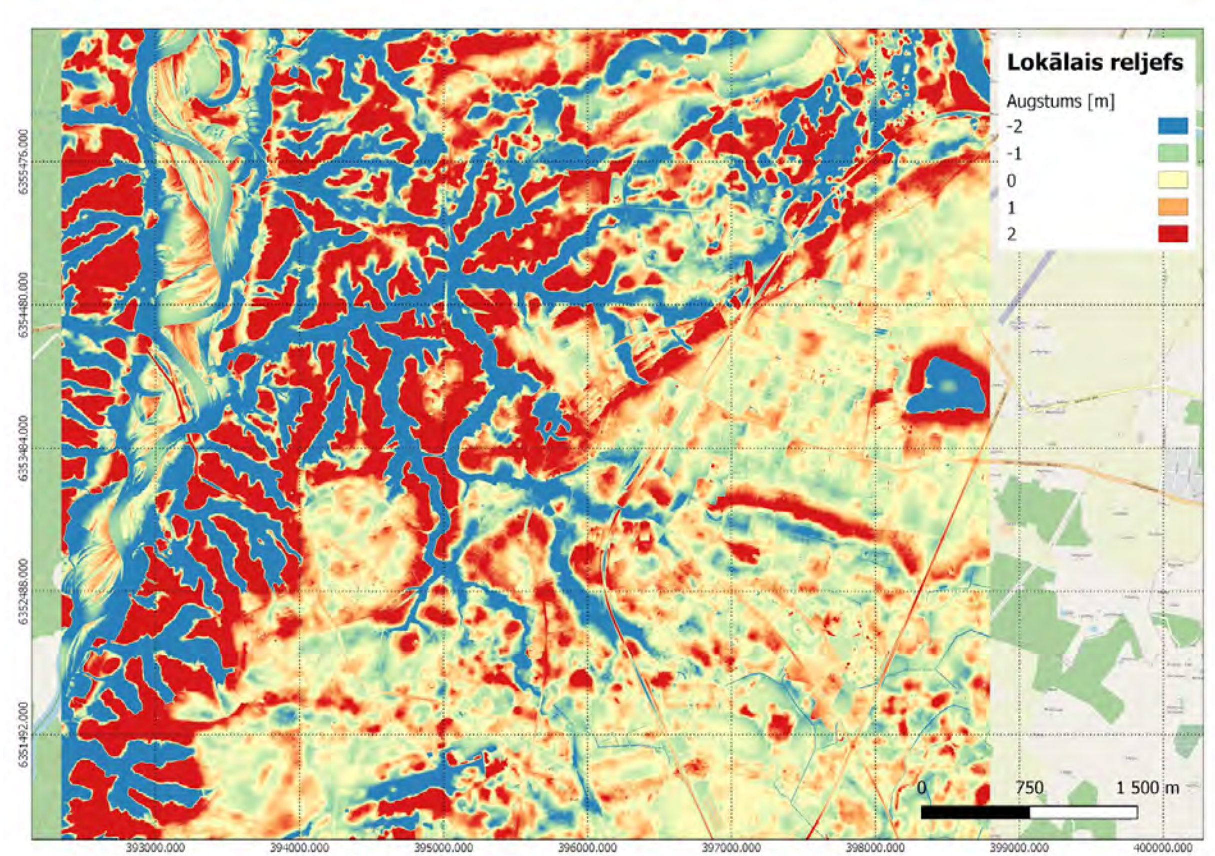


Figure 4.5. Local relief model for Cesis.

5. Object height model and classification

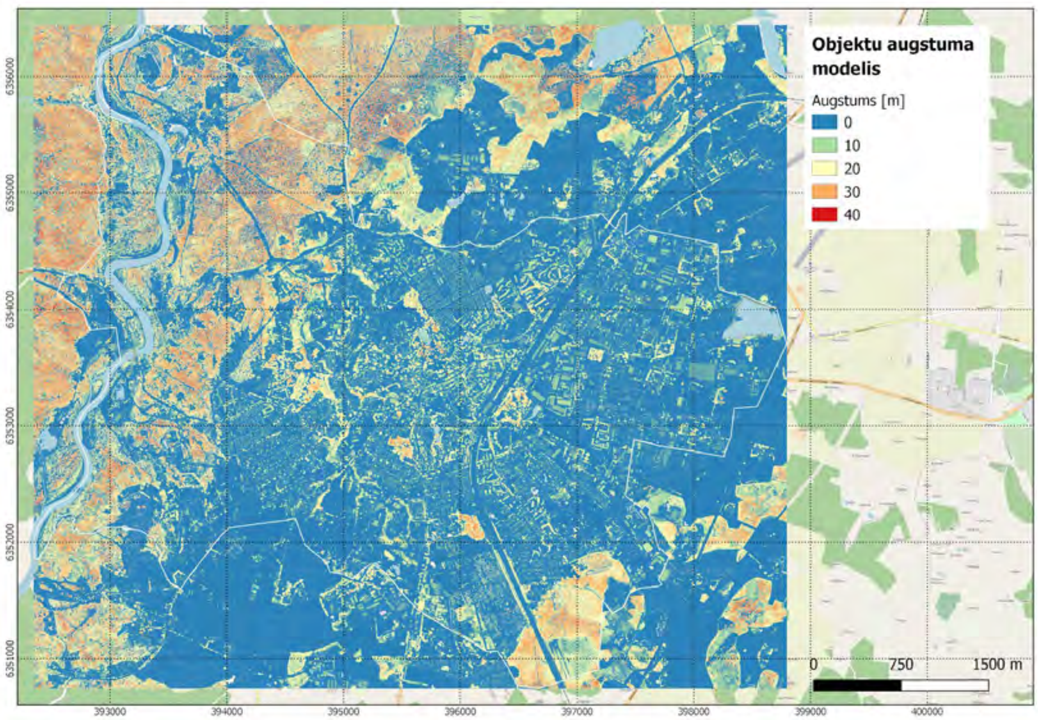
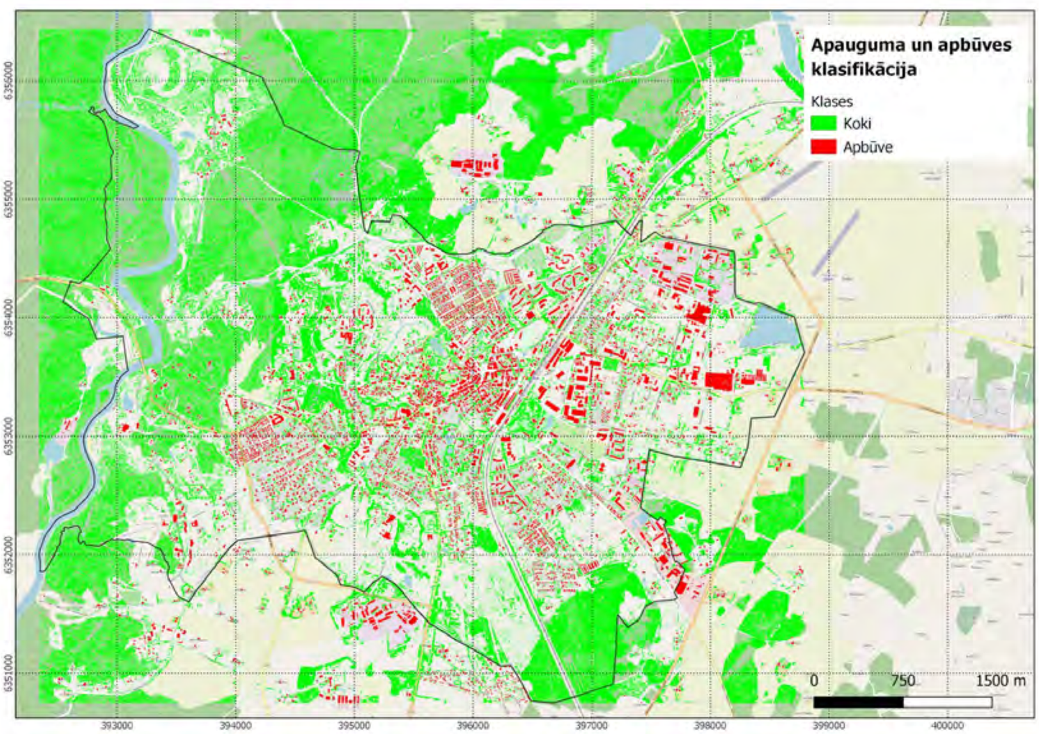


Figure 5.1. Object height model for Cesis.



Attēls 5.2. Object height model classification into trees and buildings.

Object height model is obtained by subtracting the relief model from the surface model (both obtained from laser scanning data), see the result in Figure 5.1. Further classification is performed by dividing high objects into trees and buildings, see the result in Figure 5.2. It was observed that most buildings are in height below 6,3 m that corresponds to one- or two-floor houses, see the distribution of building heights in Figure 5.3. The distribution of tree heights is multimodal with pikes at ~4 m and 14...25 m, see Figure 5.4.

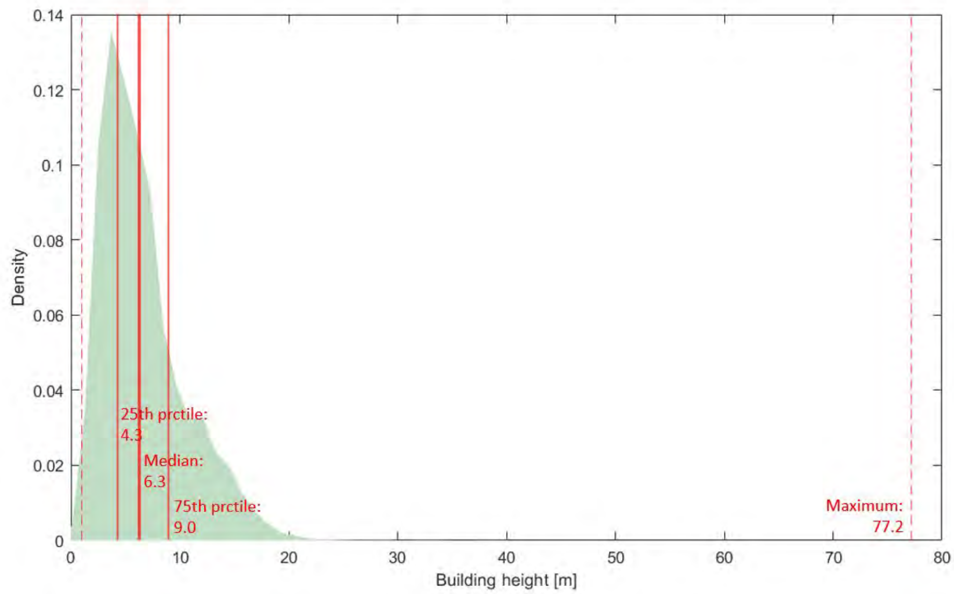


Figure 5.3. The distribution of building heights in Cesis.

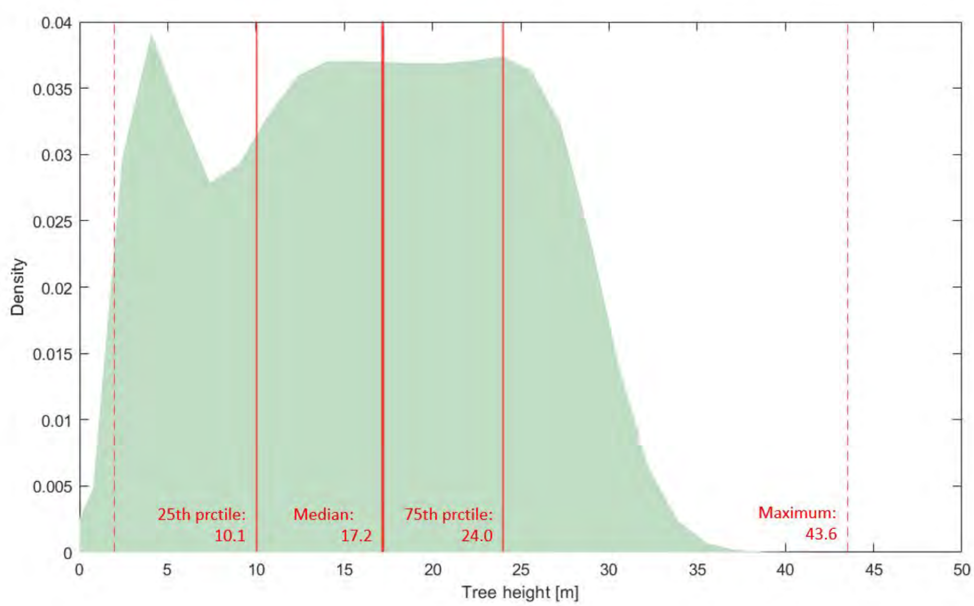


Figure 5.4. The distribution of tree heights in Cesis.

Tree canopy density

Tree canopy density represents tree canopy cover in a certain area (10 m radius) and is obtained from the tree classification layer, see the result in Figure 5.5. The threshold of 75% tree canopy density is used for forest boundary assessment in biotope mapping.

Figure 5.5. Tree canopy density for Cesis.

6. High-resolution orthophoto from 2020

Aerial data acquisition over Cesis territory was performed in 29-05-2020. Orthophoto mosaic with a spatial resolution of 10 cm/pix was created from obtained aerial images, see insight in Figure 6.1.

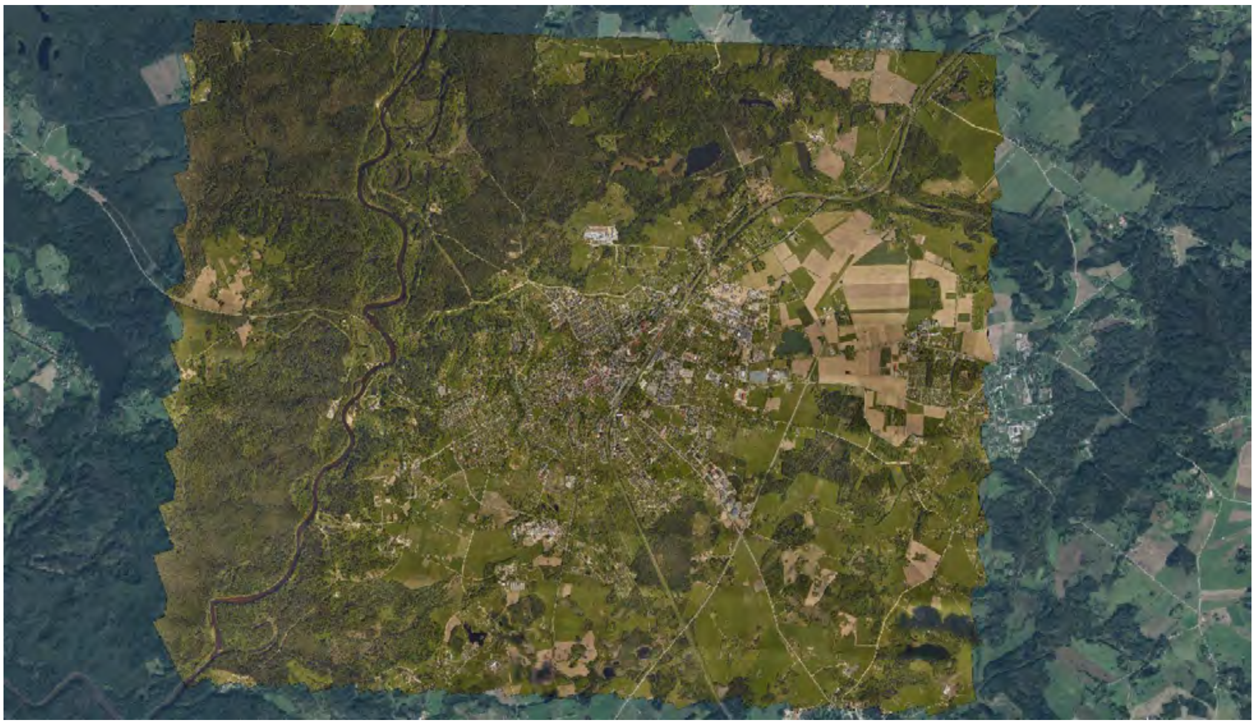


Figure 6.1. High-resolution (10 cm/pix) orthophoto mosaic for Cesis from 29-05-2020.

Prepared data products

Prepared and delivered data products correspond to their visualisations in data analysis report (figure numbers):

- ***11a_A_ndvi_max.tif*** - Vegetation maximal intensity for Cesis obtained from three airborne (ARSENAL) spectral datasets (2014-2018), see Figure 1.1.
- ***11b_A_ndvi_max_class.tif*** - Vegetation maximal intensity classification in 5 classes for Cesis obtained from three airborne (ARSENAL) spectral datasets (2014-2018) (see Figure 1.1) where values correspond:
    - 4 - NDVI > 0,75 - very dense vegetation;
    - 3 - NDVI 0,5...0,75 - dense vegetation;
    - 2 - NDVI 0,25...0,5 - sparse vegetation;
    - 1 - NDVI 0...0,25 - very sparse vegetation;
    - 0 - NDVI < 0 - bare soil or water.
- ***12a_S2_ndvi_max.tif*** - Vegetation maximal intensity for Cesis obtained from Sentinel-2 satellite spectral data (2016-2020), see Figure 1.2.
- ***12b_S2_ndvi_max_class.tif*** - Vegetation maximal intensity classification in 5 classes for Cesis obtained from Sentinel-2 satellite spectral data (2016-2020) (see Figure 1.2) where values correspond:
    - 4 - NDVI > 0,75 - very dense vegetation;
    - 3 - NDVI 0,5...0,75 - dense vegetation;
    - 2 - NDVI 0,25...0,5 - sparse vegetation;
    - 1 - NDVI 0...0,25 - very sparse vegetation;
    - 0 - NDVI < 0 - bare soil or water.
- ***13a_S2_ndvi_min.tif*** - Vegetation consistency for Cesis obtained from Sentinel-2 spectral data (2016-2020), see Figure 1.3.
- ***13b_S2_ndvi_min_class.tif*** - Vegetation consistency classification in 5 classes for Cesis obtained from Sentinel-2 spectral data (2016-2020) (see Figure 1.3) where values correspond:
    - 4 - NDVI > 0,75 - very dense vegetation;
    - 3 - NDVI 0,5...0,75 - dense vegetation;
    - 2 - NDVI 0,25...0,5 - sparse vegetation;
    - 1 - NDVI 0...0,25 - very sparse vegetation;
    - 0 - NDVI < 0 - bare soil or water.
- ***14a_S2_ndvi_2016_2018.tif*** - Vegetation changes 2016-2018: R - 2016, G - 2017, B - 2018, see Figure 1.4a.
- ***14b_S2_ndvi_2017_2019.tif*** - Vegetation changes 2017-2019: R - 2017, G - 2018, B - 2019, see Figure 1.4b.
- ***14c_S2_ndvi_2018_2020.tif*** - Vegetation changes 2018-2020: R - 2018, G - 2019, B - 2020, see Figure 1.4c.
- ***17_ndvi_a_2020.tif*** - Actual vegetation intensity or coefficient *a* value map, see Figure 1.7.

- ***18_ndvi_b_2016_2020.tif*** - Vegetation trend (2016-2020) or coefficient *b* value map, see Figure 1.8.
- ***21_LC_class.tif*** - Land cover classification for Cesis, see Figure 2.1.; land cover classification legend is described in Table 2.1.
- ***36_bio_val.tif*** - Mapping of biological value, see Figure 3.6.
- ***41_dtm.tif*** - Relief model for Cesis, see Figure 4.1.
- ***43_dtm_slope.tif*** - Relief slope model for Cesis with 15° step, see Figure 4.3.
- ***45_dtm_local.tif*** - Local relief model for Cesis, see Figure 4.5.
- ***51_ndsm.tif*** - Object height model for Cesis, see Figure 5.1.
- ***52_ndsm_class.tif*** - Object height model classification in buildings and trees for Cesis, see Figure 5.2; 1- tree, 2 - building.
- ***55_canopy cover.tif*** - Tree canopy density map for Cesis, see Figure 5.5.
- ***61_cesis_ortofoto_20200529.sid*** - High resolution (10cm/pix) orthophoto for Cesis from 29-05-2020, see Figure 6.1.