Senate Department
for Urban Development
and Housing

BERLIN

06.10.2 Vegetation Heights 2020

Overview

There are several Environmental Atlas topics that detail Berlin's urban development and its effects both on the residential structure and the distribution and use of non-built-up areas:

- "Actual Use of Built-up Areas" (06.01),
- "Inventory of Green and Open Spaces" (06.02),
- "Urban Structure" (06.07).

In addition to this information, the maps on "Urban Structural Density" (06.09) explore the degree of structural use.

These individual separate findings, however, only provide limited insight into the vertical extent of the natural structures in the city. For this reason, the Environmental Atlas presents the height development of buildings (Map "Building Heights" (06.10.1)) and that of vegetation (Map "Vegetation Heights" (06.10.2)) in two topics. The first joint "Building and Vegetation Heights" map (06.10) was produced in 2010, as part of a project with the Institute of Optical Sensor Systems of the German Aerospace Center (DLR). Today, an official, regularly updated 3D building model is available for Berlin's building stock, forming the basis for the "Building Heights" map (06.10.1). The "Vegetation Heights" (06.10.2) map that complements the "Building Heights" map, however, is still based on the Environment Atlas' own analysis of aerial photography data obtained during summer flights of the respective years.

Regarding Berlin's tree stock, a dataset that is based on the tree register of the Berlin Green-Space Information System (GRIS) is available. It includes roadside trees as well as trees growing in public green spaces and recreational areas (cf. Figure 1). However, this dataset does not include any trees in forest areas and on private land (incl. the green spaces managed by Berlin's housing associations). Therefore, a large part of the 'urban greenery' is actually not mapped. A city-wide analysis of remote sensing data is required to capture the 'urban greenery' in its entirety from above.

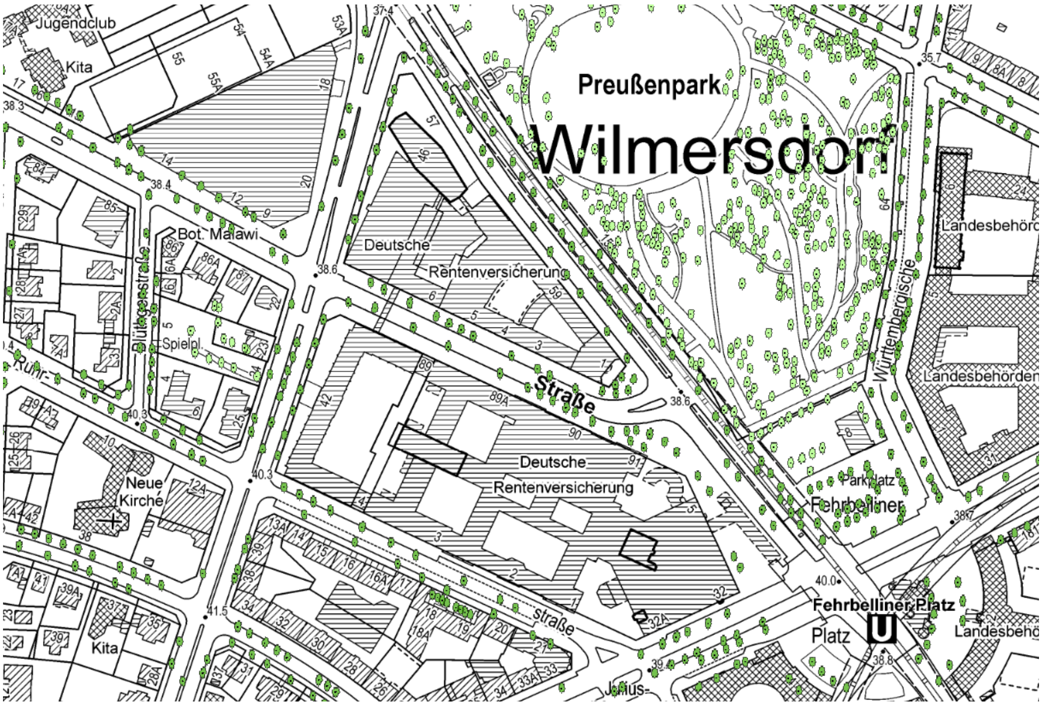

Fig. 1: Section of Berlin's tree stock, Preußenpark Wilmersdorf area, background: map of Berlin 1 : 5,000 (Source: SenStadtWohn - Geoportal Berlin, as of May 2021)

Precise and detailed information on the height and structure of vegetation areas may be important for many different use cases. The purpose of such a data base may be to provide information

- for a more precise modelling of the urban climate,
- for a more nuanced differentiation of use mappings regarding biotopes and green spaces, and
- to form a basis for deriving indicators, including the green volume number or parameters for the vegetation's capacity to form carbon.

The accuracy of each model strongly depends on the quality of the input data. For example, to enable a detailed calculation of the course of air channels and ventilation conditions, accurate information on the **aerodynamic surface roughness**, including its geometric dimensions, has to be available. Elevated objects, such as buildings or entire blocks of buildings, as well as high and dense tree structures present obstacles. They may have a wind-breaking effect or eliminate wind completely; or else these obstacles may have a channelling effect, accelerating the wind flow.

At present, the only real option of recording vegetation in detail in an area the size of Berlin is to obtain information from databases based on aerial photography, which also allows the development of urban green spaces to be observed and accounted for.

Unlike the continuously updated data base of the Official Real Estate Cadastre Information System (ALKIS) that is available for building objects, the analysis of vegetation heights in Berlin is dependent on the 5-year intervals of the high-resolution summer aerial photography flights of the geotopography and its products (only in German, cf. Methodology). This 5-year interval, however, is deemed sufficient for the identification of trends and developments.

This map updates the vegetation height mapping based on the aerial photography flights in 2009/ 2010. This update included switching to a grid-based object reference system to simplify future updates, among other things, as well as a change analysis.

Statistical Base

Surface and Terrain Models

- Image-based Digital Surface Model (iDSM, *German: bDOM*), aerial photography flights on August 1, 8, 12 and 16, 2020 (SenStadtWohn 2021d)
- Image-based Digital Surface Model (DSM, *German: DOM*), aerial photography flights in 2009/ 2010 (DLR 2013b)
- ATKIS DTM1 2021– Digital Terrain Model (*German: DGM*), aerial photography flights on February 24-25 and March 2, 2021 (SenStadtWohn 2021c)

Geo Base and Planning Data

In addition to the surface and terrain models mentioned above, the following vector data was available as statistical block and block segment areas as well as building and roadside tree data for the entire urban area of Berlin:

- Official Real Estate Cadastre Information System (ALKIS), building and structure level, as of September 6, 2021 (SenStadtWohn 2021a)
- Berlin's stock of trees (roadside trees and trees in parks/ recreational areas), as of May 11, 2021 (SenStadtWohn 2021b)
- Block (segment) area map 1 : 5,000 of the Urban and Environmental Information System (ISU5), as of December 31, 2020 (SenStadtWohn 2020a)
- Non-ALK buildings, as of May 2012 (DLR 2013b)
- Open Street Map building data, as of November 23, 2021 (OSM 2021)
- 3D building models in Level of Detail 2 (LoD 2), as of March 1, 2019 (SenStadtWohn 2019)

The ISU5 block (segment) area map constitutes the reference geometry for recording the objects to be identified and their heights. There are about 26,000 block (segment) areas in the urban area. The extracted objects are intersected with the block keys based on their unique object key, so that each individual object is not only associated with its exact location, but also its block (segment) area and borough number (cf. Figure 2).

Orthophotos

- Digital colour infrared true orthophotos (TrueDOP20CIR), aerial photography flights on August 1, 8, 12 and 16, 2020 (SenStadtWohn 2020)
- Digital colour infrared orthophotos (DOP20CIR), aerial photography flights on July 21 and August 21, 2010 (SenStadt 2011a)

Fig. 2: Section of the geo base data and factual data used: ALKIS building layer (red), ISU5 block (segment) borders (yellow), roadside trees/ objects (dark green), trees/ objects in parks or recreational areas (light green) with the true orthophotos from 2020 in the background (Source: SenStadtWohn - Geoportal Berlin)

Methodology

Approach

The process for determining the vegetation height is based on a complex workflow, which is presented here only as a rough overview. Please refer to the project report (only in German) for more details regarding each step.

When updating the dataset to the version of 2020, the entire procedure was switched from object-based sectioning (aerial photography flights in 2009/ 2010) to grid-based sectioning. This is, first and foremost, advantageous with regard to the size and completeness of the dataset and therefore its suitability for further processing. Using this method, the 2010 dataset could also be reclassified and recalculated. The two periods could therefore be compared without methodological discrepancies while also minimising potential errors. As mentioned above, the calculations of the 2010 dataset were based on image-based digital surface models from aerial photography flights in 2009 and 2010. This document, however, only indicates the year 2010 as the reference year for the mapping. This is the case as the colour-infrared orthophotos from aerial photography flights in 2010 form the main source for the vegetation index calculations.

Data Processing (DSM)

Before vegetation heights may be recorded, information on heights needs to be derived from the true orthophotos in a digital surface model first. The processing of the **image-based Digital Surface Model (iDSM)** is based on stereo photography. Orientation parameters are used to link the individual, generously overlapping, aerial photographs together via tie points. They are then joined together to form a cohesive image and transferred to the required coordinate system at the same time (Kraus 2004).

The iDSM provides coded elevations of the earth's surface including all objects located on it (buildings, roads, vegetation, etc.). This is achieved by adding the terrain elevation to the height of the object. Berlin's terrain elevation is inconsistent, despite rather small differences in topography (ranging from

~35 m to ~100 m above sea level). The absolute height of an object may therefore not be established reliably at this point. A **normalised digital surface model (nDSM)** is required for this, i.e. the terrain needs to be set to zero for the entire model. An nDSM is thus generated by subtracting the **Digital Terrain Model (DTM)** from the digital surface model (DSM):

nDSM = DSM - DTM

With regard to the subsequent classification, this simplifies the distinction between elevated and non-elevated objects and ensures the direct measurement of object heights. It permits the differentiation of roads, elevated vegetation and buildings and provides precise information on heights (cf. Figure 3).

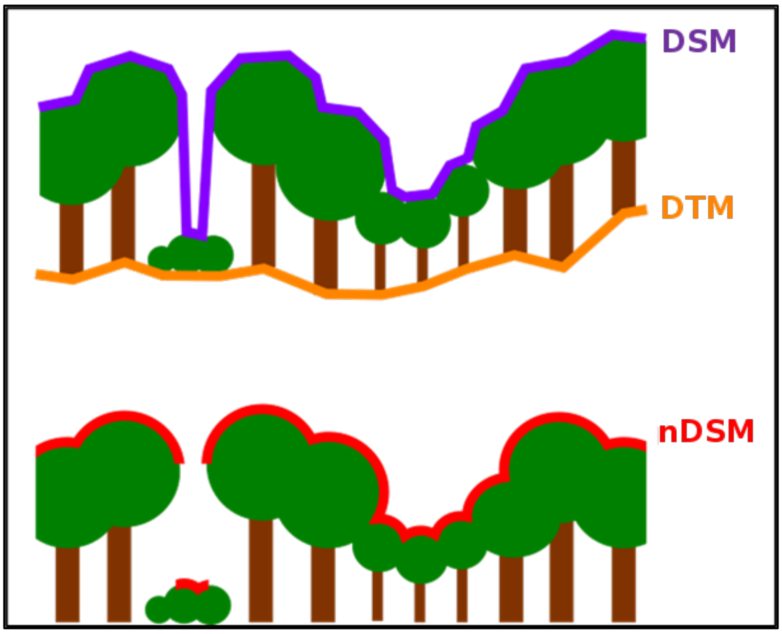

Fig. 3: Principle for generating a normalised Digital Surface Model (nDSM)
(Source: 2021 LUP)

Calculation of the NDVI

The Normalised Difference Vegetation Index (NDVI) may be calculated based on the generated true orthophotos. Using the characteristic reflective properties of plants in the spectrum of red and near-infrared wavelengths, this index may be used to identify the density and intensity of vegetation in a grid-based dataset. The NDVI is calculated from the quotient of the difference and the sum of the near-infrared channel (NIR) and the visible red channel (R) (Rouse et al. 1974):

NDVI = (NIR – R) / (NIR + R)

The NDVI ranges from -1 to 1. The higher the value, the higher the amount of green vegetation present (cf. Figure 4).

Fig. 4: top: 2020 true orthophoto, bottom: NDVI, normalised vegetation index, on the left: JVA Moabit (former prison facility) (Source: SenStadtWohn – Geoportal Berlin)

Development of the Vegetation Inventory

Supervised classification of CIR-True-Orthophotos

The true orthophotos from 2020 were classified to delineate areas with vegetation from those without. For this purpose, training areas were manually sorted into land cover categories on screen and thus digitised. The classification contained the following categories: “areas without vegetation”, “low-growing vegetation” and “high vegetation”. Due to the prolonged summer drought in 2020, large areas with low-growing vegetation (predominantly meadows) withered. The additional category of “low-growing vegetation, withered” was therefore included.

Based on these training areas, a supervised classification of the entire mosaic could be carried out using a machine learning algorithm (RandomForest, cf. Breiman 2001).

Establishing a rule base and deriving vegetation heights for 2010 and 2020

Five smaller sample areas were selected to further develop the process (cf. Figure 5). These sample areas met the following criteria:

- distributed across the urban area with varying urban and vegetation structures:
    - heterogeneous inner-city location,
    - forest area,
    - transition from forest to residential area,
    - transition from forest area to body of water,
    - agricultural structure on the periphery,
- deviating topography.

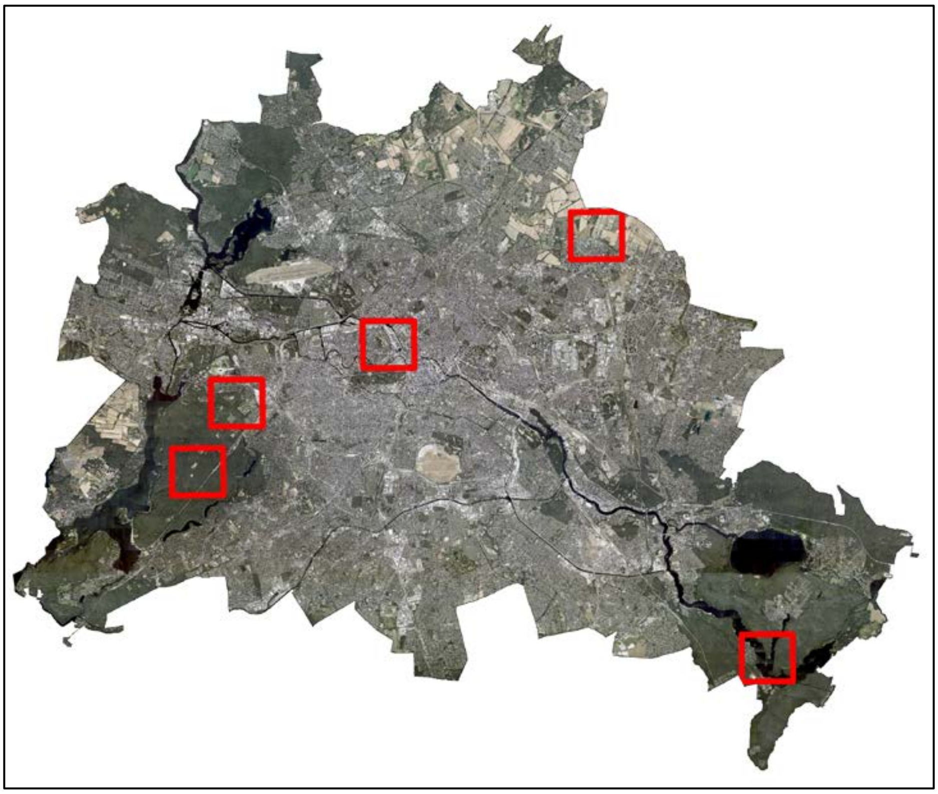

Fig. 5: Location of the sample areas used for method development, background: true orthophotos from 2020 (Source: 2021 LUP)

A rule base for differentiating 5 classes that distinguish between different types of changes that have occurred since 2010 was established with the help of the sample areas to prevent errors as much as possible during the analysis phase. This was necessary as the true orthophotos of the 2009 and 2010 aerial photography flights were not available. The existing data could therefore not be reclassified directly. Digital orthophotos (DOP) from 2010 and the nDSM from 2010 were used instead, as well as vegetation sections from the 2010 mapping.

The rule base defines queries regarding the vegetation sections from the 2010 mapping, the NDVI in 2010 and 2020, any ALK or ALKIS and OSM buildings at the relevant times, as well as the normalised surface height (see the project report for more details, only in German).

Following these rules, the following 5 classes are created, forming the grid of thematic changes:

- Class 1: Vegetation sections are missing mistakenly in 2010, vegetation is still present in 2020,
- Class 2: Vegetation is present in 2010 and 2020,
- Class 3: Vegetation is present in 2010 but not in 2020,
- Class 4: Vegetation is present in 2020, no vegetation in 2010,
- Class 5: Vegetation sections are missing mistakenly in 2010, no vegetation in 2020.

Using the grid of thematic changes, vegetation heights were derived from the respective nDSM at a grid resolution of 1 x 1 m² for both 2010 and 2020.

Calculation of vegetation heights and shares at block (segment) area and road level

For all block (segment) areas and road sections of the 2020 ISU5, a zonal analysis (zonal statistics) was carried out to calculate the mean, maximum, minimum and median of the vegetation heights based on the two vegetation height grids. Furthermore, the vegetated area within a block (segment) area (in percent) was determined for both years.

The data display in the FIS Broker includes the following information on the block (segment) area or road area that has been selected:

Tab. 1: Attribute label and factual data display of the 2020 Vegetation Heights dataset	
Attribute label	**Description**
ANTEIL_OEFF_BAUM2020	Area share (%) of the road section that contains trees from the tree register
ANTEIL_VEG_2010	Area share (%) covered with vegetation (2010)
ANTEIL_VEG_2020	Area share (%) covered with vegetation (2020)
change_anteil	Change in the above shares between 2010 and 2020 (2010 minus 2020)
MAX_OEFF_BAUM2020	Maximum height (m) of trees in the tree register within a road section (2020)
MAX_VEGH_BL2010	Maximum height (m) of vegetation (2010)
MAX_VEGH_BL2020	Maximum height (m) of vegetation (2020)
MEAN_OEFF_BAUM2020	Average height (m) of trees in the tree register within a road section (2020)
MEAN_VEGH_BL2010	Average height (m) of vegetation (2010)
MEAN_VEGH_BL2020	Average height (m) of vegetation (2020)
MED_VEGH_BL2010	Median height (m) of vegetation (2010)
MED_VEGH_BL2020	Median height (m) of vegetation (2020)
MIN_VEGH_BL2010	Minimum height (m) of vegetation (2010)
MIN_VEGH_BL2020	Minimum height (m) of vegetation (2020)

Tab. 1: Attribute label and factual data display of the 2020 Vegetation Heights dataset

Map Description

The classification process was carried out for the entire mosaic of the 2020 true orthophotos. Figure 6 presents a section of the result of the classification in the Großer Tiergarten area.

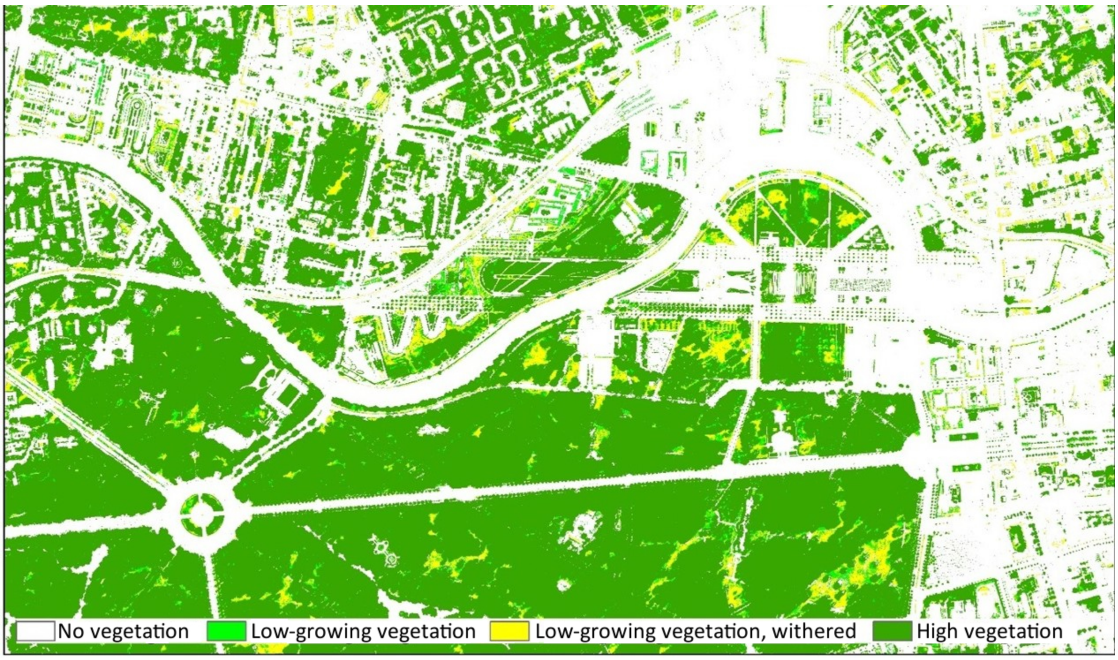

Fig. 6: Section of the result of the classification in the Großer Tiergarten area

Some 56,000 ha of the entire urban area are covered with vegetation. For a total area of about 89,100 ha, this corresponds to a percentage of approx. 63 %. It is important to note here that the vegetation is analysed in plan view, due to the use of remote sensing data. This means that areas covered with vegetation also include areas that are impervious underneath the vegetation cover, e.g. yards that are covered with trees but are largely paved. Areas covered with vegetation are therefore not the same as vegetated soil.

A comparison with the area sizes of those block (segment) areas that have been categorised as purely green and open space use in the Urban and Environmental Information System (ISU) (Map "Inventory of Green and Open Spaces" (06.02), Tab 2, SenStadtWohn 2020b) shows that about 19,000 ha of vegetated areas are located outside the "traditional" green spaces, i.e. on road areas and in areas associated with structural uses. This accounts for roughly 54% of the total of 35,000 ha of green and open spaces according to the 2020 ISU and illustrates the **substantial resources of urban green space in Berlin's residential areas, but also in other built-up areas of the city**.

Comparing the absolute sizes of areas covered with vegetation in the 12 boroughs of Berlin, it is evident that the largest such areas are also found in the boroughs with the largest total area that are located outside the City Rail Circle Line. These boroughs contain large forest areas, e.g. the Köpenicker Forst in Treptow-Köpenick, the Bucher Forst in Pankow, the Spandauer Forst in Spandau, the Tegeler Forst in Reinickendorf and the Grunewald in Steglitz-Zehlendorf and Charlottenburg-Wilmersdorf (cf. Figure 7, sorted according to the borough numbering system based on the *Verwaltungsgliederung* (administrative division) of Berlin.).

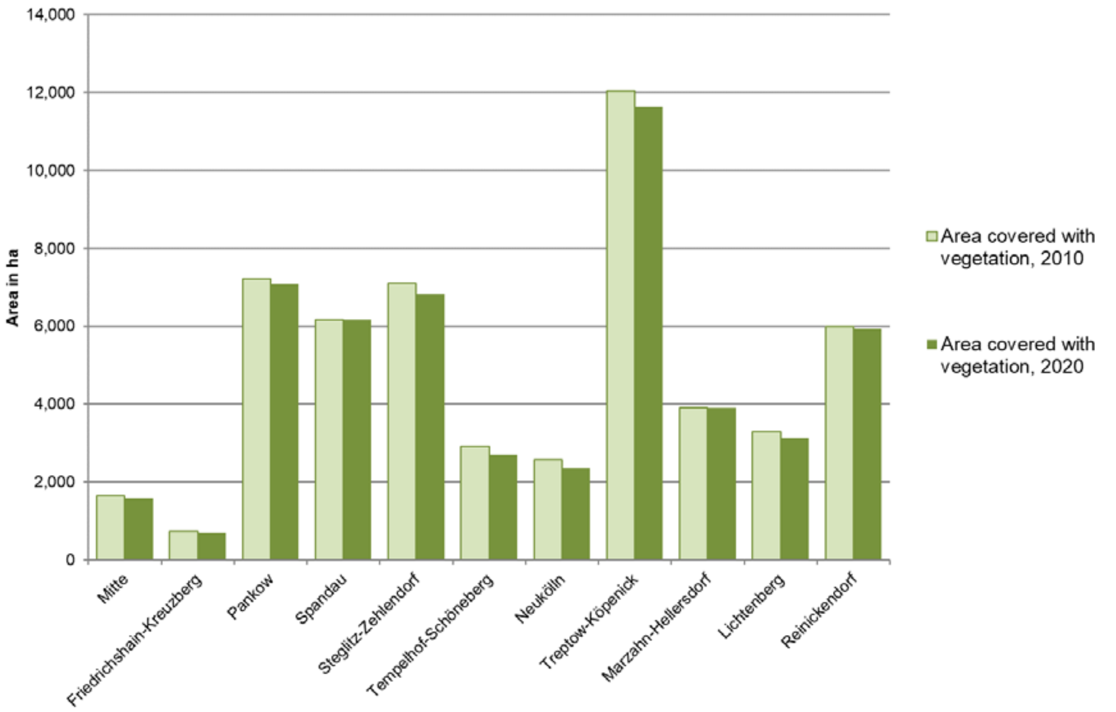

Fig. 7: Absolute sizes of areas covered with vegetation in the 12 boroughs of Berlin in 2010 and 2020

The distribution (in percent) of vegetated areas in Figure 8 reveals that more than 50 % of almost all boroughs are covered with vegetation. Again, it should be noted that the area covered with vegetation was recorded in plan view and is not the same as pervious, vegetated soil. The area covered with vegetation drops below 40 % only in the inner city boroughs of Friedrichshain-Kreuzberg and Mitte.

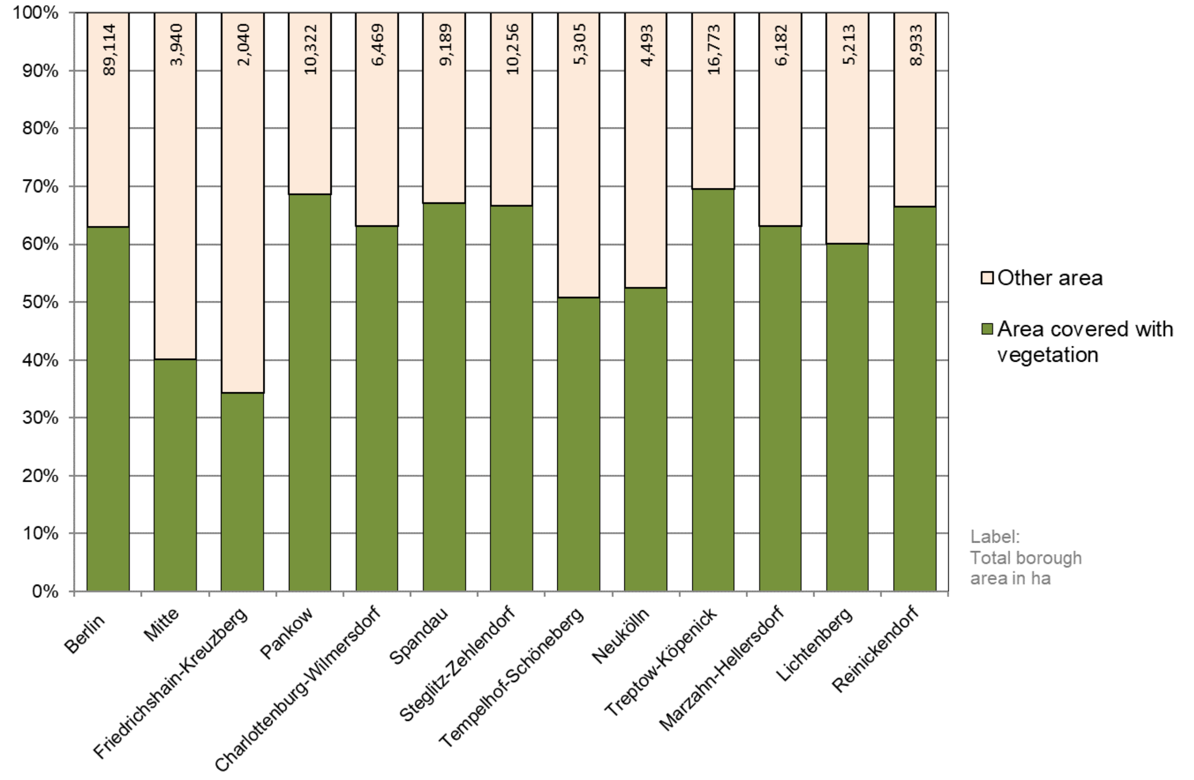

Fig. 8: Distribution (in percent) of the area covered with vegetation in the 12 boroughs of Berlin (as of August 2020)

It is worth noting that even in the inner city, not all areas are densely built-up and impervious. On the contrary, the old Wilhelminian quarters – in this case north and south of the former Görlitz railway station – often feature rather generous greenery in private or semi-public areas, with very old trees in some areas. It emerges that, after 1918, open spaces became more important also in residential areas, at least in some parts of the inner city (cf. Figure 9).

This effect is even more pronounced in estates for which a “lose development interspersed with yards” was chosen as the construction style. Figure 10 illustrates this effect using two examples on the outskirts of the city centre, the “Neu-Tempelhof” estate and the row development with landscaped residential greenery south of “An der Wuhlheide” street in the borough of Treptow-Köpenick.

Fig. 9: Results of the classification in Berlin's inner city: dense, highly impervious inner-city development on both sides of Friedrichstraße (left) and Wilhelminian block development with a high share of greenery in the area of Görlitzer Park (right)

Fig. 10: Results of the classification in the area of loose, very green development on the edge of the inner city (inside the City Rail Circle Line): row houses and duplexes with yards in "Neu-Tempelhof" (left) and row development with landscaped residential greenery south of "An der Wuhlheide" in Treptow-Köpenick (right)

The chosen classification showcases the (height) structure in the parks such as the Großer Tiergarten, the green spaces of the Gleisdreieck or the Görlitzer railway station rather impressively. Area shares occupied by meadows may be easily distinguished from areas with higher vegetation types and those with trees. This applies similarly to forests and forest-like stands of trees.

Results of the change analysis

The total vegetation area in the entire urban area of Berlin amounted to 56,259 ha in 2020. This corresponds to 95.5 % of the total vegetation area of 58,907 ha that was still present in 2010 (cf. Table 2).

Tab. 2: Shares of the change classes (in %) in relation to the total area covered with vegetation in Berlin, compared to the year 2010 (as of August 2020)		
Total vegetation area unchanged between 2010 and 2020 (classes 1, 2)	55,333 ha	93.9 %
Vegetation area, new in 2020 (class 4)	926 ha	1.6 %
Total of vegetation area loss between 2010 and 2020 (classes 3, 5)	3,574 ha	6.1 %
Total of vegetation areas, 2020 (classes 1, 2, 4)	56,259 ha	**95.5 %**
Total of vegetation areas, 2010 (classes 1, 2, 3, 5)	58,907 ha	**100 %**

Tab. 2: Shares of the change classes (in %) in relation to the total area covered with vegetation in Berlin, compared to the year 2010 (as of August 2020)

Class description:

- *Class 1: Vegetation not recorded in the initial analysis of 2009/ 2010, still present in 2020,*
- *Class 2: Vegetation present in 2010 and 2020,*
- *Class 3: Vegetation present in 2010, no vegetation in 2020,*
- *Class 4: Vegetation recorded in 2020, no vegetation in 2010,*
- *Class 5: Vegetation not recorded in the initial analysis of 2009/ 2010, no vegetation in 2020.*

Overall, this means that the total area covered with vegetation in Berlin decreased by 2,648 ha between 2010 and 2020. This value represents both a loss of 3,574 ha (6.1%) of vegetation areas that were still present in 2010 and a gain of 926 ha (1.6%) of areas that were not yet vegetated in 2010. The total loss of vegetation areas that no longer exist corresponds to approximately 12 times the size of the Großer Tiergarten, i.e. a sizable area.

93.9 % of the area covered with vegetation in the reference year of 2010 remains a vegetation area in 2020. This corresponds to a vegetation area of 55,333 ha that remains unchanged.

The shares of specific vegetation height groups of the total vegetation area hardly changed between 2010 and 2020. Figure 11 shows the distribution for 2020. More than one third of the area is occupied by low-growing vegetation < 1 m.

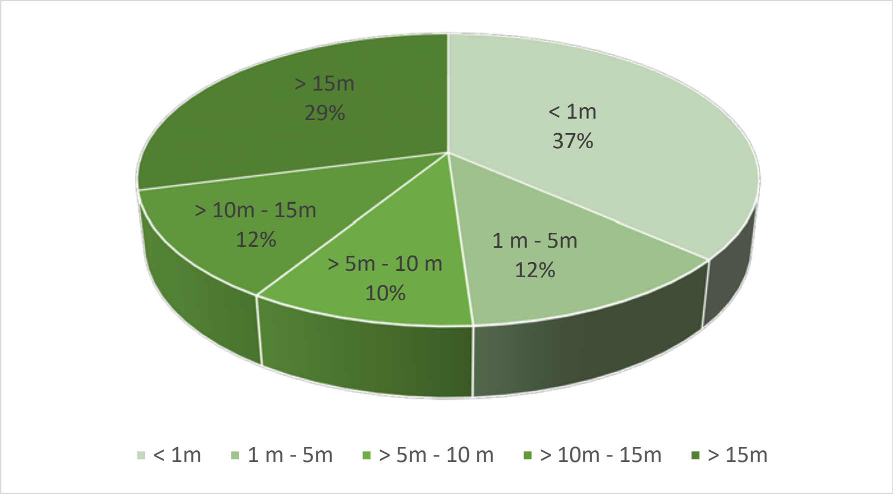

Fig. 11: Shares of vegetation heights of the total vegetation area in Berlin in 2020

Considering the change in the vegetation area share at the block (segment) area level, areas with increased construction activity and densification within blocks are clearly discernible (cf. Figure 12). These areas are distributed across the entire urban area.

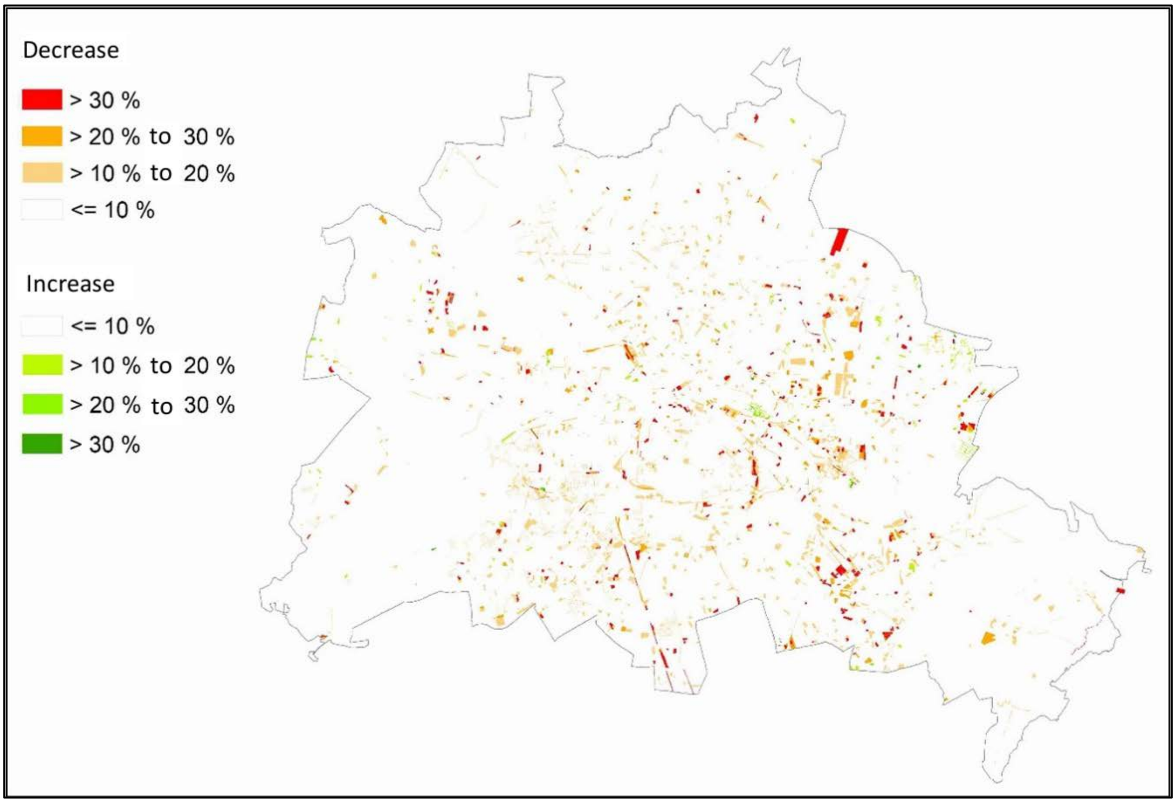

Fig. 12: Changes in the vegetation area shares (in %) of the block (segment) areas between 2010 and 2020

Taking a look at the change in vegetation height at grid level (cf. Figure 13), it becomes apparent that forest areas, too, experienced considerable decreases in vegetation height. There does not seem to be a simple answer as to what caused this. Rather, it may be assumed that there were various influences at play at the same time. On the one hand, mature trees dying as a result of the dry summers may have been an influencing factor. On the other hand, consequences associated with human intervention, including the use of wood and the effects of the *Mischwaldprogramm der Berliner Forsten* (mixed forest programme of the Berlin Forests, only in German) to produce resistant forests with a large variety of species may have had a serious impact.

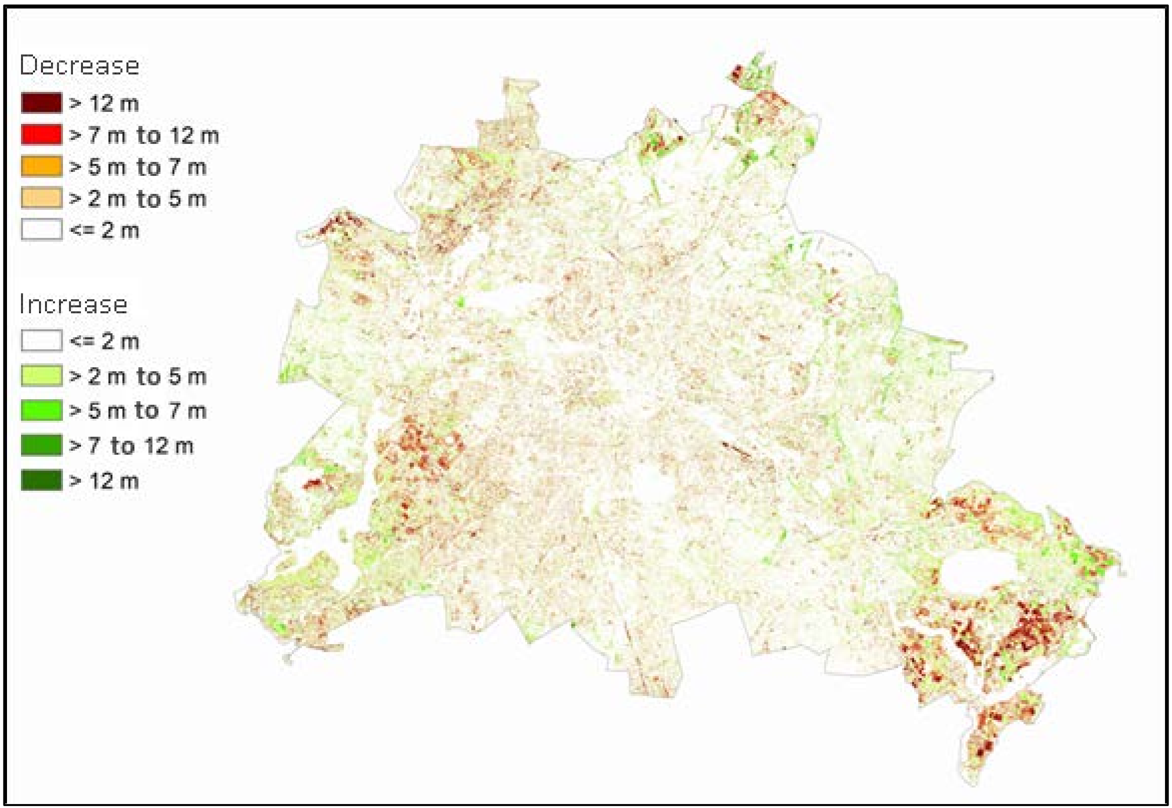

*Fig. 13: Changes in vegetation height in metres at grid level (1*1 m²) between 2010 and 2020*

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