ASITIS UpGreen

Greenery audit

Copenhagen

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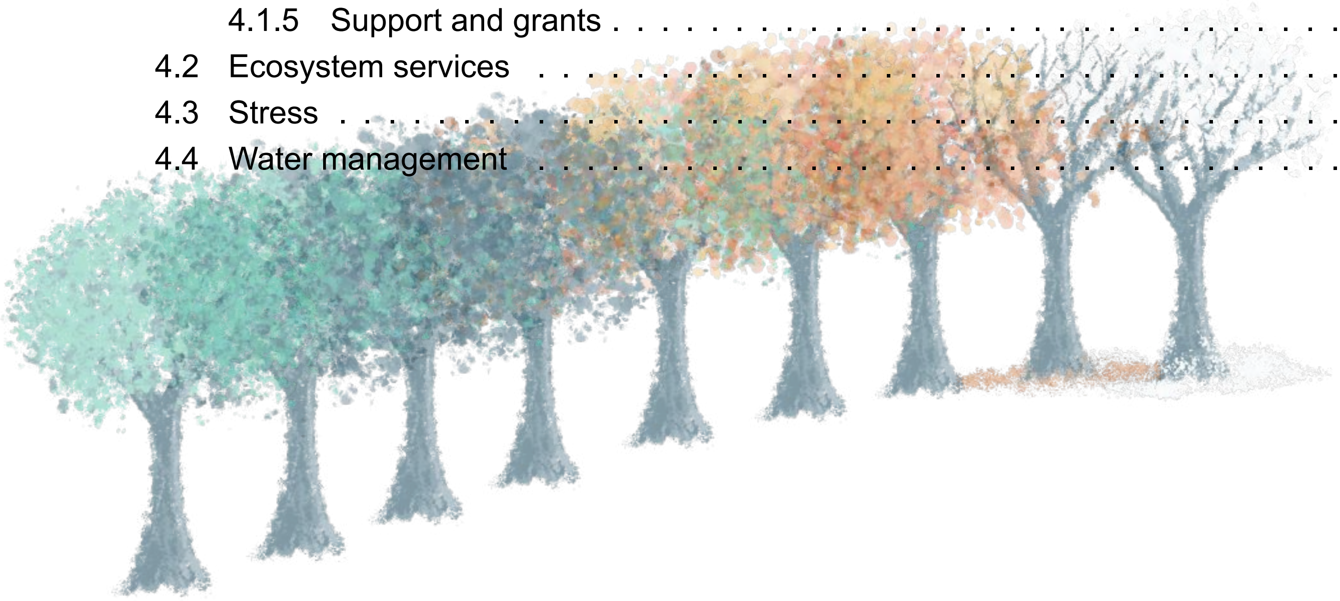

Introduction

Climatic conditions: current state and future scenarios

The City of Copenhagen, located on the eastern coast of Denmark, lies within a temperate maritime climate zone, characterised by mild temperatures, moderate rainfall, and relatively small seasonal temperature variations. The average annual temperature in Copenhagen is approximately 9.1°C. Winters are cool, with average January temperatures of around 1.4°C, while summers are mild to warm, with July averages typically around 18°C and average daily maxima around 21-22°C.[1]

Annual precipitation in Copenhagen averages about 646 mm, with rainfall fairly evenly distributed throughout the year. However, the city tends to experience higher rainfall during July to October, with occasional dry spells in spring and early summer.[2] Copenhagen is less prone to prolonged dry periods compared to other European cities, although some dry spells may occur, especially during warmer months.

Regarding future climate scenarios, Copenhagen, like the rest of Denmark, is expected to experience rising temperatures, shifting precipitation patterns, and a higher frequency of extreme weather events. According to projections from the Danish Meteorological Institute (DMI) and the Danish Energy Agency (DEA), average temperatures in Copenhagen are expected to rise by 1°C by mid-century and by more than 3°C by the end of the century under high-emission scenarios.[3] This will likely result in warmer summers, with more frequent days exceeding 25°C, and milder winters with fewer frost days. Projections also indicate an increase in heavy rainfall events and intense storms, potentially leading to localised flooding, with summers experiencing more frequent dry spells.

The primary climate-related challenges for Copenhagen will include a higher frequency of warm days, extended dry periods during summer, and increased risk of localised flooding due to heavy rainfall events. To ensure a liveable and sustainable environment, Copenhagen should prioritise the planting of drought-tolerant, heat-resilient plant species, alongside implementing effective water management strategies for green spaces and urban planning.

[1] https://www.dmi.dk/fileadmin/Rapporter/2021/DMIRep21-02.pdf
[2] https://www.dmi.dk/fileadmin/Rapporter/2021/DMIRep21-02.pdf
[3] https://climateknowledgeportal.worldbank.org/country/denmark/climate-data-projections

UpGreen methods

Segmentation

Based on the infrared component of the light spectrum corresponding to the presence of chlorophyll, tree crowns are identified using machine learning (U-Net Neural Networks). Subsequently, only crowns larger than 30 m^2 are filtered. If a digital surface and terrain model is available, shrubs with a height of less than 5 m are filtered out.

Productivity

Productivity reflects the amount (concentration) of chlorophyll in each tree crown. The primary function of this green pigment in leaves is photosynthesis, i.e., the conversion of atmospheric inorganic carbon into organic carbon compounds — sugars. These sugars are then used by the tree for building its tissues or as an energy reserve. A tree with low chlorophyll photosynthesizes less and thereby loses its essential ecosystem functions: carbon sequestration, cooling effect, and consequently, its aesthetic function. It either does not grow or grows very little, lacks sufficient reserves, and is therefore significantly more vulnerable in the case of extreme weather fluctuations.

Another important function of chlorophyll is protecting tissues from stressors, such as oxidative stress, helping regulate leaf temperature by reflecting radiation, or synthesizing other protective substances.

Productivity thus combines information about acute stress, leaf quantity, and their health status.

To assess the state of productivity, the Enhanced Vegetation Index (EVI) is used, evaluated for each tree (segment) individually. Time series of EVI are extracted from satellite data. The EVI integral between the start and end of the main growing season is then assessed. Seasonal integrals are subsequently standardized based on tree size. The resulting value indicates how green the tree is compared to other trees of the same size.

Interpretation of productivity in the analyzed city is as follows: productivity primarily indicates stress. If productivity does not align with the evaluated level of stress – i.e., a heavily stressed tree appears unusually green or a very low productive tree is not stressed – the tree should be checked by a green space management worker. Such a tree may have reduced vitality or may begin to ddecline soon.

Identified trees with reduced productivity in areas where the stress level is low (such as parks or cemeteries) are:

- Old trees,
- Trees with lowered vitality,
- Unidentified conifers,
- Cut or pruned trees.

Productivity is a dimensionless quantity, and interpreting its absolute value is meaningless. The threshold values for categorizing productivity were empirically derived based on ground measurements:

- None: < -30
- Very low: -30 - -15
- Low: -15 - -10
- Average: -10 - 10
- High: 10 - 15
- Very high: > 15

Stress

Stress refers to environmental conditions that exceed the optimal range for a given species. Plants have mechanisms to cope with short-term stress, but prolonged stress can lead to a gradual decline in vitality. Examples include drought, heat, soil salinization, air pollution, soil compaction, lack of space for root growth, permanent shading, or light pollution. All of these factors act simultaneously, and the more of them there are, the more severe the consequences can be. Combined with the fact that species are often planted in cities that have their optimal living conditions far beyond the limits of the conditions they are placed in, it naturally results in a significantly shorter lifespan.

Stress level is calculated as a composite parameter consisting of three criteria with equal weights: long-term drought stress, heat stress, and other stress sources approximated by distance from the road and traffic intensity.

Drought Stress is calculated using air humidity (VPD = Vapor Pressure Deficit), which drives the transpiration flow (and thus water loss), and precipitation levels, which serve as an estimate of water availability in the soil. All criteria are considered over the long term to assess the general conditions for a specific tree at a given location. A tree is considered stressed by drought if at least one of the following conditions is met:

- The daily maximum VPD exceeds 8 hPa at least 21 times during the growing season,
- There is at least one 14-day period without rain (precipitation <0.5 mm/day),
- The precipitation sum over the previous 30 days does not exceed 10 mm.

Heat Stress is evaluated based on surface temperature (LST = Land Surface Temperature): if LST exceeds 40 °C for at least 7 days during the main growing season, the tree is considered stressed by heat.

Distance from Road can serve as an indicator of various stress sources, such as air pollution, light pollution, insufficient space for root growth, soil compaction, water availability in the soil, soil salinization, or soil contamination with heavy metals. Three buffer zones are evaluated (10 m, 50 m, and 100 m). Each zone is checked for the presence of a road, and points are assigned according to the traffic level and zone. Each road is counted only for the smallest zone in which it is present.

The stress values are then categorized into 5 categories based on the computed index value:

- None: 0-0,75
- Low: 0,76-1,25
- Moderate: 1,26-1,75
- High: 1,76-2,25
- Extreme: >2,25

Survival capacity

The survival capacity indicates the current potential of a tree to thrive in unchanged conditions over the long term. Prolonged stress reduces vitality and shortens the tree's lifespan, while trees with already reduced vitality respond more strongly to increased stress. Therefore, this index consists of a combination of current stress factors and productivity. To minimize the risks and costs associated with tree mortality, it is advisable to focus care on individuals in the "Vulnerable" and "Endangered" categories.

The assessed categories of the survival capacity are:

- Prospering: In excellent condition, able to withstand stress and maintain productivity with minimal difficulties.
- Resilient: Has a strong ability to cope with stress and maintain function even in challenging conditions.
- Stable: Survival ability is moderate, but the individual is not in optimal conditions. It has a good chance of survival, although it may face problems.
- Vulnerable: Survival ability is low, but collapse is not imminent. Risks exist, and the individual is vulnerable to external influences.
- Endangered: Survival ability is critically low, and the risk of failure or collapse is imminent.

Carbon sequestration

Net Ecosystem Production (NEP), which indicates the total amount of inorganic carbon (in the form of CO_2) stored by a plant from the atmosphere, can be considered as an estimate of carbon sequestration when neglecting pruning, leaf fall, and harvesting. Information on the total biomass removed can be obtained from green space management.

Based on long-term measurements using the Eddy Covariance (EC) method worldwide, average NEP values can be obtained for any type of ecosystem. In UpGreen, we distinguish between coniferous and broadleaf tree species. The average sequestration value for healthy mature broadleaf trees is 12.8 t(CO_2)/ha, while for healthy mature coniferous trees, it is approximately 6 t(CO_2)/ha. These values are then scaled according to the seasonal integral of the Enhanced Vegetation Index (EVI) obtained from satellite data.

Cooling effect

The cooling effect is caused by the combination of two main effects of vegetation: transpiration and radiation blocking. Cooling is most important during the summer when the heat is most intense. This clearly shows that if a tree lacks sufficient amount of water, the transpiration component is eliminated, and thus, it cannot effectively cool its surroundings. The calculation is performed for an 8-hour window during the light part of a hot summer day. For each tree, two components of the energy balance are calculated: evapotranspiration and radiative cooling.

Evapotranspiration:
Evapotranspiration (ET) cools the surrounding environment using energy consumed during the phase change of water. The calculation uses physical relationships. Estimated ET obtained from satellite data and latent heat of evaporation are used to convert the amount of water released into the air into consumed energy. By using the specific heat capacity of air and the volume of air being cooled, the energy is converted into degrees Celsius.

Radiative cooling:
Each tree reduces the surrounding temperature by blocking incoming solar (shortwave) radiation that would hit the ground if the tree were not present. Each object also passively emits some radiation (longwave), depending on its temperature. Half of this energy is emited back into the atmosphere. Some of the energy is also consumed by photosynthesis and stored in organic carbon compounds. All these components depend on the size of the tree and the temperature of its surface. The same approach as for evapotranspiration is applied to convert the energy loss into cooling in degrees Celsius.

The sum of both components of the cooling effect represents the potential of each tree. This potential is strongly dependent on the condition of the tree. Therefore, a correction is made based on productivity, as the vegetation index shows the amount of chlorophyll, reflecting the tree's actual water regime, vitality, and stress.

Monetary value of a tree

The value of greenery is a composite index calculated as a combination of the monetary value derived from the average property price typical for the given locality and the Ecosystem Services Index (ESI).

ESI is a comprehensive metric designed to assess the benefits that ecosystems provide for human well-being. These benefits, known as ecosystem services, include a wide range of natural processes and functions that support life and contribute to economic, social, and environmental health. Here, we use ESI to estimate the value of a tree based on its size, productivity, and location:

ESI = (size + produktivity + location) / 3

The size of the tree is calculated as its volume (area * height) and weighted using the Gompertz function to assign a higher value to larger trees. Productivity indirectly includes the cooling effect and carbon sequestration. Location (the importance of the tree to local residents) is derived based on the number of buildings visible from the tree's location. The value is then divided by the average importance in the city.

The price of the tree is derived from the average property price in the area, based on the assumption that properties near trees have a higher value than corresponding properties in areas without vegetation. The average price of a tree should be 20

Data sources

Input data sources:

- PlanetScope (8 bands, daily, 3.7 m)
- Landsat 8–9 (30 m, 8-day revisit)
- EURO-CORDEX (~12.5 km)
- ERA5
- Digital surface Model, Digital Elevation Model (0.4m)
- Municipal tree inventory - polygons
- Open Street Maps - Road network, Building footprint, Land use
- Local economic parameters

Tree segments smaller than 30 m^2 were excluded from the analysis due to the limited resolution of satellite imagery.

Results

Analysis results

The cadastral area of the Copenhagen municipality is divided into 10 Bydel, 67 Kvarter, and 399 Roder settlement units. Outputs from the analysis of the green space condition are processed for Bydele units and individual trees, displayed in summaries. The results are presented for each evaluated indicator of condition separately.

Whole area

Within the entire analyzed area, 280 192 trees with a crown larger than 30 m^2 have been identified. The graph in Figure 1 shows the total number of identified trees in each administrative unit. The statistics include all trees, regardless of whether they are located on private property or are under the municipality's management. Bydele units with the lowest number of trees per hectare of the unit area are Indre By with 18.3 trees/ha, followed by Østerbro with 21.5 trees/ha, and Amager Øst with 24.8 trees/ha.

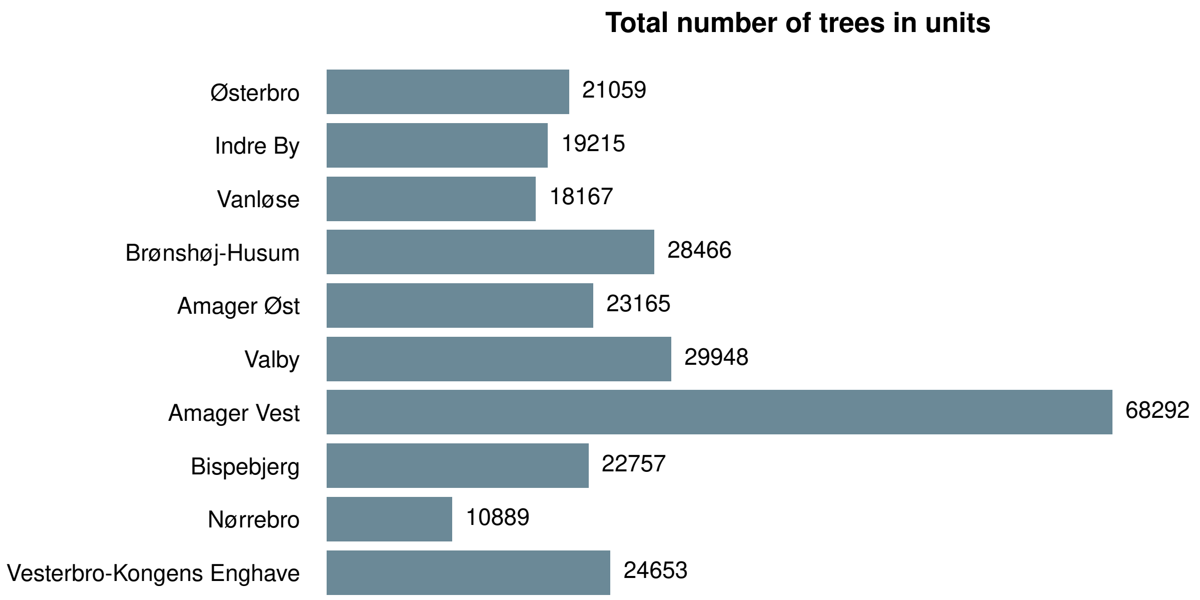

Figure 1: *The total number of identified trees in each administrative unit*

Table 1 shows the total number of trees in each productivity and stress category, while Table 2 displays the percentage representation.

Table 1: *The overall representation of the analyzed trees in the productivity and stress categories*

Productivity level	Stress level					Total
	None	Low	Moderate	High	Extreme	
None	270	186	4	0	0	**460**
Very low	10212	14721	395	213	0	**25541**
Low	7817	21244	176	103	0	**29340**
Average	69061	101557	248	156	0	**171022**
High	16037	9443	14	7	0	**25501**
Very high	20768	7545	13	2	0	**28328**
Total	**124165**	**154696**	**850**	**481**	**0**	**280192**

Table 2: *The percentage representation of the analyzed trees in the productivity and stress categories*

Productivity level	Stress level					Total
	None	Low	Moderate	High	Extreme	
None	0.1	0.1	0.0	0.0	0	**0.2**
Very low	3.6	5.3	0.1	0.1	0	**9.1**
Low	2.8	7.6	0.1	0.0	0	**10.5**
Average	24.6	36.2	0.1	0.1	0	**61.0**
High	5.7	3.4	0.0	0.0	0	**9.1**
Very high	7.4	2.7	0.0	0.0	0	**10.1**
Total	**44.3**	**55.2**	**0.3**	**0.2**	**0**	**100.0**

Productivity

Across the entire area, 20 % of the trees have below-average productivity, with approximately half of them being trees with very low or no productivity. These trees provide ecosystem services only to a limited extent, and under increased stress, there is a risk of premature mortality. In areas with a higher proportion of such trees, it is advisable to consider increased investment in maintenance (e.g., irrigation), particularly for mature trees, which perform the most ecosystem functions, and greenery renewal. Figure 2 shows the productivity distribution within the whole city and figure 3 shows the distribution within Bydel administration units.

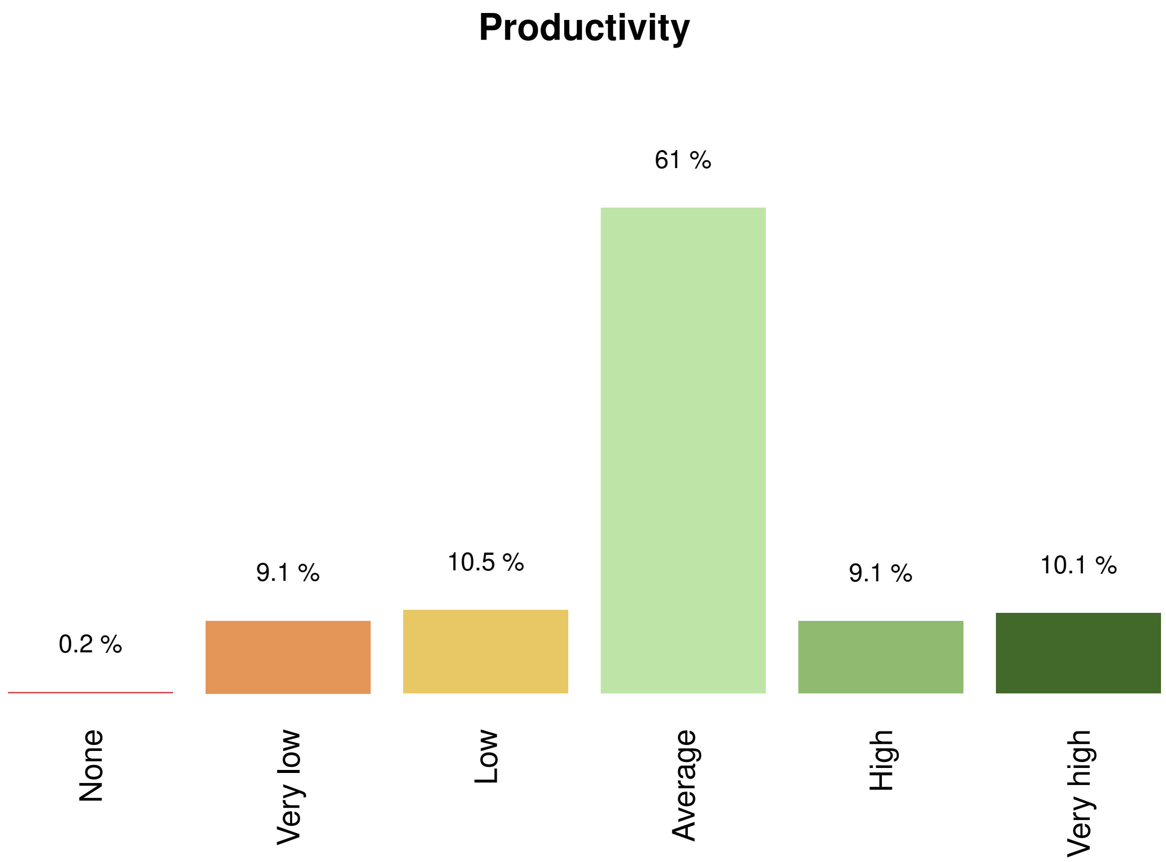

Figure 2: *The distribution of trees across the different productivity categories*

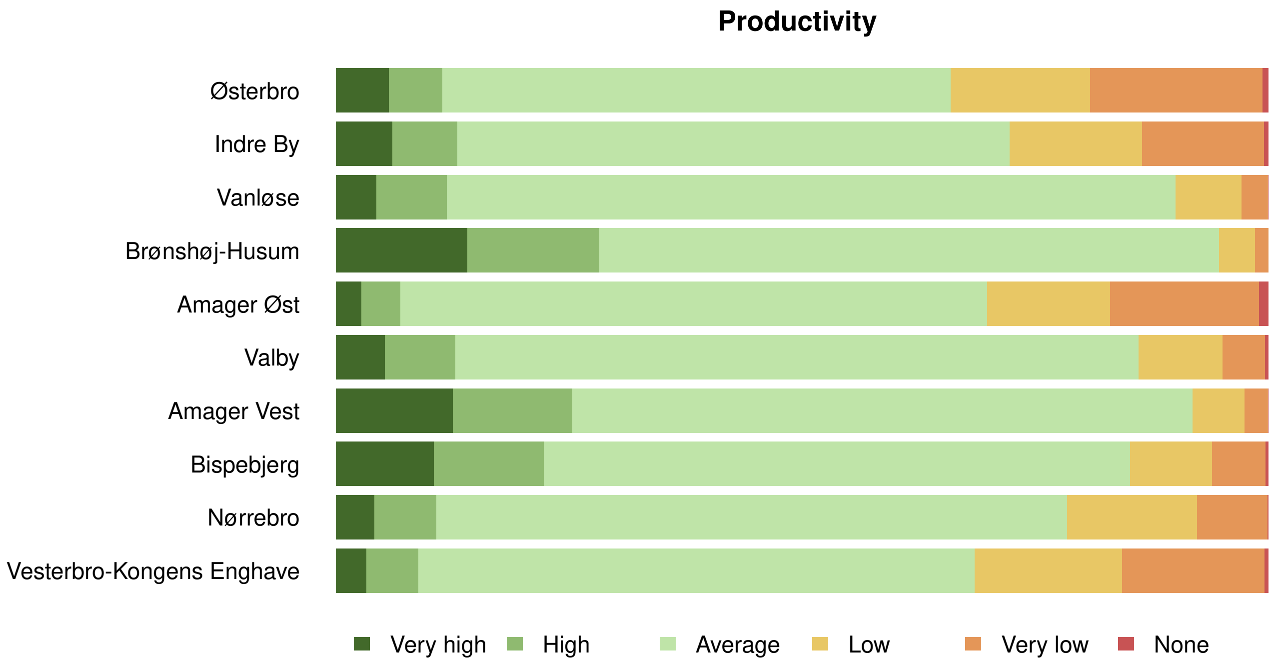

Figure 3: *Relative distribution of productivity categories within administration units*

Stress

There is generally low level of stress in the city of Copenhagen. However, a few exceptional areas with high levels of stress can be found in Bispebjerg and Østerbro. Across the entire area, 0.48 % of trees are located in areas with elevated stress levels, with 36 % of these trees experiencing high or extreme stress. In total, it is over 1 300 trees. These trees must allocate a significant amount of energy to cope with various forms of stress acting in combination. As a result, they have little energy and resources left for effective growth (producing lower-quality, more brittle wood) and are more susceptible to pathogens. In areas with a higher proportion of such trees, it is advisable to consider increased investment in improving the habitat conditions of greenery, particularly for mature trees that provide the most ecosystem functions.

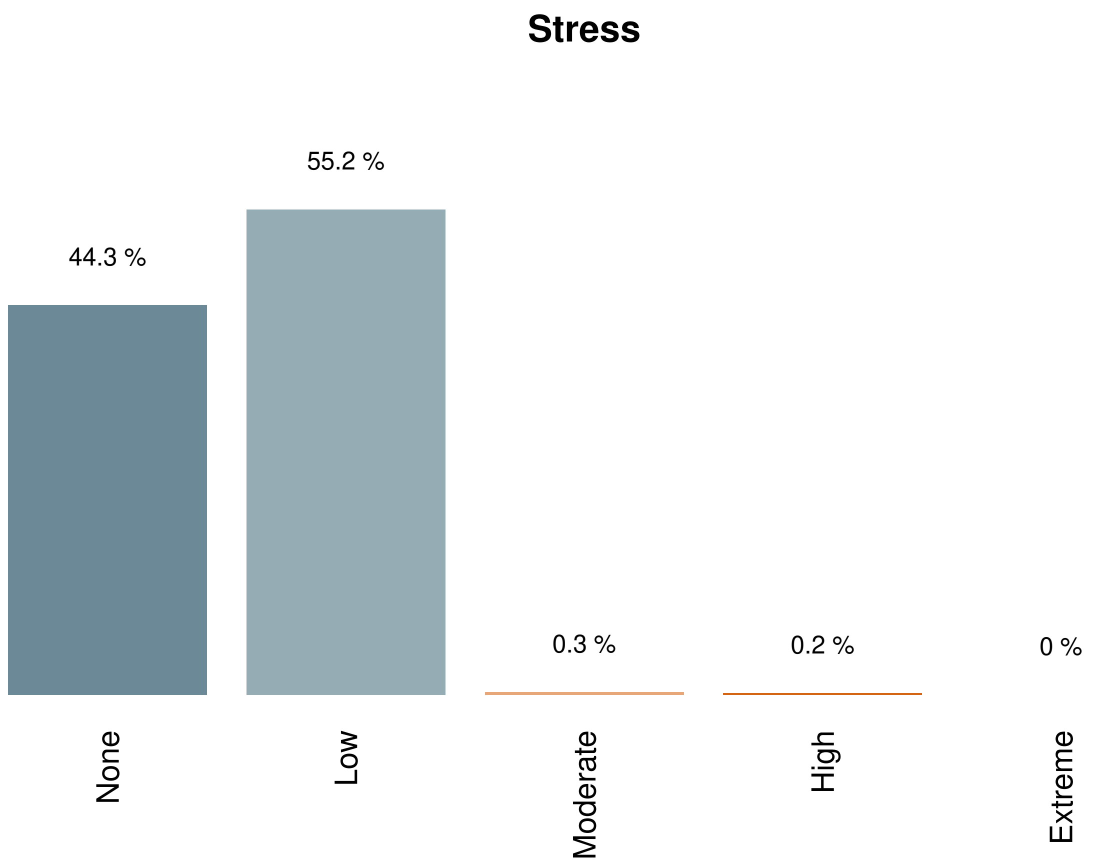

Figure 4: *The distribution of trees across the different stress categories*

The areas where trees are most stressed are shown on the map in Figure 5. The map indicates that the overall stress level across the city is low, with the most vulnerable areas being Bispebjerg (Nordvest quarter) and Østerbro (Nordhavn quarter). The distribution of trees in different stress categories across the administrative units of the city is displayed in Figure 6.

Figure 5: *Areas with the most stress trees within the Copenhagen municipality*

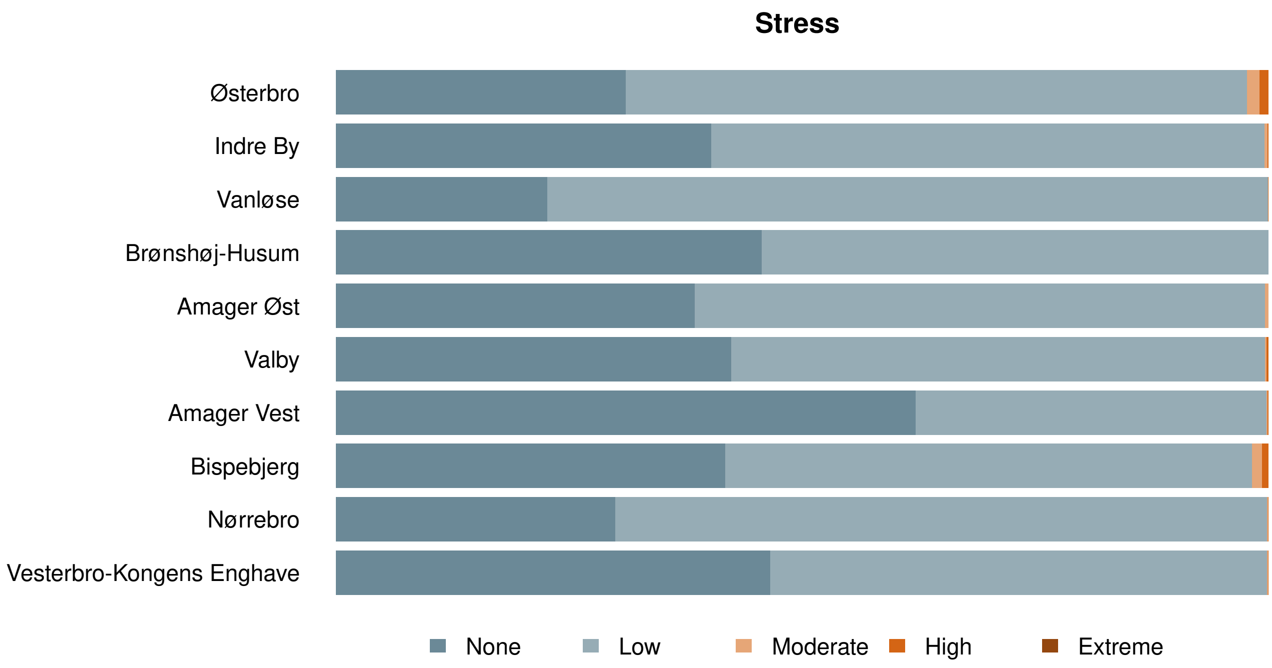

Figure 6: *Relative distribution of stress categories within administration units*

Survival capacity

Across the entire area, there are 18 563 trees (6.6 %) that are vulnerable or endangered. In areas where there is a larger number of such trees, it is advisable to consider investments in improving site conditions and, above all, to plan for renewal. The number of trees that are prospering or resilient is 108 066 (39 %). Such areas do not require significantly increased attention. There is a strong assumption that the trees will survive without the need for intervention.

Figure 7 shows the distribution of trend categories within the administrative units of the municipality.

The total numbers of vulnerable and endangered trees in the individual administrative units are shown in the chart in Figure 8.

The map in Figure 9 displays the average trend in individual administrative units.

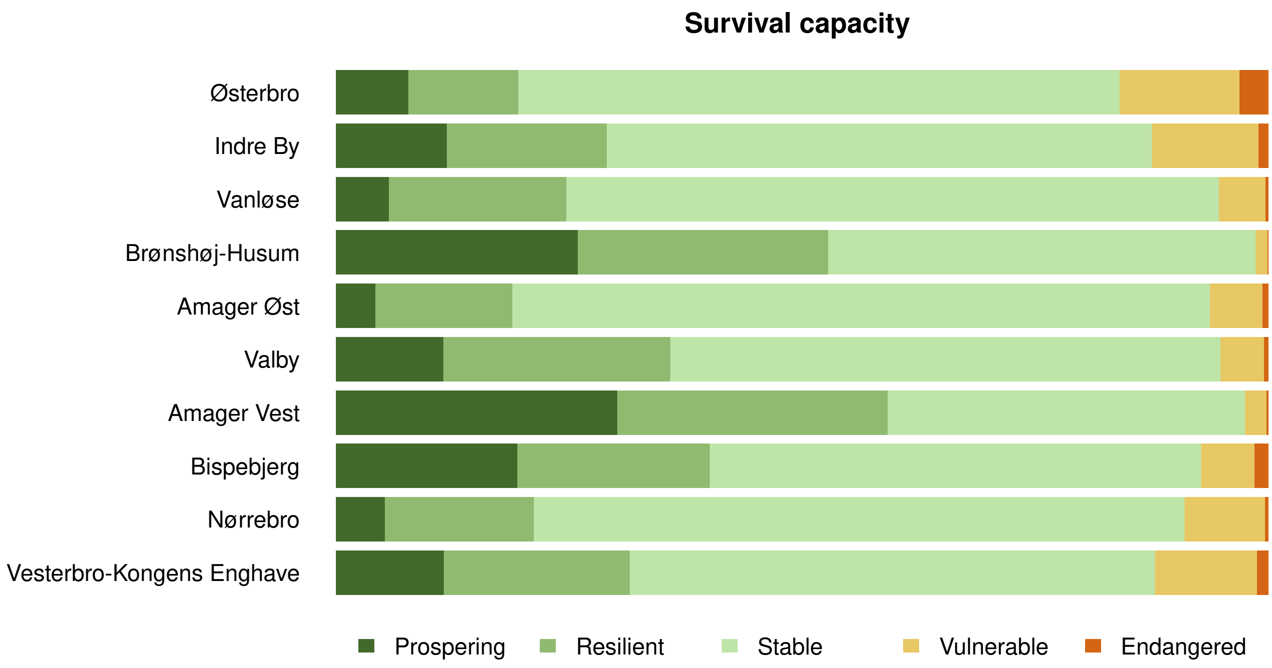

Figure 7: *Relative distribution of survival capacity categories within administration units*

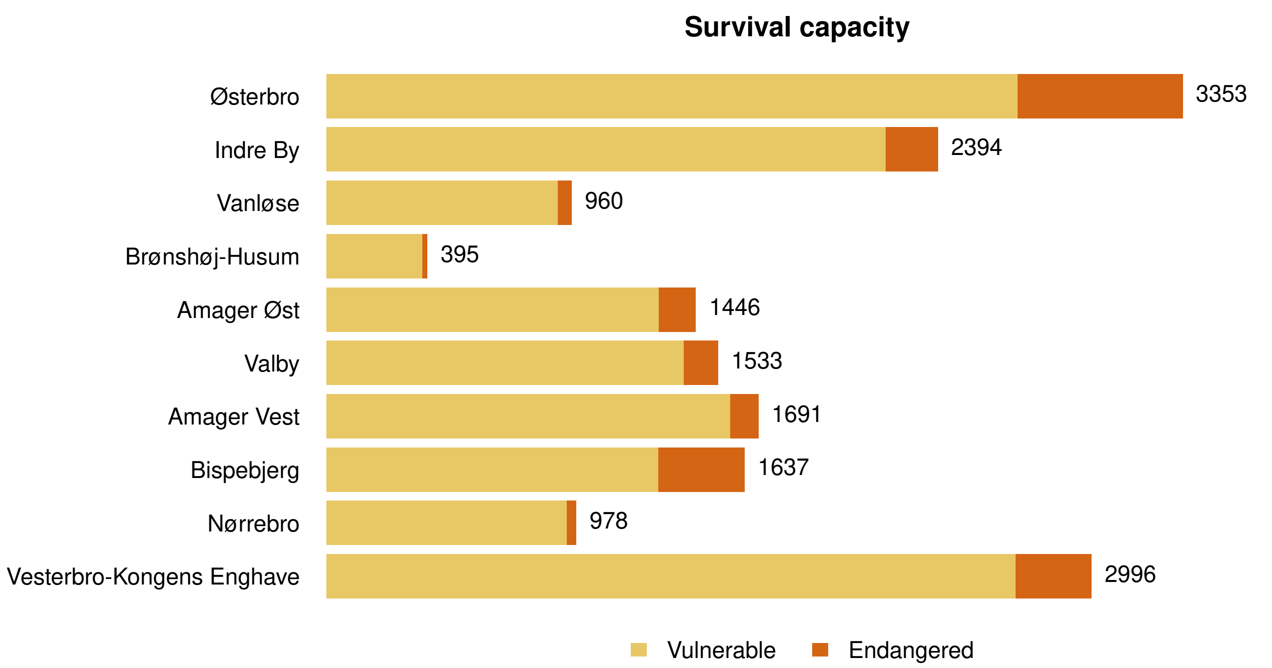

Figure 8: *The number of trees in trend categories requiring increased care within the administrative units*

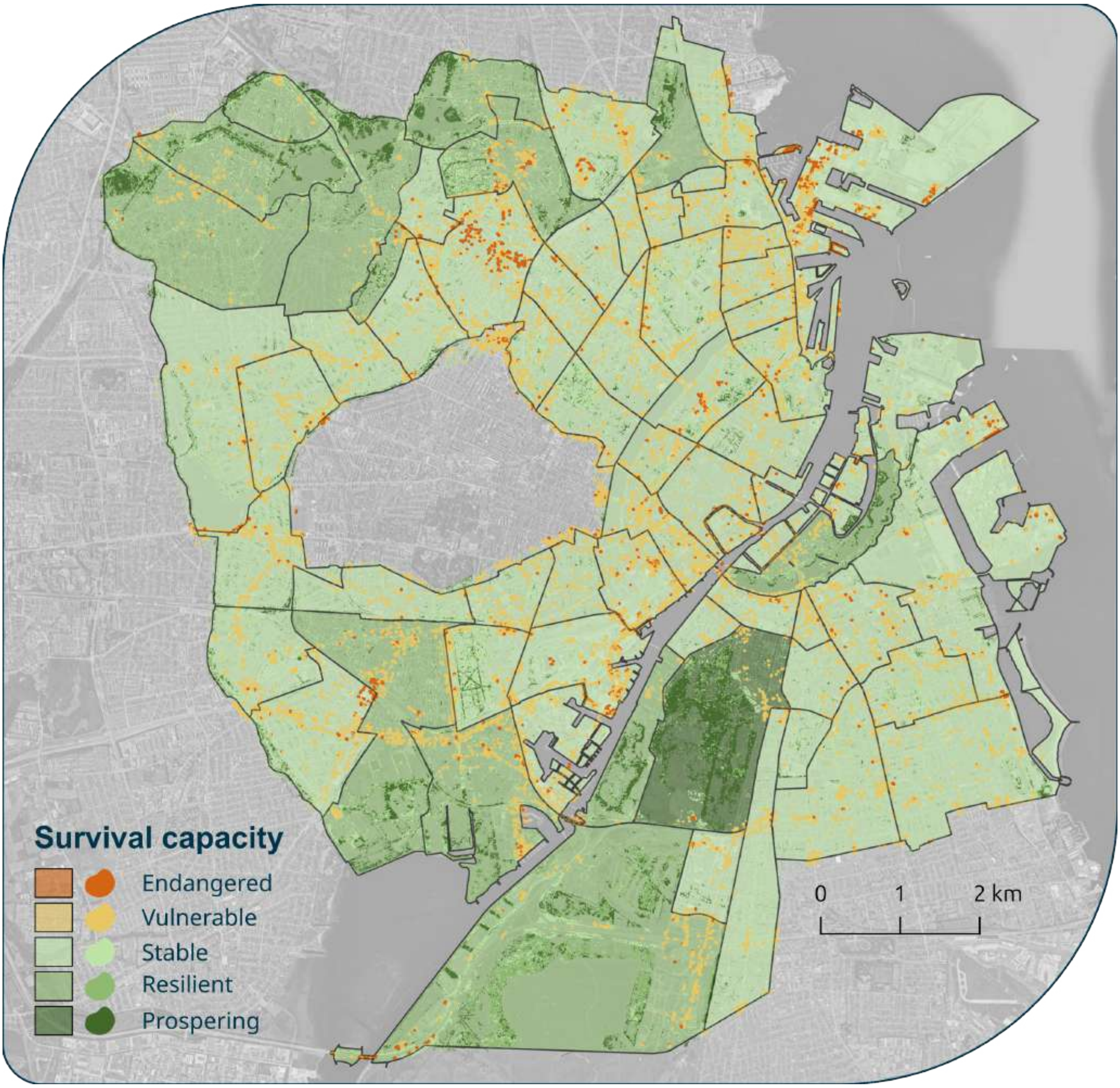

Figure 9: *Average survival capacity categories within administration units*

Critical areas

Of the units with the highest number of vulnerable or endangered trees (more than 2 000), three units have the highest representation of such trees: Østerbro, Indre By, and Vesterbro-Kongens Enghave. In all of these units, the share of such trees exceeds 10%.

Within Kvarter units most critical areas with more than 500 trees in categories ”Vulnerable” or ”Endangered” and share of such trees higher than 15 % are Metropolzonen, Nordhavn, Nordvest, Vesterbro øst, and Vesterbro syd. These areas are shown on the map in the figure 10.

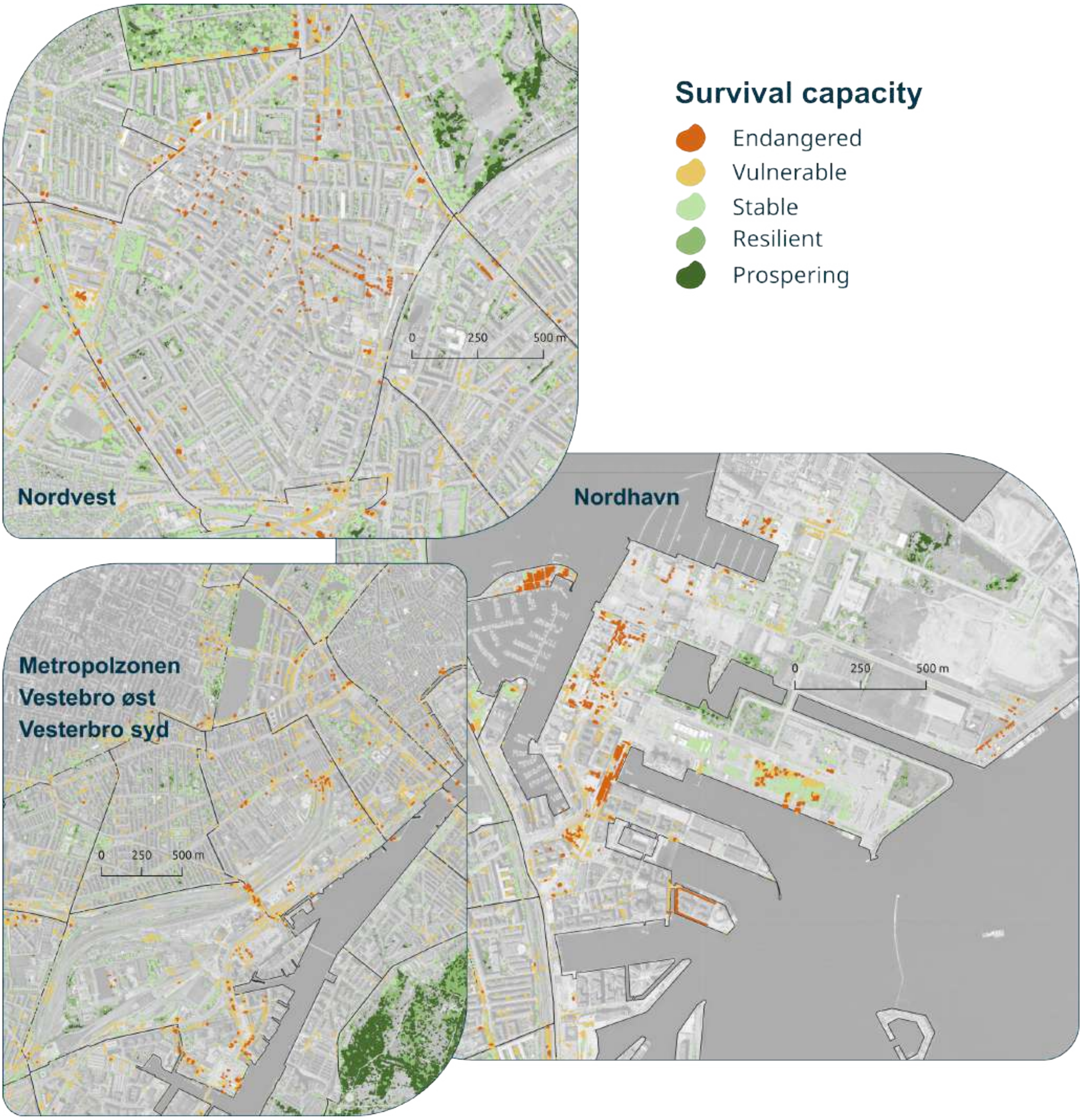

Figure 10: *Survival capacity in areas with the highest number and concentration of trees in "Vulnerable" and "Endangered" categories*

Cooling effect

The cooling effect is directly connected to productivity and stress conditions of a tree. On the administration unit level it also depends on the number of trees and buildings present in the unit. Table 3 shows the total cooling effect in Bydel units. The map on the figure 11 is showing the total cooling effect of trees in Kvarter units in the city.

Table 3: *Cooling effect and carbon sequestration of trees in Bydel units*

Bydel	Cooling (°C)	Sequestration (t CO_2)	Trees in unit
Østerbro	0.03	1055	21059
Indre By	0.04	1029	19215
Vanløse	0.09	866	18167
Brønshøj-Husum	0.13	2061	28466
Amager Øst	0.05	754	23165
Valby	0.14	1640	29948
Amager Vest	0.19	4498	68292
Bispebjerg	0.15	1428	22757
Nørrebro	0.10	562	10889
Vesterbro-Kongens Enghave	0.11	1122	24653

Kvarter units with the cooling effect lower than 0.01 °C are:

- Nord/Komponistkvarteret,
- Ny Ryvang,
- Østerbro Nord,
- Svanemøllen Syd/Øst,
- Lyngbyvej Øst/Klimakvarteret,
- Nordhavn.

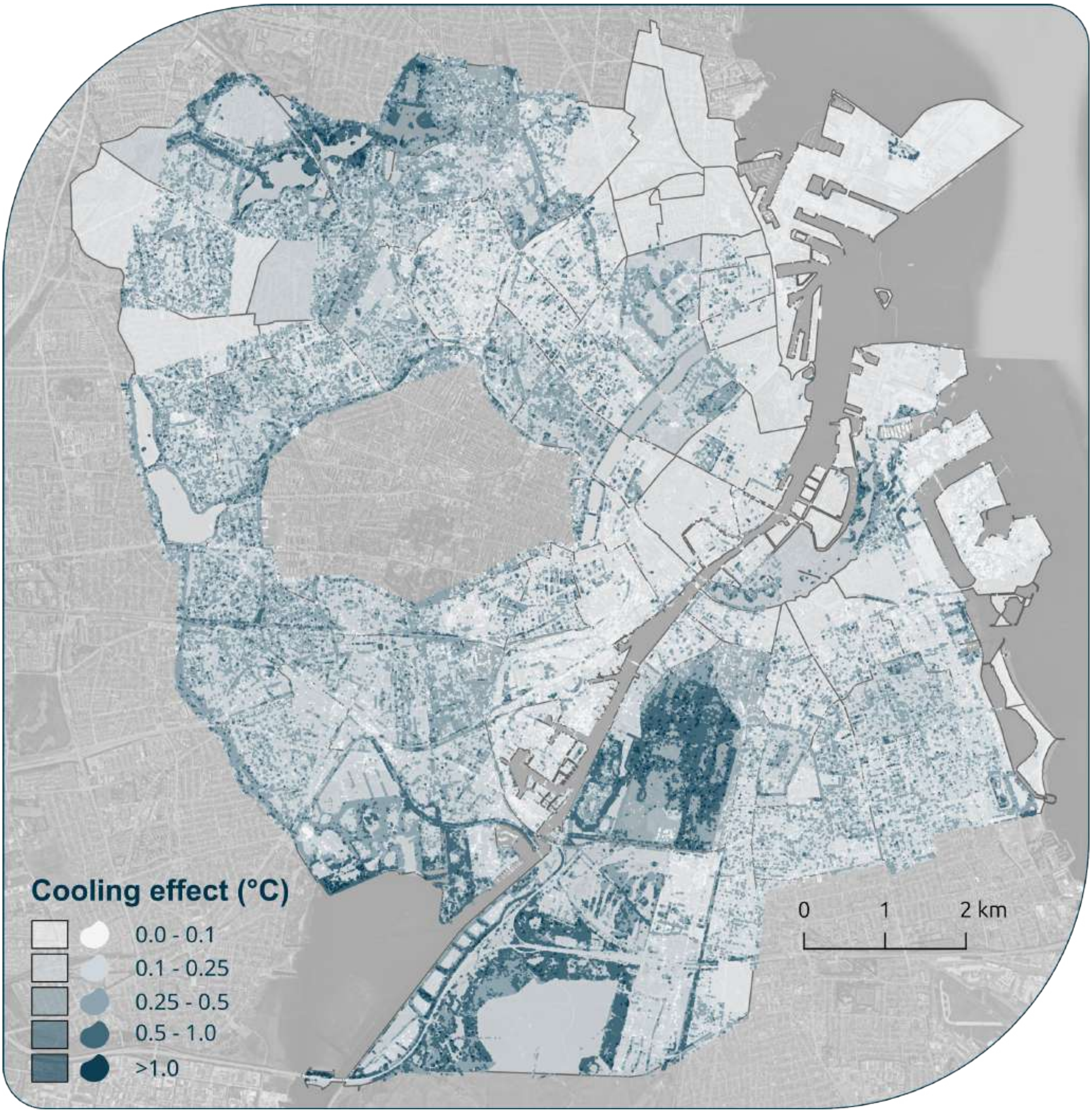

Figure 11: *Average cooling effect within administration units*

Carbon sequestration

As in the case of cooling effect, carbon sequestration is directly connected to productivity and stress conditions of a tree. On the administration unit level it also depends on the number of trees present in the unit. Table 3 shows the total carbon sequestration in Bydel units. The map on the figure 12 is showing total carbon sequestration of trees in Kvarter units in the city. Total carbon sequestration rate is 15 000 t(CO_2) per year in the whole city.

Kvarter units with the least carbon sequestration level are:

- Nord/Komponistkvarteret,
- Gammelholm og Nyhavn,
- Christianshavn Neden Vandet,
- Middelalderbyen,
- Amagerbro vest.

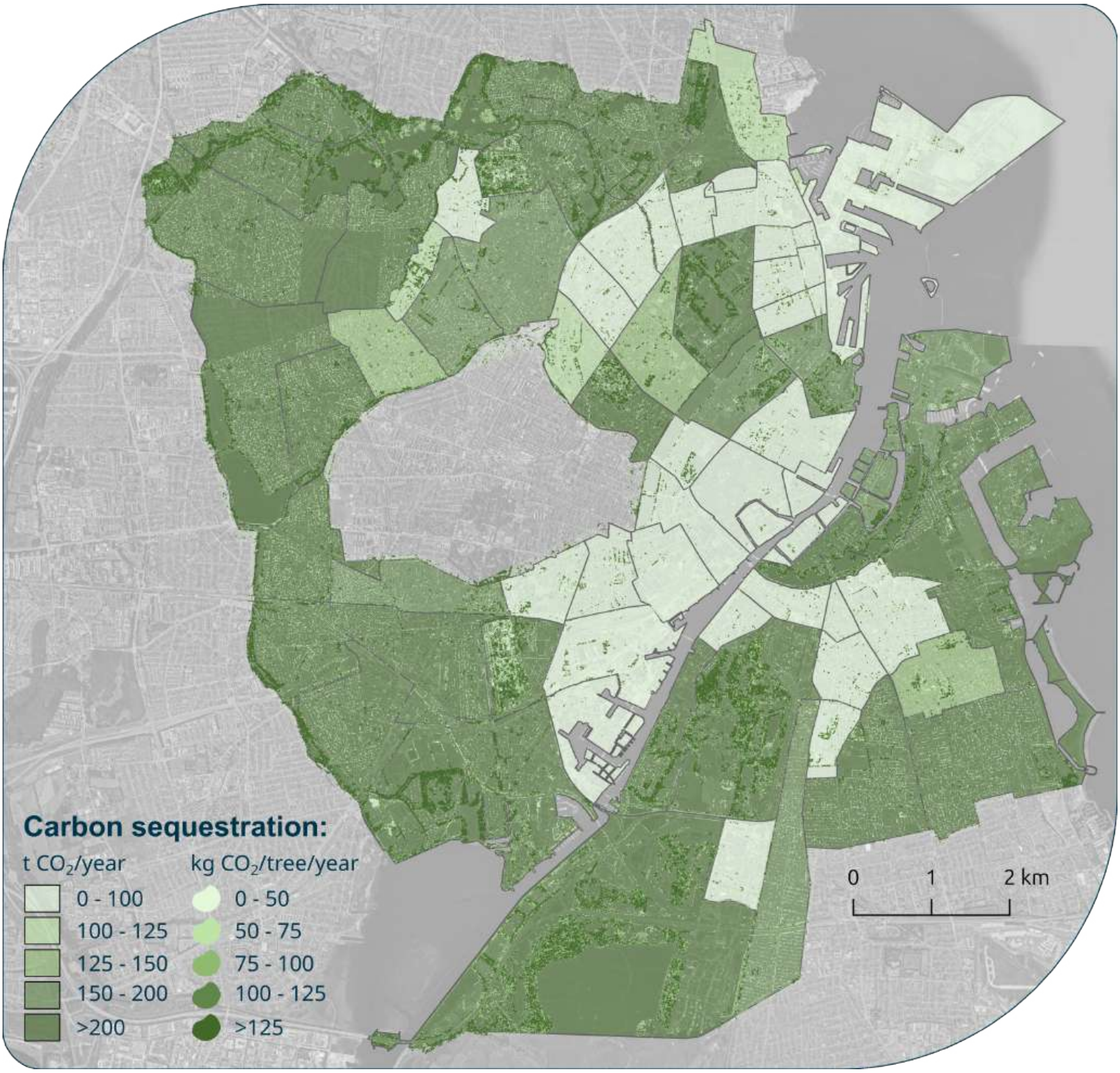

Figure 12: *Average carbon sequestration within administration units*

Conclusions

The lowest number of trees per hectare is found in Østerbro, Indre By, and Amager Øst, which are coastal areas, including the city center. Introducing new greenery might be difficult, especially in the historical part of the city.

In Østerbro, the currently present trees are also stressed and are therefore expected to have a shortened lifespan. Thus, this is the most problematic area in the city, requiring special focus and investments in new greenery.

Apart from Østerbro and Indre By, Vesterbro-Kongens Enghave also has a very high number and proportion of trees that are vulnerable or endangered and are expected to struggle in the future.

As a consequence of higher stress and a lower number of trees in these areas, there is also a low level of cooling and carbon sequestration in Østerbro, the city center, and areas to the northwest of Copenhagen's canal.

General Recommendations

General recommendations

How to introduce new greenery

In the densely built-up areas it is usually complicated to introduce new green spaces to effectively serve citizens in terms of ecosystem services, namely it is greenery effect on citizen's health, equity, aesthetic function or cooling effect among others. There are various options to do so:

Tree Planting for Shade and Cooling

If the space is not limited, it is always the best option to plant a tree. Large-canopy trees such as Tilia spp. or Acer spp. reduce urban heat island effects. Deciduous trees, in general, provide summer shade and allow winter sun. Evergreen trees, on the other hand, can serve as a windbreak in places which are exposed to strong winds in winter. Trees with high transpiration rates, such as Platanus x hispanica, can be used to enhance evaporative cooling.

Green Facades and Living Walls

Green facades and living walls are great options in places where there is a lack of horizontal space. These solutions are effective and ideal for buildings and walls without windows, such as warehouses, while still provide great amount of ecosystem services and save costs on cooling in summer. Vertical greenery systems (e.g., ivy-covered walls, modular green walls) or climbers like Parthenocissus tricuspidata, that require minimal maintenance while providing cooling effects, are great options to lower wall surface temperatures and improve insulation.

Green Roofs

Green roofs are, in general, great option in areas where there is a sufficient amount of evenly distributed precipitation. Otherwise require irrigation to stay beneficial. Extensive green roofs (sedum and grasses) for stormwater management and basic cooling can be installed on existing roofs which are not projected to hold significant amount of extra weight. Intensive green roofs (shrubs, small trees) can serve to maximize thermal comfort and biodiversity but require higher demands on the stability of the roof. Green roofs, however, do not serve to provide citizens equity, aesthetic function unless the roof is freely accessible.

Pocket Parks and Urban Forests

Micro-parks in dense areas can be introduced as cooling islands for example in roundabouts, parkings, wide pavements, etc. It is always good idea to introduce diverse native species to support biodiversity while improving aesthetics and reducing maintenance.

Support and grants

A significant amount of every city's greenery is in private areas. It is therefore always beneficial to launch financial support programmes aiming to support sustainable reconstructions of private gardens, while introducing water retention techniques and new trees planting. Under this measure can be also considered to encourage the creation of community gardens and opening up courtyards to the public, which might be very beneficial especially in densely built-up areas such as city center.

Ecosystem services

With regard to climate change, the term *ecosystem services* is increasingly being discussed. These are functions that a healthy tree can naturally provide without external help or additional measures. They represent an effective and natural way to introduce smart technologies into cities. Humans are naturally evolutionarily and genetically predisposed to direct contact with nature and greenery. However, with the ongoing trend of urbanization, the contact between most people and nature is diminishing, and in some cases, it even disappears entirely. The consequence is not only a lower quality of life but also a range of health complications, including civilizational diseases and mental health issues. More effective than treating these consequences is bringing greenery and nature back to people living in cities.

Trees have had millions of years to develop ways to effectively help maintain their surroundings in a state conducive to the life of other species. In nature, everything is interconnected, and positive feedback loops operate. That is, the better a tree thrives, the more it improves the environment around it, and the better the trees in its vicinity thrive. They mutually support each other, and with sufficient greenery, the maintenance demand decreases. For example, more trees retain more water, reducing the need for irrigation, or more trees provide greater cooling to their surroundings, so other trees are not stressed by heat, making them more vital and therefore providing their services to a greater extent. No technology can fully replace the functions of greenery because they usually only cover one or a few selected services and are not interconnected with their surroundings as a whole.

Ecosystem services include:

- Cooling effect: Every tree transpires – it evaporates water. This is an essential process for nutrient transport. Through transpiration, a tree draws energy from its surroundings and converts it into water vapor. In this sense, it can be compared to a highly efficient air conditioning system. Unlike air conditioning, however, it draws energy from the surrounding heat and requires only water. A mature tree can draw about 125 kW of energy from its surroundings during the day. This amount of power is comparable to around ten medium-powered commercial air conditioning units. As a bonus, unlike air conditioning, this type of cooling imposes no environmental burden.

- Carbon sequestration: A mature, healthy tree can store up to 1 ton of CO_2 per year in its biomass, which it absorbs from the air. Four such trees compensate for the annual operation of one public transportation bus, which in a large city transports hundreds of thousands of passengers, or the annual operation of a car used by an average household.
- Recreation and aesthetics: According to the latest surveys, greenery near homes, workplaces, or schools contributes in many ways to the health and well-being of residents. Proximity to greenery supports mental health, encourages physical activity, and reduces the risks of cardiovascular diseases.
- Air pollution filtration: Greenery plays an invaluable role, especially in industrial or drier areas, where the concentration of pollutants in the air is higher. Plants are capable of capturing and breaking down pollution, thereby reducing the risk of lung diseases among residents. However, there is also a downside – air pollution itself is a stressor for greenery. Therefore, it is essential to focus on preventing pollution in the first place.
- Shading: Unlike regular roofs and surfaces, greenery shadows ”actively”. The main difference is that a large portion of the solar spectrum is reflected by the plant’s cellular structures, whereas artificial surfaces absorb this radiation and thus heat up. The shade under trees is therefore cooler than under a roof, because the heated roof emits radiant heat, which we perceive much more intensely through the surface of our body than the air temperature itself.
- Water retention: A surface covered with greenery has a higher absorption capacity. During heavy rainfalls, it helps protect the surrounding area from overwhelming the drainage system or causing flash floods. At the same time, the retained water further supports the vitality of the vegetation and the provision of its ecosystem services.
- Noise abatement: Vegetation has a highly complex surface, which allows it to effectively break up sound waves. In addition to other functions, it thus acts as a sound barrier, but only during the period when it is leafed. When planning new plantings for noise mitigation, it is advisable to consider evergreen species with bushes understorey.
- Wind barrier: It is useful especially in cooler areas, for example near large water bodies.
- Animal shelter and biodiversity: Vegetation is a part of our natural environment and forms an important component of biodiversity. Biodiversity reflects the vitality and proper functioning of the entire ecosystem. Many plant and animal species live in symbiosis and rely on each other.

For trees to perform their functions, they must have a suitable environment and favorable conditions. In cities, however, there is a variety of non-native species, and the environment is highly stressful for all greenery. Modern technologies allow us to effectively target measures to improve the conditions for tree growth and efficiently monitor the health of greenery. Planting new greenery can also be supported, taking into account changing climatic conditions, within the broader context of the entire urban environment and over the long term.

Stress

Plants, unlike animals, cannot escape when conditions unsuitable for survival occur in their environment. These conditions are commonly referred to as stress. There are many stress factors that affect plants.

In the short term, stress is not life-threatening, and plants have mechanisms to cope with it. However, when stress persists at elevated levels for a prolonged period, the consequences are inevitable. A stressed tree:

- Is more susceptible to pathogens,
- Reduces its photosynthetic activity (grows less),
- Reduces its vitality (branch dieback, smaller leaf area, earlier leaf fall),
- Reduces its resistance to extreme conditions (heatwaves, drought),
- Reduces ecosystem services provision (cooling effect, carbon sequestration, aesthetic function, etc.),
- Poses an increased risk to inhabitants (poorer wood quality, falling branches, reduced stability).

It is important to realize that stress acts in a cocktail effect, and reducing or eliminating any component of stress is beneficial for the tree. Water and its availability play a crucial role in this process. In urban environments, trees suffer much more from drought than in comparable conditions just outside the city. Heat is a type of stress closely related to drought stress. Warmer air has lower relative humidity compared to cooler air with the same absolute water vapor content, which further promotes evaporation and water loss. Adaptation strategies to drought vary among species. However, in general, trees always have to choose between hunger (closing stomata and limiting CO_2 intake) or thirst (water loss at the cost of maintaining CO_2 intake). Drought-resistant species have deep and branched roots (they can afford to choose thirst) or are very quick to respond to water shortages by partially closing stomata (choosing hunger). Moreover, individuals within the same species may be adapted to varying degrees depending on the conditions they grow in. In extreme cases, which unfortunately are far from rare in urban environments, individuals that choose the hunger strategy can suffer damage to their assimilatory organs due to heat. A tree that closes its stomata does not cool its surface through transpiration, and during a hot summer day under direct sunlight, it can easily exceed the lethal temperature threshold on the leaf surface. This leads to the breakdown of cell membranes and loss of function, causing leaf burn.

It is therefore beneficial to focus on landscape modifications that bring water to trees and reduce stormwater runoff into the sewage system (e.g., roof drainage, sloping sidewalks, permeable surfaces).

Water management

Water management is crucial. Without smart planning and greenery architecture, there soon won't be any trees that provide ecosystem services for people living in the city. And, as everything is interconnected, trying to fulfill the 3-30-300 rule goal, it brings all other benefits altogether as well.

Urban greenery provides a wide range of ecosystem (or ecological) services. Among the most commonly mentioned are cooling functions, atmospheric carbon capture, and biodiversity. However, these also include aesthetic and recreational functions, the capture of dust and other air pollutants, and flood protection.

For greenery to perform all these functions, it must be healthy and have sufficient nutrients and, above all, water. Why?

Trees, like animals or humans, are living organisms. Unlike them, however, they cannot escape unfavorable conditions. Instead, they have developed various adaptation strategies that allow them to overcome environmental challenges. Different species have different strategies, but they all share one thing in common: they cannot tolerate everything. Every tree has its tolerance limits, and urban environments are so extreme in many respects that a large portion of trees—sometimes even the majority in certain areas—experience significant stress. This stress leads to depletion and loss of vitality, ultimately resulting in death. Consequently, trees in urban settings have significantly shorter lifespans than those in their natural habitats.

One of the most significant stress factors for urban trees is a lack of water. There are many reasons for this: compacted soil that cannot effectively absorb and retain rainwater, impermeable surfaces that prevent water from reaching the soil, or soil salinization, which prevents trees from absorbing water even when it is present in the soil. So: don't let dogs mark trees, sprinkle icy sidewalks with sand instead of salt, build hard surfaces from permeable materials, let rainwater enter the greenery (not drainage).

How it all works, and what happens when they don't have water?

Trees, as mentioned, need nutrients found in the soil. To transport these nutrients to the trunk, branches, and leaves (or needles), they need water in which the nutrients are dissolved. Water flows upward through transport pathways, and the tree determines where to send the nutrients based on where they are most needed. The flow of water through the tree trunk is a physical process. Trees do not have muscles or pumps to facilitate this. Instead, the transport relies on the difference in moisture between the soil (where there is more water) and the air (where there is less water). The less water is in the air (the hotter air is), the stronger is a force causing water loss.

After the tree absorbs water through its roots and distributes the necessary nutrients to its organs, the water leaves the tree through microscopic openings in the leaves called stomata. The water exits the tree as water vapor. For liquid water to become vapor, it must be heated. The energy required for this is taken from the leaf surface, which cools as a result, and the energy is carried away into the atmosphere with the water. In this way, the tree cools its surroundings by losing water. These stomata also serve another crucial function—they allow the tree to absorb carbon, enabling it to grow.

What happens if there isn't enough water in the soil? The tree recognizes it and closes its stomata to prevent water from escaping. It needs to conserve the water within its tissues to avoid wilting. However, by doing so, it also stops absorbing carbon from the atmosphere and distributing nutrients. The tree ceases performing its ecosystem functions. It stops cooling its surroundings, capturing carbon, purifying the air, and, if its leaves scorch (since it can no longer cool them), it also loses its aesthetic function. So: during hot summer days, irrigate your trees.

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