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A Comparative Study of Forecasted Benefits from Historical and Current Street-Trees in Downtown Oslo - Implications for Management

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Acknowledgements

The idea behind this study took shape after working as a summer intern for the Agency for Urban Environment in 2019, when I experienced first-hand the challenges faced by urban trees.

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Last, but not least, I want to thank friends, family and loved ones for being by my side during the writing of this thesis. I couldn´t have done it without your support.

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Abstract

Urban trees and forests provide environmental, economic, social, and human health benefits collectively known as ecosystem services. Todays' climate crisis and urbanization is linked to multiple challenges within cities and green infrastructure. Urban trees can help counteract these problems but must first be recognized as a part of the planning process. Across Europe, tree inventories are increasingly becoming younger and smaller as large trees are removed due to the potential risks they pose to public safety and infrastructure. The new area zoning plan for downtown Oslo (2019) attempts to protect and further develop the city's current green infrastructure. If managers and urban planners alike are to effectively work towards the "protection and further development" of the green infrastructure in downtown Oslo, it necessitates having a baseline on which to assess what such a development entails.

This study investigates such a baseline by comparing historical and current tree populations for six different sites in downtown Oslo, and their respective benefits after a 50-year forecast run in i-Tree Eco. The overall benefits provided by the current sites after the forecast were 25 %, 33% and 50% for pollution removal, carbon storage and carbon sequestration when compared to the historical trees under a hypothetical scenario of zero mortality. These results were found, despite the existing tree population being 16% larger and not accounting for the high mortalities of 18-40% associated with the establishment of street-trees. These results highlight the importance of preserving large trees.

Managers and urban planners are encouraged to have a holistic approach with target goals that better account for the higher benefits of incorporating larger trees in the municipality's tree inventory when planning future projects.

1 Introduction

1.1 Background

Urban trees and forests provide environmental, economic, social, and human health benefits collectively known as ecosystem services (Bolund & Hunhammar, 1999; David J. Nowak & Dwyer, 2007). Across the world, major tree planting initiatives are taking place in order to increase these ecosystem services (Roman, Battles, & McBride, 2016).The City Council of Oslo, Norway, has followed suit with a similar initiative in 2019 to plant 100,000 trees by 2030 (AP, MDG, & SV, 2019). Such tree planting initiatives are more easily justifiable when models can assess urban forest planting and help management and planners to increase the associated tree-benefits while limiting their costs (Hand & Doick, 2019; G. McPherson, Simpson, Peper, Maco, & Xiao, 2005; David J Nowak et al., 2008).

Todays' climate crisis is linked to multiple challenges including eclectic weather in the form of higher temperatures and the increased frequency of extreme weather (IPCC et al., 2019). According to the United Nations Association of Norway, 60% of the earth's population will live in cities towards 2030 and these cities will be responsible for 75% of climate gas emissions (FN-Sambandet, 2021). Urban forests represent a viable solution to mitigate these problems. Urban forests give numerous benefits that help to counteract problems connected to increased urbanization by microclimate regulation, rainwater drainage, air filtration, pollution removal and loading, noise reduction, sewage treatment, energy savings. Urban forests improve quality-of-life and public health, ameliorate climatic extremes, sequester carbon, provide recreation and improve cultural values (Bolund & Hunhammar, 1999; Brack, 2002; Kardan et al., 2015; David J Nowak et al., 2008). Trees are considered an inexpensive, alternate solution for halting climate change (Bastin et al., 2019).

The municipality of Oslo has released a series of strategies and central management documents that work towards the United Nation's Sustainable Development Goals. One of these documents is "*The Agency of Urban Environment´*s strategy for urban trees" (Bymiljøetaten, 2014). The Agency, which is responsible for both urban and rural forest within the municipality of Oslo as well as maintaining their tree inventory, holds a key position in the management of trees. The Agency followed up on the resolution made by the City Council of Oslo on December 15, 1993 and launched their new strategy in 2013. The strategy stated   that for every tree that is removed, a new one shall be planted – as a means of preserving Oslo as a green city (Bymiljøetaten, 2014). While the intention of the resolution is good, it has its limitations as it does not encourage the safekeeping, longevity, and continuity required to assure that smaller trees mature into big ones.

While the literature varies in regard to life expectancy for urban trees (Czaja, Kołton, & Muras, 2020), Roman and Scatena (2011) found through their meta-analysis of available literature that the life expectancy of street trees was higher than previously reported, but still only between 19-28 years. Depending on the study, young trees were experiencing mortality rates between 18% to 40% during their establishment period (David J. Nowak, McBride, & Beatty, 1990; Sklar & Ames, 1985). Most conflicts between “gray and green” infrastructure result due to contractional or design errors, improper species selection, public health and safety concerns or development concerns (London Assembly, 2007; Palmer, Liu, Matthews, Mumba, & Odorico, 2015). High mortality rates also mean that urban street-trees are not allowed to mature into big trees leading to a subsequent loss in net carbon storage in street trees (Smith, Dearborn, & Hutyra, 2019). On top of that, large and mature trees are at a particular risk of being removed due to the potential of significant damage they can cause to property or people as evident by their removal in certain urban areas (Hand & Doick, 2019). Urban tree inventories are therefore progressively becoming younger and smaller, because smaller trees are perceived to pose less of a risk (London Assembly, 2007), which is of particular concern from an ecosystem services perspective.

Previous studies have found that the ecosystem services provided are directly related to the mature size of trees (Hand & Doick, 2019; E. G. McPherson, 2014), and that trees break even from a cost-benefit perspective after around 30-40 years. (GreenBlue Urban Ltd., 2018; Horváthová, Badura, & Duchková, 2021). Big trees may reach their peak after as much as 200 years – frequent tree removal is thereby an unnecessary loss of resources which calls for a long term approach when governing city trees (GreenBlue Urban Ltd., 2018).

Oslo received the European Green Capital Awards in 2018 and aims to become a robust zero-emission city by 2030 in accordance with the Paris agreement (Klimaetaten, 2020) and currently has an urban forest worth billions of Norwegian kroner (Barton, Vågnes Traaholt, Blumentrath, & Reinvang, 2015). Trees with their many ecosystem services can play an integral part to realize set goals. And while it can be challenging to translate the benefits produced by trees into monetary terms, , the actual incidence of costs vs benefits being difficult to ascertain (David J. Nowak & Dwyer, 2007), quantifying ecosystem services in an urban environment is a powerful tool to improve tree management (Raum et al., 2019). Through careful design and planning it is possible to maximize the net function (benefits) from urban trees and forests and return the greatest value to society (David J. Nowak & Dwyer, 2007).

1.2 The objectives of this study

This thesis uses the Agency of Urban Environment´s tree inventory in conjunction with the software program i-Tree Eco (referred to as i-Tree in this study) to evaluate the benefits provided by trees in monetary terms for historical and current sites. A percentage comparison between the services were made, to see how ecosystem services are reflected in the urban tree management in downtown Oslo (first and foremost the ones belonging to the agency) by looking at six different field sites.

The main objectives of this study are:

- Utilize techniques for comparing current and future ecosystem services at sites of interest using i-Tree
- Create selection criteria for choosing field sites in downtown Oslo
- Compare the historical and current tree populations at the selected sites and their changes in benefits over
- Discuss how benefits can be used to improve management of urban trees

2 Input data

2.1 Historical data

This study compares both historical and current data. Tree measurements for the trees that had been removed were based upon historical information recorded from four different "databases":

- <u>LiDAR</u>
- <u>Google earth</u>
- <u>Google street view</u>
- <u>Geobank</u>

Figure 2.1 Olav V's gate as seen with Google Street view (left) and with Lidar data (right)

2.2 Tree inventory

In the Urban Environment Agency (UEA) there have been recorded 1617 trees in the downtown Oslo district. These trees are distributed into two main categories: street trees and park trees (see figure 2-2).

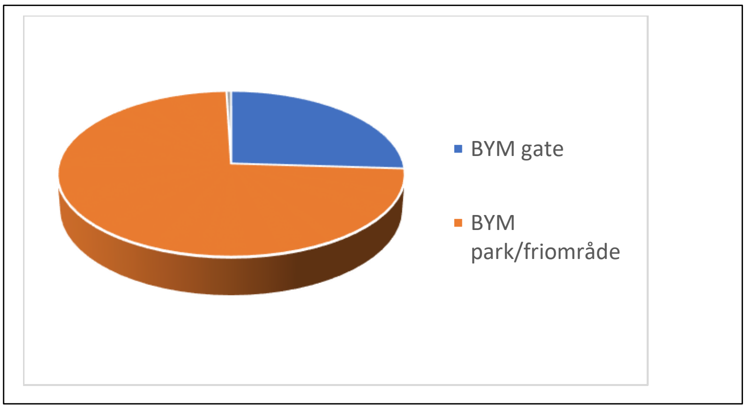

Figure 2-2 Distribution of downtown Oslo trees between streets (gate) and parks (park/friområde).

When looking at the species distribution in the entire database for the downtown Oslo district, the largest category is NA (not identified) at 38% (Appendix 1, figure 21-23). However, when accounting for the location of trees (street vs. park), we can see that most street trees have been identified by species (NA category is reduced to 5%) (Appendix 1, figure 21-23), while the NA category for park trees is 45%. This means that most of the unidentified trees in downtown Oslo are in the parks (Appendix 1, figure 21-23).

3 Study area

The study area for the selection of field sites for this study is shown in figure 3-1. Field sites were chosen for field surveys and digital analysis of their monetary ecosystem services. Digital information available to the public was used to estimate the ecosystem services for the trees that had been removed and field surveys no longer were possible. Several of the sites have undergone a re-design that has led to the old trees being removed in favor of new ones.

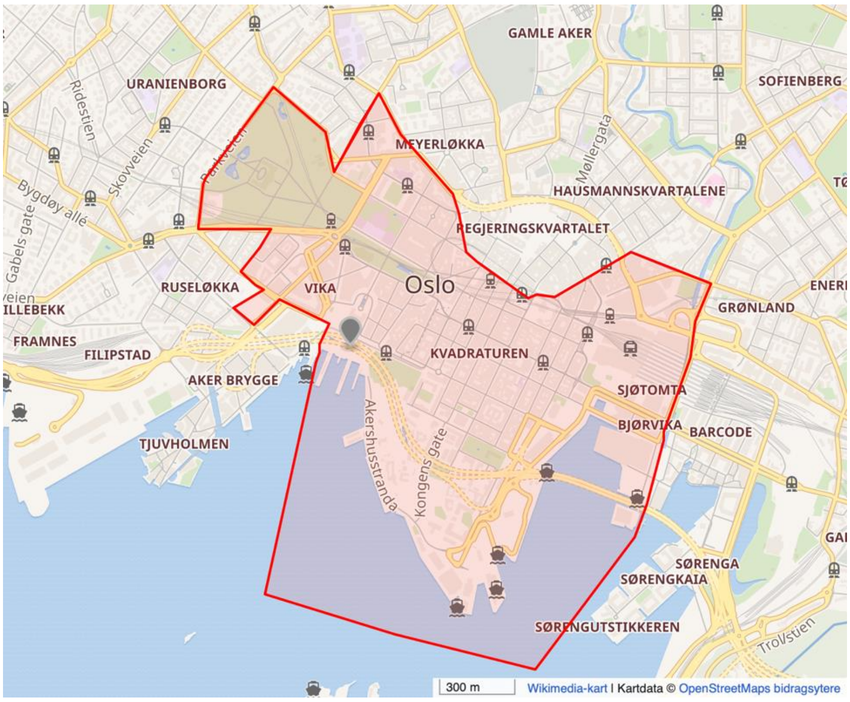

Fig. 3-1 Map of the study area (red outline) in Oslo. (Source: Wikipedia)

Initially, the field site Olav Vs gate was selected for an ecosystem service evaluation in part due to the recent media storm that was created when several old trees were removed during street renovation work. But the replacement with new trees also made it possible to compare the ecosystem services before and after tree replacement. To further understand how the general tree-scape has changed and is changing in downtown Oslo – an evaluation of additional sites is warranted.

In order to find additional sites, the Assistant Director General and the Manager for city trees in the agency´s park management section were asked about potential sites where trees recently have been replaced in similar situations to Olav Vs gate. A selection criterion was that the trees should not have been removed prior to 2011, since that's the first year with available LiDAR data (Hoydedata.no). In addition, a map analysis of the Agency of Urban Environment's tree inventory was conducted using filters for removed and newly established trees.

The following potential sites were identified for ecosystem service evaluations:

- Bogstadveien 3
- Brynjulf Bulls plass
- Europarådets plass
- H. Kjerulfs plass
- Hoffsveien
- Innspurten 12
- Langbølgen
- The new National museum
- Nygata
- Olav V´s gate
- Professor Aschehougs plass
- Ris skolevei 15
- Storgata 6
- Storgata 53
- Tullins gate 6
- Thorvald Meyers gate

3.1.1 Criteria for selecting field sites

The potential sites were then evaluated, which led to the development of a series of criteria that needed to be satisfied if the site was to be selected. The criteria served to homogenize/create a baseline from which the sites could later be compared while making sure sufficient data was available. Also, since a full analysis would be conducted of the field sites, it was also necessary to limit the scope of the paper by reducing the number of sites.

The following criteria were developed in selecting field sites for this study:

I. The study area must be located within downtown Oslo
II. The trees of interest must be in a street
III. Trees must be managed by the Agency for Urban Environment
IV. The site must have replaced old trees with new ones
V. The development project must have occurred in or after 2011
VI. Essential data must have been recorded in the municipalities tree inventory

3.1.2 Reasons for choosing the selection criteria

The reasoning behind choosing these six criteria was as follows:

Criteria I- The study area must be located within downtown Oslo

Downtown Oslo comes in addition to the 15 districts in the municipality of Oslo. While it only has roughly 1400 citizens (Statistikkbanken Oslo kommune, 2021), it is the hub of Oslo and Norway with the head of state, in addition to an extensive network of public transportation, shopping malls, retailers, office buildings, governmental buildings(Governmental departments, the Storting, the Townhall, the Courthouse) , the Royal Palace, the Opera house and the central train The trees of interest must be located along a street. This creates a high pressure on the green infrastructure, which is of particular importance in an area dominated by grey infrastructure. The several stories tall buildings and a high number of impermeable surfaces also makes downtown susceptible to the heat island effect, flooding, wind-tunnels, and lack of air filtration.

To preserve trees and vegetation in downtown Oslo, the City Council of Oslo adopted a new area zoning plan (Section 4.3.3) on July19, 2019 that stated that all the green vegetation in downtown Oslo should be protected while continuously being developed further. Trees that succumbed to old age, pests, wind or similar, need to be replaced. It placed especially emphasis on soil volume and quality, selecting the correct species for the right place and to improve biodiversity and esthetics while avoiding toxic and allergy inducing species. Finally, trees needed to be placed in such a manner that they don’t inhibit accessibility for pedestrians, public transportation, or bicyclists.

Since this study would conduct full inventories of the trees at each field site, downtown Oslo seemed like a natural cut-off boundary to limit the study area, while also being a place where trees are needed. The 2019 area zoning plan is potentially a powerful tool for their safe-keeping and although the plan had not been adopted at the point of tree removal in this study, it creates a basis for reevaluating the tree-scape in the future and the effectiveness of the plan.

Criteria II - The trees of interest must be located along a street

Street-, yard- and park trees have been found to have different annual mortality rates and survivorship rates (E. G. McPherson, 2014). In addition, as highlighted in the report from the Millions Trees LA (MTLA) initiative, the distribution of mature tree size-classes were different between street, yard, and park trees and therefore the potential ecosystem services will vary depending on location planted (E. G. McPherson, 2014). Therefore, this study will focus exclusively on street trees to have a somewhat similar baseline for comparison between the sites.

The parameter *street* or *park tree* have already been defined for individual trees in the municipalities tree inventory and will function as a criterion for site selection. For clarification, a street tree will be defined as a tree planted on a sidewalk, walking street or road/street.

Criteria III - Trees must be managed by the Agency for Urban Environment

The Agency of Urban Environment is responsible for the majority of streets, parks and forests, and has been assigned the academic responsibility for trees (Bymiljøetaten, 2014). The agency keeps a tree inventory primarily over its own trees, with a small percentage of trees belonging to other agencies, legal authorities, and private properties as donated by "P" in the map database.

Since the inventory functions as the primary data source for site selection, species, location and DBH – the trees must belong to the Agency of Urban Environment. Another advantage gained from limiting the study to trees belonging to the agency, is the historical insight from coworkers regarding the trees at the various locations.

Criteria IV - The site must have replaced old trees with new ones.

As this study focuses on the comparison between the ecosystem services provided by trees prior to removal, and the services provided by the replacement trees and discrepancies – it's a prerequisite that trees were at some point removed and new ones were planted. The number of times this process has occurred per site, however, was not accounted for prior to this study, and as such varied quite a lot.

The study also aims to evaluate the different tree species, function, and form before and after the re-design of the various areas, and their prioritization from a planning perspective.

Criteria V - The development project must have occurred in or after 2011.

This criterion coincides with the third criterion; however, they are not mutually inclusive as not all the agency´s trees have been registered in the database. As is highlighted in the results section, many trees have been registered, but lack data beyond location, and being registered as a deciduous species. Therefore, historical trees that have been removed need to have been registered with the parameter species and ideally DBH in the database. In the cases where the DBH have not been recorded, it will be approximated from Google Street View. These two parameters are essential for running the i-Tree Eco analysis (USDA Forest Service, 2020b).

Criteria VI - Essential data must have been recorded in the municipality's tree inventory.

To collect the height parameter for the trees, the project (tree removal) would have to have taken place after 2011 since the available LiDAR data available from hoydedata.no is from 2011, 2014, 2017 and 2019. This was to ensure that data for the various "historical" trees could be retrieved since the i-Tree model recommends that you collect additional parameters beyond the base requirement for a more accurate analysis, which includes height (USDA Forest Service, 2020b).

The following table summarizes the proposed field sites and selection criteria.

Table 3-1 Summary of the proposed field sites and which criteria were satisfied (green), unsatisfied (dark grey), or unknown (orange).

Address	Criterion					
	I	II	III	IV	V	VI
Bogstadveien 3	⬛	🟩	🟩	⬛	🟩	🟩
Brynjulf Bulls plass	🟩	🟩	🟩	⬛	⬛	⬛
Europarådets plass	🟩	🟩	🟩	🟩	🟩	🟩
H.Kjerulfs plass	🟩	🟩	⬛	🟩	🟩	⬛
Hoffsveien	⬛	🟩	🟩	🟧	🟩	🟩
Innspurten 12	⬛	⬛	🟩	🟩	🟩	🟩
Langbølgen	⬛	🟩	⬛	⬛	🟩	⬛
The new National Museum	🟩	🟩	⬛	⬛	🟩	⬛
Nygata	🟩	🟩	🟩	🟩	🟩	🟩
Olav V´s gate	🟩	🟩	🟩	🟩	🟩	🟩
Professor Aschehougs plass	🟩	🟩	🟩	🟩	🟩	🟩
Ris skolevei 15	⬛	🟩	🟩	🟩	🟩	⬛
Storgata 6	🟩	🟩	🟩	🟩	🟩	🟩
Storgata 53 (ved legevatken)	⬛	🟩	🟩	⬛	🟩	🟩
Tullins gate 6	🟩	🟩	🟩	🟩	🟩	🟩
Thorvald Meyers gate (trikk og gate opprustning)	⬛	🟩	🟩	🟩	🟩	🟩

3.1.3 Comments on field sites that did not meet the selection criteria

It should be noted that several of the potential sites such as Hoffsveien and Langbølgen also generated news and a public outcry like Olav Vs gate when trees were removed in favor of establishing bicycle lanes (Berge & Lilleås, 2021). The new National Museum and Brynjulf Bulls plass, where all the trees were removed due to the building of the museum, is also an interesting site as a quick count of trees from aerial photos indicates that roughly 250 trees were removed as a result of the project (see figure 3-2). Despite not fulfilling all the criteria, the site was still considered due to its number of trees for a single plot. If the trees had belonged to the agency, they would have accounted for around 15% of the agency´s trees in downtown Oslo. However, since no new trees have been planted, this site was excluded.

Figure 3-2 Aerial photos showing the new National Museum and Brynjulf Bulls plass before 2001 (left) and in 2020 (right). (Source: Retrieved from kart.finn.no, "historiske Oslo-2020 and Oslo-vest-2001´, map data: Norkart.).

3.2 Selected field sites for this study

The following field sites (in alphabetical order) met the selection criteria and were chosen for this study:

- Europarådets plass
- Nygata
- Olav V´s gate
- Professor Aschehougs plass
- Storgata 6
- Tullins gate 6

The selected sites are shown in figure 3-3.

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Figure 3-3 Map showing the location of the six selected sites in downtown Oslo (Source: Norkart).

3.2.1 Historical and current tree configurations

The current and previous configuration of trees for the varying sites is shown in this section and have been retrieved from the Agency of Urban environment´s tree inventory archive (Bymiljøetaten, 2021).

Trees were both planted and removed at various times in the selected sites (table 3-2).

Table 3.1 summarizes when trees were planted and removed.

Location	**Planted, year (amount)**	**Removed**
Olav Vs gate	1985 (16)	2019 (14), 2014 (2)
Professor Aschehougs plass	2007 (8)	2017/2018 (6), 2011(3)
Tullins gate	1971-1975 (12)	2018(4), 2014 (4), 2004-2007(4)
Europarådets plass	1975-1980(6)	2019 (6)
Storgata	1997-2001 (2)	2006 (1), 2020(1)
Nygata	2007 (5)	2017 (5)

The symbols that should be noted in the following figures are:

- Pink circle- “Tre fjernet, ikke replantes” which means the tree will not be replaced
- Green circle - “Løvtre” which means deciduous tree

Europarådets plass

Figure 3-4 shows the configuration of 6 Norway maple trees from ca. 1980 until 2019.

From historical pictures and orthophoto 5 trees of the type Norway maple (Acer platanoides) were planted between 1975 and 1980 and another 6th one added in 2009 at what is today known as Europarådets plass, with a configuration as indicated below (Fig.3-4). The trees were later removed in 2019.

Later in 2019, 15 new cherry trees were planted, five of the type Prunus serrulate Kanzan and the remaining trees were of the type Prunus sargentii var. Rancho (Fig. 3-5, 3-6).

Figure 3-5 shows the new cherry trees planted in 2019.

Figure 3-6 shows the configuration of the new cherry trees planted in 2019

It should be noted that four of the 15 trees were planted in pots, two of which were dead upon the survey.

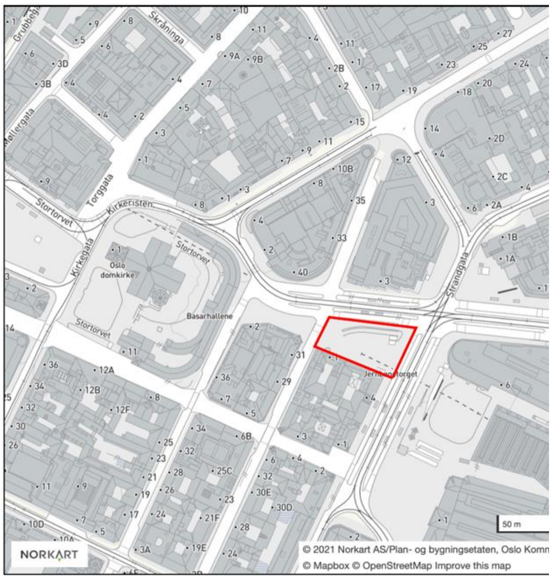


Figure 3-7 shows the location of Europarådets plass in downtown Oslo.

Figure 3-8 shows Europarådets plass ca. 1975 without trees. Photo: Sohlberg Foto as. Oslo Museum/OB F22984, from Oslobilder.

Figure 3-9 shows Europarådets plass ca. 1980 with trees. Photographer: Ørsted, Henrik. Oslo Museum/OB.A8711, from Oslo bilder.

Nygata

From orthophoto, the first trees that appear to have been planted at this location were five oak trees of the variant *Quercus robur var*. “fastigata” in 2007 (Fig. 3-10). Historical data for DBH was not recorded and would therefore be estimated from Google Street View. The trees were later removed as a part of a building project in 2017.

Figure 3-10 shows the layout of the five oak trees in Nygata, which remain unchanged.

Five new oak trees of the same type were planted in 2019 (Fig. 3-11). Field measurements were limited to 3/5 trees as two of the trees were incased by fencing due to an ongoing building project. Measurements of DBH were therefore estimated based upon the other three trees and the tree inventory.

Figure 3- 11 shows two of the five new oak trees planted in 2019.

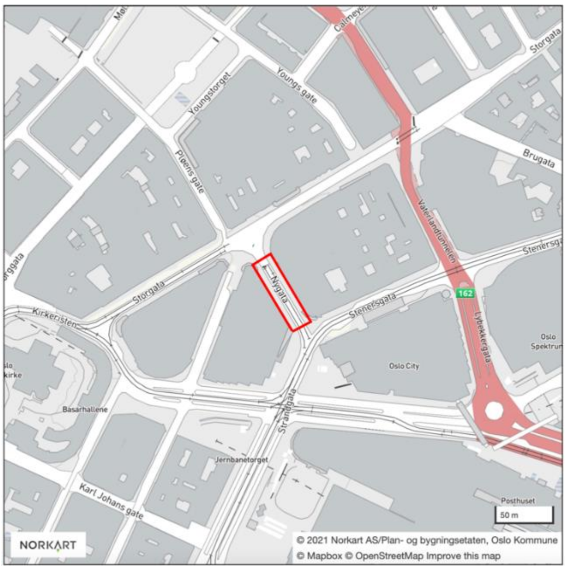


Figure 3-12 shows the location of Nygata in downtown Oslo.

Figure 3-13 shows Nygata (center left) ca. 1978 without trees. Photographer: Ørsted, Henrik. Oslo Museum/OB.A9360, retrieved from Oslobilder.

Olav Vs gate

Historically, there were 16 small-leaved lime trees (Tilia cordata) in Olav Vs gate that were likely planted in 1985 at the age of 5 years when the street was upgraded (Moldestad, 2011)(Fig. 3-14).

Figure 3-14 shows the configuration of the trees in Olav Vs gate until they were removed in 2019. Pink symbols signify that the trees will not be replaced.

Two of the trees were removed in 2014, due to what looks like facade maintenance. The remaining 14 trees were removed when the street was upgraded in 2019. In 2020, 12 red maple trees (*Acer rubrum* "Brandywine") were planted in Olav Vs gate in a new configuration (Fig. 3-16).

Figure 3-15 shows a project taking place were two trees previously had been standing. Retrieved from kart.finn.no ´historiske, Oslo-2019´. Map data: Norkart.

Figure 3-16 shows the new configuration of the 12 red maple trees planted in 2020 in Olav Vs gate.

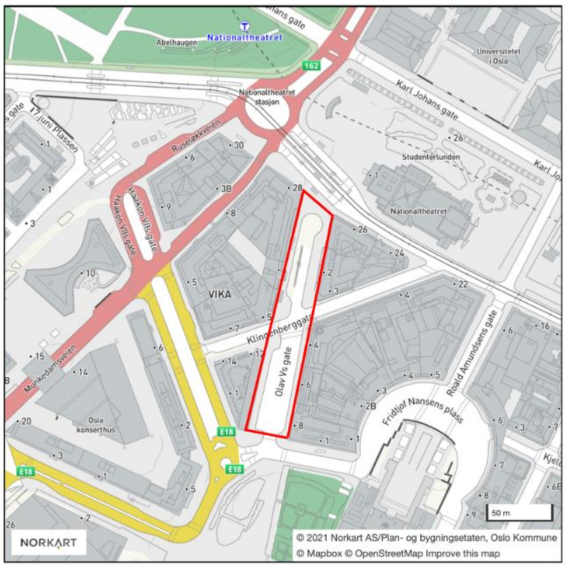


Figure 3-17 shows the location of Olav Vs gate in downtown Oslo.

Figure 3-18 shows Olav Vs gate ca. 1980 without trees. Photographer: Ørsted, Henrik. Oslo museum/OB.9348, from oslobilder.no

Figure 3-19 shows the historical trees in Olav Vs gate in 2014 using the historical street view function in google.

Professor Aschehougs plass

Historically, Professor Aschehougs plass has undergone several changes throughout the years.

The first tree was planted in the square between 1950-1956. From orthophoto an additional two trees were planted in the square between 1974 and 1984. These trees could have been removed when the square was upgraded in 2004 (Wasim K. Riaz, 2005)(Fig. 3-20).

Nine oak trees of the type *Quercus robus* ´Fastigata´ were planted between 2005-2007 because of the upgrade and will be used as the basis for the “previous ecosystem services” as there is insufficient data for the previous trees (Fig. 3-21). By the time the oak trees were removed in 2017-2018, only six trees remained (Fig. 3-22).

Figure 3-20 shows three "original" trees in 2004 that likely were removed around 2005. Retrieved from kart.finn.no ´historiske, Oslo-2004´.

Figure 3-21 shows the configuration of the nine oak trees planted after the upgrade of the square

In 2018. Norwegian maple (Acer platanoides var. ´Globosum´) trees were planted in the square.

Figure 3-22 shows the location of the six planted maple trees after the redesign of the square in 2017-2019.

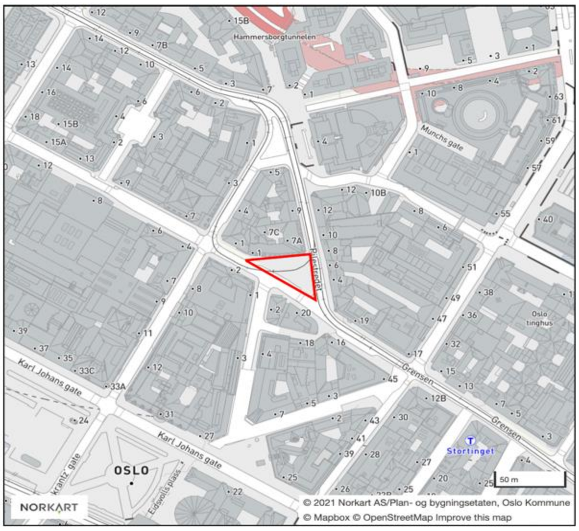


Figure 3-23 shows location of Professor Aschehougs plass in downtown Oslo.

Figure 3-24 shows Professor Aschehougs plass ca. 1950 without trees. Photographer: Harstad, Karl; Harstad, Karl. Oslo Museum/OB.F12024b, from Oslobilder.no.

Figure 3-25 shows Professor Aschehougs plass ca. 1956 with a single tree. Photographer: Dagbladet. Norsk Folkemuseum/NFDB.26108-198, from Oslobilder.no.

Storgata

Based on orthophoto (kart.finn.no ´historiske, Oslo-vest-2001´) two European hornbeam (*Carpinus betulus*) trees were planted by Storgata 15 between 1997-2001. One of the trees appeared to have died and removed in 2007 (Fig. 3.26).

Figure 3-26shows the configuration and the two trees that were removed in 2019/2020 during the redesign of the street (kart.finn.no ´historiske, Oslo-vest-2020´).

The 13 new trees planted in the street in 2020 consisted of four different species: two katsura (*Cercidiphyllum japonicum*), four Kabushi Magnolia (*Magnolia kobus* ‘Solitær’), one Yoshio flowering cherry (*Prunus* x *yedoentis*) and six Black locust (*Robinia pseudoacacia*)(Fig. 3-26).

Figure 3-27 shows the configuration of the 13 new trees planted in 2020. Note the layout of the street has not been updated since the upgrade.

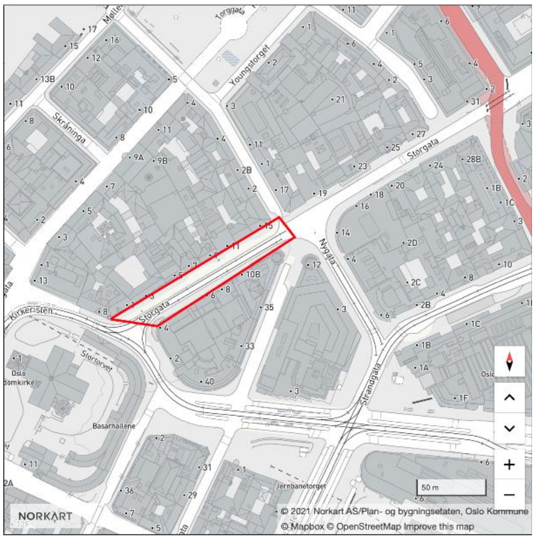


Figure 3-28 shows the area of Storgata which was in focus.

Figure 3-29 shows Storgata without trees ca. 1975-1980. Photo: Ørsted, Henrik. Oslo Museum/OB.A9843, from Oslobilder.no.

Tullins gate

Historically, there appeared to be 3-5 large mature trees in the street in 1971 (kart.finn.no, ´historiske Oslo-1971´), which appear to have been removed between 1971-1975, and 12 trees that appear to be of the type small-leaved lime trees (Tilia cordata) were planted. By 2017, only 4 of 12 trees remained (Fig. 3-30). Historical DBH measurements did not exist for these and were therefore estimated using Google Street View.

Figure 3-30 shows the configuration of Tullins gate until 2004-2007. Symbols in pink were trees that had been removed after that time period and were not to be replaced.

In 2018, seven European Hornbeam (Carpinus betulus f. Lucas) trees with a pyramidal shape were planted in Tullins gate according to the tree-configuration after 2007 (Fig. 3-31).

Figure 3-31 shows the current configuration of the Hornbeam trees since 2018.

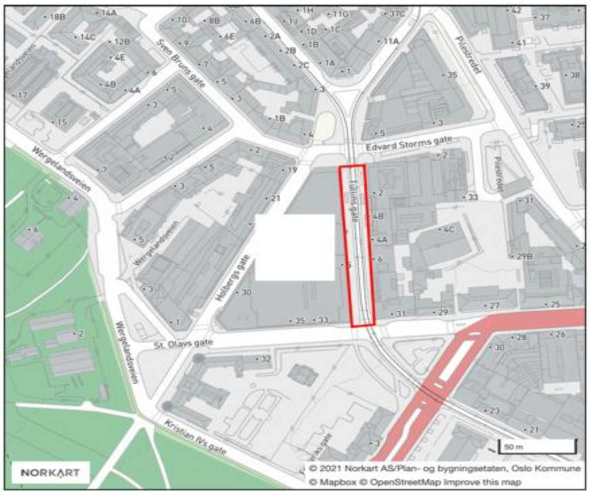


Figure 3-32 shows the location of Tullins gate in downtown Oslo.

Figure 3-33 shows the trees in Tullins gate in ca. 1975. Photographer: Ørnelund, Leif. Oslo Museum/OB.Ø75/1205, from Oslobilder.no

4 Methodology

According to the USDA Forest Service (2020b) i-Tree user manual (2020b), for any i-Tree Eco project with a complete inventory, the two tree variables that must be collected in order to run an ecosystem services analysis are:

- Species
- Diameter at breast height (DBH)

However, running the model with base requirements has substantial limitations and it is therefore strongly recommended to include the following tree measurements to improve the model's analysis:

- Live tree height
- Total tree height
- Height to crown base
- Crown light exposure
- Crown width
- Percent crown missing
- Actual land use

For this paper, the data collection process for the above-mentioned variables was divided into two distinct approaches depending on whether the trees had been removed or were still alive: a post-removal digital data collection process referred to as "historical trees" or field surveys if the trees were still there referred to as "living trees". For historical trees it is important to note that the number of trees generally declines after being planted, and ecosystem services will therefore vary depending on what point in time you use as a baseline.

I-Tree Eco allows for dynamic modelling by including mortality and tree planting rates when projecting future services. The current and projected ecosystem services for historical trees will be based upon the last measurements taken, unless otherwise stated, meaning the percentage of trees left upon removal will be the baseline instead of the original number of trees planted.

All the investigated field sites have at some point had trees that have been removed and been replaced, and in some cases this process has been repeated multiple times. The exact location of the replacement trees also varied as several of the sites were at some point in time re-designed.

4.1 Living trees (2021)

For the current tree field sites, data was collected through field surveys following the approach presented in the i-Tree Eco Field Guide (USDA Forest Service, 2020a). The municipalities tree inventory (ArcGIS) was used as a basis for species (Bymiljøetaten, 2021), while DBH measurements were taken and updated during the survey. The other variables collected were live tree height, total tree height, height to crown base, crown width, percent crown missing and actual land use. The variable crown light exposure was in addition assessed using aerial photos provided in the municipalities database.

4.2 Historical trees

To collect the different tree variables recommended by the i-Tree user manual, a series of different databases had to be used, which in part depended upon the amount of data collected in the municipalities tree inventory. These databases will colloquially be referred to as “digital tools” and consisted of using a combination of the municipalities tree inventory for the variables species and DBH. Google earth, Google street view and the Norwegian database “Hoydedata.no” was used to determine the variables total tree height and crown width, and finally Google Street view was used to determine the variables height to live crown base, percent crown missing, DBH if missing from the tree inventory (or outdated/inaccurate), and live tree height (in combination with Hoydedata.no). If DBH could not be determined, the average DBH for that site was used. This was also the case for some of the historical which was gone by the time of the earliest historical Google Street view pictures. In such cases the missing values were derived from the average of the rest of the population at that site.

Below follows table 4-1 which shows the different field sites, the different “points in time” when they were assessed, and which digital tool was used to determine which variable.

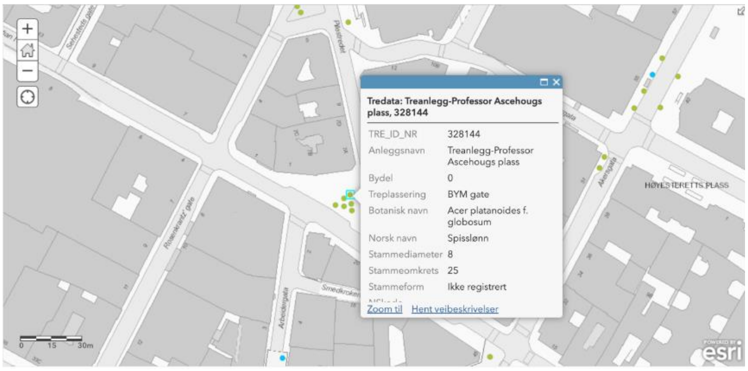
Unless otherwise stated, the data collection was done according to the i-Tree Eco field manual.

Table 4-1 The different input variables for the i-Tree Eco analysis and which data source was used for which variable. Dark grey area were additional variables that were not strictly necessary and were not collected due to the scope of this study.

i-Tree Eco Variables	Data source for selected site (year)											
	Olav V´s gate 2014	Olav V´s gate 2021	ProfAschehougs plass 2017	Prof Aschehougs plass 2021	Tullins gate 2017	Tullins gate 2021	Europarådets plass 2019	Europarådets plass 2021	Nygata 2017	Nygata 2019	Storgata 2020	Storgata 2021
Species	Geo-bank	Geo-bank	Geo-bank	Geo-bank	Geo-bank	Geo-bank	Geo-bank	Geo-bank	Geo-bank	Geo-bank	Geo-bank	Geo-bank
Diameter at breast height (DBH)	Geo-bank	Field survey	Google street view 2017	Field survey	Google street view 2017	Field survey	Geo-bank	Field Survey	Google street view 2014	Field Survey	Geo-bank	Field survey
Total height	Google earth/ Oslo byggesone 2014 (Hoydedata.no)	Field Survey	Google Street view 2017	Field Survey	Google Street view 2017	Field Survey	Google earth	Field Survey	Google Street view	Field Survey	Google earth	Field Survey
Crown to base height	Google street view 2017	Field Survey	Google street view 2017	Field Survey	Google street view 2017	Field Survey	Google street view 2016	Field Survey	Google street view 2014	Field Survey	Google street view 2019	Field Survey
Crown width	Hoyde data 2014 (QGIS)	Field Survey	Hoyde data 2011	Field Survey	Hoyde data 2011	Field Survey	Hoyde data 2017	Field Survey	Hoyde data 2014	Field Survey	Hoyde data 2017	Field Survey
Percent crown missing	Google street view 2017	Field survey	Google street view 2017	Field survey	Google street view 2017	Field survey	Google street view 2016	Field survey	Google street view 2014	Field survey	Google street view 2019	Field survey
Crown light exposure (CLE)	Google maps	Google maps	Google maps	Google maps	Google maps	Google maps	Google maps	Google maps	Google maps	Google maps	Google maps	Google maps
Crown health (condition/dieback)	Google street view 2017	Field survey	Google street view 2017	Field survey	Google street view 2017	Field survey	Google street view 2016	Field survey	Google street view 2014	Field survey	Google street view 2019	Field survey
Pollution	i-Tree	i-Tree	i-Tree	i-Tree	i-Tree	i-Tree	i-Tree	i-Tree	i-Tree	i-Tree	i-Tree	i-Tree
Field land use	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial	Commercial
Distance to building												
Direction to building												
Percent tree cover												
Percent shrub cover												
Percent building cover												
Ground cover composition												

4.3 Species

For all field sites investigated, all trees mapped in the database had been specified by species (figure 4-1). Some sites did not go far enough back to see what species originally were planted, but those trees were only used as a reference point for the historical context and not the actual i-Tree analysis.



Tredata: Treanlegg-Professor Ascehougs plass, 328144

TRE_ID_NR	328144
Anleggsnavn	Treanlegg-Professor Ascehougs plass
Bydel	0
Treplassering	BYM gate
Botanisk navn	Acer platanoides f. globosum
Norsk navn	Spisslønn
Stammediameter	8
Stammeomkrets	25
Stammeform	Ikke registrert

Figure 4-1 shows the recorded tree information publicly available on the agencies site "Park & Trær forvaltet av BYM – Innsyn" (Bymiljøetaten, 2021)

To run the i-Tree analysis the species needed to be recorded in the i-Tree database. Cultivars used in downtown Oslo were often missing from the species database. If the species was missing, another species within the same genus with the most similar species characteristics was used as a proxy. The table 4-2 in Appendix 1 shows the varying tree species included in this study, potential proxy, and the species characteristics and potential discrepancy between the two used in the model.

Van der berk nurseries have additional categories to aid the selection process for trees in relation to site by adding additional categories such as crown shape, soil moisture, soil type, paving tolerance, wind and frost resistance and fauna trees (value for insects). I-Tree species also plan to improve their model by adding local species limitations such as soil tolerances. Tolerance to salt is another parameter that could be important in countries experiences colder winters.

Increasing the number of parameters will further help managers in selecting the appropriate species better adapted to the local conditions, stressors, and increased survivability.

4.4 Diameter at breast height

During the field survey, diameter at breast height (DBH) was calculated from the tree circumference measured one meter above ground level in centimeters. For trees that were unreachable (within an ongoing building project), the other nearby trees were used as a basis for estimating their circumference.

The historical trees DBH was measured using google street view if the measurements had not previously been recorded in the municipalities tree inventory or deemed not be representative (if outdated). In addition, objects like tiles, that were still there during the field survey, were measured to approximate the scales in the picture.

4.5 Live tree height

For field surveys, the methodology was followed according to the i-Tree Eco field manual. In addition, the mobile application “Arboreal heights” was used as a helping tool to determine tree heights to the nearest half meter, along with a visual evaluation. After agreeing upon a tree height for certain trees, they were used as a reference point for the remaining street trees in that facility.

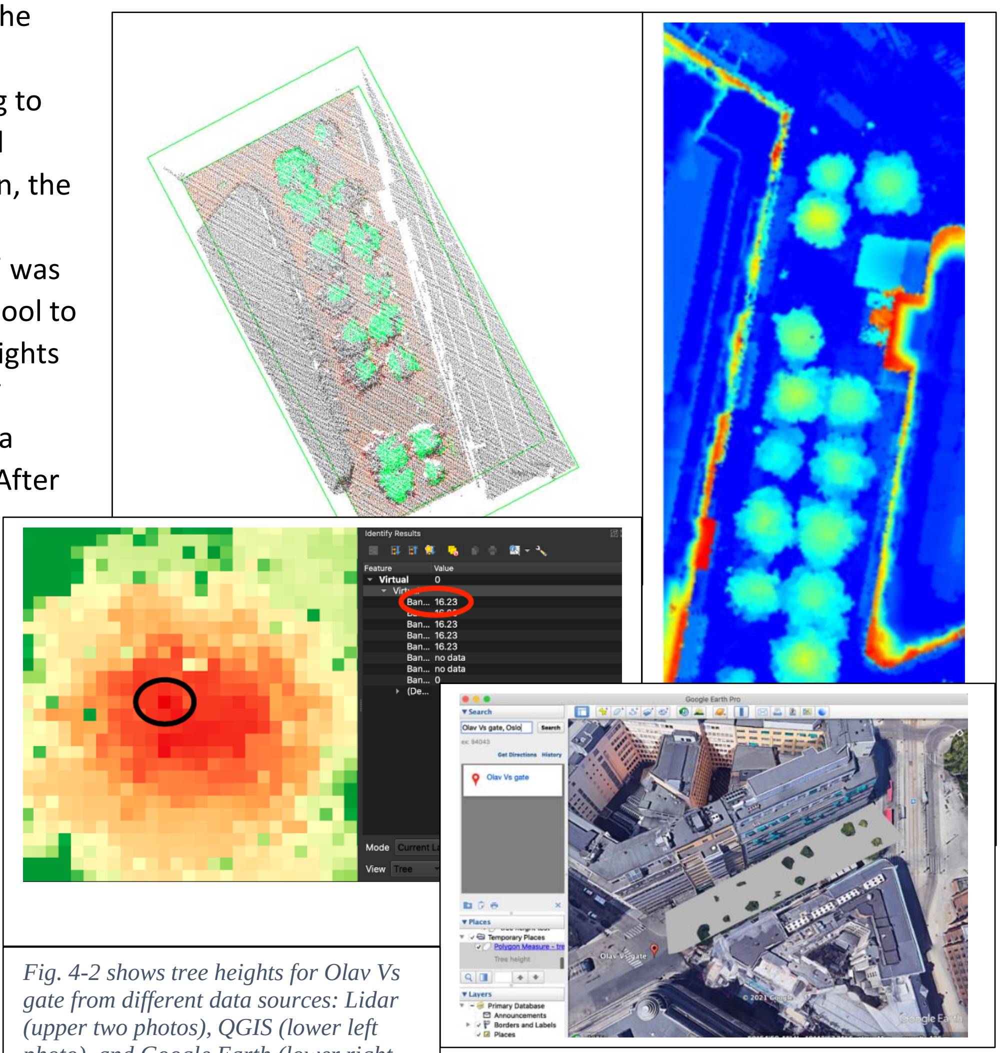


Fig. 4-2 shows tree heights for Olav Vs gate from different data sources: Lidar (upper two photos), QGIS (lower left photo), and Google Earth (lower right photo).

For historical trees, live tree height was measured using LiDAR data retrieved from Hoydedata.no and google street view. A LAZ file was downloaded from Hoydedata.no. A visual check of the data was done by using the program LAS view from the LAS toolkit. The field sites were then trimmed out from the surrounding area and the data points were categorized into ground cover and vegetation. Data point anomalies and buildings were removed, and a CHM-plot was then made following this approach. In addition, the data was processed to remove any holes in the tree cover.

A raster was then created according to height intervals of the data points. The different rasters were then uploaded into QGIS, and a band color gradient was used to color the data points according to their height. The height was then measured by finding the highest data point.

The approach using planar polygons in Google Earth Pro was also used to find estimates of tree height by figuring out which intervals of polygons the tree fall within (Forests, 2015; Sutherland, 2015). Based on the imagery, it was then decided which polygon the tree crown was closest to and the parameter was measured to the nearest meter.

Below follows a table comparing the two approaches for Olav Vs gate.

Table 4.2 Comparison of QGIS/Lidar and Google Earth tree heights for Olav Vs gate

Tree	QGIS/LiDAR	Google Earth
1	12m	11-12m
2	16m	15-16m
3	13m	11-12m
4	14m	14-15m
5	10m	9-10m
6	13m	11-12m
7	12m	11-12m
8	9m	8-9m
9	12m	12-13m
12	12m	12-13m
13	12m	12-13m
14	13m	12-13m
15	12m	11-12m
16	15m	15-16m
Note: trees 10 and 11 are missing, averages were taken.		

This methodology was used going forwards (for Europarådets plass and Storgata) as being less labor intensive while producing estimates comparable to the LiDAR data.

4.6 Total tree height

During the field survey the methodology was done in accordance with the i-Tree Eco field manual, noting whether the top of the tree was dead.

For historical trees, live tree height and total tree height were assumed to be the same unless pictures from Google Street view suggested otherwise.

4.7 Height to crown base

Similar to the height of trees, the approach using planar polygons in Google Earth ro was used to find estimates of height to live crown base (Forests, 2015; Sutherland, 2015).

In accordance with the i-Tree Eco Field manual the parameter 'height to live crown base' is measured from the bottom of the trunk to the lowest live foliage of the tree crown perpendicular to the main trunk. To measure the 'height to live crown base' a set of polygons with different heights were created from 1m to 6m, with a 1m interval (to the nearest meter according to the manual), in google earth similar to the polygon shown above.[1] Google Street view was then used to view the actual tree trunks. The polygons were then applied to get an approximation of the 'height to live crown base' where the polygon and live foliage intersected. For trees with an obstructed view of the trunk, the 2009 google street view images were also used to give a better idea of the crown size and thereby estimating the height to live crown base. Since google earth doesn't have an option to view the historical street view images, the above approach could not be used in the browser version of google street view.

Height to crown base was measured to the nearest meter.

For the field survey the approach was done according to the i-Tree eco field manual.

For the historical trees the height was measured using Google Earth following the approach outlined by, which functioned by making a series of polygons at 1m intervals above ground level. The trees were then viewed in google street view and the different polygons were turned on until one intersected with the foliage on the tree.

4.8 Crown light exposure

Crown light exposure was determined using aerial photo for both historical and re-designed sites according to the i-Tree Eco field manual.

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[1] https://www.researchgate.net/post/Do_anyone_know_how_can_I_measure_tree_height_from_Google_Earth_Pro_street_view_Is_there_any_tool_present_measure_tree_height_from_street_view polygon approach 30.3.2021

4.9 Crown width

Crown width was measured to the nearest half meter.

Since the trees were newly established for most of the sites for the field survey (last 3 years), the crown width was measured using two people and a measuring tape. The crown width was measured both in North to South, and East to West directions.

For the historical trees the crown width was measured using QGIS, from a North to South and East to West direction in accordance with the i-Tree eco field manual.

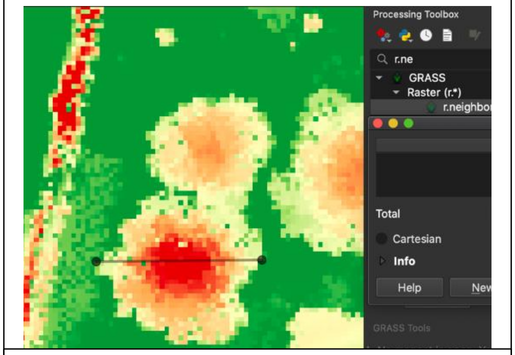


Fig. 4-3 East to West crown width /black line) measured in QGIS.

4.10 Percentage crown missing

For the field survey, the percent crown missing was estimated in accordance with the i-Tree field manual (Fig. 4-4). The crown was evaluated from two directions perpendicular to each other while standing at a distance from the tree equal to 1-2 times its height. Two people were used to evaluate percent crown missing, by first doing an individual assessment before conferring with each other and agreeing upon a percentage.

Fig. 4-4 One crown projection used for evaluating percentage crown missing.

4.11 Condition

Condition was evaluated in a similar approach to percent crown missing, by determining how much of the tree consisted of dead branches. The inverse percentage was then taken to get the condition of the tree.

4.12 Actual land use

All field sites were set too industrial/commercial (C) as they were surrounded by public transportation, shops, and pavement.

4.13 Additional assumptions

One inherent limitation in using multiple databases to estimate ecosystem services for historical trees, is that it is challenging to retrieve the respective parameters needed from the same point in time. The analysis, while not being representative of any point in the historical timeline, will also likely be an underestimation, as some parameters are collected at different times, giving different data which do not consider the changes in growth and tree health conditions during this time difference. This is also the case for the tree-inventory Geobank, which has the last recorded measurements.

5 Results

The results are divided into three main sections. The first part shows a comparison between the benefits provided by the historical and current sites as generated by the i-Tree eco report, their percentage differences, and their respective conditions. These benefits and conditions created the basis for the second section which looks at how these benefits change during a 30-year forecast with default mortality rates. Finally, the third section will look at a 50-year forecast of the historical and current sites with zero mortality. The results will also show the variability between the forecasted runs.

5.1 Provided benefits

5.1.1 Europarådets plass

Number of trees and species composition

The number of trees at Europarådets plass has increased by 150% in comparison to the historical number. The species composition has changed, as classified by the i-Tree species database, from the species ‘Schwedleri’ (*Acer platanoides* ‘Schwedleri’*)* with a fast growth rate, medium size, and long longevity (appendix 1, table 2) too two new species of cherry. The Sargant cherry (*Prunus sargentii* ‘Rancho’) has a fast growth rate, short longevity, and short size while the Kanzan cherry (*Prunus serrulate* ‘Kanzan’) has a moderate growth rate, moderate size, and a medium size category (Appendix 1, table 2).

Key points in changes of benefits:

- Carbon storage has the biggest discrepancy when compared to the historical at 18% (table 5.1).

- Avoided runoff has increased compared to the historical by 4% (table 5.1).

- Gross carbon sequestration was the highest per year benefit for both the historical and current trees (table 5.1).

- The historical trees had the highest structural value, and the Kanzan cherry had the second highest structural value, despite being 50% less trees when compared with the Sargant cherry (table 5.1).

Derived variables

When looking at the condition between the two cherry species the Kanzan cherry (*Prunus serrulata* ‘Kanzan’) was found to have a higher condition (100%) when compared to the Sargant cherry (75%) (Appendix 1, table 1). When comparing the derived variables, the overall condition between the trees were found to be similar between historical (86%) and current trees (83%) (Appendix 1, table 1). The leaf biomass was found to be double for the new trees compared to the old trees, while the dry weight of the historical trees was 13 times higher than the current trees (Appendix 1, table 1).

Table 5-1 The various benefits derived from current (2021) and historical trees for Europarådets plass, and the relative change in comparison between the two.

Stratum	Species	Tree nr.	Carbon Storage (metric ton)	Value (NOK)	Gross Carbon Seques-tration (metric ton)	Value (NOK/yr)	Avoided Runoff (m^3/yr)	Value (NOK/yr)	Pollution Removal (metric ton/ yr) <0,01	Value (NOK/yr)	Structural Value (NOK)
Europarådets plass historical	Acer platanoides 'Schwedleri'	6	1,33	2037	0,07	104,1	0,87	15,78	<0,01	62,73	54168,48
	Total	6	1,33	2037	0,07	104,1	0,87	15,78	<0,01	62,73	54168,48
Europarådets plass 2021	Prunus sargentii	10	0,15	221,76	0,03	51,18	0,56	10,28	<0,01	30,89	13584,34
	Prunus serrulata	5	0,1	150,09	0,02	32	0,34	6,19	<0,01	18,6	16639,61
	Total	15	0,24	371,85	0,05	83,18	0,9	16,47	<0,01	49,49	30223,95
% of historical		250,00	18,05	18,26	71,43	79,90	103,45	104,37	<0,01	78,89	55,80

5.1.2 Nygata

Number of trees and species composition

The number of trees and species composition of columnar oak trees (*Quercus robus* 'Fastigata') at Nygata have remained the same (Appendix 1, table 2). The species, based on the i-Tree Database, have a moderate growth rate, long longevity, and a large size class (Appendix 1, table 2).

Key points in changes of benefits:

- All benefits were reduced when compared to the historical trees (table 5-2).

- Carbon storage had the least discrepancy, compared to other benefits. when compared to the historical trees at 74% (table 5-2).

- Pollution removal has the highest discrepancy compared to the historical trees, with 10% (table 5-2).

- Gross carbon sequestration was the highest per year benefit for both the historical and current trees (table 5-2).

- The current trees had 15% of the structural value compared to the historical trees (table 5-2).

Derived variables

The average health condition of the historical trees was found to be 92% compared to 23% of the current trees, while the tree dry weight was similar at 0,28 metric ton, to 0,21 metric ton for the historical and current trees, respectively (Appendix 1, table 1).

Table 2-2 The various benefits derived from current (2021) and historical trees for Nygata, and the relative change in comparison between the two.

Stratum	Species	Tree nr.	Carbon Storage (metric ton)	Value (NOK)	Gross Carbon Seques-tration (metric ton)	Value (NOK/yr)	Avoided Runoff (m^3/yr)	Value (NOK/yr)	Pollution Removal (metric ton/ yr)	Value (NOK/yr)	Structural Value (NOK)
Nygata historical	Quercus robur 'Fastigiata'	5	0,14	215,82	0,02	33,33	0,2	3,64	<0,01	14,47	15256,28
	Total	5	0,14	215,82	0,02	33,33	0,2	3,64	<0,01	14,47	15256,28
Nygata 2021	Quercus robur 'Fastigiata'	5	0,1	158,92	0	4,75	0,03	0,49	<0,01	1,49	2342,72
	Total	5	0,1	158,92	0	4,75	0,03	0,49	<0,01	1,49	2342,72
% of historical		100,00	71,43	73,64	0,00	14,25	15,00	13,46	<0,01	10,30	15,36

5.1.3 Olav Vs gate

Number of trees and species composition

The number of current trees at Olav Vs gate is 75% of the historical trees, and the species have been changed from small-leaved lime trees (*Tilia cordata*) with a moderate growth rate, moderate longevity, and a large size class to Brandywine red maple, with a medium size class (appendix 1, table 2, longevity and growth rate not registered in the i-Tree database).

Key points in changes of benefits:

- All benefits were reduced compared to the historical trees (table 5-3).

- Pollution removal had the highest discrepancy when compared to the historical trees, at 4% (table 5-3).

- Avoided runoff has increased compared to the historical trees by 4% (table 5-3).

- Gross carbon sequestration was the highest per year benefit for current trees, and had the least discrepancy compared to the historical trees (68%) (table 5-3).

- The avoided runoff was the highest benefit per year for the historical trees (table 5-3).

- The current trees had 12% of the structural value compared to the historical trees (table 5-3).

Derived variables

The average health condition of the historical trees was found to be 98% compared to 92% of the current trees, while the tree dry weight, leaf area and leaf biomass were between 9-50 times lower for the current trees (Appendix 1, table 1).

Table 5-3 The various benefits derived from current (2021) and historical trees for Olav Vs gate, and the relative change in comparison between the two.

Stratum	**Species**	**Tree nr.**	**Carbon Storage (metric ton)**	**Value (NOK)**	**Gross Carbon Seques-tration (metric ton)**	**Value (NOK/yr)**	**Avoided Runoff (m^3/yr)**	**Value (NOK/yr)**	**Pollution Removal (metric ton/ yr)**	**Value (NOK/yr)**	**Structural Value (NOK)**
Olav Vs gate historical	**Tilia cordata**	**16**	**3,5**	**5351,3**	**0,1**	**157,06**	**17,64**	**321,57**	**<0,01**	**1278,39**	**318687,25**
	Total	**16**	**3,5**	**5351,3**	**0,1**	**157,06**	**17,64**	**321,57**	**<0,01**	**1278,39**	**318687,25**
Olav Vs gate 2021	**Acer rubrum 'Brandywine'**	**12**	**0,39**	**600,73**	**0,07**	**106,3**	**1,02**	**18,65**	**<0,01**	**56,03**	**38290,88**
	Total	**12**	**0,39**	**600,73**	**0,07**	**106,3**	**1,02**	**18,65**	**<0,01**	**56,03**	**38290,88**
% of historical		**75,00**	**11,14**	**11,23**	**70,00**	**67,68**	**5,78**	**5,80**	**<0,01**	**4,38**	**12,02**

5.1.4 Professor Aschehougs plass

Number of trees and species composition

The number of trees at Professor Aschehougs plass is 67% of the historical value, columnar oak trees (*Quercus robus* 'Fastigata'), with a moderate growth rate, long longevity and a large size class too the proxy species cultivar Rocky Mountain maple (simulating *Acer platanoides* 'Globosum'), with moderate growth rate and longevity and short size class, as per the i-Tree databse (Appendix 1, table 2).

Key points in changes of benefits:

- Avoided runoff and pollution removal have increased by 98% and 50% compared to the historical trees, respectively (table 5-4).

- Carbon storage has the biggest discrepancy when compared to the historical trees at 60% (table 5-4).

- Gross carbon sequestration was the highest per year benefit for both the historical and current trees (table 5-4).

- The current trees had 65% of the structural value compared to the historical trees (table 5-4).

Derived variables

The average health condition of the historical trees was found to be 84% compared to the 97% of the current trees, while the tree dry weight was 0,26 (metric ton) for the current trees compared to the 0,43 (metric tons) of the historical trees (Appendix 1). Leaf area was the same for historical and current trees with 0.01 ha (Appendix 1, table 1).

Table 5-4 The various benefits derived from current (2021) and historical trees for Professor Aschehougs plass, and the relative change in comparison between the two.

Stratum	Species	Tree nr.	Carbon Storage (metric ton)	Value (NOK)	Gross Carbon Sequestration (metric ton)	Value (NOK/yr)	Avoided Runoff (m^3/yr)	Value (NOK/yr)	Pollution Removal (metric ton/ yr)	Value (NOK/yr)	Structural Value (NOK)
Professor Aschehougs plass historical	Quercus robur 'Fastigiata'	9	0,22	328,71	0,03	51,98	0,17	3,07	<0,01	12,22	22784,32
	Total	9	0,22	328,71	0,03	51,98	0,17	3,07	<0,01	12,22	22784,32
Professor Aschehougs plass 2021	Acer glabrum	6	0,13	196,09	0,03	44,6	0,33	6,09	<0,01	18,28	14895,22
	Total	6	0,13	196,09	0,03	44,6	0,33	6,09	<0,01	18,28	14895,22
% of historical		66,67	59,09	59,65	100,00	85,80	194,12	198,37	<0,01	149,59	65,37

5.1.5 Storgata

Number of trees and species composition

The number of trees at Storgata has increased by 550% compared to the historical number of trees, and the species composition has changed from European hornbeam (*Carpinus betulus*) which has a moderate growth rate, longevity, and medium size class to four new species (Appendix 1, table 2). The new species were as follows:

- Katsura tree (*cercidiphyllum japonicum*) with a moderate growth rate, longevity and medium size class (Appendix 1, table 2).

- Magnolia Leonard Messi (*Magnolia* x *loebneri* 'Leonard Messi', proxy for *Magnolia kobus* due to its small size in the database) with a medium size class (growth rate and longevity missing in the i-Tree database) (Appendix 1, table 2).

- Black locust (*Robinia pseudoacacia*) with fast growth rate, short longevity, and large size class (i-Tree database).

- Yoshino flowering cherry (*Prunus* x *yedoensis*) with a moderate growth rate, short longevity, and small size class (i-Tree database).

Today's number of trees at Europarådets plass have close to tripled (250%) in comparison to the historical number of trees.

Key points in changes og benefits:

- All benefits, except for carbon storage, have increased with 100-200% compared to the historical benefits (table 5-5).

- Carbon storage had the biggest discrepancy when compared to the historical benefit at 21% (table 5-5).

- Avoided runoff has increased compared to the historical benefit by 4% (table 5-5).

- Pollution removal was the highest benefit per year for historical and current trees, with a 128% increase compared to the historical trees (table 5-5).

- Black locust had the highest structural value (table 5-5).

Derived variables

The average health condition of the historical trees was 37% compared to the 96% of the current trees, while the tree dry weight was 4-5 times bigger for the historical trees with 1,14 metric tons (Appendix 1, table 1). The leaf biomass was found to be the same, while the leaf area was twice as big for the current trees with 0,02 ha (Appendix 1, table 1).

Table 5-5 The various benefits derived from current (2021) and historical trees for Storgata, and the relative change in comparison between the two.

Stratum	**Species**	**Tree nr.**	**Carbon Storage (metric ton)**	**Value (NOK)**	**Gross Carbon Seques-tration (metric ton)**	**Value (NOK/yr)**	**Avoided Runoff (m^3/yr)**	**Value (NOK/yr)**	**Pollution Removal (metric ton/ yr)**	**Value (NOK/yr)**	**Structural Value (NOK)**
Storgata historical	**Carpinus betulus**	**2**	**0,57**	**873,25**	**0,01**	**9,75**	**0,25**	**4,51**	**<0,01**	**17,92**	**10444,77**
	Total	**2**	**0,57**	**873,25**	**0,01**	**9,75**	**0,25**	**4,51**	**<0,01**	**17,92**	**10444,77**
Storgata 2021	**Cercidiphyllum japonicum**	**2**	**0,01**	**13,37**	**0**	**1,9**	**0,12**	**2,26**	**<0,01**	**6,79**	**4084,18**
	Magnolia x loebneri	**4**	**0,04**	**55,21**	**0**	**6,69**	**0,19**	**3,39**	**<0,01**	**10,19**	**7124,62**
	Prunus x yedoensis	**1**	**0,02**	**29,02**	**0**	**3,51**	**0,1**	**1,87**	**<0,01**	**5,63**	**2132,33**
	Robinia pseudoacacia	**6**	**0,06**	**88,71**	**0,01**	**13,19**	**0,33**	**6,09**	**<0,01**	**18,31**	**10879,84**
	Total	**13**	**0,12**	**186,31**	**0,02**	**25,29**	**0,75**	**13,62**	**<0,01**	**40,92**	**24220,97**
% of historical		**650,00**	**21,05**	**21,34**	**200,00**	**259,38**	**300,00**	**302,00**	**<0,01**	**228,35**	**231,90**

5.1.6 Tullins gate

Number of trees and species composition

The number of trees at Tullins gate compared to the historical number is 58% (table 5-6). The species composition has changed from Littleleaf Liden trees (*Tilia cordata*), with moderate growth rate, longevity and large size class to European hornbeam which has a moderate growth rate and longevity but a moderate size class (Appendix 1, table 2).

Key points in changes of benefits:

- All benefits have gone down in comparison to the historical values.

- Carbon storage has the biggest discrepancy when compared to the historical discrrepancy at 3% (table 5-6).

- Pollution removal was the highest per year benefit for both the historical and current trees (table 5-6).

- The current trees had a structural value 8% compared to the historical trees (table 5-6).

Derived variables

The average health condition of the historical trees was found to be 59% compared to 100% of the current trees, while the dry weight was 50 times lower, the leaf biomass 10 times lower, and the leaf area 13 times lower compared to the historical trees (Appendix 1, table 1).

Table 5-6 The various benefits derived from current (2021) and historical trees for Tullins gate, and the relative change in comparison between the two.

Stratum	Species	Tree nr.	Carbon Storage (metric ton)	Value (NOK)	Gross Carbon Seques-tration (metric ton)	Value (NOK/yr)	Avoided Runoff (m^3/yr)	Value (NOK/yr)	Pollution Removal (metric ton/ yr) <0,01	Value (NOK/yr)	Structural Value (NOK)
Tullins gate historical	Tilia cordata	12	2,54	3878,8	0,05	71,4	3,35	60,99	0	242,47	123 037,89
	Total	12	2,54	3878,8	0,05	71,4	3,35	60,99	0	242,47	123037,89
Tullins gate 2021	Carpinus betulus	7	0,09	131,47	0,01	17,41	0,47	8,48	0	25,48	9 751,41
	Total	7	0,09	131,47	0,01	17,41	0,47	8,48	0	25,48	9751,41
% of historical		58,33	3,54	3,39	20,00	24,38	14,03	13,90	0,00	10,51	7,93

5.1.7 Overall summary of historical vs. current trees

Number of trees and species composition

The number of trees across all sites increased by 16% compared to the historical number of trees (table 5-7). Historical trees at the six sites consisted of five different species, while the current trees consist of 10 species (Appendix 1, table 2). Overall, based on the i-Tree database, the historical trees have 3 of 5 species in the large size class, 4 of 5 trees with moderate growth rate, and 3 of 5 trees in the long longevity category (Appendix 1, figures 23-28). For the current trees it was a split between the short and medium categories accounting for 8 of 10 species, with 6 of 8 having a moderate growth rate and 4 of 8 having a moderate longevity (3 in short longevity category, Appendix 1, figures 23-28). For a complete overview see figures 23-28 in the appendix.

Key points in changes of benefits:

- All benefits have gone down in comparison to the historical values.

- Carbon storage has the biggest discrepancy when compared to the historical storage at 3% (table 5-7).

- Pollution removal had the biggest discrepancy when compared to the historical removal at 12 % (table 5-7).

-Pollution removal had the highest per year benefit for the historical trees, while gross carbon sequestration was the highest per year benefit for the current trees. Pollution removal was the biggest discrepancy when compared to the historical trees, at 12 % (table 5-7).

- The current trees had a structural value of 8% compared to the historical trees (table 5-7).

Derived variables

The average health condition of the historical trees was found to be 80% compared to 86% of the current trees (Appendix 1, table 1). The historical trees had an 8 times higher tree dry weight biomass, 13 times higher leaf biomass and 11 times the amount of leaf area compared to the current trees (Appendix 1, table1).

Table 5-7 The various benefits derived from current (2021) and historical trees for all sites, and the relative change in comparison between the two.

Stratum	**Species**	**Tree nr.**	**Carbon Storage (metric ton)**	**Value (NOK)**	**Gross Carbon Seques-tration (metric ton)**	**Value (NOK/yr)**	**Avoided Runoff (m^3/yr)**	**Value (NOK/yr)**	**Pollution Removal (metric ton/ yr)** <0,01	**Value (NOK/yr)**	**Structural Value (NOK)**
Study summary historical		**50**	**8,31**	**12685**	**0,28**	**427,62**	**22,47**	**409,56**	**<0,01**	**1628,2**	**544379,00**
Study summary 2021		**58**	**1,08**	**1645,4**	**0,18**	**281,53**	**3,5**	**63,8**	**<0,01**	**191,69**	**119725,14**
% of historical		**116,00**	**13,00**	**12,97**	**64,29**	**65,84**	**15,58**	**15,58**	**<0,01**	**11,77**	**21,99**

5.2 A 30-year forecast of current and historical trees with default mortality rate

A 30-year forecast was run for the two populations with default annual mortality rates. The annual mortality rates are assigned based upon the health of the tree measured as percentage condition. Healthy trees (51-100% condition) have an annual mortality of 3%, sick trees (26-50% condition) have an annual mortality of 13.1% and dying trees (0-25% condition) have an annual mortality rate of 50%. The trendlines for all figures are averages of five runs with uncertainty bars showing one standard deviation (σ).

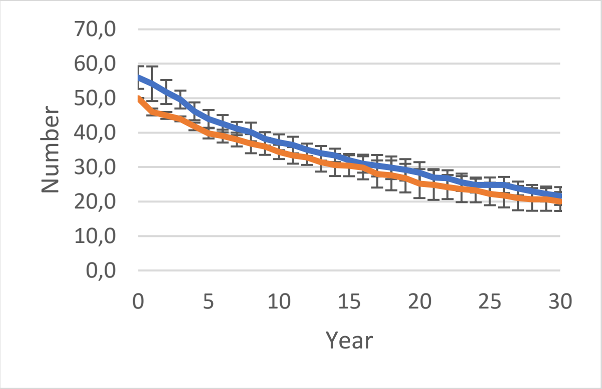


Figure 5-1 shows current trees (blue) and historical sites (brown) aggregated over a 30 year forecast with default mortality rates.

For the overall tree population when grouped as historical and current trees, the historical trees appeared to have around a 60% mortality after the 30-year forecast, while the current trees had between a 60-65% reduction in number of trees (figure 5-1). The current trees appeared to have a somewhat steeper drop in the number of trees compared to historical trees for the first five years of the forecast (figure 5-1).

In terms of carbon storage, the historical trees start off with a carbon storage of close to 8 times that of current trees (figure 34). The gradient for historical trees is relatively constant, meaning the overall storage of carbon does not change much over the 30-year forecast (figure 5-2). For the current trees, however, the starting carbon storage has a steeper gradient and appears to converge towards the historical trees and end up at around 60% of carbon storage of historical trees – at about 5 metric tons by the end of the forecast (figure 5-2). At around 21 years into the forecast the gradient for the current trees appears to decrease (figure 5-2).

For carbon sequestration the current trees appear to have a steeper gradient than the historical trees in the first five years of the forecast (figure 5-3). The historical trees, like for carbon storage, appear to have a somewhat level gradient while lowering at the end of the 30-year forecast (figure 5-3).

While the current trees initially have an increase in leaf biomass, it appears to level off at the end of the 30-year forecast, increasing by around 100 kilograms (figure 5-4). For the historical trees the leaf biomass consistently drops from 700 to 600 kg during the 30-year forecast (figure 5-4).

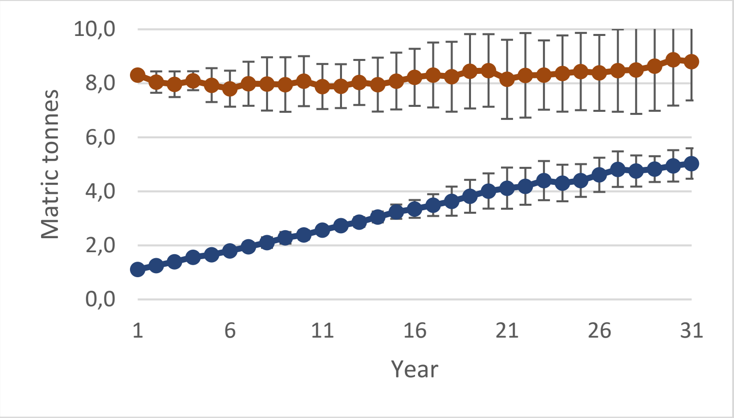


Figure 5-2 shows the current trees population (blue) and historical trees population (brown) and change in carbon storage over the 30 year forecast with default mortalities.

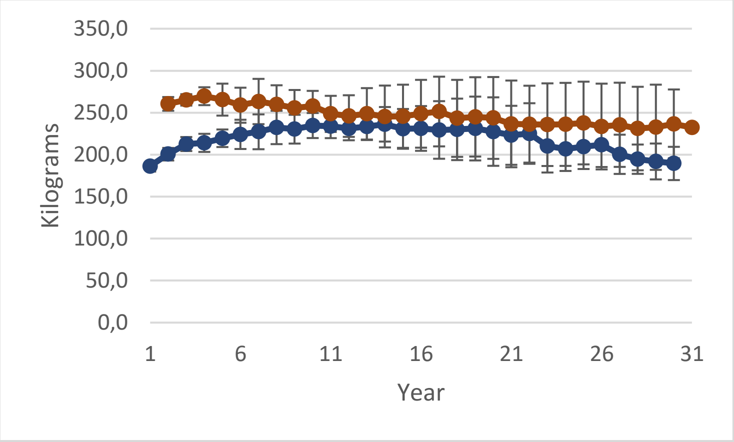


Figure 5-3 shows the current trees population (blue) and historical trees population (brown) and change in carbon sequestration over the 30 year forecast with default mortalities.

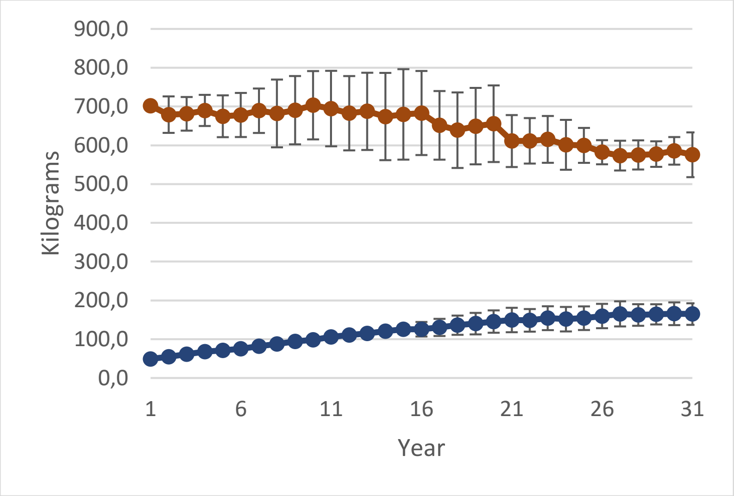


Figure 5-4 shows the current trees population (blue) and historical trees population (brown) and change in leaf biomass over the 30 year forecast with default mortalities.

5.3 A 30-year forecast with uncertainties – individual runs current trees.

The tree population for the five different forecast-runs for the current population started off at the same initial tree population but ended at what appears to be between 16-25 trees depending on run (figure 5-5). Run 4 is more than one standard deviation from the average from year 15 – 30 for the forecast (figure 5-5). Despite the runs having similar trends, they appear to diverge around year 15, all the while having inconsistent gradients that varied between the different runs (figure 5-5). At some points the gradients appeared to be somewhat constant while at other points in time while quite steep at others reminiscent of a wave pattern (figure 5-5).

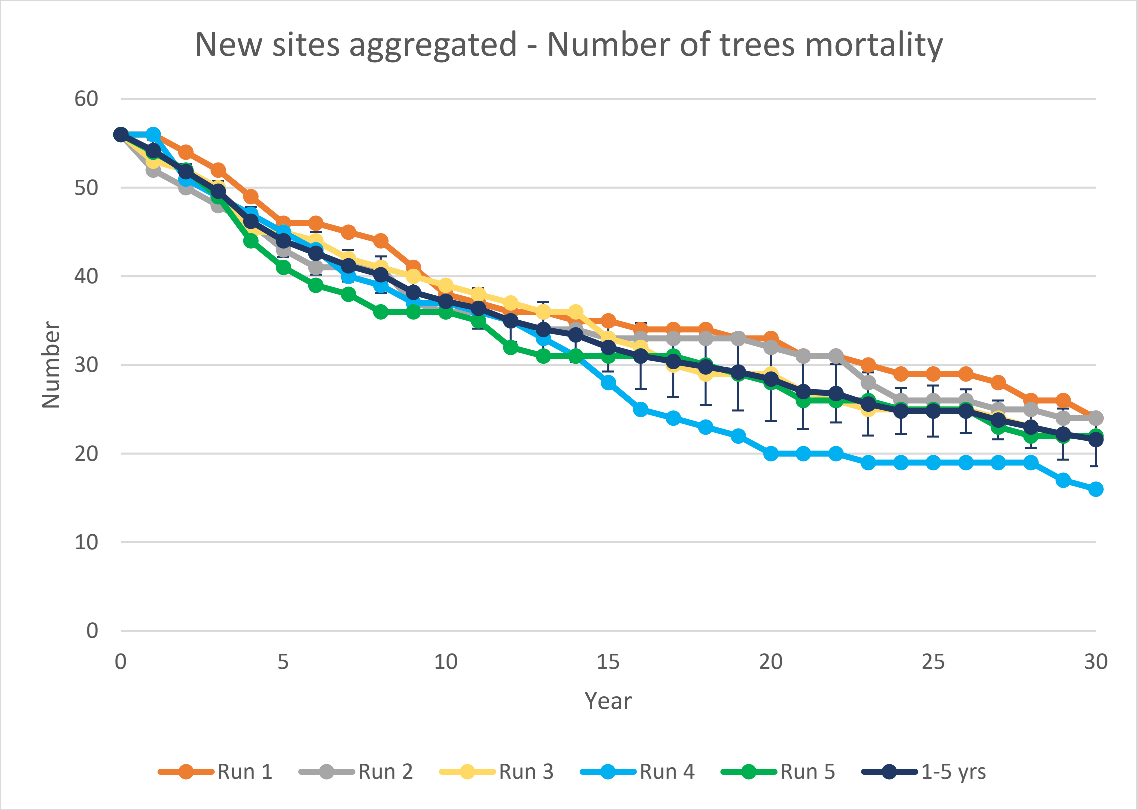


Figure 5-5 shows five different 30 year-forecast runs, and the average, with default mortality for current trees with the same input data.

The forecast for leaf biomass showed similar trends to tree mortality in the regard that they appear to diverge around year 15 of the forecast, with run 4 dropping off compared to the other runs (Figure 5-6). After starting at in initial leaf biomass of 50 kilograms, they ended up at 125-200 kilograms depending on run (figure 38). Carbon storage and carbon sequestration have similar variability (Appendix 1, figures 19 and 20).

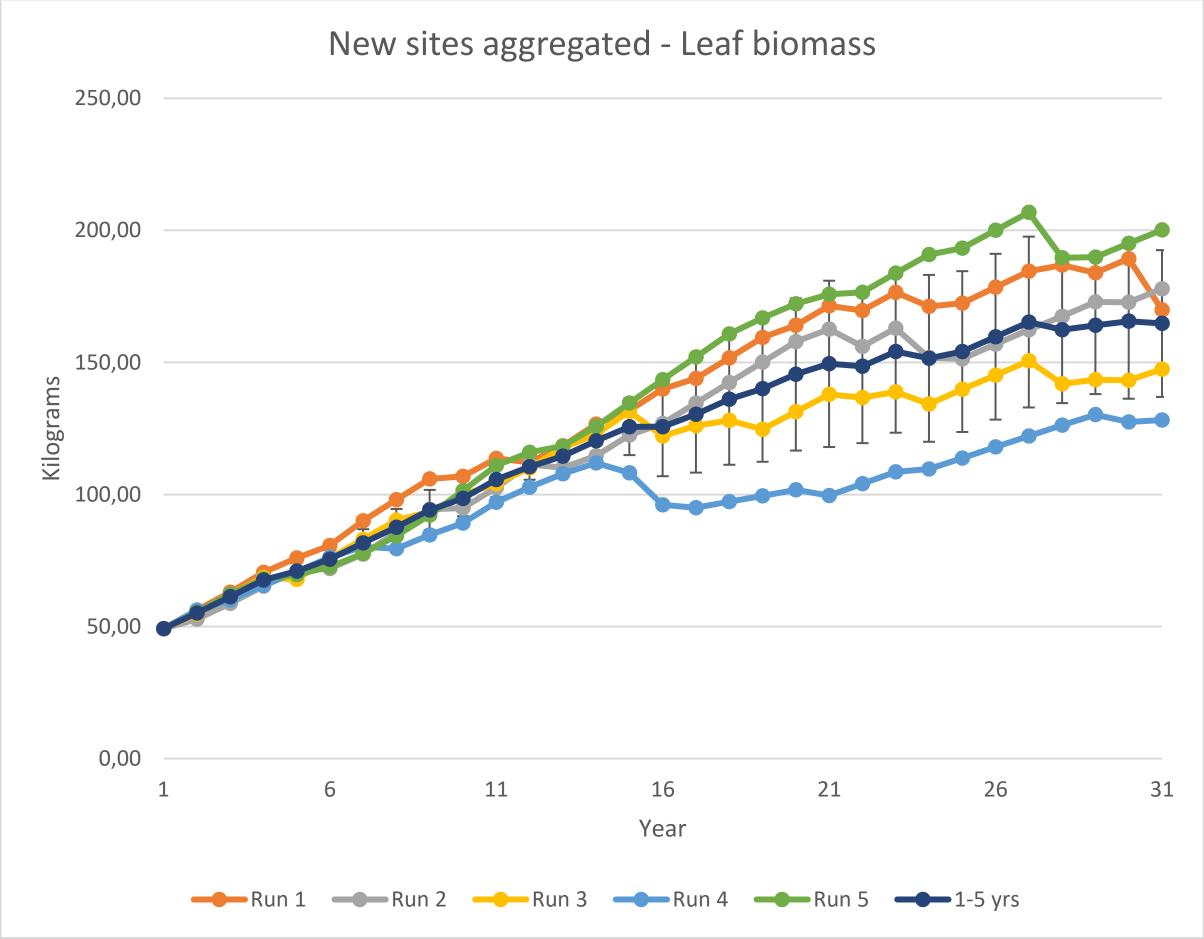


Figure 5-6 shows how the leaf biomass changes with time

5.4 A 50-year forecast with no mortality

5.4.1 Historical trees

Olav Vs gate and Europarådets plass have the overall highest contributions by the end of the forecast (figure 5-7). After around 15 years of the forecast Europarådets plass passes Tullins gate to end up in second place in terms of overall carbon storage contribution of the six sites by the end of the 50-year forecast (figure 5-7). Tullins gate, after Storgata, appears to stagnate at the end of the forecast, while the three other sites appear to increase in carbon storage (figure 5-7). Overall, the carbon storage appears to increase in a curvilinear manner (figure 5-7).

When looking at carbon sequestration contributing factors of the different sites, Olav Vs plass, Europarådets plass and Professor Aschehougs plass seem to be somewhat similar by the end of the 50-year forecast (figure 5-9). Professor Aschehougs plass, however, had a larger increase when compared to the two other sites (figure 5-9).

For leaf biomass, Olav Vs gate appears to start off with 85% of the biomass and account for roughly 67% of the overall biomass by the end of the 50-year forecast (figure 5-11). Both Tullins gate and Professor Aschehougs plass have similar leaf biomasses by the end of the forecast, while the latter has increased the most percentage wise (figure 5-11). Finally, the overall rate of increase is going up by the end of the forecast (figure 5-11) – similarly to figures 5-7 and 5-9. For the historical trees, the site Storgata has the least contribution for all parameters.

5.4.2 Current trees

For the current trees, the carbon storage was initially quite small at around 1 metric ton, but by the end of the 50-year forecast the amount of carbon storage had increased 20-fold where Olav Vs gate accounted for about half (figure 5-8). For the duration of the forecast, Nygata had the least amount of change, and one should also note the slight leveling off of benefits for Europarådets plass, Tullins gate and Professor Aschehougs plass (figure 5-8.) By the end of the forecast, the carbon storage has a linear trend (figure 5-8).

Overall, the carbon sequestration appeared to level off after around 30 years (figure 5-10). For the sites Olav Vs gate and Europarådets plass the first 30 and 10 years, respectively, appeared to have higher increases in annual carbon sequestration before gradually leveling off and eventually decreasing at the end of the 50-year forecast (figure 5-10). For Professor Aschehougs plass, a similar trend was seen, while for Tullins gate and Storgata the annual rate of carbon sequestration appeared to be on the rise after the forecast (figure 5-10). For Nygata the sequestration was marginal (figure 5-10).

The sites that contributed the most to the leaf biomass by the end of the 50-year forecast were Olav Vs gate and Europarådets plass, followed closely by Storgata. Tullins gate and Professor Aschehougs plass had less leaf biomass than the former sites (figure 5-12). Nygata had the least amount of leaf biomass (figure 5-12).

5.4.3 Summary

In terms of carbon storage, current trees start at around 1 metric tons, while the historical trees start at around 8 metric tons (figure 5-7). By the end of the 50-year forecast, current trees have around 60% carbon storage compared to the historical trees, at around 20 and 35 metric tons respectively (figure 5-7 and 5-8). For carbon sequestration, the current trees leveled off after about 30 years while for the historical trees the benefit kept increasing after 50-years and was twice as much as the current trees (figure 5-9 and 45-11). The leaf biomass for the current trees was about 33% of the historical trees by the end of the 50-year forecast (figure 5-11 and 5-12). The pollution removal for the historical trees, while having an initial high value, doubles over the course of the 50-year forecast ending with what appears to be linear growth (figure 5-13). For current trees, they start off at a lower initial value, but quadruple over the course of the 50-year forecast (figure 5-14). However, by the end of the

50 year forecast the rate of pollution removal appears to slow down as the gradient decreases (figure 5-14).

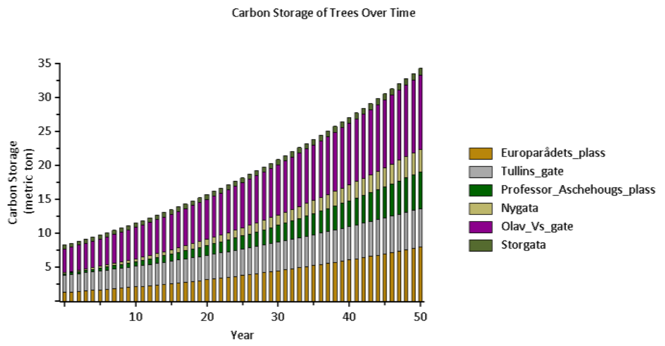


Figure 5-7 shows the historical trees population and changes in carbon storage over the 50 year forecast with zero mortality for all six sites and their relative distribution to each other.

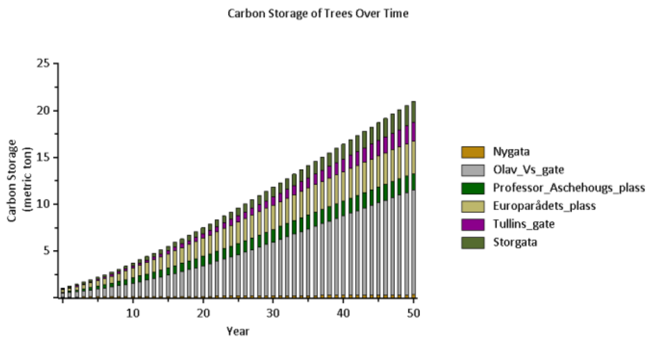


Figure 5-8 shows the current tree population and changes in carbon storage over the 50-year forecast with zero mortality for all six sites and their relative distribution to each other.

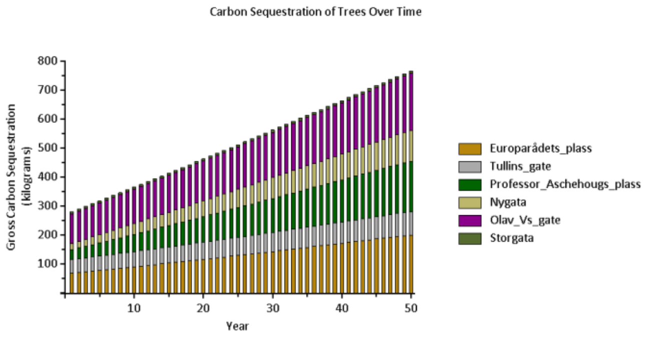


Figure 5-9 shows the historical trees population and changes in carbon sequestration over the 50-year forecast with zero mortality for all six sites and their relative distribution to each other.

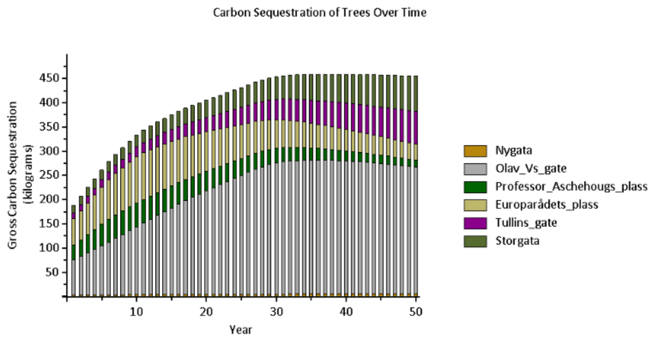


Figure 5-10 shows the current tree population and changes in carbon sequestration over the 50-year forecast with zero mortality for all six sites and their relative distribution to each other.

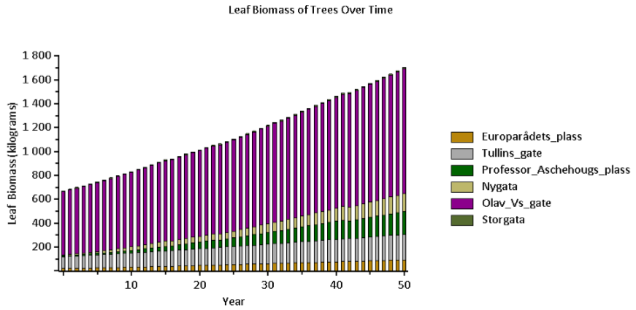


Figure 5-11 shows the historical tree population and changes in leaf biomass over the 50-year forecast with zero mortality for all six sites and their relative distribution to each other.

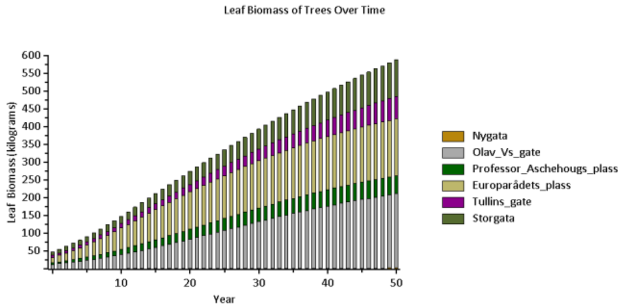
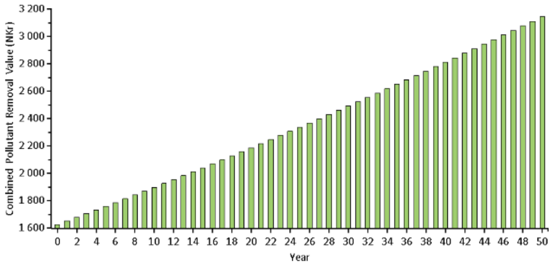


Figure 5-12 shows the current tree population and changes in leaf biomass over the 50 year forecast with zero mortality for all six sites and their relative distribution to each other.



Figur 5-13 shows a linear rate of pollution removal for the historical trees which has doubled its annual rate of removal by the end of the 50-year forecast with no mortality.

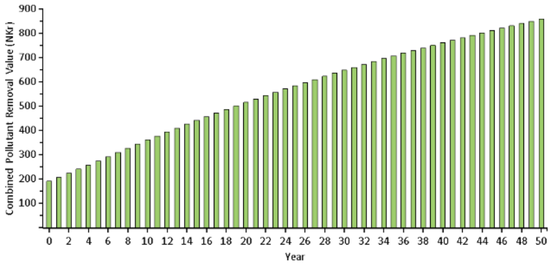


Figure 5-14 shows the pollution removal for the current trees which appear to have a trend where the annual rate of pollution removal is slowing down by the end of the 50 year forecast.

5.4.4 Breaking down the 50-year forecast by individual sites summary

When looking at the individual sites and the respective differences between historical and current trees for each site and the variables annual growth, carbon storage and carbon sequestration, one can more easily discern how the different values change over the 50 year forecast (Appendix 1, figure 1-20).

For DBH annual growth rate between historical and current trees for the 50 year forecast with no mortality (Appendix 1, figures 1-6):

- For Europarådets plass, the historical trees have a constant growth rate, while they initially start off high for the current trees before dropping of 9-fold by the end of the forecast (Appendix 1, figure 1).
- -For Nygata, historical trees and current trees have constant growth rates, but the current trees have a higher growth rate (Appendix 1, figure 2).
- -For Olav Vs gate the historical trees have a constant growth rate, while the current trees have a high initial growth rate which converges toward the historical trees by the end of the forecast (Appendix 1, figure 3)

- For Professor Aschehogs plass, historical trees have a constant but high growth rate for the duration of the forecast, while current trees have an initial high growth rate before it drops down 8-fold (Appendix, figure 4).
- For Storgata, the historical trees have a constant growth rate, while the current trees have initially higher growth rates which appear to be slowing down (Appendix, figure 5).
- For Tullins gate, both the historical and current trees have constant growth rates, but the current trees have a higher constant growth rate (Appendix 1, figure 6)

For carbon storage between historical and current trees 50 year forecast with no mortality (Appendix 1, figures 7-12)

- -For Europarådets plass, the carbon storage increases for both historical and current trees, while the latter appears to be slowing down at the end of the forecast (Appendix 1, figure 7).
- -For Nygata, both the historical trees have a curvilinear trend, while the current trees have a slight increase (Appendix 1, figure 8).
- -For Olav Vs gate, both the historical and current trees have an increase in carbon storage, with the current trees converging and surpassing the historical trees after 44-48 years (Appendix 1, figure 9).
- For Professor Aschehougs plass, both historical and current trees, the carbon storage is increasing, the rate at which appears to increase for the historical trees but eventually slows down for the latter (Appendix 1, figure 10).
- For Storgata, the historical trees have a linear trend in carbon storage, while the current trees have a steeper gradient and surpass the historical trees after around 20 years (Appendix 1, figure 11).
- For Tullins gate, the historical and current trees have similar trends, but the latter being 2-3 times less throughout the forecast (Appendix 1, figure 12).

For Carbon sequestration between historical and current trees 50 year forecast with no mortality (Appendix 1, figures 13-18)

- For Europarådets plass, carbon sequestration for the historical trees shows a linear trend, while the current trees reach a peak at around 10 years, before decreasing below initial values by the end of the forecast (Appendix 1, figure 13).
- -For Nygata, the historical trees have a steep linear trend, while the current trees have a marginal increase during the forecast (Appendix 1, figure 14).
- -For Olav Vs gate, the historical trees have a linear trend, while the current trees have a steeper gradient for carbon sequestration, that surpass the historical trees at around 7 years before leveling off/slightly decreasing (Appendix 1, figure 15).
- For Professor Aschehougs plass, the historical trees have a linear trend, while the current trees have a similar rate to the historical trees until 9 years into the forecast, before dropping off (Appendix 1, figure 16).
- For Storgata, the historical trees have a marginal increase, while the current trees have a much steeper linear trend (Appendix 1, figure 17).

- For Tullins gate, both historical and current trees have linear trends, where the current trees have a slightly steeper gradient and appear to converge towards the historical trees by the end of the forecast (Appendix 1, figure 18).

The following table distributes by category the historical and current tree populations in downtown Oslo.

Table 5-7 Tree species distributed by category in the historical and current tree populations in downtown Oslo. (Note: Longevity and growth rates for the tree species Acer rubrum 'Brandywine' and Magnolia X. loebneri were not recorded in the i-Tree database.)

	Tree populations in downtown Oslo	
Tree categories	Current	Historical
Longevity		
Short	3	0
Moderate	4	2
Long	1	3
Growth rate		
Slow	0	0
Moderate	6	4
Fast	2	1
Size class		
Small	4	0
Medium	4	2
Large	2	3

6 Discussion

To assess the results from the forecasts from i-Tree Eco presented in this paper, it is helpful to understand how the program works as described by Nowak (2020b).

6.1 Modelled results

When running a forecast for different parameters like carbon storage, carbon sequestration, tree height, crown height, and crown width, the computer model first has to generate increments of the annual increase in DBH. The model calculates the annual increments of DBH based upon six factors: standard growth, base growth, species growth rates, tree competition, tree condition, and tree height. The interaction between these factors can be seen for the current trees at Nygata, and the historical trees at Storgata, which both had the lowest annual growth rates because of their low health conditions. While the specific formulas for each factor are found in the manual, it is important to note that growth is based upon the species characteristics found in the i-Tree database.

Of the above-mentioned factors, one should pay particular attention to the sixth factor (tree height) as it regulates the overall output of growth rate. Once a tree exceeds 80% of its average height at maturity (maximum height recorded in the i-Tree database), the growth rate is reduced proportionally until it reaches 2.2% of the full growth rate at 125% of the average height at maturity (Nowak, 2020b). For example, a tree with an average height at maturity of 10m would have its annual growth rate proportionally decreased once it surpasses 8 m height, the rate reducing to 2.2% by the time it reaches a height of 12.5m.

This effect of the sixth factor on the overall output of growth rate, is evident for the current sites at Europarådets plass, Olav Vs gate, Professor Aschehougs plass and Storgata, as seen by their drop in average growth rates. This drop is a result of the combination of moderate to fast growth rate and their small to medium size classes. For the current trees at Storgata, the drop in annual growth rate is somewhat staggered due to there being a combination of species that are a mix of trees, with moderate to fast growth rates, and small to large size classes. The current trees in Tullins gate, however, have a constant annual growth rate during the forecast due to their large size class, and moderate growth rates, which means their height is not modulated during the 50-year forecast. One should note that the current trees that are planted at Tullins gate are of the cultivar “Lucas” of the European hornbeam. When they are added to the database, they would be classified as small trees, and therefore will likely follow the same pattern as the other sites.

For all the historical trees, the annual growth rate was constant, indicating that they have not been restricted by the sixth factor (tree height) for annual growth rates. This is likely due to a combination of higher size classes, and moderate growth rates, when compared to the current trees, and it shows that the benefits from large trees will continue to increase after 50 years, when compared to the small size classes.

The i-Tree database is open for the public to submit species data (including height), although the data is reviewed prior to acceptance by the i-Tree team. The new height measurements may affect subsequent i-Tree forecasts. The overall growth rate is regulated by the factor tree height, and the bigger the discrepancy between database values compared to other literature, the larger are the implications that the forecasted services are either projected too high or capped too early. This was the case at Storgate, where several trees (*Magnolia kobus*) had a tree height less than reported in the literature. A proxy tree was therefore used to better represent the actual tree.

In the i-Tree database, tree size classes, also play a part in mortality rates of trees in the forecasts. Trees are categorized into three different size classes: small (<12.2m), medium (12.3-18.3m), or large (>18.3m) and each of these three size classes has a unique distribution with a set of seven “mortality by diameter” classes (Nowak, 020b). These seven classes are grouped as relative percentages of maximum diameter at breast height (DBH). To calculate the changes in height, the program uses models created for the specific species, genus, family, etc. When a particular species or cultivar does not have a model for height, the program will move up taxonomic levels until it finds one (Nowak, 2020b). Since these models start on a species level, and not cultivar, small cultivars of relatively large species will therefore be assigned a model with a large maximum DBH. When a small size class is attributed to a large maximum DBH, the growth rate is proportionally reduced after reaching 80% height of the average height at maturity. This means the species/cultivar will remain in the middle of the “mortality by diameter” class distribution, where relative mortality rates are lower.

When looking at some of the individual components of the forecast, there were clear trends between annual growth, carbon storage, and carbon sequestration, as their calculations are based on one another (Nowak, 2020b). When the annual growth rates were constant, carbon sequestration was linear, and carbon storage was curvilinear. For the current trees that had a drop in annual growth rates, the carbon storage would start to even out as the annual growth rate went down, and subsequently the carbon sequestration, while initially peaking, would decrease as it is calculated from the increments of carbon storage.

6.2 Assessing the benefits

When looking at the benefits from the different sites, the benefits from the large size classes of historical trees, compared to the current trees, are higher despite there being less trees. Size at maturity for trees is directly related to the benefits produced by trees (Hand & Doick, 2019). These findings were not particular surprising as the criteria for site selection themselves favored the historical trees which had time to grow compared to the newly established trees. What was interesting, however, was how these benefits would develop into the future based upon their “current conditions” as registered and generated by the i-Tree Eco report.

The overall benefits of the current sites were smaller when compared to the historical trees, even after a 50-year forecast that does not account for the mortality. By the end of the 50-year forecast, the annual benefits of the current trees were 25 %, 33% and 50% for pollution removal, carbon storage and carbon sequestration, when compared to the historical trees. It should also be noted that the current trees appeared to stabilize in terms of their provided benefits, while for the historical trees it kept increasing. This means that if the forecast would have had a longer time frame, the discrepancy would likely have increased even more.

While this study looked primarily at the benefits possible to forecast in i-Tree Eco, such as pollution removal, carbon storage and carbon sequestration, there are numerous benefits associated with trees that should ideally been included. While i-Tree Eco has planned improvements to add additional benefits once peer-reviewed (David J. Nowak, 2020), it remains to be seen if tit will be possible to forecast these additional benefits and how that might impact results. It stands to reason that if the provided benefits are size dependent, they would further increase the discrepancy between the historical and current trees.

6.3 Forecasts with and without mortality

Initially, after comparing the benefits between historical and current trees, a forecast would be run to look at how the benefits change over a 30-50 year perspective with default mortality. When the forecasts were run, they were found to be quite variable despite being based upon the exact same data. These differences between the runs were linked to the variability in how the program randomly decides which (parts of) cohorts are killed off (Erika at i-Tree support, personal communication, August 9, 2021). These differences are exaggerated for small populations sizes. As a result, when forecasting with such variability and small population sizes, there would be a cascading effect that in turn made considerable impacts on the end results. For the 30-year perspectives, these differences were attempted to be corrected by taking the average of 5 runs. (Ideally, more runs would give an even better approximation, 30 in the case of a normal distribution. But this amount was deemed impractical for the scope of this study).

I-Tree also allows for planting scenarios, and the initial goal was to investigate how many new trees were needed to compensate for the discrepancy between current and historical trees after a 50-year time period, but this was not pursued as a result of the variability. One option would be to plant trees in a forecasting scenario with no mortality. However, you would lose out on the higher relative mortality rate embedded in the model for younger trees. Furthermore, newly planted street-trees still in their establishment period have been found to have mortality rates between 18-40% (Nowak, McBride and Beatty, 1990; Sklar and Ames, 1985). As such, planting trees with 0 associated mortality would be counter intuitive and take away from the main findings of this paper, that species with large size classes should be protected to maximize the benefits. It could be argued that even with no mortality of trees within the 50-year forecast, the health conditions of the trees are still incorporated, meaning that trees that are struggling will still be reflected in the forecasts. This was seen for the historical trees in Storgata and the current trees at Nygata with their marginal contributions of benefits when compared to the other sites. These trees were rated as having a percentage tree health condition between 20-30%, which means during a forecast which used default mortality, they would die after a year.

One must therefore be wary of forecasting and comparing the results for small populations and be very cautious when interpreting the results. Despite the variability in the 30-year forecasts with mortality, it was interesting to note the relationship between carbon sequestration and leaf biomass, and the increase of benefits even when the overall populations were decreasing. For the historical trees, which for the most part are large mature trees, they have the highest benefits during the initial years of the forecasts; the benefits drop off as the population decreases. For the current trees, the effects of the first 10 years of the mortality appear to be off-set by quick growth rates, with the leaf biomass increasing the first 25 years. Eventually, when no new trees are planted, the mortality decreases the benefits as more and more trees die.

The 50-year forecasts with no mortality were done for two reasons. The first reason was because the variation between runs with mortality was found to be too considerable due to the small sample sizes. The second reason was in order to see the development of the services over a long enough time frame, to see how the sites contributed in respect to one another, and how the historical and current benefits changed in regards to one another under hypothetical scenarios.

6.4 Management implications

Nature based solutions, which are copied or inspired by nature, are resilient and have tremendous potential to be resource and energy-efficient, but must be tailored to local conditions in order to be successful (European Commission, 2020). While green infrastructure has a promising opportunity for adaptation, it must first be recognized as a part of the planning process (Gill, Handley, Ennos, & Pauleit, 2007). Good urban management of trees is needed in order to maximize the net functional value of urban forests which will provide greatest value to society (David J. Nowak & Dwyer, 2007). When trees are lost, the associated costs can be substantial due both the unrealized benefits provided by the trees, as well as the subsequent replacement costs (Widney, Fischer, & Vogt, 2016).

Maximizing benefits, however, is not a straightforward process from a management perspective, as multiple considerations must be given. One consideration is that managers must evaluate the potential risk trees pose for public safety, and like other European cities, this study also finds an apparent trend that the municipality's tree inventory is becoming younger and smaller, likely as a result of these risks (Hand & Doick, 2019; London Assembly, 2007). A second consideration for mangers is that they must also consider the potential conflict between public transportation, as seen for Tullins gate, Nygata and Professor Aschehougs plass which depending on species that will require different amounts of management resources. As such, it might be beneficial to have species with smaller tree crowns in order to lower otherwise high maintenance costs – thereby freeing resources to allocate elsewhere (Wells, personal communication, Aug 10, 2021).

Randrup and Persson (2009) found that public park organizations often are divided according to maintenance functions and project-planning functions. It should be questioned as to what extent this division has on the Agency of Urban Environment's utilization of trees, as a climate and health improving tool in downtown Oslo. Only recently, the agencies lack of intra-communication between their experts in park management and bicycle-planners, led to the failure of safe-guarding street trees when establishing new bicycle lanes as part of overarching political-bicycle goals (Asdøl, 2020).

The agency's tree manager should ideally be consulted on species selection at the start of new project planning. When this consultation occurs later during project development, the species choices are limited and must be tailored according to the constrains of the project itself (Wells, personal communication, August 8, 2021). It may initially be unrealistic to think that trees should be given such a high priority in project developments. However, the increasing understanding of the importance of trees in increasing public health and in "climate-proofing" cities (Brack, 2002; David J Nowak et al., 2008; Smith et al., 2019) should help to protect the trees and further enhance their future benefits for society.

If park administrations are mainly concerned with direct operations, like maintenance, instead of a long-term planning, then the green spaces will likely fade away and degenerate due to the secondary role trees play in the project development process, in comparison to other more pressing and well-formulated operations (Randrup & Persson, 2009). This highlights the importance of having clear target goals on which to base future work. Some species can become exceptionally old, if given the chance, but their importance must first be recognized by planners.

If managers and urban planners alike are to effectively work towards "protection and further development" of the green infrastructure in downtown Oslo, as stated in the area zoning plan for downtown Oslo (section 4.3.3), it necessities having a baseline on which to assess what such a development actually entails. This study also highlights how the Agency for Urban Environment´s "tree for a tree" policy from 1993 is not in itself sufficient to maintain or develop ecosystem services in downtown Oslo and should therefore be updated in recognition of the importance of protecting trees and addressing the challenges they face.

The recent initiative for planting 100,000 trees in Oslo is a unique opportunity to utilize trees to improve the environments within the city and tackle local climatic challenges. In order to maximize the benefits provided, one should consider setting specific target goals related to tree-size and benefits that better address challenges – rather than focusing on just the number of trees. By forecasting future benefits, policy makers and managers will be able to better assess how species distribution may impact overall results and help maximize benefits. Larger trees should be given a higher priority in urban management and be seen as most cost-effective from a management standpoint. If the importance of large trees is recognized and incorporated into future projects, like the one seen at Storgata, downtown Oslo might once again relive its former splendor.

7 Conclusion

To ascertain whether green infrastructure in downtown Oslo is being protected and further developed as required by the new area zoning plan (Section 4.3.3), a baseline was established to assess and determine the effectiveness of the area zoning plan itself.

Currently, when extrapolating the results based upon the six distinct sites investigated in this study, it appears that the ecosystem services looked at are decreasing over time. Importantly, it also shows how the Agency for Urban Environment's (AUE) "tree-for-a-tree" policy from 1993 is insufficient from an ecosystem perspective to neither increase or maintain the benefits provided by the historical green infrastructure in downtown Oslo. This means that the AUE's strategy in itself is insufficient to fulfill the requirements set forth in the new area zoning plan (Section 4.3.3) for downtown Oslo. However, while the overall amount of benefits is going down, it is a positive sign that the tree inventory is increasing – particularly for streets which historically have had no trees.

The overall trend of the species composition, when comparing between historical and current sites, points toward a shifting size class distribution favoring smaller species and cultivars. While this study has not gone into detail regarding the reasons for the re-designs of the six sites, and selected species thereafter, one can see a similar trend in other European cities where the changes likely reflect a changing risk-perspective (lowered tolerance) associated with large trees and limited soil volumes in an increasingly- and highly urbanized environment.

From a management perspective, choosing smaller species poses less of a risk while lowering operational costs when caring for trees. This allows managers to reallocate funds which can be used elsewhere in further developing AUE's tree inventory (M. Wells, personal communication, August 6.2021).

To better meet the new area zoning plan, the AUE should consider introducing target goals for trees that are size dependent. Parameters like tree cover, leaf biomass or measured benefits, also help to convey the importance of including large trees in downtown projects.

Put another way, due to the continued urbanization in downtown Oslo, and the limited amount of suitable places to incorporate large trees – project developers should have to preserve large trees while being given incentives to incorporate and prioritize large trees in new projects in order to meet target goals. Such goals would also highlight the importance of having a long-term perspective of trees and forecasting their benefits.

Another benefit of a long-term management plan is the increased likelihood for the trees becoming cost-efficient while simultaneously optimizing the municipalities resources usage for the advancement of public health and climate change resilience in downtown Oslo.

8 Suggestions for future studies

Several areas of this study could be given more attention to further understand both the observed results, and the results from the i-Tree analyses:

- Develop an i-Tree option to automatically run multiple forecasts for small population tree sizes which show averages and the variability within the analysis
- Perform plot-based analyses of growth rates of trees in downtown Oslo to better reflect local conditions and improve analysis.
- Actively update the i-Tree species database to improve analysis. Growth rates can be added at a later stage if findings from research sheds a new light on current assumptions.
- Update the agency urban tree strategy with target goals that can help decision makers evaluate current conditions in relation to overarching goals to support funding for increased climate resilience, particularly in downtown Oslo.
- Create a local database and tree selection tool, through inter-agency work and in corroboration with the developers of i-Tree species, by mapping local hardiness zones in relation to known abiotic variables like precipitation, temperature, air pollution, biological diversity and public/infrastructure conflicts.
- Overall, the shift towards smaller size classes that are less cost-efficient should be taken seriously and future research is needed to verify this trend.

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10 Appendices

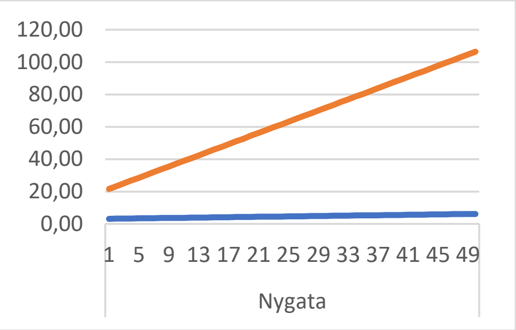
Table 1 Calculated site parameters for i-Tree

Stratum	**Species**	**Number of trees**	**Leaf Area (ha)**	**Leaf Biomass (metric ton)**	**Tree Dry Weight Biomass (metric ton)**	**Average (health) Condition (%)**
Europarådets plass historical	*Acer platanoides* 'Schwedleri'	6	0,04	0,02	2,67	86,00
	Total	6	0,04	0,02	2,67	86,00
Europarådets plass 2021	*Prunus sargentii*	10	0,01	0,01	0,29	74,90
	Prunus serrulata	5	0,01	0,01	0,20	99,50
	Total	15	0,02	0,02	0,49	83,10
Nygata historical	*Quercus robur* 'Fastigiata'	5	0,01	0,01	0,28	92,10
	Total	5	0,01	0,01	0,28	92,10
Nygata 2021	*Quercus robur* 'Fastigiata'	5	0,00	0,00	0,21	22,80
	Total	5	0,00	0,00	0,21	22,80
Professor Aschehougs plass historical	*Quercus robur* 'Fastigiata'	9	0,01	0,01	0,43	84,17
	Total	9	0,01	0,01	0,43	84,17
Professor Aschehougs plass 2021	*Acer glabrum*	6	0,01	0,00	0,26	97,83
	Total	6	0,01	0,00	0,26	97,83
Olav Vs gate historical	*Tilia cordata*	16	0,71	0,53	7,01	93,75
	Total	16	0,71	0,53	7,01	93,75
Olav Vs gate 2021	*Acer rubrum* 'Brandywine'	12	0,02	0,01	0,79	91,75
	Total	12	0,02	0,01	0,79	91,75
Olav Vs gate historical	*Tilia cordata*	16	0,71	0,53	7,01	93,75
	Total	16	0,71	0,53	7,01	93,75
Olav Vs gate 2021	*Acer rubrum* 'Brandywine'	12	0,02	0,01	0,79	91,75

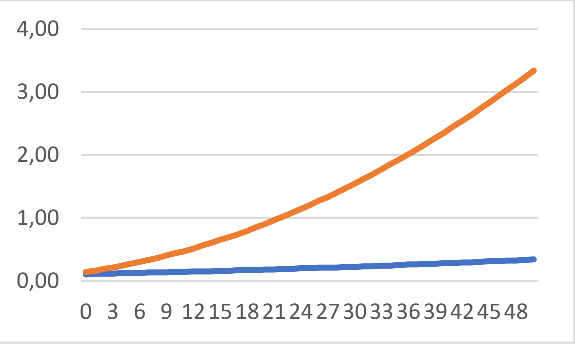
Stratum	Species	Number of trees	Leaf Area (ha)	Leaf Biomass (metric ton)	Tree Dry Weight Biomass (metric ton)	Average (health) Condition (%)
	Total	12	0,02	0,01	0,79	91,75
Storgata historical	*Carpinus betulus*	2	0,01	0,01	1,14	37,50
	Total	2	0,01	0,01	1,14	37,50
Storgata 2021	*Cercidiphyllum japonicum*	2	0,00	0,00	0,02	94,50
	Magnolia x loebneri	4	0,00	0,00	0,07	98,25
	Prunus x yedoensis	1	0,00	0,00	0,04	99,50
	Robinia pseudoacacia	6	0,01	0,00	0,12	94,17
	Total	13	0,02	0,01	0,24	95,88
Tullins gate historical	*Tilia cordata*	12	0,13	0,10	5,08	58,96
	Total	12	0,13	0,10	5,08	58,96
Tullins gate 2021	*Carpinus betulus*	7	0,01	0,01	0,17	99,50
	Total	7	0,01	0,01	0,17	99,50
Study Area 2021		58	0,08	0,05	2,16	86,06
Study Area historical		50	0,90	0,67	16,62	80,33

Table 2 i-Tree database and proxies

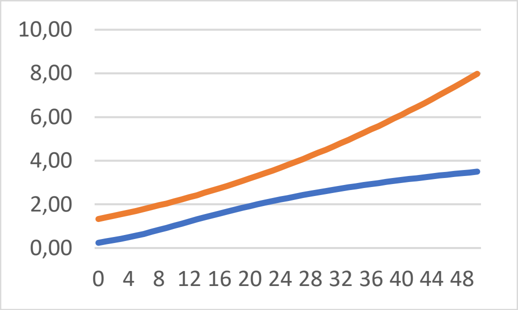
Genus species 'cultivar'	Common name	Growth rate	Longevity	Height at maturity i-Tree (m)	Category (small, medium, large)
Acer platanoides	Norway maple	fast	-	-	large
Proxy	Acer platanoides 'Schwedleri'	fast	long	15	medium
Acer platanoides 'Globosum'	-	-	-	-	Short
Proxy	Rocky mountain maple	Moderate	moderate	6	short
Acer rubrum 'Brandywine'	Brandywine redmaple	-	-	14	Medium
Proxy	-	-	-	-	-
Carpinus betulus	European hornbeam	moderate	moderate	12	Short
Proxy					
Carpinus betulus 'Lucas'	-	-	-	-	short
Proxy	European hornbeam	moderate	moderate	12	Short
Cercidiphyllum japonicum	Katsura tree	Moderate	moderate	13	Medium
Magnolia kobus	-	-	-	2,5	short
Magnolia x loebneri		-	-	12	Short
Prunus sargentii 'Rancho'	Sargant cherry	fast	short	12	Short
Proxy	-	-	-	-	-
Prunus serrulata 'Kanzan' (Pruns kanzan)	Kanzan cherry	Moderate	moderate	14	Medium
Proxy	-	-	-	-	-
Quercus robus 'Fastigata'	Columnar english oak	Moderate	long	25	Large
Proxy	-	-	-	-	-
Tilia cordata	Littleleaf linden	Moderate	moderate	30	Large
Proxy	-	-	-	-	-



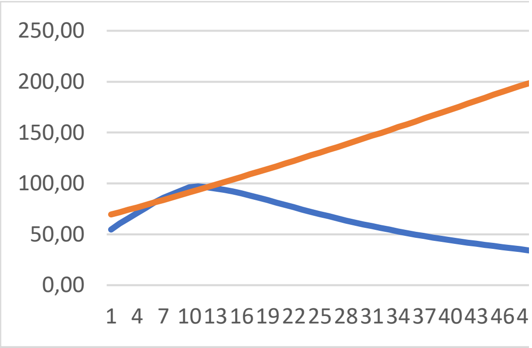
Figur 1 Nygata comparison between historical (orange) and current (blue) carbon sequestration (kilograms) over a 50 year forecast with zero mortality.



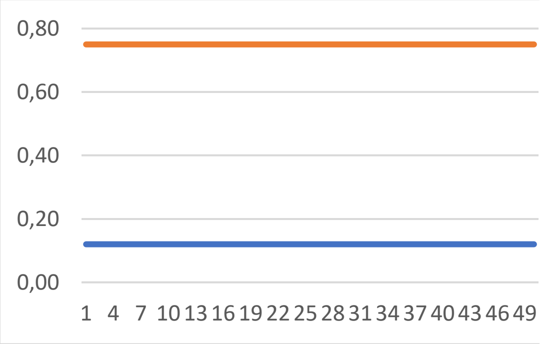
Figur 4 Nygata comparison between historical (orange) and current (blue) carbon storage (metric tons) over a 50 year forecast with zero mortality.



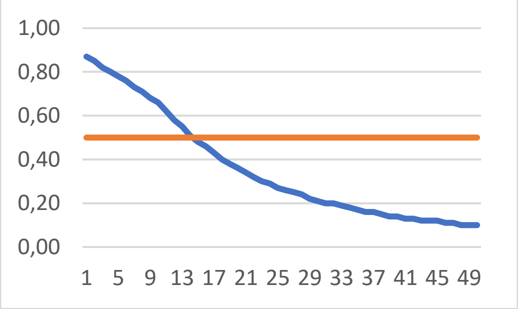
Figur 3 Europaråets plass comparison between historical (orange) and current (blue) carbon storage (metric tons) over a 50 year forecast with zero mortality.



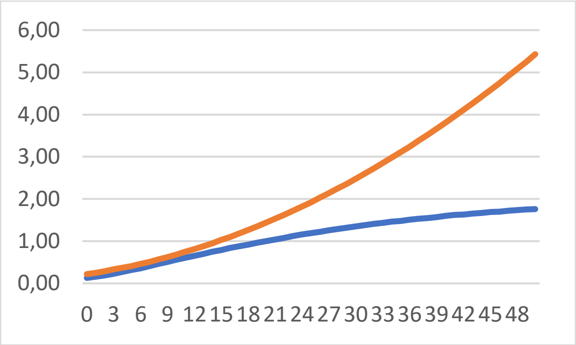
Figur 2 Europarådets plass comparison between historical (orange) and current (blue) carbon sequestration (kilograms) over a 50 year forecast with zero mortality..



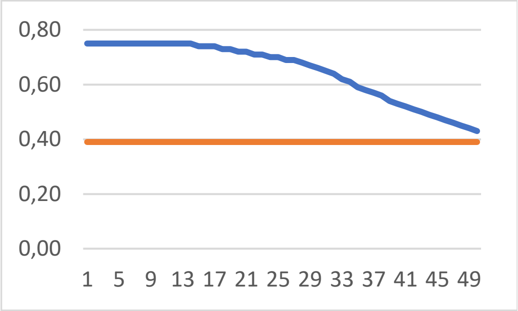
Figur 6 Nygata comparison between historical (orange) and current (blue) average DBH growth (cm) over a 50 year forecast with zero mortality.



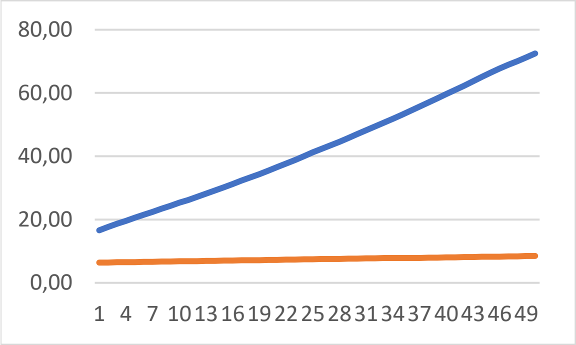
Figur 5 Europarådets plass comparison between historical (orange) and current (blue) average DBH growth (cm) over a 50 year forecast with zero mortality.



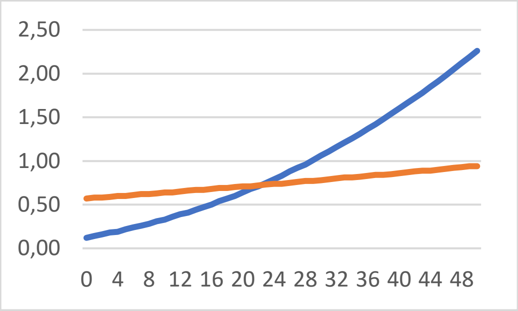
Figur 9 Professor Aschehougs plass comparison between historical (orange) and current (blue) carbon storage (metric tons) over a 50 year forecast with zero mortality.



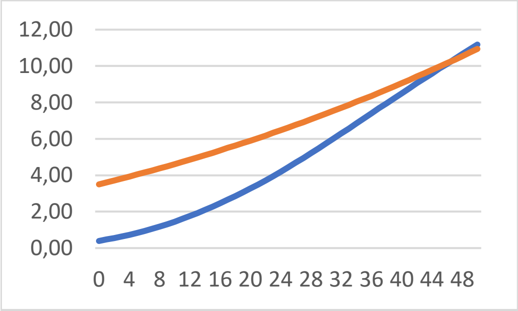
Figur 11 Olav Vs gate comparison between historical (orange) and current (blue) average DBH growth (cm) over a 50 year forecast with zero mortality.



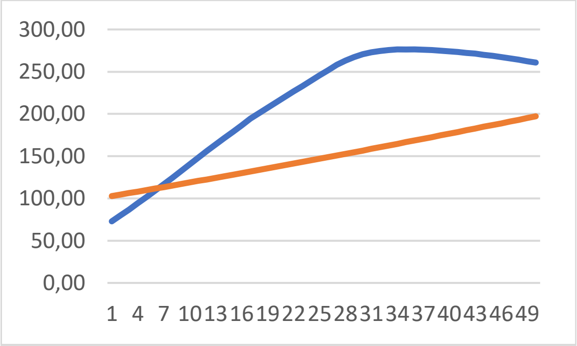
Figur 8 Storgata comparison between historical (orange) and current (blue) carbon sequestration (kilograms) over a 50 year forecast with zero mortality.



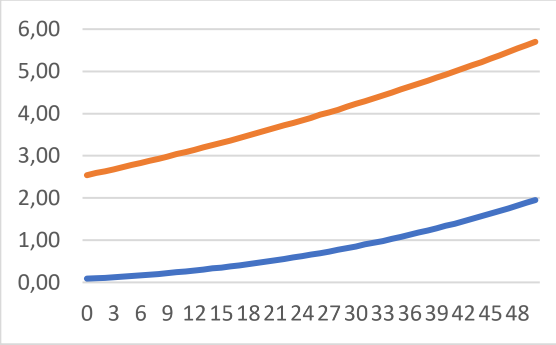
Figur 10 Storgata comparison between historical (orange) and current (blue) carbon storage (metric tons) over a 50 year forecast with zero mortality.



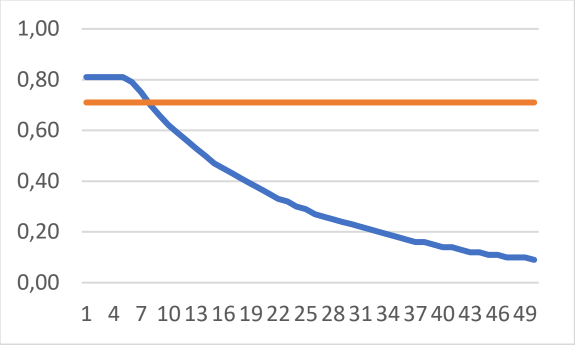
Figur 12 Olav Vs gate comparison between historical (orange) and current (blue) carbon storage (metric tons) over a 50 year forecast with zero mortality.



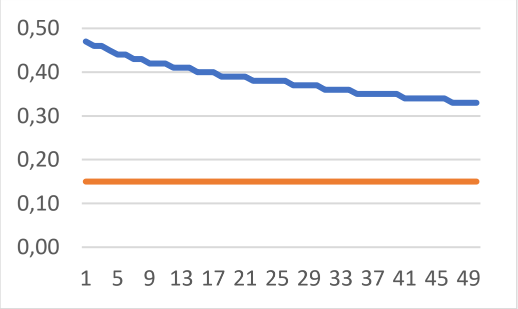
Figur 7 Olav Vs gate comparison between historical (orange) and current (blue) carbon sequestration (kilograms) over a 50 year forecast with zero mortality.



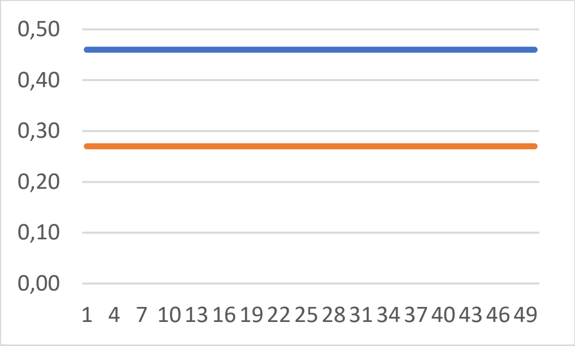
Figur 13 Tullins gate comparison between historical (orange) and current (blue) carbon storage (metric tons) over a 50 year forecast with zero mortality.



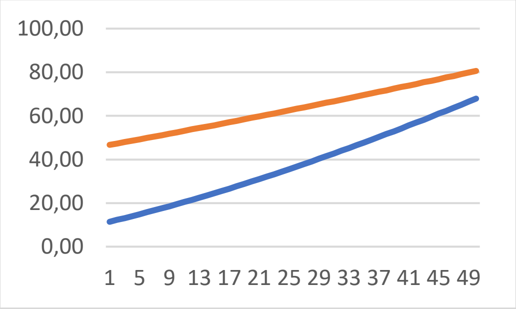
Figur 14 Professor Aschehougs plass comparison between historical (orange) and current (blue) average DBH growth (cm) over a 50 year forecast with zero mortality.



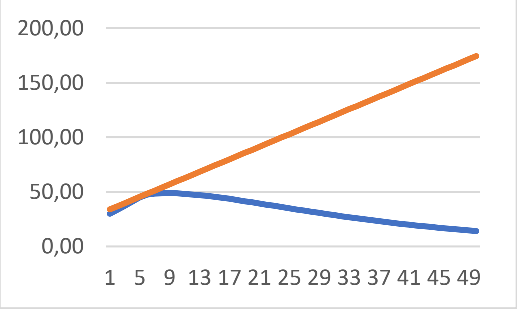
Figur 17 Storgata comparison between historical (orange) and current (blue) average DBH growth (cm) over a 50 year forecast with zero mortality.



Figur 15 Tullins gate comparison between historical (orange) and current (blue) average DBH growth (cm) over a 50 year forecast with zero mortality.



Figur 18 Tullins gate comparison between historical (orange) and current (blue) carbon sequestration (kilograms) over a 50 year forecast with zero mortality.



Figur 16 Professor Aschehougs plass comparison between historical (orange) and current (blue) carbon sequestration (kilograms) over a 50 year forecast with zero mortality.

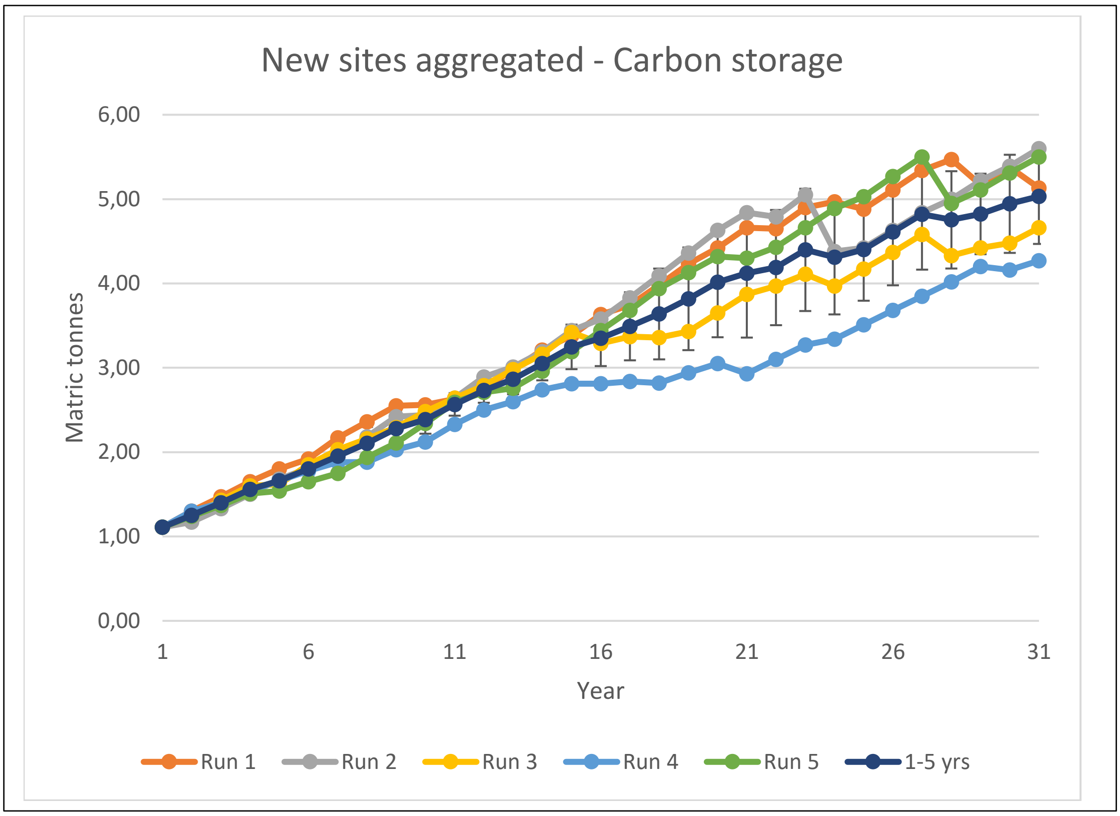


Figure 19 New sites aggregated over 30 years – carbon storage

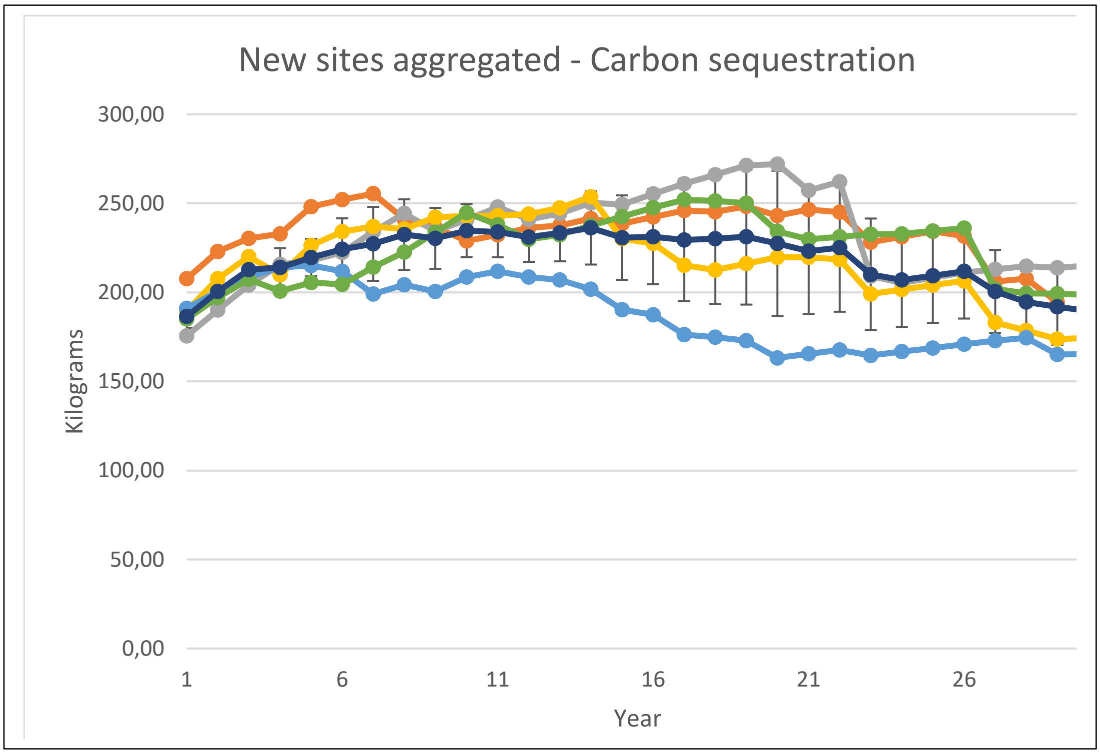


Figure 20

Figure 20 New sites aggregated over 30 years – carbon sequestration

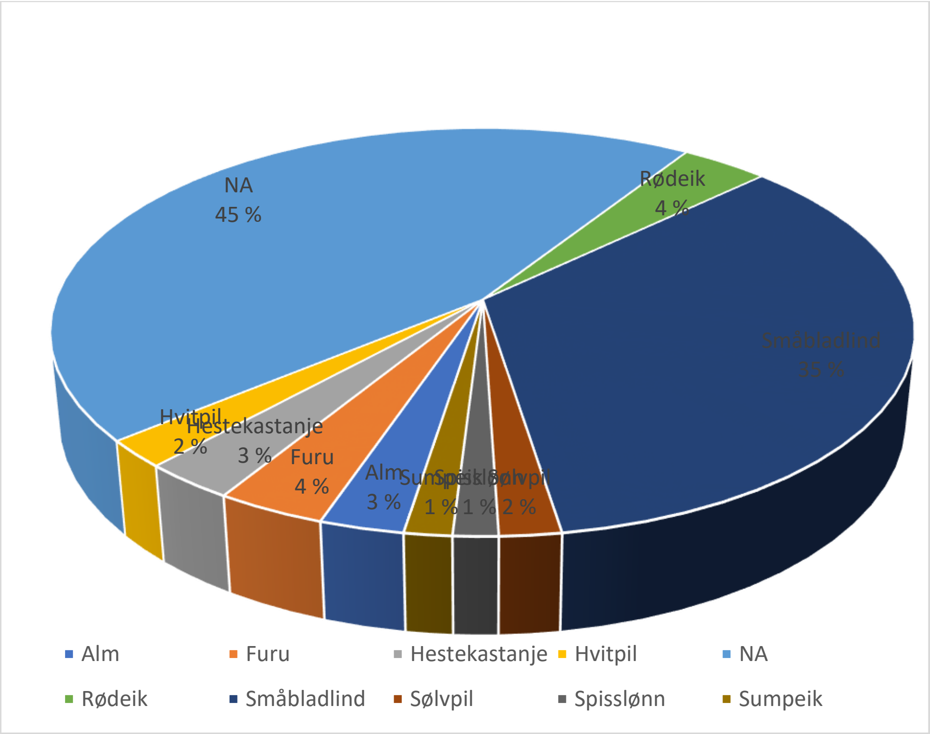


Figure 21 shows species the distribution of park trees and the number of trees that have been identified and registered by species.

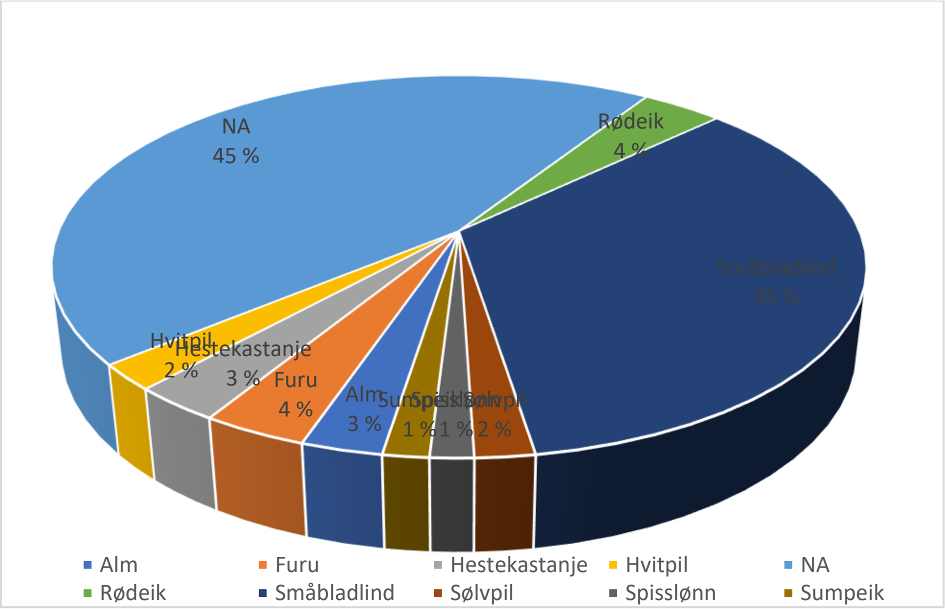


Figure 22 shows species the distribution of all trees and the number of trees that have been identified and registered by species.

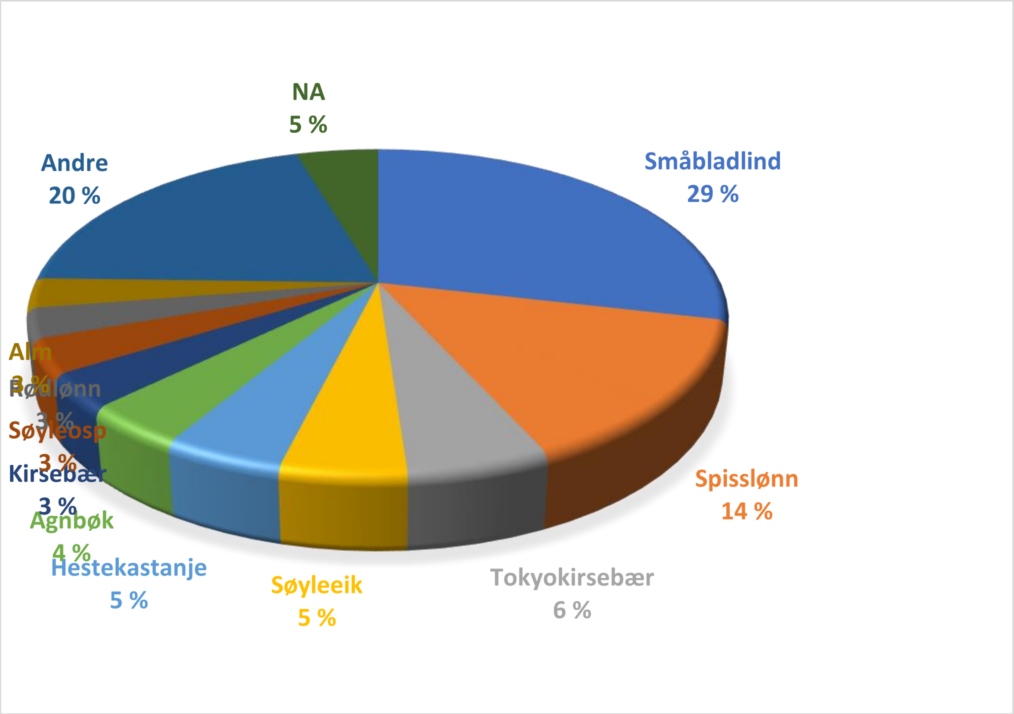


Figure 23 shows species the distribution of top ten species of street trees in Oslo Centrum.

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