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Rose Kennedy Greenway Natural Carbon Stock Report

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The Rose Kennedy Greenway Conservancy

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Executive Summary

The value of the Greenway to the city of Boston cannot be understated. It is a place of congregation, celebration and connections that brings natural ecosystems into the city and links people to nature. Its gardens, trees, and lawns provide numerous aesthetic, health and economic benefits to the city. Its natural ecosystems also store a modest, but notable, amount of carbon while providing these community benefits. As the role of nature-based solutions emerge as a critical element of combating climate change, understanding this component of its natural assets will allow the Greenway to better align its operational and educational missions with global climate objectives.

This report provides an accounting of the Greenway's natural carbon stock. A natural carbon stock is the amount of carbon that has been sequestered from the atmosphere within the biomass and soil. Increasing natural carbon stocks reduces carbon dioxide (CO_2) in the atmosphere. This report uses tree inventory data kept by the Conservancy to estimate the amount of carbon stored in its trees, soils and plants. The methodology applies standard tree-carbon models and local estimates of soil and non-tree above ground carbon. The results below can be used by the Conservancy to understand the magnitude of its carbon stock, relative to its annual operation emissions and other activities. The underlying data and calculations are included as an Excel workbook appendix to this report.

Table 1 lists values associated with the Greenway's natural carbon stock. The total carbon stock is approximately 112.8 tonnes carbon (tC)[1] or 413 tonnes of CO_2. This is 2.4 times the Greenway's 2019 emissions from energy consumption. This carbon is spread relatively evenly across its soils, trees and other plants.

Table 1. Summary Data for the Rose Kennedy Greenway

Total Area (acres)	17
Garden Beds (acres)	4.2
Lawn (acres)	4.3
Tree Count	757
Tree Carbon (tC)	28.6
Lawn Above Ground (tC)	9.3
Lawn Soil (tC)	18.6
Bed Above Ground (tC)	27.7
Bed Soil (tC)	28.6
Total (tC)	112.8
Tones per acre	6.6
CO_2 equivalent (t)	4

[1] Carbon stocks are typically reported in mass carbon as opposed to the mass of CO_2. The CO_2 equivalence of the stored carbon is 44/12 times measured carbon content – this is stoichiometric ratio of CO_2 to C.

In terms of managing its natural assets to maximize carbon storage, the Greenway should continue to prioritize protecting existing natural assets. This is of particular importance for its trees because they require a number of years to build up their carbon stock, which could be quickly released if damaged. Increasing the carbon stock would be most effectively achieved by the addition of more trees, however this strategy would need to be balanced with the Greenway's programmatic and landscape objectives.

Introduction

The corridor carved through Boston by the Greenway has been one of the most visually recognized spaces in Boston before and after the Greenway's creation. The Greenway's path and Atlantic Avenue lie atop mostly fill that was used to transform the Shawmut peninsula into Boston. For most of Boston's history, Atlantic Avenue served as a demarcation between Boston's inland environs and its waterfront wharfs. By the second half of the 20th century it became home to the elevated John Fitzgerald Expressway Central Artery that visibly, socially and economically cut the North End and the waterfront away from Central Boston. Boston's Big Dig put the expressway underground opening the potential to create a park that connected Boston's waterfront to the rest of the City.

The creation of the Greenway and the installation of trees, lawns, and garden beds created a stock of natural carbon in a part of Boston that has historically had very little. Due to its age and fragmented sections, the Greenway ecosystem is not as carbon rich as forested ecosystems of the same size. Its presence, however, serves as a visual reminder to Boston's residents, workers, and visitors of the importance and value of natural spaces. As climate change becomes more prevalent it can serve as a reminder of the role that trees, plants and soils play in storing carbon.

Global mitigation efforts recognize an increasing importance of the role of sustainable land use in facilitating the removal of carbon dioxide from the atmosphere. The Intergovernmental Panel on Climate Change's Special Report on Global Warming of 1.5˚C explicitly identifies the need for negative emissions such as those that come from afforestation and restoring of natural ecosystems[2]. Although the Greenway's contribution to such efforts to remove carbon from the atmosphere has been and will be modest, it has the ability to remind its visitors that natural solutions play an important role to mitigate global climate change alongside the other benefits that it gives to a city.

[2] https://www.ipcc.ch/sr15/

Data

The Conservancy provided the project team with descriptive data of their natural assets (Table 2). Using this data, the project team was able to estimate the above ground tree and non-tree carbon along with soil carbon. Measurement of biological carbon stocks is considerably more challenging than the measurement of emissions from the use of fossil fuels. Biological systems are highly variable and complex. For example, factors influencing tree growth in an urban environment (air quality, shading, water availability) may differ greatly from a forest environment that serves as the basis for estimation of tree biomass. However, our approach applies both widely used and well-developed inventory methods and local data to provide a reasonable estimate of carbon stocks.

The availability of the 2016 tree height and diameter at breast height (DBH) inventory data allowed for a comprehensive assessment of tree carbon stocks using a detailed methodology described below. The Greenway's 2010 inventory and 2019 inventory were incomplete and could not be used as points of comparison, but we were able to calculate carbon estimates for the limited trees included in the 2019 inventory – included in the Excel workbook. Soil testing data was found to be too variable to estimate soil carbon content consistently by parcel; instead, lawn and bed areas were used to estimate soil and non-tree aboveground carbon as described below.

Table 2. Data received from RKGW

Data	Description	Year	Application
Tree Inventories	Direct measurement of tree diameter at breast height (DBH) and tree height	2010	Not used: incomplete and dated
		2016	Used for above ground tree carbon calculations and summary
		2019	Included in above ground tree carbon calculations (not included in summary): incomplete
Tree Survey with Map	Geospatial visualization of 2016 inventory	2016	Used to ground-truth data
Master Plant Inventory	Listing of plants and trees maintained	2020	Not used: there is no practical methodology for assessing carbon stocks from diverse non-tree biomass
Lawn & Bed Area	Surface area of lawns and garden beds	Current	Used to estimate soil and non-tree above ground carbon.
Soil Data Set	Long-term tracking of soil test results	Various	Not used: carbon content not consistently measured
Soil Test Results	Most recent soil test results	2019	Not used: carbon content not consistently measured

Methods

Above Ground Tree Carbon Stocks

Tree carbon stock inventories were developed using the United Stated Department of Agriculture (USDA) Forest Service's Forest Inventory and Analysis (FIA) National Program Database (FIADB)[3] under the framework provided by the Climate Action Reserve's Urban Forest Protocol[4]. The FIADB is a set of methods and factors used to estimate forest carbon stocks developed from statistical analysis of trees[5]. It uses a series of species-specific regression equations to estimate a tree's volume and biomass from variables such as a tree's height (h) and diameter at breast height (DBH).

The Greenway's 2016 Tree Inventory's measurements were mapped to analogous species in the FIADB. Trees with missing DBH and h were dropped, leaving 757 trees for the carbon estimation. A global regression was used to fill in for missing DBH (33) or h (55) values when only the other value was available[6]. Using the equations of Woodall[5] for species in the FIADB, the volume and biomass of tree components (bole, bark, stump, stem, branch and foliage) were calculated to estimate total tree above ground biomass and above ground carbon. In the absence of direct measurements, it was assumed that tree stumps extended 1 foot above the ground – this assumption has little impact on the overall results. Calculations were conducted by tree to retain tree-level meta-data such as parcel.

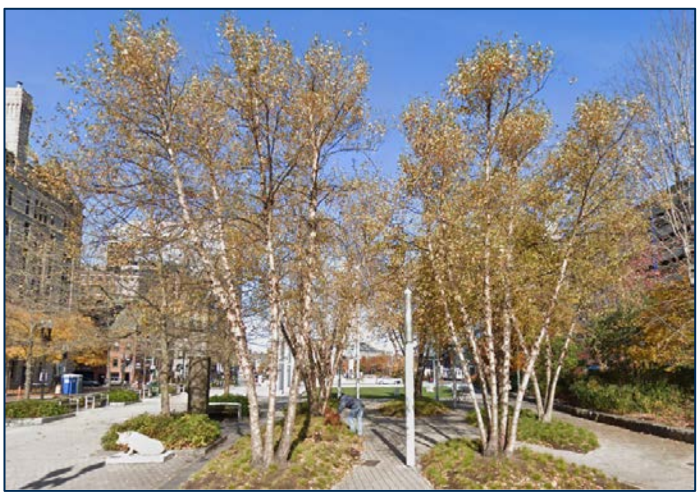

Figure 1. Google Street view image of Greenway's Betula nigra plantings showing multiple trunks associated with each planting.

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[3] https://www.fia.fs.fed.us/library/database-documentation/

[4] http://www.climateactionreserve.org/how/protocols/urban-forest/

[5] Woodall et. al. Methods and Equations for Estimating Aboveground Volume, Biomass, and Carbon for Trees in the U.S. Forest Inventory (2011) https://www.nrs.fs.fed.us/pubs/gtr/gtr_nrs88.pdf

[6] These values were flagged as "MISSING" in the Conservancy's tree inventory data

Limitations

As noted above, measurement of biological carbon stocks can be uncertain. Despite this, our analysis provides a representative estimation of above ground carbon using well-established measurement and analysis techniques.

One significant discrepancy was observed with the species *Betula nigra* (River Birch). There are 10 trees of this species listed in the inventory. Despite this species accounting for only 1% of the Greenway's tree stock, it represented 12% of the carbon stock using 2016 measurements. Visual inspection of *Betula nigra* sites on the Greenway found that these plantings consisted of multiple-trunk formations. The approach of DBH measurement in the inventory is likely inconsistent with the approach used to calibrate the *Betula nigra*'s parameters in the FIA model leading to an overestimate in our results. Tree volume, and thus carbon content, scales exponentially relative to DBH. DBH measurements in the 2019 inventory were significantly lower than those reported in 2016, suggesting the use of inconsistent DBH measurement methods. To correct for this significant discrepancy, we applied 2019 values to the 2016 inventory. This reduced the fraction of the contribution of this species from 12% to 5%, which is still noticeably higher than the share of the tree count, but likely more representative of the actual carbon stock. A more accurate estimation would require a detailed review of DBH measurement methodology for this species and ensuring that it is consistent with the FIA approach.

Soil Carbon and Non-Tree Above Ground Carbon

The project team used the methodology of Raciti (2012) from the Hutyra Lab at Boston University to estimate both soil and non-tree above ground carbon. This study measured soil and above ground carbon at approximately 135 plots in the Boston Metropolitan area, in urban and non-urban areas under three land use classifications: forest, residential, and other developed. We assumed that the Greenway's bed carbon stock aligned with study's residential urban typology and the lawn's corresponded to "other developed" areas. Raciti's carbon factors assumes 1 meter of depth. Guidance from RKGW staff indicated that soil depths on the Greenway may not be as deep. The Greenway provided guidance on the depth of the lawns and beds ranging from 0.3-0.45 meters as described in the attached Excel appendix.

Limitations

The Greenway is a heavily managed urban landscape, and as a result may have higher than average soil carbon. Further, other factors may have impacts on local soil carbon conditions. However, Raciti's work demonstrated that soil carbon stocks in the Boston area are relatively homogenous.

Results

Above Ground Tree Carbon Stocks

Our analysis of 757 trees found that there is 28.6 tonnes of carbon stored in the Greenway's trees. We were able to map the Greenway's species to 49 distinct species classifications in the FIA database; 41 trees (5% of count) could not be mapped and were allocated to a catch-all "Other" category that was estimated to be 5% of the tree carbon stock, based on the FIA's estimate for species not included in their database.

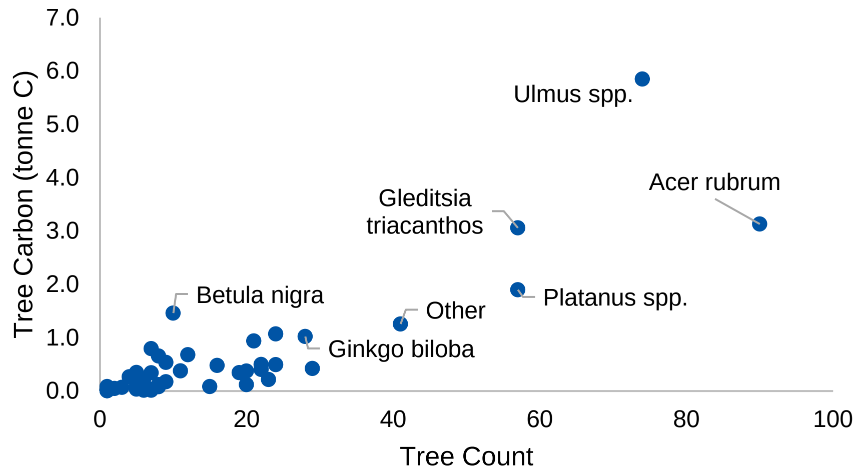

Figure 2. Mapping of tree count and tree carbon showing significant species.

Table 3 shows the top 10 species with the highest carbon content. These species account for over half of the Greenway's trees and 72% of the tree carbon stock. These trees should thus be of particular focus for assessing species-wide risks from climate change (flooding, invasive species, temperature changes).

Table 3. Top 10 species by total carbon stock.

Species	Tonnes C	Tree count	Carbon Percentage	Tree Count (%)
Ulmus spp.	5.8	74	20%	10%
Acer rubrum	3.1	90	11%	12%
Gleditsia triacanthos	3.1	57	11%	8%
Platanus spp.	1.9	57	7%	8%
Betula nigra	1.5	10	5%	1%
Amelanchier spp.	1.1	24	4%	3%
Ginkgo biloba	1.0	28	4%	4%
Prunus spp.	0.9	21	3%	3%
Liriodendron tulipifera	0.8	7	3%	1%
Taxodium distichum	0.7	12	2%	2%
Ulmus americana	0.7	8	2%	1%
Total Top 10	**20.6**	**388**	**72%**	**51%**

Soils and Non-Tree Above Ground Carbon

In addition to its trees, the Greenway has two distinct carbon-storing land types:

- **Lawns:** Mostly open grasses and wildflowers (4.3 acres or 16,000 m^2)[7]
- **Beds:** Maintained garden beds (4.2 acres, or 17,000 m^2)[7], mostly non-tree plantings

Both types are assumed to be similar to other maintained residential or commercial lawns and gardens. Calculations on the soil carbon and the non-tree above ground carbon were conducted for each land type based on the methodology described above.

Total soil carbon is estimated to be 47.3 tonnes C based on an assumption of 4.0 kgC/m^3 and 4.3 kgC/m^3 for the lawns and beds respectively assuming a depth of 0.3m – 0.45m (8”-18”)[8]. The Greenway’s shallow soil depth disadvantage its ability to store carbon relative to other systems in which carbon stocks are measured to 1 meter of depth. Even despite this limitation, this number appears relatively large compared to the tree carbon stock, it is a testament to the composition and density of soil underfoot. This is typical

[7] The Greenway’s total area is 17 acres with the balance consisting of walkways and structures.

[8] These values were provided as rough estimates from the Conservancy on a parcel level and are included in the data appendix.

of sparsely wooded lands. If the Greenway had the tree density of a typical climax growth forest, the trees carbon stock would exceed the carbon stored in the soil.

Total non-tree above ground carbon is estimated to be 37 tonnes C based on an assumption of 0.6 kgC/m^3 and 1.9 kgC/m3 for the lawns and beds respectively. Again, this value appears relatively large compared to the tree carbon stock, and due to the variability in above ground non-tree plants. Our assumptions for this land type are possibly the most uncertain of this study. Still such values are of a fair estimate given the diversity of plantings that go beyond cut lawns and garden flowers. These include shrubs, tall grasses, wildflowers, and other dense plantings. This density is thus also a significant store of carbon. While much of the above ground carbon is released in the winter, it is still considered a biological store of carbon as the overall carbon in the atmosphere would be greater in its absence.

Synthesis and Parcel Level Results

A breakdown of carbon stocks by parcels is shown in Table 5. Generally, stocks are driven by the number of trees and landscaped areas. The Greenway's total natural carbon stock is estimated to be **112.8 tonnes C,** which is equivalent to **413.5 tonnes CO_2**.[9] A comparison to several common emissions generating activities is shown in Table 4.

The Greenway averages **6.6 tonnes of carbon per acre**. For comparison: local forests store approximately 60 tC per acre (Raciti 2012).

[9] The conversion from mass C to mass CO_2 is performed by diving by the molecular weight of carbon (12) and multiplying by the molecular weight of carbon dioxide (44)

Our assessment of the Conservancy's GHG emissions for 2019 was 172 tonnes of CO_2. The carbon stored in the Greenway's trees, soils and plants thus represents about 2.4 years of the Conservancy's emissions. For further comparison, in 2017 Boston emitted 6.1 million tonnes of CO_2e.[10] While the Greenway's emission may seem relatively modest, its existence, particularly in relationship to what it replaced, serves as an important reminder of the role of natural carbon stocks.

Table 4. Greenhouse gas equivalences for the Greenway's Natural Carbon Stock based on the EPA's Greenhouse Gas Equivalences Calculator.[11]

89	Passenger vehicles in one year
1,026,000	Miles driven by an average passenger vehicle
46,500	Gallons of gasoline consumed
47.7	Home's energy use for one year
15,700	Incandescent lamps switched to LEDs

[10] 2017 Boston GHG Inventory. https://www.boston.gov/departments/environment/bostons-carbon-emissions

[11] https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Table 5. Carbon stocks by land type and by parcel. Zero values indicate no data was available for the parcels and the land use type. *The Federal Reserve is managed by the Greenway but is not included in total carbon stocks.

Parcel	Tree Count	Tree Carbon (tC)	Lawn Above Ground (tC)	Lawn Soil (tC)	Bed Above Ground (tC)	Bed Soil (tC)	Total (tC)	tCO_2 equivalent
19	93	3.2	1.9	3.7	3.0	3.1	14.9	54.7
18	132	6.9	1.0	2.0	0.9	1.0	11.8	43.2
17	84	2.0	1.0	1.9	2.5	2.6	10.0	36.8
8	75	1.3	1.1	2.1	1.9	2.0	8.3	30.6
10	72	1.4	0.5	1.0	2.4	2.5	7.7	28.3
22	0	0.0	1.0	2.1	1.9	2.0	7.0	25.6
16	39	2.9	0.5	1.1	1.1	1.1	6.7	24.7
21	0	0.0	0.7	1.3	2.1	2.1	6.1	22.5
14	79	2.4	0.3	0.6	1.2	1.3	5.9	21.5
23	90	5.2	0.0	0.0	0.0	0.0	5.2	19.0
12	0	0.0	0.0	0.0	2.4	2.5	4.9	17.9
6	17	0.6	0.0	0.0	1.4	1.5	3.5	12.7
125 Summer	0	0.0	0.4	0.7	1.2	1.2	3.4	12.5
13	23	0.5	0.2	0.3	1.1	1.1	3.1	11.2
CT	0	0.0	0.0	0.0	1.4	1.4	2.8	10.4
15	28	0.4	0.4	0.8	0.5	0.5	2.7	9.8
PK	0	0.0	0.0	0.0	0.6	0.6	1.3	4.6
PG1	0	0.0	0.0	0.0	0.5	0.6	1.1	4.0
5	3	0.4	0.0	0.0	0.3	0.3	0.9	3.3
PD2	0	0.0	0.0	0.0	0.4	0.4	0.7	2.6
PD1	0	0.0	0.2	0.5	0.0	0.0	0.7	2.5
PD3	0	0.0	0.0	0.0	0.3	0.3	0.7	2.4
J2	6	0.5	0.0	0.0	0.0	0.0	0.5	1.9
H	3	0.4	0.0	0.0	0.0	0.0	0.4	1.4
PJ1	0	0.0	0.1	0.3	0.0	0.0	0.4	1.4
PJ2	0	0.0	0.1	0.3	0.0	0.0	0.4	1.4
PC	0	0.0	0.0	0.0	0.2	0.2	0.4	1.3
PE	0	0.0	0.0	0.0	0.2	0.2	0.4	1.3
PH	0	0.0	0.0	0.0	0.2	0.2	0.4	1.3
G1	7	0.4	0.0	0.0	0.0	0.0	0.4	1.3
J1	6	0.3	0.0	0.0	0.0	0.0	0.3	1.2
PG2	0	0.0	0.0	0.0	0.1	0.1	0.2	0.7
Total	**757**	**28.6**	**10.4**	**22.0**	**32.4**	**33.6**	**127.0**	**465.7**

Recommendations for Managing Greenway Assets for Carbon

The Conservancy's primary focus for managing Greenway's assets for carbon should be on preserving and enhancing its existing carbon stocks. The potential for additional carbon storage is limited relative to the potential stock at risk.

In particular, ensuring the health of its existing tree stock should continue to be the Greenway's top priority for managing its carbon stock. The tree stock is the least resilient compared to the soils and non-tree above ground carbon stocks – taking decades to regenerate rather than years. As part of its physical asset management assessment, the Greenway should identify trees most at risk of flooding and other threats and undertake reasonable efforts to mitigate such risks. Further, Table 3 lists the species that comprise 72% of the Greenway's tree carbon stock. The Greenway could evaluate climate risks such as temperature stress or invasive pests specific to these species and develop a management plan to address any potential risks. Increasing the Greenway's trees would increase its carbon stock, however this would occur over a long time horizon and would need to be considered in the context of the use of the space – the Greenway could become a dense urban forest but it would lose many of the programmatic, community-building and cultural elements of its mission.

Due to the Greenway's active management and application of organic-rich compost, the soils and above ground carbon stocks are likely to be saturated with carbon. While *carbon farming* – practices that increase the rate that CO_2 is removed from the atmosphere by plants – is an emerging strategy for increasing the carbon content of soils, its potential is quite uncertain and there is little research into the long-term effectiveness of such practices in urban parks. Again, efforts to protect the lawns and beds from flooding or conversion will ensure that these carbon stocks remain.

These strategies will need to be evaluated in the context of the Greenway's operations and programmatic activities.

Data recommendations

Continued tree inventories measuring DBH and height at multi-year (~5) intervals will allow the Conservancy to evaluate changes to its tree carbon stocks over time. Tree measurement practices should be standardized to ensure consistent measurements across tree types. The project team recommends the Conservancy develop a data inventory in which each tree's location and physical properties are tracked as a row for a given measurement year. This will allow the Conservancy to conduct long-term assessments of its natural stock. The Conservancy has been provided with a Tree Carbon Calculator as an appendix to this report. It can be updated periodically using measurements of tree height and DBH.

Due to the relatively stable nature of carbon stocks associated with its lawns and beds, as well as uncertainties in the methods used to estimate such stocks, there is little benefit to be gained from pursuing additional data regarding soil and non-tree above ground carbon. The Greenway should focus on maintaining its landscape in line with its programmatic objectives while continuing standard soil measurements to monitor the health of the soils.