Green Infrastructure Tree and Soil Study

2014-2016 Baseline Data

Introduction

The NYC Urban Field Station (UFS) is a partnership between the NYC Department of Parks & Recreation (NYC Parks), the USDA Forest Service Northern Research Station (NRS), and the Natural Areas Conservancy. The mission of the UFS is to improve quality of life in urban areas by conducting, communicating, and supporting research about social-ecological systems and natural resource management.

Executive Summary

In 2010, NYC Department of Environmental Protection (DEP) signed a Modified Consent Order with the NYS Department of Environmental Conservation (DEC) to invest $2.4 billion over the next 20 years to develop green infrastructure (GI) practices in previously impervious surfaces across the city to manage storm water runoff and reduce combined sewer overflows (NYC DEP, 2012). This report focuses on baseline data collected in 2014-2016 from GI practices that are managed by NYC Department of Parks & Recreation (NYC Parks) or co-managed by DEP and NYC Parks along the right-of-way and include trees. This project was a collaboration between researchers at NYC Parks and the USDA Forest Service Northern Research Station (NRS) and is based out of the NYC Urban Field Station (UFS).

We found that tree stress varied across species, GI type, and borough. On average, *Gleditsia triancanthos* was the most stressed and *Ginkgo biloba* was the least stressed. Trees growing in right-of-way-bioswales were significantly more stressed when compared to trees growing in street tree beds. Trees in the Bronx experienced more stress than trees in Queens. Currently, we do not have enough information to determine the underlying drivers of those differences. Some soil and foliar heavy metals varied with tree health, but they did not correspond to differences in tree health across GI type. In fact, despite the high concentrations of soil and foliar arsenic and soil aluminum (generally harmful to tree health) in stormwater greenstreets and street tree beds, on average, trees in those GI types were healthier than those growing in right-of-way bioswales. Thus, differences in tree health may be caused by variables not measured in this study: e.g., water infiltration rates, littering rates, tree stock provenance, frequency of stewardship activities.

In the years since the pilot data were collected, DEP has shifted its focus towards maintaining and encouraging stewardship of existing right-of-way bioswales. Thus, we recommend that future research should be focused more on how the level of care and maintenance of different GI practices affect tree health while accounting for species and site characteristics.

Types of GI in This Study

Street Tree

Typically one tree planted in a rectangular pit (4'-5' wide, 10'-20' length, up to 2' deep) that is along a curb line.

Right-of-Way Bioswale (ROWB)

A modified street tree pit with inlets to intercept more storm water than a typical street tree pit and contains up to one tree and various herbaceous species.

Stormwater Green Street (SGS)

Planted areas typically placed in street medians and traffic islands that are 10-20x larger than ROWB and contain at least 1 tree and various herbaceous species.

Background

This study focuses on the tree health and soil properties of three types of GI managed by NYC Department of Parks & Recreation (NYC Parks) – right-of-way bioswales (ROWB), stormwater greenstreets (SGS), and traditional street trees. The greenstreets program was developed by NYC Parks in 1997 as a citywide community beautification initiative. As part of this initiative, more than 2,100 streetscape sites were turned into greenstreets. In 2006, the first generation of stormwater capture sites were piloted, which led to a partnership between NYC Parks and the NYC Department of Environmental Protection (DEP). Since 2010, thousands of ROWB and SGS have been constructed in the Bronx, Brooklyn, and Queens by DEP in partnership with NYC Parks, and more are slated to be completed in the next few years.[1]

Currently, the majority of data collected on the new GI is focused on stormwater capture, and less is known regarding the health of trees and soil conditions. Trees and soils are important components of ROWB and SGS because of their ability to absorb and filter storm water, and replacing dead trees can be costly in terms of time and resources. Thus, this study aimed to better understand what factors influence GI tree health and potential actions that improve GI tree health.

The main objectives of this study are to determine:

1. Are there differences in tree health across the 3 green infrastructure (GI) types?
2. Does tree health vary across species?
3. Does tree health correlate with differences in soil or foliar chemistry?

[1] NYC DEP Green Infrastructure Program Map: https://www.arcgis.com/home/webmap/viewer.html?webmap=a3763a30d4ae459199dd01d4521d9939

Study Design

Study Sample

This pilot study includes 148 ROWBs, SGS and street trees pits constructed in 2013 or 2014 (see **Table 1** & **Figure 1**). Because different tree species can have different responses to land use, stormwater inputs, soil, and other components of GI design, this study focuses on 5 commonly planted tree species: *Acer rubrum* (red maple), *Ginkgo biloba* (ginkgo, maidenhair tree), *Gleditsia triacanthos var. inermis* (Thornless Common Honeylocust), *Quercus bicolor* (swamp white oak), and *Quercus palustris* (pin oak). All ROWBs and SGS in Queens and the Bronx maintained by NYC Parks that were planted in 2013 or 2014 with any of the 5 tree species were included in the study. Due to the large number of street trees planted, only 6-9 street trees of each species per borough were sampled. These trees were also planted in 2013 or 2014 and randomly selected out of all street trees that are within 2 miles of the nearest ROWB or SGS. The only exception is *Acer rubrum*: trees were randomly selected within a 4 mile radius of the nearest ROWB or SGS because of the limited number of nearby *Acer rubrum* within 2 miles. All data were collected during July and August of 2014, 2015, and 2016.

Table 1. Number of trees in each location (BX = Bronx, Q = Queens) & GI Type

Tree Species	**ROWB**		**SGS**		**Street Trees**		**Total**
	BX	Q	BX	Q	BX	Q	
Acer rubrum	4	10		2	9	8	33
Gingko biloba	2	3			6	8	19
Gleditsia triancanthos var. inermis		11			9	8	28
Quercus bicolor	2	16		3	8	8	37
Quercus palustris	3	7	5		8	8	31
Grand Total	**11**	**47**	**5**	**5**	**40**	**40**	**148**

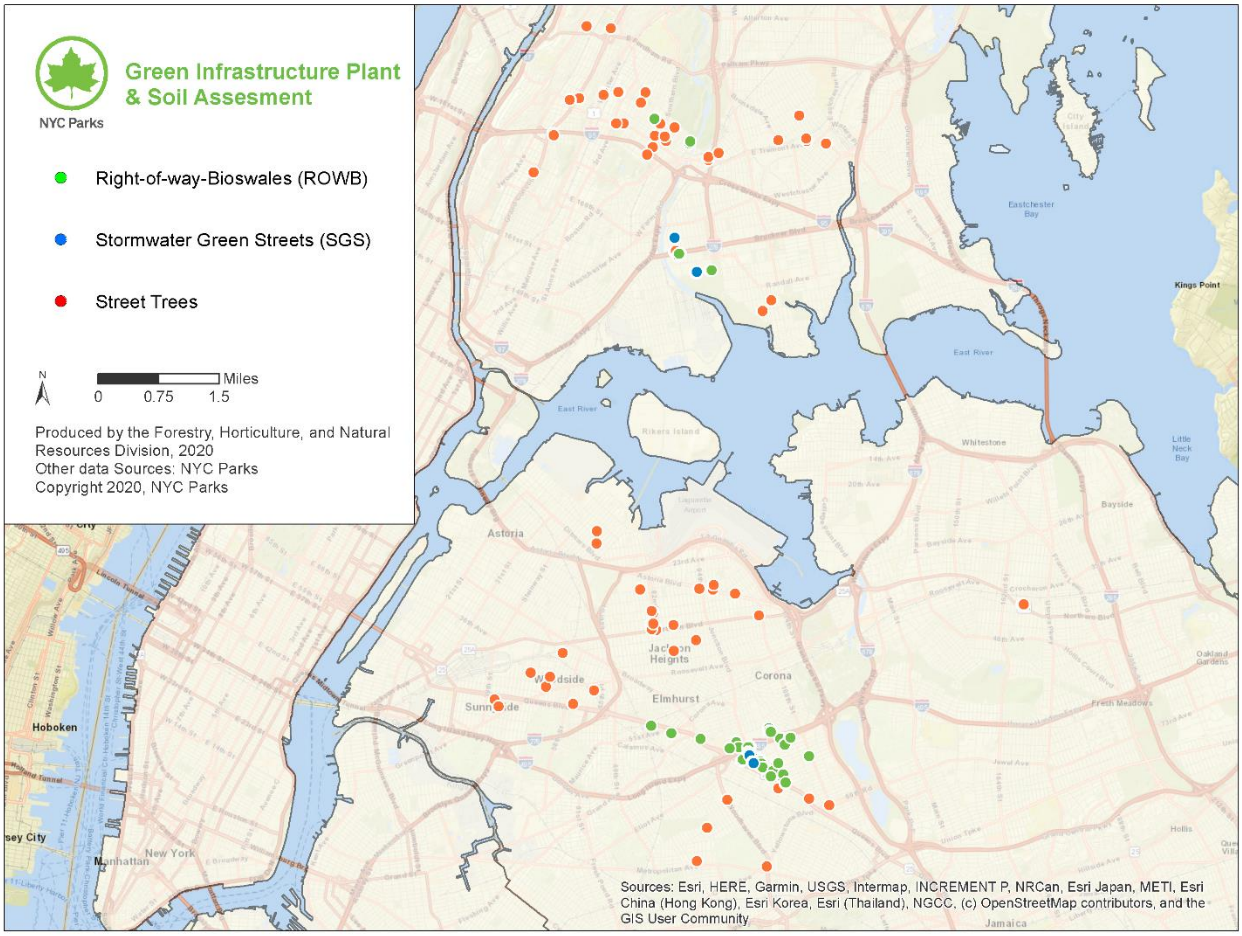

Figure 1. Map of all ROWB, SGS, and Street Trees in the Study

Tree Health

Tree health was assessed using a protocol developed by the USDA Forest Service Northern Research Station (Pontius & Hallett 2014), which combines various tree health indicators into a tree stress index. This protocol is used in a variety of tree health studies in NYC and other urban and rural areas. In our study, the following tree health indicators were measured and combined into a tree stress index that was stratified by species:

- **Percent crown dieback**: Dieback is recently mortality starting at the tips of branches and occurs near the upper and outer portions of the tree. This metric is assessed visually.
- **Percent discoloration**: Discoloration is any abnormal color change not due to season or young growth. This metric is assessed visually.
- **Percent canopy transparency**: The percentage of tree canopy that is missing. This metric is calculated by taking canopy photos and processing them using Cellprofiler, a free image analysis software.
- **F_v/F_m**: This is the ratio of variable chlorophyll fluorescence (F_v) to the maximum chlorophyll fluorescence (F_m), an indicator of the efficiency of photosynthesis, and it is measured using a PEA (Plant Efficiency Analyzer) Chlorophyll Fluorimeter. When plants experience stress, this can decrease the F_v/F_m ratio.

- **PI**: The performance index of photosynthesis (PI) combines multiple structural and functional performance measures of photosynthesis into a single index. This metric can often be more sensitive to environmental effects than F_v/F_m.

In addition to the indicators above, we also measured **diameter at breast height (dbh)** and **height** each year.

Soil Properties & Foliar Chemistry

Surface soil samples (top 10 cm) were collected within 2-3 feet from each tree in 2014 and 2015. Samples were analyzed by the USDA Forest Service Northern Research Station lab for the following properties:

- **Bulk density:** The mass of dry soil divided by its volume, which provides information on water drainage through the soil.
- **Soil texture**: The percentage of sand, silt, and clay, which provides information on water drainage through the soil.
- **Heavy metals**: The concentrations of aluminum, arsenic, cadmium, chromium, cobalt, copper, lead, nickel, strontium, and zinc in the soil, which can be sources of stress for plants.
- **Salinity**: The concentration of soluble salts in the soil, which can be a source of stress for plants.
- **Organic content**: The concentration of organic content in the soil, which can be a source of health for plants and is measured using the loss on ignition method.
- **Soil nutrients**: The concentrations of boron, calcium, potassium, magnesium, manganese, and phosphate in the soil, which can be source of health for plants.
- **pH**: A measure of the acidity or basicity of the soil, which can affect the ability of plants to take up nutrients and heavy metals.

Roughly 5-15 mature leaves were collected from each tree, and leaf samples were analyzed by the USDA Forest Service Northern Research Station lab for the following properties:

- **Heavy metals**: The concentrations of aluminum, arsenic, cadmium, chromium, cobalt, copper, lead, nickel, strontium, and zinc in the soil, which can be sources of stress for plants.

Other Variables

In addition to tree health, soil properties, and foliar chemistry, we also recorded two other variables:

- **Hydraulic loading ratio (for ROWB and SGS only)**: This is the ratio of the impervious tributary area divided by the size of the ROWB or SGS. It provides us with a sense of the volume of stormwater inputs into a given ROWB and SGS, assuming that water flow rates through the ROWB and SGS are the same.

- **Surrounding land use**: We noted whether the tree was in a residential, commercial, or industrial area while collecting other data.

Statistical Analysis

All statistics were analyzed using R v. 4.0.0.

We used a linear mixed model to examine the response of tree health to a suite of random (borough, year) and fixed effects (tree species, green infrastructure type, land use). We ran multiple models to determine which set of variables best predict tree stress based on the Akaike information criterion (AIC). Tree stress indices were square root transformed to ensure analyses were performed on a normally distributed dataset.

We performed correlation tests to examine the relationship between tree health and various soil and foliar chemistry metrics. When we found a statistically significant correlation between tree health and a given soil or foliar chemistry metric, we used a one-way ANOVA compare variations in that metric across green infrastructure type. We performed a correlation test to examine the relationship between tree health (for ROWB and SGS only) and hydraulic loading ratio.

Results

Tree Health

The best-fit model includes the variables in **Table 2**.

Variables	P Value
Species	**<0.0001**
Green Infrastructure Type	**0.0031**
Land Use	0.1912
Year	0.1071
Borough	**0.0001**

Table 2. Summary of P-values from a linear mixed model. P-values under 0.05 are considered statistically significant and in bold.

We found that tree stress index varies with species, green infrastructure type, and borough (Table 2 and Figure 2). On average, *Gleditsia triancanthos* were the most stressed and *Ginkgo biloba* were the least stressed. Trees growing in ROWB were significantly more stressed compared to trees growing in street tree beds even though ROWB were larger than street tree beds on average. Trees in the Bronx experienced more stress than trees in Queens. Although a preliminary analysis of this study's first year of data found that land use influenced tree stress, when data were analyzed across all three years, land use had no effect on tree stress. Hydraulic loading ratio (an indicator of stormwater inputs) also had no effect on tree stress.

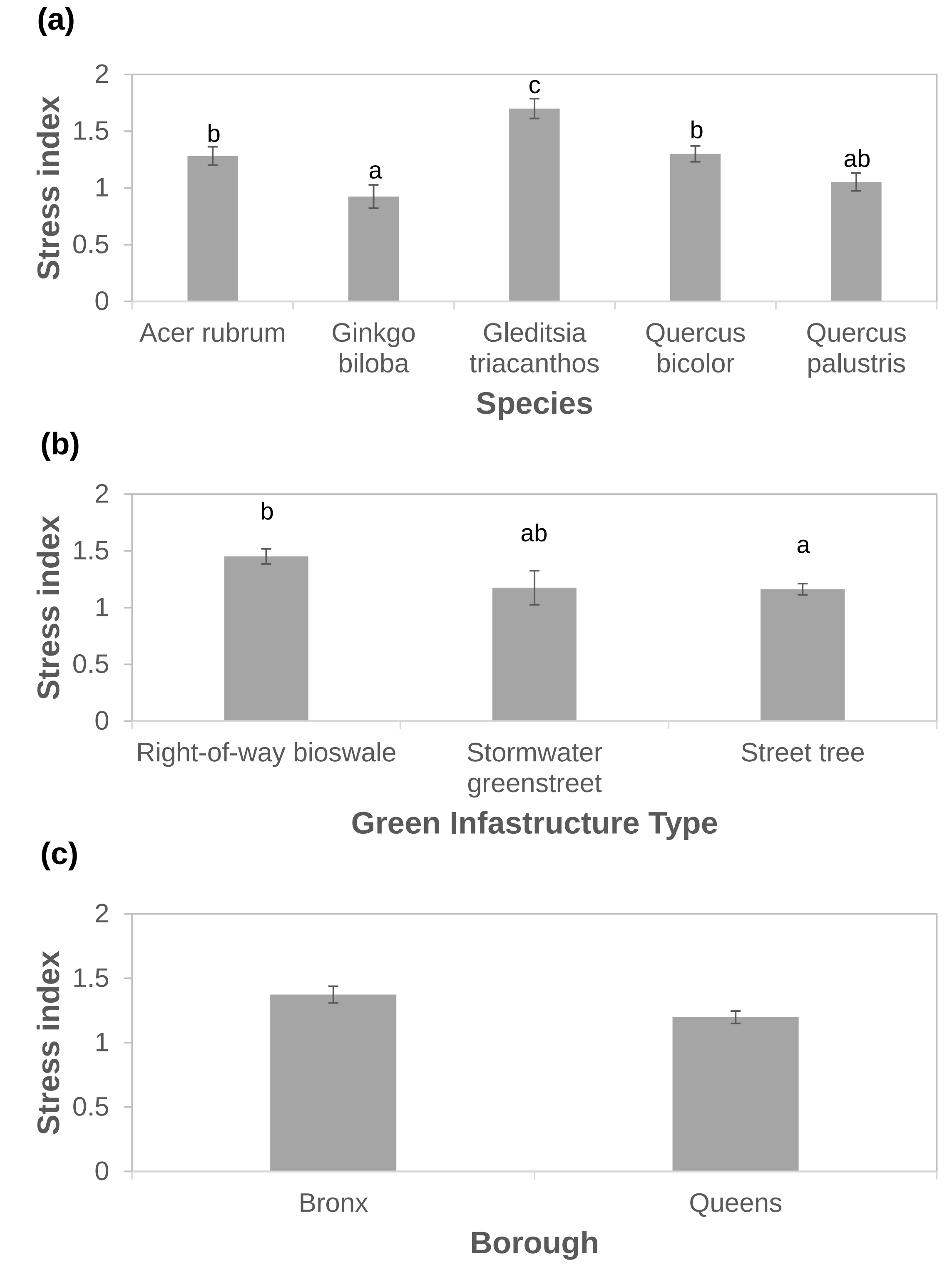

Figure 2. Tree stress varied across (a) species, (b) green infrastructure type, and (c) borough. Error bars represent standard error. Letters "a", "b", and "c" symbolize significant differences ($p < 0.05$) from Tukey's Honest Significant Difference (HSD) across species.

Soil Properties

Out of all soil property variables, only three were correlated with tree stress (see **Table 6**) and only aluminum and nickel varied across green infrastructure types (see **Table 7, Figures 6 & 7**). While high levels of aluminum and nickel can cause stress, the highest average soil aluminum and nickel concentrations were within stormwater green streets (where trees had the lowest average stress) and not right-of-way bioswales (where trees had the highest average stress).

Soil chemistry variable	Spearman's Rho	P-value
Aluminum	0.150187	*0.06752*
Nickel	0.163517	**0.0463**
Phosphorous	-0.1531364	*0.06225*

Table 6. Soil chemistry variables correlated to tree stress. Significant correlations are shown in bold ($P<0.05$) and marginally significant correlations are shown in italics ($0.05 \leq p < 0.1$).

Soil chemistry variable	P Value
Aluminum	**0.02363**
Nickel	**0.001827**

Table 7. Summary of P-value and numerator degrees of freedom from one-way ANOVA tests. Denominator degrees of freedom is 146.

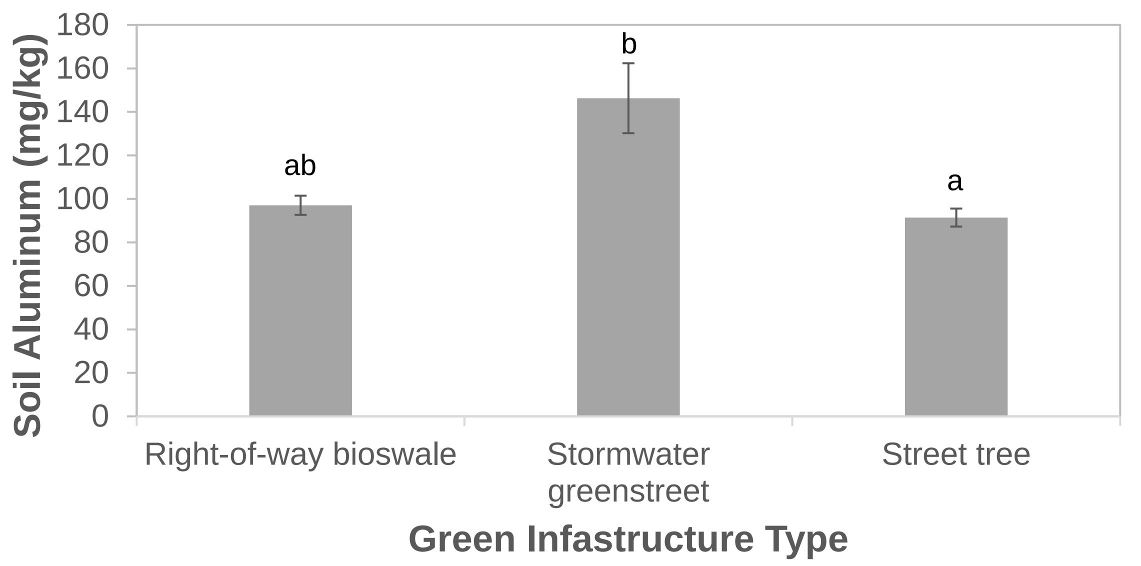

Figure 6. Aluminum concentrations varied across green infrastructure type. Error bars represent standard error. Letters "a" and "b" symbolize significant differences from Tukey's Honest Significant Difference (HSD) across green infrastructure type.

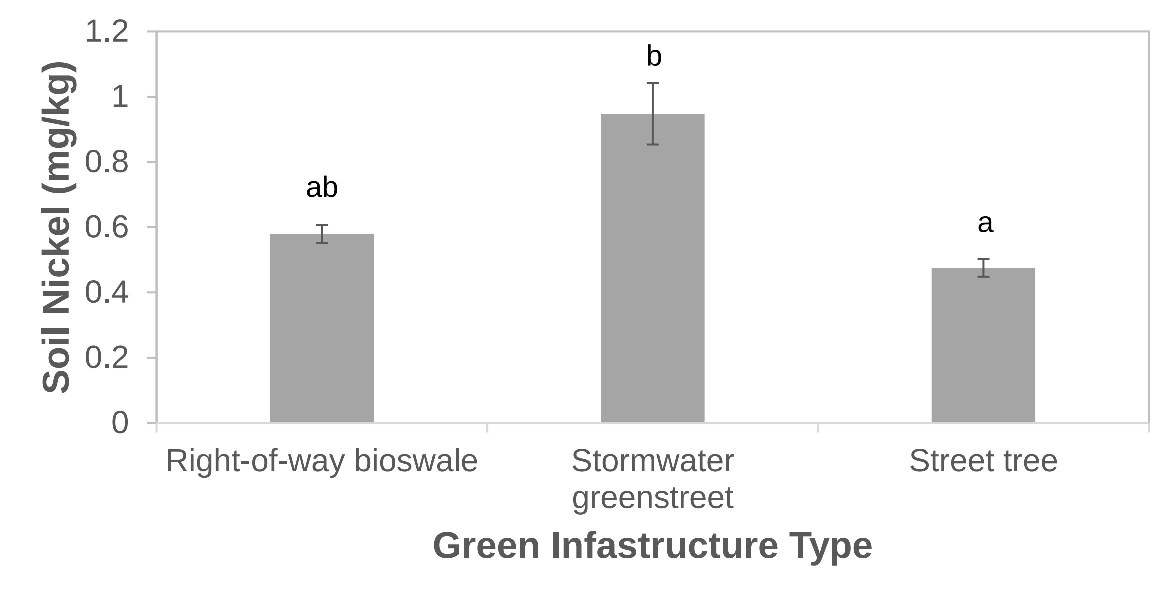

Figure 7. Nickel concentrations varied across green infrastructure type. Error bars represent standard error. Letters “a” and “b” symbolize significant differences from Tukey’s Honest Significant Difference (HSD) across green infrastructure type.

Foliar Chemistry

Multiple foliar chemistry variables were also correlated with tree stress (see **Table 8**), and based on the correlation coefficients, these correlations were slightly stronger than correlations between soil chemistry and tree stress. Additionally, arsenic, potassium, and lead varied across green infrastructure type (see **Table 9**). Average foliar arsenic and potassium concentrations were highest and lead levels were lowest in street trees compared to other green infrastructure types (see **Figures 8,9,10**).

Foliar chemistry variable	Spearman’s Rho	P-value
Aluminum	0.2893852	**0.01874**
Arsenic	-0.2716418	**0.02767**
Cadmium	-0.27494	**0.02578**
Chromium	0.2353617	*0.05732*
Copper	0.2556936	**0.03853**
Iron	0.2595345	**0.03563**
Lead	0.3897084	**0.001219**
Manganese	-0.2542323	**0.03968**
Potassium	0.2557771	**0.03846**
Sodium	0.5180879	**1.137e-05**

Table 8. Foliar chemistry variables correlated to tree stress. Significant correlations tests are shown in bold (P<0.05) and marginally significant correlations are shown in italics (0.05 ≤ p < 0.1).

Foliar chemistry variable	P-value
Arsenic	**0.002192**
Lead	**0.02143**
Potassium	**0.0003836**

Table 9. Summary of P-value and numerator degrees of freedom from one-way ANOVA tests. Denominator degrees of freedom is 63.

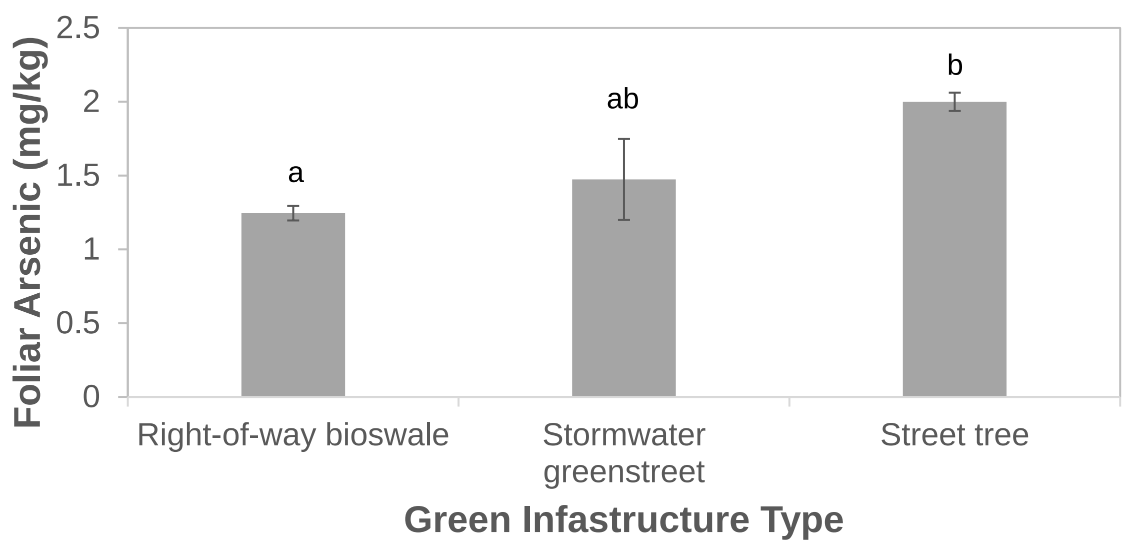

Figure 8. Foliar arsenic concentrations varied across green infrastructure type. Error bars represent standard error. Letters “a” and “b” symbolize significant differences from Tukey’s Honest Significant Difference (HSD) across green infrastructure type.

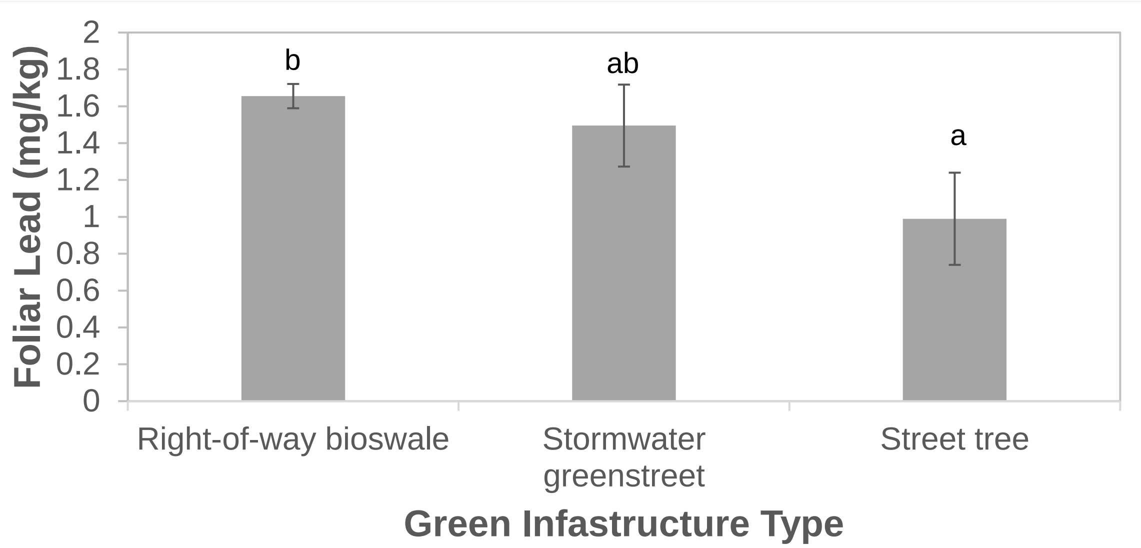

Figure 9. Foliar lead concentrations varied across green infrastructure type. Error bars represent standard error. Letters “a” and “b” symbolize significant differences from Tukey’s Honest Significant Difference (HSD) across green infrastructure type.

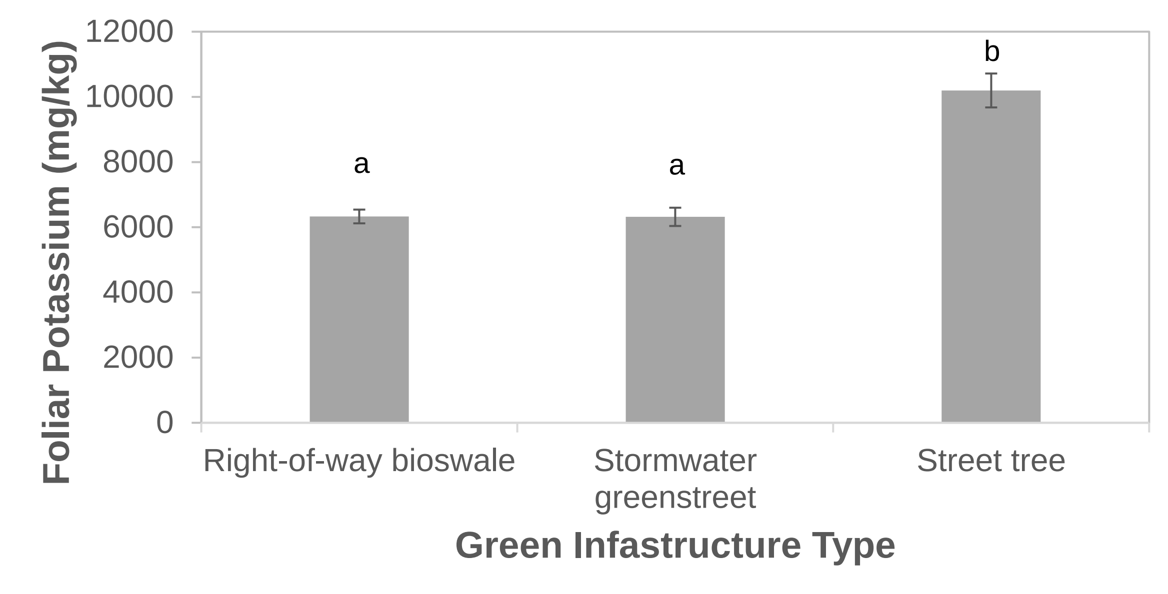

Figure 10. Foliar potassium concentrations varied across green infrastructure type. Error bars represent standard error. Letters “a” and “b” symbolize significant differences from Tukey’s Honest Significant Difference (HSD) across green infrastructure type.

Discussion & Recommendations

Based on our baseline data, we found that tree health varies across species, GI type, and borough. Notably, land use was not a significant determinant of tree health, which may be an indication that our current street tree species selection process is adequately accounting for land use characteristics.

On average, *Gleditsia triancanthos* was the most stressed and *Ginkgo biloba* was the least stressed, trees growing in right-of-way-bioswales were more stressed compared to trees growing in street tree beds, and trees in the Bronx were more stressed than ones growing in Queens. Currently, we do not have enough information to determine the underlying drivers of those differences. Some soil (aluminum, nickel, phosphorous) and foliar characteristics (aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, potassium, sodium) varied with tree health, but they did not correspond to differences in tree health across GI type. In fact, despite the high concentrations of soil and foliar arsenic and soil aluminum (generally harmful to tree health) in stormwater greenstreets and street tree beds, on average, trees in those GI types were healthier than those growing in right-of-way bioswales. Thus, differences in tree health may be caused by variables not measured in this study: e.g., water infiltration rates, littering rates, tree stock provenance, frequency of stewardship activities.

In the years since the baseline data were collected, DEP has shifted its focus away from constructing new right-of-way bioswales and towards maintaining and encouraging stewardship of existing right-of-way bioswales through its Harbor Protectors program, for example. Thus, we recommend that future research should be focused more on how the level of care and maintenance of different GI practices affect tree health while accounting for species and site characteristics.

References

Pontius, Jennifer and Richard Hallett (2014) *Comprehensive Methods for Earlier Detection and Monitoring of Forest Decline*. Forest Science 60(6): 1156-1163

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