USDA Forest Service

Urban Forest Connections

Second Wednesdays | 1:00 – 2:15 pm ET
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More Than Good Looks: How trees influence urban stormwater management in green infrastructure practices

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More Than Good Looks: How trees influence urban stormwater management in green infrastructure practices

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Urban Forest Connections Webinar Series
May 8, 2019
Urban Stormwater Challenges

- Impervious surfaces limit infiltration, increase runoff quantity delivered to receiving waters, leading to degraded stream conditions.
- Pollutants associated with urban areas (sediment, nutrients, heavy metals) impact chemistry and aquatic ecosystems of receiving waters.

Introduction
Livesley, S. J. et al. (2016)

BVOC = Biological volatile organic compounds
Increased urban forest canopy can:
- reduce the urban heat island
- reduce urban particulate pollution
- reduce runoff and increase infiltration
Knowledge Gaps

• Many studies are limited to grasses, shrubs, and sedges, leaving the need to explore other plant types in bioretention

• Few studies have explored the specific role of trees in bioretention

• Very little research has produced guidance for tree species selection based on physiological aspects that may account for performance contributions
Research Overview

Study 1
Field health survey of trees in existing bioretention practices in Tennessee and North Carolina

Study 2
Field-scale study of two suspended pavement systems designed to function as bioretention practices
Bioretention Tree Health Surveys

- June-August ‘15
- 38 practices
- 97 trees from 22 species
  - Six species accounted for ~75% of total

Study 1: The Health of Trees in Bioretention Practices
Crown Condition Indicators

Rating Crown Condition Indicators

Density/Transparency Scale

Foliar Transparency

Crown Dieback

Study 1: The Health of Trees in Bioretention Practices
Composite Crown Indicators (CCI)

• Tree health based on 3D crown shape:
  • Crown Volume
    \[ CCV = \left(0.5\pi R^2 (CL)\right) \left(\frac{CDEN}{100}\right) \]
  • Crown Surface Area
    \[ CSA = \frac{4\pi CL}{3R^2} \left[\left(R^2 + \frac{R^4}{4CL^2}\right)^{1.5} - \left(\frac{R^4}{4CL^2}\right)^{1.5}\right] \left(\frac{CDEN}{100}\right) \]
  • Larger CCI Values = Increased Tree Health

Zarnoch et al. (2004)
How does the health of bioretention trees compare to other urban trees?
Bioretention vs. Non-bioretention Trees

Study 1: The Health of Trees in Bioretention Practices

\[ p < 0.05 \]

\[ p < 0.1 \]
Comparing Tree Health

- Many species were *less healthy* in bioretention.
- Incompatibility with species-specific growing preferences for soil moisture, texture, etc.

<table>
<thead>
<tr>
<th>Species</th>
<th>Soil pH</th>
<th>Saturated or very wet soil</th>
<th>Moist, well-drained soil</th>
<th>Occasionally dry soil</th>
<th>Very dry soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bald Cypress</td>
<td>4.5-6.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pin Oak</td>
<td>4.5-6.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>River Birch</td>
<td>3.0-6.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red Maple</td>
<td>4.7-7.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Redbud</td>
<td>5.0-7.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lacebark Elm</td>
<td>4.8-7.0</td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

Bassuk et al. (2009)
Comparing Tree Health

- **Eastern redbud**: not found in sandy soils
- **River birch**: prefer tight clay soils, high soil moisture
- **Pin oak**: found in heavy-textured, poorly drained soils
- **Bald cypress**: best growth in moist, fine sandy loam soils without competition
What bioretention parameters influence tree health?
Factors Influencing Health

• Species selection
• Soil pH
• Soil Chemistry
  • Nutrients, metals
• Soil Composition
  • % Sand, % Fines, OM
• Bioretention Design
  • Surface Area
  • Tree planting location
  • Ponding Depth

Study 1: The Health of Trees in Bioretention Practices
# High-Importance Design Parameters

<table>
<thead>
<tr>
<th>Category</th>
<th>Predictor Variable</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioretention Media Composition</td>
<td>Fines (%)</td>
<td>Reinforces findings in tree health comparison study; media should align with species-specific habitat preferences</td>
</tr>
<tr>
<td></td>
<td>Sand (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Organic Matter (%)</td>
<td>Influences soil fertility, structure; OM standards vary</td>
</tr>
<tr>
<td>Bioretention Media Chemistry</td>
<td>Buffer pH</td>
<td>Controls fluctuations in soil pH which could impact root function; influences nutrient availability in media</td>
</tr>
<tr>
<td></td>
<td>Copper</td>
<td>Micronutrient; deficiency leads to crown defoliation and dieback (other micronutrients are also key)</td>
</tr>
<tr>
<td></td>
<td>Potassium</td>
<td>Vital to plant functions (photosynthesis, water regulation, cell expansion); required in large amounts</td>
</tr>
<tr>
<td>Tree Selection and Planting</td>
<td>Planting Location</td>
<td>Should reflect tree tolerance to inundation</td>
</tr>
<tr>
<td></td>
<td>Species Selection</td>
<td>Species should be tolerant of bioretention environment</td>
</tr>
</tbody>
</table>
Tree Health Survey Conclusions

1. Trees should be selected based on their ability to tolerate the unique conditions found in bioretention practices. Species-specific preferences for growing conditions should be considered during selection.

2. Species selection should be guided by analysis of bioretention media composition, prioritizing high-importance parameters.
Suspended Pavement Systems - Introduction

- Urban soil conditions present challenges to tree, root growth
  - High compaction, low nutrients, poor aeration (Craul et al., 1985)
- Suspended pavement systems improve root access to air and water in an uncompacted soil matrix; take advantage of limited land availability in ultra-urban landscapes
- Very little research on suspended pavement systems designed as subsurface bioretention to-date
  - Suspended pavement system lined with impermeable membrane in Wilmington, NC (Page et al., 2015)
  - Peak flow rates reduced by 62%; significant pollutant removal
  - Lined system may not be applicable to installations outside research
Construction and Installation

Study 2: Bioretention Suspended Pavement Systems
Study 2: Bioretention Suspended Pavement Systems
Hydrologic Monitoring Results

- Total of 1922mm of rainfall recorded (median event of 8 mm) between April 2016 and July 2018
- 146 and 148 storm events collected for north and south sites
- Exfiltration from upper soil layers may have outweighed low infiltration rates of underlying soils
- 83% of storms completely captured by south site (123/148 storms); 79% at north site (116/146 storms)

<table>
<thead>
<tr>
<th></th>
<th>North Site</th>
<th>South Site</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(mm)</td>
<td>(%)</td>
</tr>
<tr>
<td>Inflow</td>
<td>1775</td>
<td>-</td>
</tr>
<tr>
<td>Outflow</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Overflow</td>
<td>3.3</td>
<td>0.2</td>
</tr>
<tr>
<td>Exfiltration/ET</td>
<td>1772</td>
<td>99.8</td>
</tr>
</tbody>
</table>

Study 2: Bioretention Suspended Pavement Systems
## Pollutant Removal Performance

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Influent</th>
<th>Effluent</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS (mg L(^{-1}))</td>
<td>167 (69)</td>
<td>6 (21)</td>
<td>(p&lt;0.05)</td>
</tr>
<tr>
<td>(\text{NH}_4^+)-N (mg L(^{-1}))</td>
<td>0.01 (0.01)</td>
<td>0.01* (0.00)</td>
<td>-</td>
</tr>
<tr>
<td>(\text{NO}_x)-N (mg L(^{-1}))</td>
<td>0.05 (0.13)</td>
<td>0.11 (0.63)</td>
<td>-</td>
</tr>
<tr>
<td>(\text{PO}_4^{3-}) (mg L(^{-1}))</td>
<td>0.06 (0.03)</td>
<td>0.06* (0.00)</td>
<td>-</td>
</tr>
<tr>
<td>Cu (μg L(^{-1}))</td>
<td>0.5 (1.9)</td>
<td>0.3 (0.08)</td>
<td>-</td>
</tr>
<tr>
<td>Pb (μg L(^{-1}))</td>
<td>1.6* (0.0)</td>
<td>1.6* (0.0)</td>
<td>-</td>
</tr>
<tr>
<td>Zn (μg L(^{-1}))</td>
<td>7.9 (8.8)</td>
<td>7.9 (18.2)</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: Asterisk (*) indicates that pollutant levels in all ten samples were below method detection limit.
Conclusions

• Suspended pavement systems are effective at reducing runoff volumes

• Limited storage volume ("bowl volumes") in suspended pavement systems can lead to oversized practices
  • Sizing criteria may need to be revisited to account for small ponding volumes and the soil volumes required for tree growth

• Further research on pollutant removal performance needed – potentially linked to low influent concentrations and small sample size
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