Exploring Regenerative Planting Strategies for Green Rainwater Infrastructure:

Increasing connectivity through designed plant communities in the right-of-way.

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July, 2020

Acknowledgements

This report was created on traditional, ancestral and unceded territory of the Coast Salish peoples–Sḵwx̱wú7mesh (Squamish), Stó:lō and Səl̓ílwətaʔ/Selilwitulh (Tsleil-Waututh) and xʷməθkʷəy̓əm (Musqueam) Nations. The author recognizes that all recommendations made in this report relate to the stewardship of this land.

The author would like to thank the following individuals for their contribution, feedback, and support throughout this project.

Julie McManus, Planner, City of Vancouver

Cameron Owen, Senior Planner, City of Vancouver

Patrick Mooney, Melody Smale, and Duncan Chambers for sharing their research underway at University of British Columbia.

Thank you to all participants of the municipal survey for sharing their practices and helping to frame the direction of this report, and to interview subjects for generating excitement for the potential of regenerative planting strategies in road right-of-way green rainwater infrastructure. The support of all participants was integral to the creation of this report.

All illustrations by Kendra Scanlon

Additional illustration credits:
Christen Oakes illustrated the single-family home on page 45.

This report was produced as part of the Greenest City or Healthy City Scholars Program, a partnership between the City of Vancouver and the University of British Columbia, in support of the Greenest City Action Plan and the Healthy City Strategy.

This project was conducted under the mentorship of City staff. The opinions and recommendations in this report, and any errors, are those of the author, and do not necessarily reflect the views of the City of Vancouver or The University of British Columbia.

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Project Background

Project Purpose

In November 2019, the City of Vancouver adopted the Rain City Strategy, a 30-year plan to change how the city manages rainwater. It is a green rainwater infrastructure (GRI) and rainwater management initiative that will transform Vancouver's streets though nature-based infrastructure solutions. These systems capture and treat rainfall where it lands, mimicking the natural water cycle.

GRI offers a number of co-benefits beyond rainwater management that make it a key tool in meeting multiple city-wide objectives, including improved water quality, mitigation of urban heat island effect, added green space, and climate adaptation. The Strategy is based on the premise that all water has value and is a fundamental building block in city planning. This report aims to help Vancouver achieve its Rain City Strategy goals and objectives by looking at regenerative, low maintenance planting strategies that can deliver on a wide variety of co-benefits — functional, environmental, and aesthetic.

The Strategy aims to manage rainwater from 40% of impermeable surfaces in the City by 2050. Currently 49% of the City of Vancouver is impervious, and of that, 19% falls within streets and public spaces. Treating urban rainwater runoff through green rainwater infrastructure on the road right-of-way (ROW) can contribute greatly to reaching those targets.

Green infrastructure in ROWs can do more than just manage rainwater. The ROW accounts for 28% of total land use in the City of Vancouver, offering abundant opportunities to provide connections between people and places in space that is already managed by the City. The goal is to shift the notion of ROWs from utility corridors to blue-green systems. Blue-green systems work with the natural flow of water to create a network of streets, parks, and open spaces that encourage biodiversity, connectivity, and community beautification while also providing important water management functions.

This report discusses the potential for regenerative, high performance planting design to contribute to economies of scale necessary for creating a water-sensitive city. Regenerative planting design is explored as a method for reducing overall maintenance needs while increasing community support and biodiversity.

Quebec & 1st Street
Flagship GRI design in
Vancouver, BC

Crown Street in Southlands, Vancouver. Naturalized residential GRI system including permeable planted pavers and bioswale. This implementation runs across the whole block. Some plantings are cared for by residents while others are left to grow wild.

Research

Methodology

To provide the City of Vancouver with recommendations and direction for the possibility of planting design in blue-green systems, this report seeks to present current and developing strategies for regenerative planting design by:

- Conducting a literature review and precedent study which engages knowledge from horticultural and landscape architectural perspectives to create new benchmarks for GRI planting design.
- Conducting a survey with municipalities throughout North America with a focus on the Pacific Northwest and Atlantic coast to gain an understanding of 'low maintenance' definitions and planting practice.
- Conducting informal interviews with thought leaders in regenerative and high-performance planting design.
- Summarizing key findings
- Providing recommendations for future study

Previous GCS Reports

Past Greenest City Scholar reports have provided a foundation for this research. Exploring Alternative Models for Green Infrastructure Maintenance (2019) outlined the GRI operations and maintenance of several municipalities to frame challenges and capacities, defining the need for low maintenance planting strategies that are legible for maintenance contractors and community stewards.

Reports on Bird Friendly Landscape Design Guidelines (2013) and Resilient Landscapes (2018) also support this report by providing insight into the need for planting designs which react to increased need for enhanced biodiversity, and that are adaptable to a changing climate.

Survey

A questionnaire survey was conducted which asked 5 municipalities with established GRI practices to describe their planting practices in road right-of-way GRI. Participating municipalities included Kitchener, Philadelphia, Portland, Seattle, and Toronto.
The purpose of the survey was to gain a general understanding of typical practice while looking for innovative trials or ideas that could be explored in Vancouver. Questions centered around designs which required the lowest level of maintenance and elements which were considered high performers. Municipalities also provided details on successes and failures of different planting methods.

Results showed that municipalities share similar goals for GRI, which are largely centered on function (specifically infiltration properties). However, Toronto was a standout example of a municipality which prioritized co-benefits exclusively, indicating that a shift in the vision for GRI to enhance communities for the immediate benefit of people is underway. This echoes the evolving views within the City of Vancouver that aim to extend the benefits of GRI beyond individual system functionality into a larger vision that enhances livability.

Several innovative strategies were presented that had been trialled by respondents including:

- Plant community approaches
- Succession planting with self-seeders
- Sowing in-situ with plug overlays
- Welcoming volunteer species
- Conducting vegetation surveys

These methods reflect current conversations surrounding regenerative design and have contributed greatly to the framework of this report.

An extended discussion on the results of the survey is included in Appendix A.

Fairford Parkette, Toronto

Sedgwick Station, Philadephia

Prompting a shift

There are 140 bioretention/bioswale facilities in Vancouver. Block or mass planting is a common design strategy. Vancouver GRI siting standards recommend 3-5 plant species in traffic bulge systems. These plants are generally spaced horizontally according to potential growth habit/ spread, then supported by a layer of mulch to limit weed establishment and erosion.

The placement of these systems in ROWs present certain constraints. A recommended maximum height of 0.75-1m (~3ft) accounts for safety concerns related to sight lines at street corners, and natural surveillance.

In the past, these have been implemented as systems isolated from the surrounding context, taking shape as traffic bulges, curb bump outs, and sections of 2m boulevard.

The City of Vancouver's knowledge and understanding of GRI design is growing as more sites come online. Some of the early constructed bioretention bulges are being looked at for rehabilitation to improve performance.

In 2017, seven of these sites were proposed for rehabilitation, accounting for 679 m^2 of planted area, with a plant schedule of 22 species. This equates to 0.03 species per square meter, which may not be enough to meet the goals, objectives and targets described in the 2016 Biodiversity Strategy.

Exploring new planting approaches offers opportunities for GRI to meet maintenance capacities while providing extensive benefits to community resilience, livability, and biodiversity.

The City of Vancouver is reassessing and trialling new ideas that encompass a larger context, with flagship facilities such as 63rd and Yukon setting an example for the potential for GRI to meet a broader set of design objectives.

Examples of bioretention facilities in Vancouver listed for rehabilitation.

Areas where GRI can contribute to the Biodiversity Strategy (2016)

Goal

Increase the amount and ecological quality of Vancouver's natural areas to support biodiversity and enhance access to nature.

Objectives

1. Restore habitats and species.
2. Support biodiversity within parks, streets, and other City-owned lands.
3. Protect and enhance biodiversity during development.
4. Celebrate biodiversity through education and stewardship.
5. Monitor biodiversity to track change and measure success.

Target

Restore or enhance 25 ha of natural areas by 2020.

Priority Action #4

Incorporate smaller natural areas and features such as pollinator meadows into new and redeveloping parks and city-owned lands.

Example of potential for diverse planting in ROWs. This is a non-GRI feature that appears to be maintained by residents.

CASE STUDY:

63rd & Yukon, Vancouver

Location: Vancouver, Canada

Planting Design:
GI Engineering Services,
City of Vancouver

Scheme Design:
GI Engineering Services,
City of Vancouver

Maintenance:
Blue Pine Enterprises Ltd.
(Establishment)

Completion:
Spring 2018

Overview

63rd and Yukon is one of Vancouver's flagship designs that articulate goals of the recently adopted Rain City Strategy. The project was completed alongside a new development which allowed for a re-imagining of the typical grid-like street and sidewalk system of Vancouver. Transitioning from single family homes to a multi-unit building allowed for a takeover of the street corner, widening pedestrian pathways, increasing separation from the road, and providing seating and gathering space. The bioretention area covers an area of $102m^2$ and accounts for a drainage area of $1170m^2$.

A block planting approach was used which contributed to an aesthetic vision that connected the bioswale to a buried stream nearby. The planting plan includes 6 species of trees and a combination of 12 grasses, forbs, and shrubs from native and non-native species, including some self-seeders. Onsite soils were amended to meet bioretention infiltration needs. The use of native soils helped to keep the microbial soil structure intact.

BIG IDEAS

- Use of native soils instead of bioretention media
- Self-seeding perennials
- Increasing resilience with native and non-native planting
- Pedestrian-focused
- Creating community space with GRI
- Connecting historical stream in the site context

Results:

After 2 years of establishment, overall plant health is strong, which may be a result of the healthy native soils amended for the project. Douglas aster (*Symphyotrichum subspicatum*), a native species and competitive self-seeder, has spread and developed a strong presence on-site since first planting. Species within the highest inundation zones appear the healthiest, whereas those closer to dry zones and streets are more sparse, perhaps due to foot traffic or under watering.

The space is frequented by neighborhood residents, with benches occupied on sunny days and consistent foot traffic. The design is integrated into the overall aesthetic of the accompanying development, but not to the effect that it feels separate from the rest of the community.

Interpretive signage describes the function of the system as an educational opportunity that shows the public that GRI is not just a landscaped feature but also provides important infrastructural functions. This project presents a more holistic approach to design, encompassing the many benefits of GRI.

Main bioretention area showing planting design, healthy growth, and community gathering space at 63rd & Yukon in May 2020

Photos by:
Kendra Scanlon

REGENERATIVE PLANTING STRATEGIES

Based on survey responses, interviews with thought leaders, and a desktop review of numerous precedents in green rainwater infrastructure projects by landscape architects, a picture for possibilities in regenerative design in GRI landscapes has developed.

In order for a plant design to be regenerative, a number of criteria were explored including designs which:

- Connect people to place
- Increase habitat and biodiversity
- Create symbiotic relationships with humans and non-humans
- Create or work towards closed loop systems
- Operate within current and future management capacity

The plant community approach taken by leaders in planting design and innovative GRI strategies, such as Thomas Rainer, Claudia West, Piet Oudolf, Nigel Dunnett, James Hitchmough, and Future Green Studio holds the most promise for achieving regenerative GRI designs. The following explores the plant community approach, including structural elements, competition and succession, maintenance, and methods for designing on a municipal scale.

Designed Plant Communities

What is a plant community?

Patrick Mooney (2019) describes a natural plant community as “a group of plants that occur together” which share similarities in growing conditions encompassed by a “range of critical abiotic factors that determine where it will thrive” (p. 86-87). Processes such as competition are natural factors within plant communities, creating systems which survive through continued evolution or succession. This concept is central to regenerative planting design.

What is a designed plant community?

Traditional planting strategies place emphasis on sustaining individual species within a design, attempting to ensure that each plant survives the life cycle of the design. This creates static systems that are in opposition to changing conditions. Stagnation becomes particularly problematic in the face of climate change, where adaptability is necessary to account for more extreme conditions.

A designed plant community is the translation of natural communities into the anthropogenic realm. It does not produce a replica of a plant community, but rather aims to understand and emulate the structural elements and basic growing conditions required for that community to survive.

> *“The survival of individual plants is less important than the survival of the whole”*

Central to this idea is that “the survival of individual plants is less important than the survival of the whole” (Kingsbury, 2012, p. 2). This is a departure from traditional ideas of design and maintenance. With the designed plant community approach, the intent is to create a functioning whole that uses the dynamic processes such as competition and succession as assets (Rainer and West, 2015).

Native vs. Non-native plants

James Hitchmough is an expert in horticultural ecology who specializes in the design and management of herbaceous vegetation. He describes the need to consider urban conditions outside of historical localized niches, recognizing that “because urbanization often radically changes these factors one cannot assume that what vegetation once occurred on a site will be well-fitted post-urbanization” (Hitchmough, 2008, p. 6). The focus should not be on what once grew here, but on what is capable of surviving current and future conditions.

Many green infrastructure planting guides call for the use of native plants, but the inclusion of non-natives may increase resiliency. The 2019 study *Implications of non-native species for mutualistic network resistance and resilience* suggests that non-native species “bolster the ecological resistance or functional persistence of ecosystems in the face of disturbance” (Aslan, 2019) when planted alongside native species.

Native plantings have been shown to encourage native pollinators (Smale quoted in Mooney, 2019), therefore a combination of native and non-native species should be used to build a planting design which is best suited for the context.

Indications of Care

Regenerative practice calls for designs which appear to be more wild than traditional planting methods. This aesthetic change may accompany misinterpretation from the public as a landscape that is not cared for (Nassauer, 1995). Naturalized designs such as the bioswale on Ontario Street at Walter Hardwick Avenue have prompted some concern from community members. However, as suggested by Nassauer, including indicators of care within “messy” landscapes tend to re-frame the benefits of those plant communities and help people reevaluate aesthetic preference. The City of Vancouver has included an educational sign board at the Ontario Street bioswale and is evaluating the effect this has on overall public opinion.

When designing naturalized landscapes, it is important to consider which indicators of care will best support the design goals and address existing and future aesthetic preferences. Nassauer describes a number of cues to care including flowering species, mowing, linear planting design, and frames that surround naturalized or “messy” designs. Designs such as the Queen Elizabeth Olympic Garden demonstrate how naturalized designs and clean edges can work together for maximum aesthetic impact.

GRI often features clean edges defined by sidewalks, curbs, streets, and bike paths. These urban frames provide an opportunity for plant community approaches that are more naturalized in appearance.

Layering technique

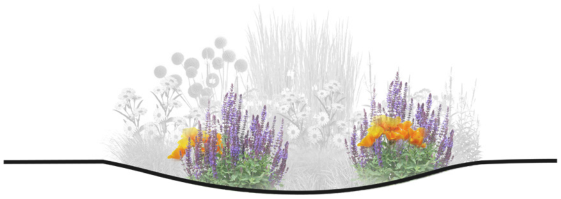
The designed plant community is created creating layers that emulate the structural makeup of natural plant communities. The layering technique is used in matrix planting schemes which will be discussed in more detail.

The following diagrams illustrate the structural design layers of grassland and woodland communities, described at length in *Planting in a Post-Wild World.*

Ontario Street bioswale with interpretive signage.

GROUNDCOVER

Low growing grasses and runners with generally shallow rooting habitats. These plants are highly effective as attenuators in GRI.



SEASONAL THEMES

Plants which provide interest and visual impact depending on the season. This element is important to sustaining the interest of pollinators and people, often referring to flowering elements.

FILLER

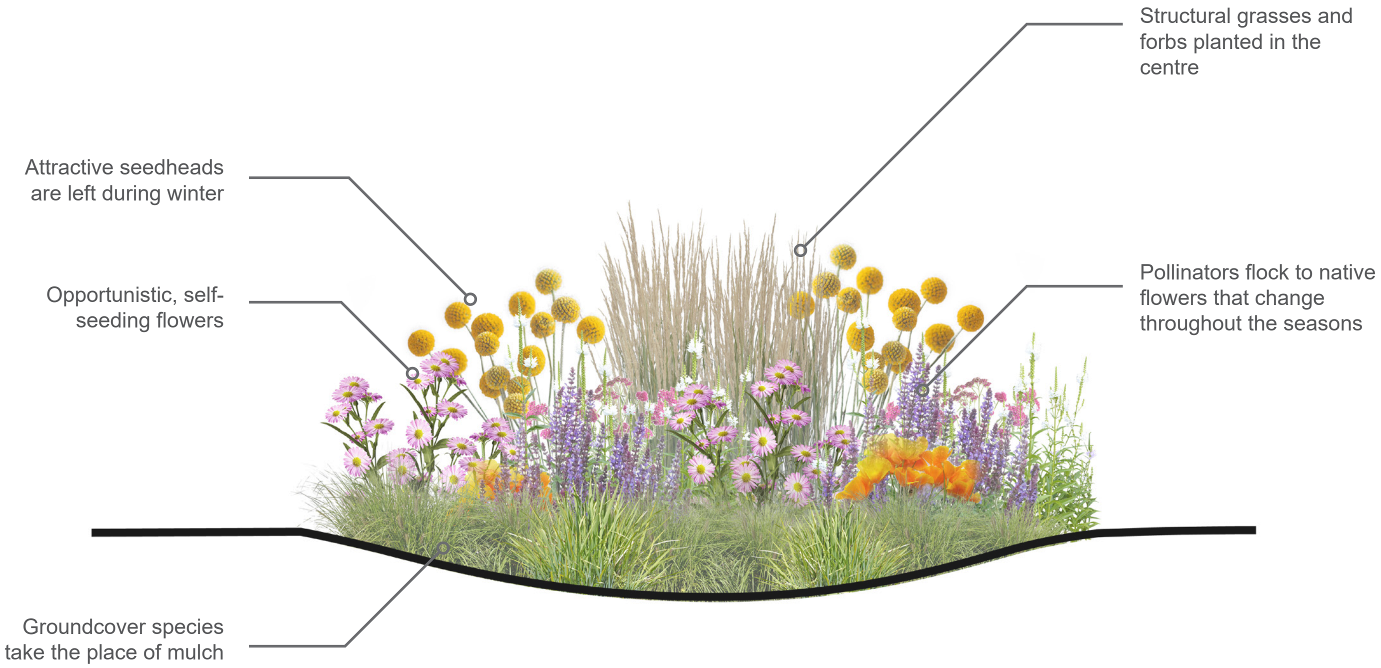
Highly-competitive, opportunistic self-seeders or rhizomatous growers which move around the design depending on where space is available. An example of this is Douglas aster (Symphyotrichum subspicatum) which has an increasing presence in the City of Vancouver’s 63rd and Yukon project.

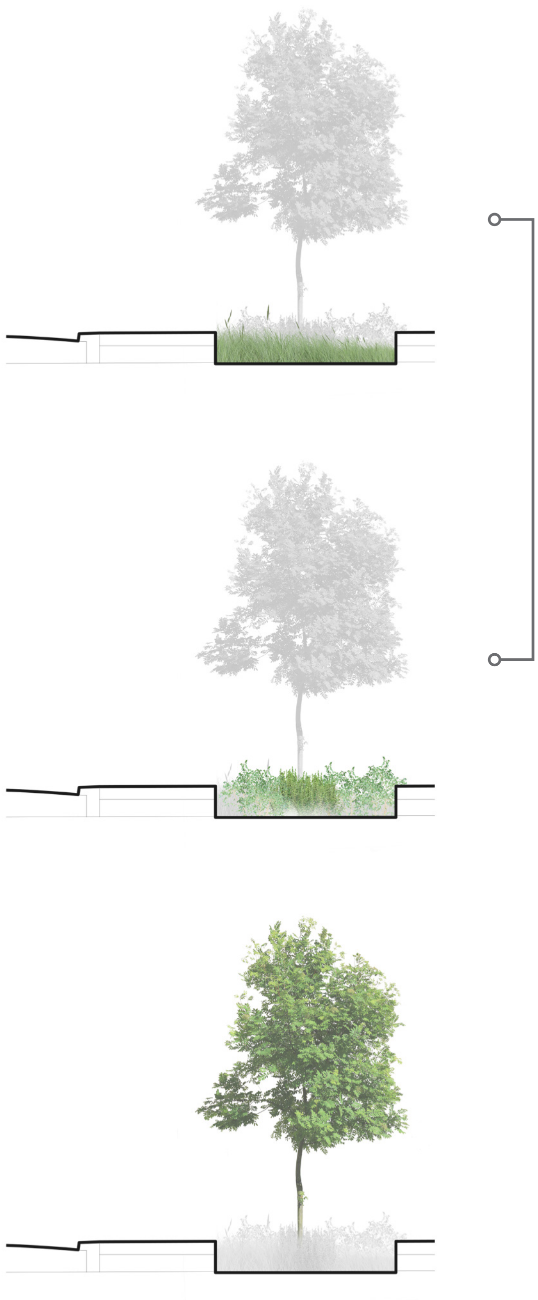
STRUCTURAL

More permanent forbs and grasses provide consistent structure. These might include species with showy seed heads that carry forth visual impact in the winter despite dormancy. Due to their height, they should be planted closer to the middle of ROW GRI in order to preserve sight lines and avoid spilling out onto pathways and roads.

GRASSLAND COMMUNITY

Grasslands exist along the hydrological gradient from wet marsh-like communities to dry meadows, but share common layers in each condition.
The layering of grasslands presents suitable frameworks for GRI tools such as bioretention cells, bioswales, and stormwater planters.


Structural grasses and forbs planted in the centre
Attractive seedheads are left during winter
Opportunistic, self-seeding flowers
Pollinators flock to native flowers that change throughout the seasons
Groundcover species take the place of mulch



HERBACEOUS AND WOODY

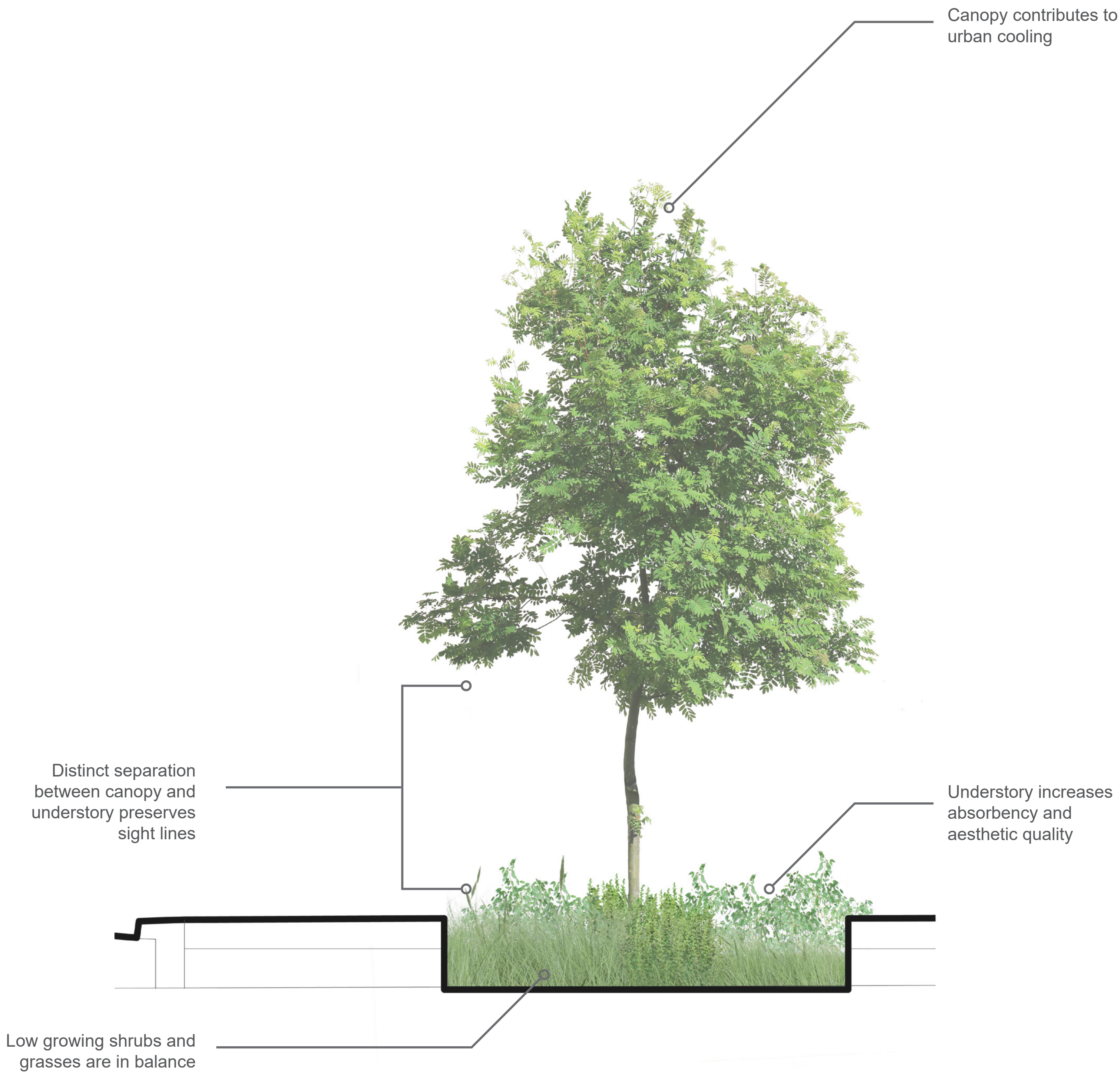
Low growing woody or herbaceous plants such as grasses and shrubs, make up groundcover at different heights, without reaching into the mid canopy. This layer is at the human scale.

CANOPY

These canopies are not completely closed, allowing for sunlight to reach the ground at different times throughout the day or season.

WOODLAND COMMUNITY

Woodlands are most closely associated which conditions of rainwater tree-trenches and/or adjacent stormwater planters where canopy cover is present. The addition of shrubs and grasses to the understory creates savana-like experiences when kept from growing into the mid-canopy.



According to Rainer and West, woodland plantings can easily go awry if left to grow unmanaged, creating messy landscapes with poor sight lines.

They suggest forming distinct layers through block planting, while avoiding shrubs that excel when pruned (p. 103). Dwarf varieties of shrubs are preferred.

Planting Design Methods

Block Planting

Block planting is a method employed by modernist landscape architects which uses “massed plantings to define space and for simple visual appeal” (Mooney, 2019). It is the most common tactic employed in GRI and can be identified through geometric planting patterns and groupings of single species. Varying hydrologic zones in GRI have facilitated the widespread uptake of this method, where graminoids are often planted in blocks throughout inlet and high inundation zones.

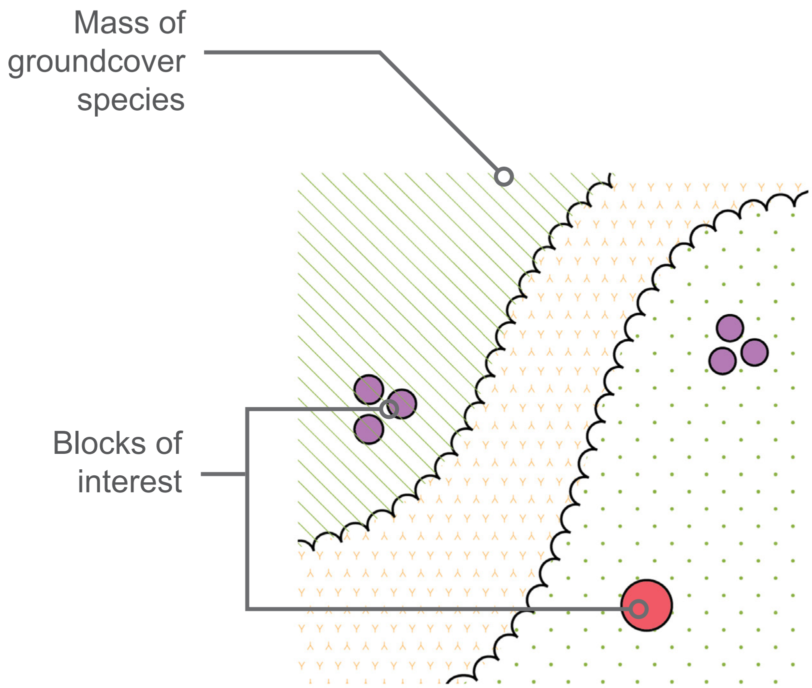
This method achieves a formal aesthetic often related to dense urban conditions. It implies a more rigid structure that will remain aesthetically similar throughout the life cycle of the system. Block planting has a low-tolerance for the shift of species throughout the site, with any volunteers being more easily identified as species-out-of-place. The systems are static, with the full expression of the design being achieved once plants have established, and maintenance efforts working to ensure it remains in that state.

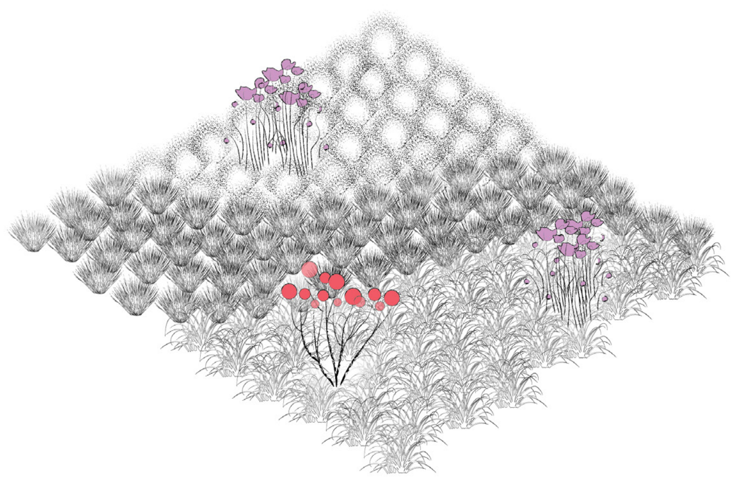
Municipalities in this study have praised the legibility of block plantings, making maintenance simpler to understand, however “they demand a more perfect, weed- free appearance to achieve a unified effect” (Mooney, 2019) which results in higher life cycle costs.

If a block planting approach is chosen, it is still necessary to ensure species diversity throughout the system in order to contribute to overall biodiversity and pollinator needs.

Minimal or monocultural approaches are not recommended due to the possibility of complete system failure if the species do not tolerate environmental stresses (including disease, pests, and GRI-specific conditions).

Depending on the current and projected maintenance capacity for GRI, block planting may remain the favored method. However, the following matrix method is more reflective of a plant community approach that offers an innovative and promising perspective on regenerative design.





BLOCK PLANTING

- Formal aesthetic
- Simplicity in pattern
- Familiar to maintenance crews
- Low in structural diversity
- Static

Matrix Planting

Matrix planting is a technique pioneered by acclaimed plant designer Piet Oudolf. He has implemented this tactic in notable landscape designs such as the Highline in New York City. The basis of this method is replicating the vertical stratification and horizontal dispersion of a natural plant community. It is often referred to as naturalistic design.

This strategy creates “multi-dimensional communities of plants by successively layering the vegetation, one above the other” (fix.com) while paying attention to the natural scattering and patterns of individual species. The matrix “is made up of a small number of species that largely remain quiet but impactful through the seasons so that a relatively continuous backdrop is retained throughout the year” (Guild Park & Horticulture Plans). Matrix planting is typically applied to the emulation of grassland (meadow) communities; however, vertical stratification and horizontal dispersion principles can be implemented in shrub and woodland communities as well.

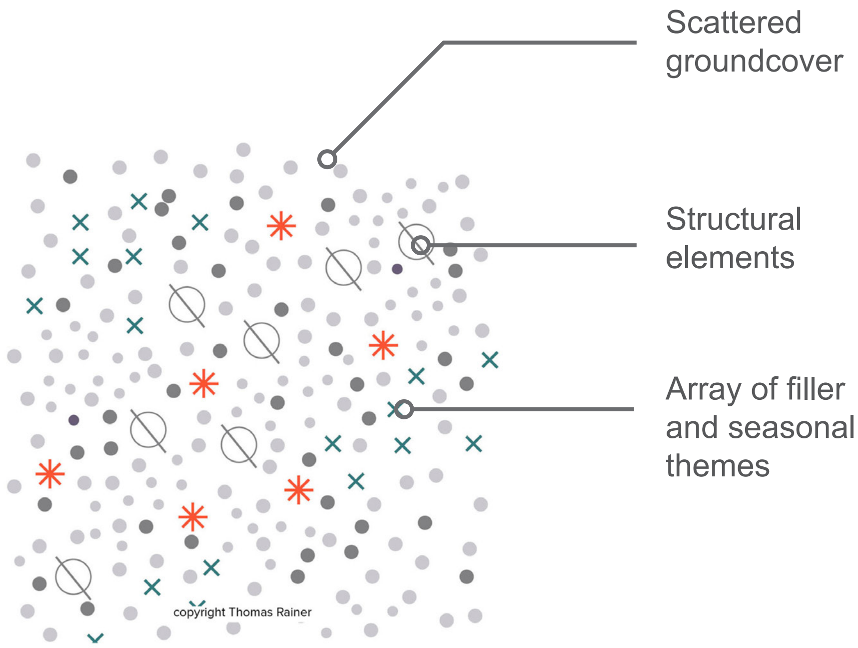
In the case for meadow habitats, the main structure of the matrix is created by light, clumping grasses that act as groundcover and are planted generously and randomly, not in rows or grids. These groundcover species are distributed first, then layered with filler and seasonal theme species, followed by structural species that act as “visual anchors” (Rainer, Grounded Design, 2017).

The structural diversity of a matrix design is the main benefit of this method. It also allows for migration and movement of species throughout the scheme, in addition to competition and succession reflective of natural landscapes. Species within a matrix should require similar broad-strokes management techniques. In the ideal case for GRI, this means an annual mowing or cut back of herbaceous growth.

Matrix designs may present maintenance challenges for contractors who are unfamiliar with regenerative design, due to the less distinct patterning. This could result in the removal of unrecognized but desired species.

However, success has been seen in this realm. The Highline planting scheme sets a precedent for matrix design that can be managed by a team of volunteers. The Highline planting design is celebrated and widely acclaimed. It can be argued that the enjoyment of the site may contribute to the overall interest people have in volunteering to participate in annual management.

Inspiring volunteer management in GRI aligns with the 2019 Greenest City Scholars report on alternative maintenance models, suggesting an increase in community stewardship could help achieve wide-spread implementation.



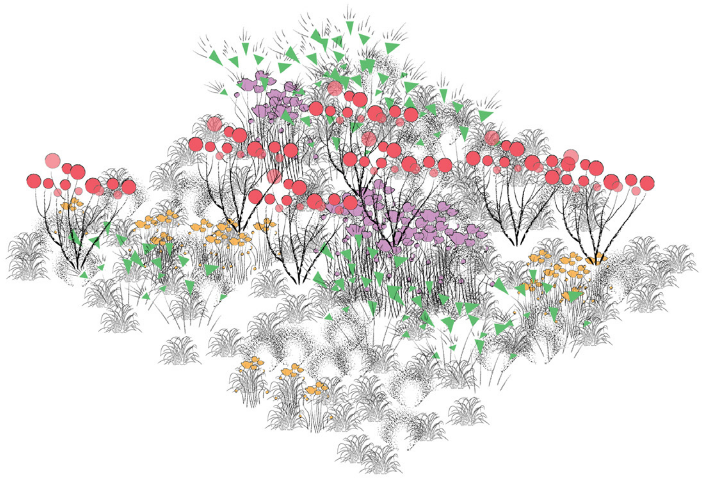


Illustration built from 2017 diagram (top) by Thomas Rainer in Grounded Design article describing matrix components.

MATRIX PLANTING

- Naturalized aesthetic
- Less distinction in pattern
- New, possibly less, maintenance requirements
- High in structural diversity
- Dynamic, evolving system

Modular Matrix Planting

The foundations of matrix design can be applied to the build out of planting modules. The creation of a single unit can be repeated across a GRI site, creating legible, patterned designs that allow for evolution and design clarity without being completely.

This approach presents high potential for rainwater management practice on a municipal scale which requires some level of standardization in order to be feasible. Modules can take on any square footage, applying to any size of site. Considerations of scale are integral. Matching site size with the texture and scale of the plants within a matrix will help achieve visual cohesion.

The repetition of pattern is effective in creating legible designs which could potentially simplify maintenance instruction for contractors or community stewards.

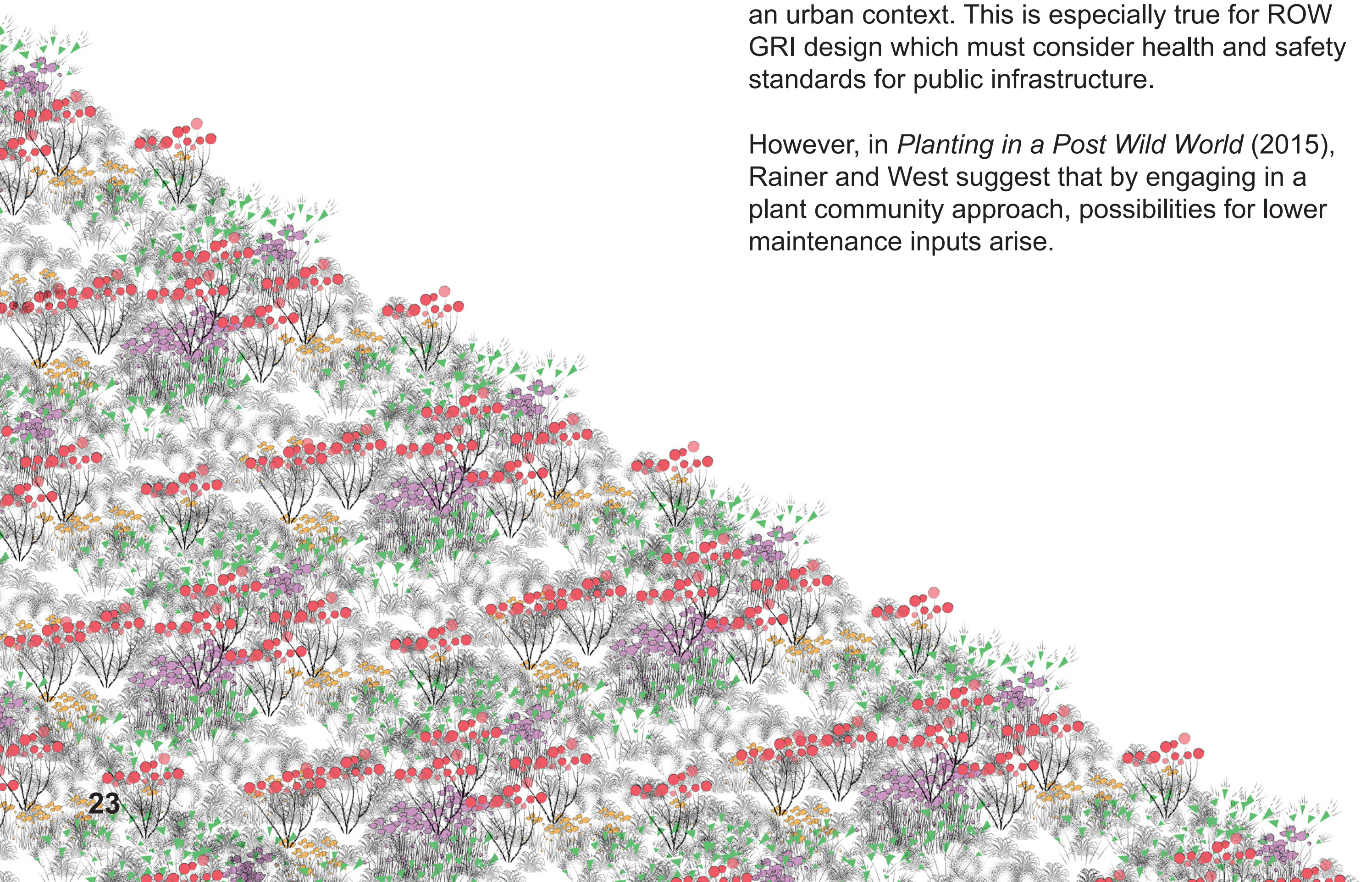
The concept of modular design may offer promise in addressing challenges for maintenance. However, industry leaders and municipalities surveyed through this study continue to express the need for maintenance crews and contractors who are familiar with innovative planting design in order to consider naturalistic planting designs successful.

Lower Maintenance Designs

Senior Research Scientist at Harvard University's Arnold Arboretum, Peter Del Tredici, argues that "there is no landscape that is self-sustaining — all landscapes will develop into something different than they are if left to their own devices — so if you want to hold a landscape at a certain stage of development or design, then there are going to have to be significant maintenance inputs" (Riano, 2012).

Del Tredici is correct in his assessment that some level of maintenance will always be required within an urban context. This is especially true for ROW GRI design which must consider health and safety standards for public infrastructure.

However, in *Planting in a Post Wild World* (2015), Rainer and West suggest that by engaging in a plant community approach, possibilities for lower maintenance inputs arise.



This theory is argued in terms of the scale of action and is reflective of natural area management techniques. Often in natural areas, fire acts as the disturbance which initiates new growth in meadow and woodland communities (Stewart, 2016). In the case of GRI, fire is replaced with mowing.

An example of this can be seen in The Lurie Garden at the Art Institute of Chicago, which is managed by professional crews who use a "mechanized brush cutter fitted with a mulching blade set at five-inch height" (Stewart, 2016) once a year in late winter.

Giving attention to an entire community of plants that require a similar, broad stroke action such as a single annual cut back or mowing requires less input than giving special attention to individual species through "watering, mulching, spraying, [and] pruning" (Rainer & West, 2015, p. 61). This suggests a re-framing of maintenance as management.

Initial establishment of plants may require more intensive maintenance strategies such as consistent watering and weeding but once the establishment period ends, maintenance shifts into management. The management phase persists throughout the rest of the GRI life cycle, guiding the evolution of a plant community rather than attempting to maintain or hold a design in its original form. By allowing natural processes to occur, the overall appearance of the design will ultimately evolve as well.

The importance of choosing species that respond similarly to broad-strokes management tasks can not be stressed enough. Complexities arise when special attention needs to be given to one specific species. The extra time required for this special care is reflective of traditional plant care that does not account for competition and succession of a plant community, and contributes to schemes which are currently regarded as unfeasible on a city-wide scale.

This method marks a shift in paradigm that requires increased knowledge from maintenance crews and contractors on innovative planting, and a willingness to trial new ideas on a municipal level. The promise is a higher capacity for maintenance through less intensive methods, shifting the focus from maintaining static designs to guiding dynamic, healthy plant communities.

Innovative Establishment Methods

Building in Competition and Succession

Competition is inherent to natural plant communities but is often muted in traditional planting strategies in order to preserve the original design. Designing with competition in mind can create healthy, evolving plant communities, but it also accounts for the sometimes-troublesome establishment phases which lack visual interest and face weed pressure.

One method of designing competition is to include quick-to-establish, short-lived, self-seeding species within planting schedules — in combination with slower growing, but longer lasting species. The fast growers may be more dominant in the system in the beginning but will eventually give way to more permanent fixtures of the design (Rainer, interview correspondence).

On a basic level, a recommended 8-12 plants per m^2 is said to promote competition within a designed plant community (Kingsbury, 2012).

Guiding biotic succession with annual management strategies that allow for competition and succession is an emerging field of study in planting design (Mooney, personal correspondence). It requires further study and is being embarked upon by the plant design experts mentioned in this report.

In-situ Seeding

In-situ seeding has received mixed reviews as an effective way for establishing plants in GRI by participants in the municipal survey. Philadelphia has tried, with some success, to use seeds alongside a plug overlay to help prevent washout. Other respondents communicated little to no success with seeding.

However, James Hitchmough has successfully achieved this in GRI designs including the extensive drainage swales at London Olympic Park using an innovative method of his own design. The method includes using a thick layer of sand, rock, and organic matter that acts as a “sowing mulch layer” where seeds can establish. This sowing mulch layer suppresses weeds growing up from the topsoil, but also holds the seed mixtures created by Hitchmough.

Patrick Mooney and Melody Smale are conducting studies on pollinators in rain gardens at the University of British Columbia and have included sown seeds in many of their test plots. They have relayed anecdotes suggesting cost reductions and increased availability of otherwise hard to find species in plugs or containers, as well as successful establishment of those sown.

Sowing seed in-situ could offer substantial cost reductions and contribute to the succession and evolution of GRI systems. This concept is exciting and offers promise, requiring further exploration and study.

London Olympic Park shows how indications of care, in-situ sewing, and naturalized planting works together to grand effect. Planting design by Sarah Price, Nigel Dunnett, and James Hitchmough. (Photo by Hargreaves and Associates))

Matrix planting design in GRI by Claudia West. Pollinator attractor and community beautification at work. (Photo by Phyto Studio)

CASE STUDY:

Grey-to-Green, Sheffield

Overview

Sheffield City center's Grey-to-Green project showcases the possibility for rainwater infrastructure to contribute to a naturalized ecosystem in a highly urban context. By annexing lanes from a semi-redundant roadway, the design created a pedestrian and pollinator friendly corridor. The design employs linear bioswales and dry beds planted with perennials, grasses, and semi-mature trees across 1 km. The master plan extends to 1.6 km, eventually connecting with the river Don.

Plant designers Nigel Dunnett and Zac Tudor used a layered, matrix planting approach to create biodiversity at all levels. Flowers bloom throughout 3 seasons, with structured elements such as seed heads and grasses creating winter interest. The edges are generally tidy, with some plants spilling over into the hard edge of the sidewalk.

During establishment, Dunnett and Tudor used quick-growing, short-lifespan flowering species such as cowslip (Primula veris) to compete against weeds and create early visual interest while more permanent, slow growing perennials were established. Weeds were also controlled with 50mm of crushed sandstone mulch.

Bioswales and dry beds were planted in a similar visual language while taking into consideration differing hydrological conditions.
A 3-year establishment phase was managed by contractors with knowledge of innovative landscape management.

Location:
Sheffield, United Kingdom

Planting Design:
Nigel Dunnett and Zac Tudor

Scheme Design:
Sheffield City Council with
Robert Bray Associates

Maintenance:
Green Estate Ltd

Completion:
2016

BIG IDEAS

- Dry beds to limit fragmentation
- Matrix/layered planting scheme for maximum human and habitat benefit.
- Pedestrian focused
- Succession planting
- Groundcover and 50mm crushed sandstone for mulch
- High impact flowering perennials and grasses

Results:

The result is an urban ecosystem that involves water, plants, pollinators, and people in equal measure. The naturalized aesthetic is not at odds with the highly urban context, despite a less formal planting approach. This was achieved through careful plant selection and horticultural expertise which balanced abundant flowering species with structural grasses that appear managed but not completely wild.

The linearity of the system acts as a human and habitat corridor that connects with the larger ecosystem of the river Don through dense planting and increased canopy cover. Observable new habitats for pollinators are created through the diversity and length of flowering times, while urban heat reduction and air quality measures are being studied.

The combination of bioswales and dry beds allowed for a biodiversity enhancement and visual continuity by expanding outwards beyond the bounds of the functional rainwater feature. Succession planting considerations established early community uptake of the space, bridging what is often an awkward gap between establishment and realization of a planting design.

Maintenance for this system after the establishment phase includes a single annual cut completed in early spring.

Left: March 2016, Initial establishment phase showing sandstone mulch, fencing to deter trampling, and cowslip succession planting. Below: Early summer 2016, plants 3 months into establishment.

Photos by: Nigel Dunnett

Opposite: Bioretention planting in full bloom in 2019.
Left: Community gathering and pedestrian focused space showing naturalized design in dense urban environment .

Photos by:
Nigel Dunnett

BIODIVERSITY

Planting for biodiversity

Achieving structural diversity is integral to the longevity and health of any plant community, and is necessary for creating regenerative, high performance GRI. When structural diversity is increased, biological diversity is also increased by encouraging the “number and quality of habitats found on a site” (Mooney, p. 102, 2019).

True diversity includes a range of rooting depths and structures which aid in soil stabilization necessary for the high erosion potential of GRI. Variance in root structures also increases microbial health, biomass, and invertebrate populations in soil, according to a study which examined the impact that composition and height of meadows had on biodiversity (Norton, Bending, et. al 2019). Heightened biodiversity is an integral factor in creating healthy plant communities.

Melody Smale (quoted in Mooney, 2019) has identified 10 criteria for creating pollinator-focused habitat which she describes at length in her master’s degree thesis project. Her suggestions include site standards which include the need for sufficient sunlight, space large enough to host for drifts of “at least 8 different flowering species,” and the connection of smaller pollinator habitats with larger ones. Size constraints of GRI present a challenge to meeting the second site criteria which requires larger drifts of flowering species. However, ROWs connect the public sphere through the urban grid, therefore the strategic siting and planting of GRI in ROWs has the opportunity to create pollinator corridors that connect to the necessary larger habitat.

Smale also describes principles for creating nesting habitat. These include:

1. Providing habitat for ground-nesting bees
2. Providing nesting resources within 330 feet (100m) of floral resources
3. Planting diverse flowering species that attract a variety of pollinators
4. Ensuring that bloom times overlap through the growing season
5. Focusing on native plants to attract native pollinators
6. Using non-native plants to extend the bloom season
7. Exploring no-mow methods with wildflower meadows

No-mow or delayed mow methods have a demonstrable impact on biodiversity, with studies showing that "invertebrate abundances in the medium height plots (which were cut low in the winter) were very similar to those of the short plots, and less than the tall plots suggesting that maintaining longer vegetation during winter is critical" (Norton, Bending, et. al 2019). Consistency of sight lines is necessary for safety in planted road ROWs, so the need for annual or semi-annual cutbacks may still be necessary. However, assessing the timing of these cutbacks and delaying these tasks until late winter may improve overall pollinator presence in GRI.

Room for Flowers

High quantities of grasses, sedges and rushes are used in GRI systems because of proven attenuation properties. However, a recent study which tested and found substantial evidence for flood resilience in 11 perennial forbs (Yuan & Dunnett, 2018) indicates that more options exist for inundation zones beyond graminoids. These discoveries suggest the feasibility for matrix planting schemes in GRI which move away from traditional block planting and present opportunities for increased biodiversity and human appeal.

The species studied by Yuan and Dunnett were:

- *Amsonia tabernaemontana var. salicifolia*
- *Astilbe 'Purple Lance'*
- *Caltha palustris*
- *Filipendula purpurea*
- *Gaura lindheimeri*
- *Hemerocallis 'Golden Chimes'*
- *Iris sibirica*
- *Rudbeckia fulgida var. deamii*
- *Sanguisorba tenuifolia 'Purpurea'*
- *Thalictrum aquilegifolium*
- *Veronicastrum virginicum.*

Soil and Microbial Health

The City of Vancouver usually uses a bioretention media mix which is designed to drain within 48 hours. Bioretention media has been studied at length for its infiltration properties, but new research is exploring the impact of denitrifying bacteria and mycorrhizal fungi on overall GRI function such as infiltration and purification (Waller, Krometis et al., 2018. Poor, Balmes, et al., 2018). Mycorrhizal fungi and plant roots form a mutually symbiotic relationship, with the fungi promoting nutrient and water uptake in host plants (Kennedy, de Luna, 2005). Arbuscular mycorrhizal (AM) fungi form structures alongside plant roots which encourage nutrient and water uptake.

> *"Presence of mycorrhiza in biofilters could have implications for nutrient and metal uptake in plants"*

Nascent studies such as *Arbuscular mycorrhizal fungi in Australian stormwater biofilters* (2017) suggest that the "presence of mycorrhiza in biofilters could have implications for nutrient and metal uptake in plants, and thus enhance removal of target pollutants” (Winfrey, Hatt & Ambrose) which would have positive impacts on overall GRI functionality. This study suggests inoculating bioretention media with mycorrhizal fungi after construction to encourage these associations.

Other promising studies explore how mycorrhizal fungi can increase the salt tolerance and water uptake in plant species (Porcel, Aroca et al, 2012. Wang et al., 2018). These studies have shown that species which form relationships with mycorrhizal fungi could contribute to the overall health of GRI plant communities by “improving quality of soil structure, enhancing plant community diversity, improving rooting and plant establishment...[and] enhancing plant tolerance to (biotic and abiotic) stress” (Smith and Read 2008, quoted in Porcel, Aroca et al., 2012).

If the presence of mycorrhiza can increase salt tolerance, there is reason to believe that AM associated species may survive GRI conditions and increase opportunities for more diverse planting.

This also opens avenues for exploring plants with high evapotranspiration rates – a field of research that exists largely in agricultural industries.

The inclusion of soil health in overall structural diversity considerations is important to establishing healthy plant communities in stressful conditions such as GRI. Healthy soils are integral to the survival of any plant community.

Community beautification

While structural diversity has been extensively studied for its role in creating healthy plant communities, diversity indicators are also preferred by humans. A study conducted by Lindemann-Matthies & Bose (2007) at a Swiss botanical garden asked people to choose from a large selection of local wild plants in order to construct their own meadow plot. Participants “often explicitly stated diversity as their main assemblage criterion” (p. 303), choosing plants with variable plant height and leaf forms while gravitating to flowering plants and grass mixes. The results of this study are supported by research conducted by Hoyle and Hitchmough (2017) which “assessed human aesthetic reaction, restorative effect and perceived biodiversity” related to woodland, shrub and herbaceous planting. Perceived biodiversity was closely linked with positive aesthetic responses, with areas having more than 27% colorful plant cover marking the most preferred planting schemes (Hoyle, Hitchmough et al., 2017).

According to the survey conducted for this study, community beautification is often a lower priority design goal for GRI in most municipalities. However, with the opportunity for community stewardship programs to increase capacity for maintenance, and thus wider implementation, it is integral to consider aesthetic quality as equally important to ecological functionality.

> *“A threshold for preference was reached when a landscape appeared to serve more function than aesthetic.”*

Hayden & Cadenasso (2015) examined best management practices for water conservation on private landscapes, finding that a threshold for preference was reached when a landscape appeared to serve more function than aesthetic. Ideally, GRI systems will offer both in equal measure but according to Nigel Dunnett, in order to encourage community advocacy designers must “make these things so beautiful, dynamic and multi-functional, that people start demanding to have them in their neighborhood” (interview correspondence, 2020).

The City of Vancouver is embarking upon a design process which centers on co-benefits of GRI. The City recognizes that GRI can act as a tool to enhance livability in an increasingly dense urban environment, and that focusing on the human experience of GRI will generate community support for sustainable rainwater management.

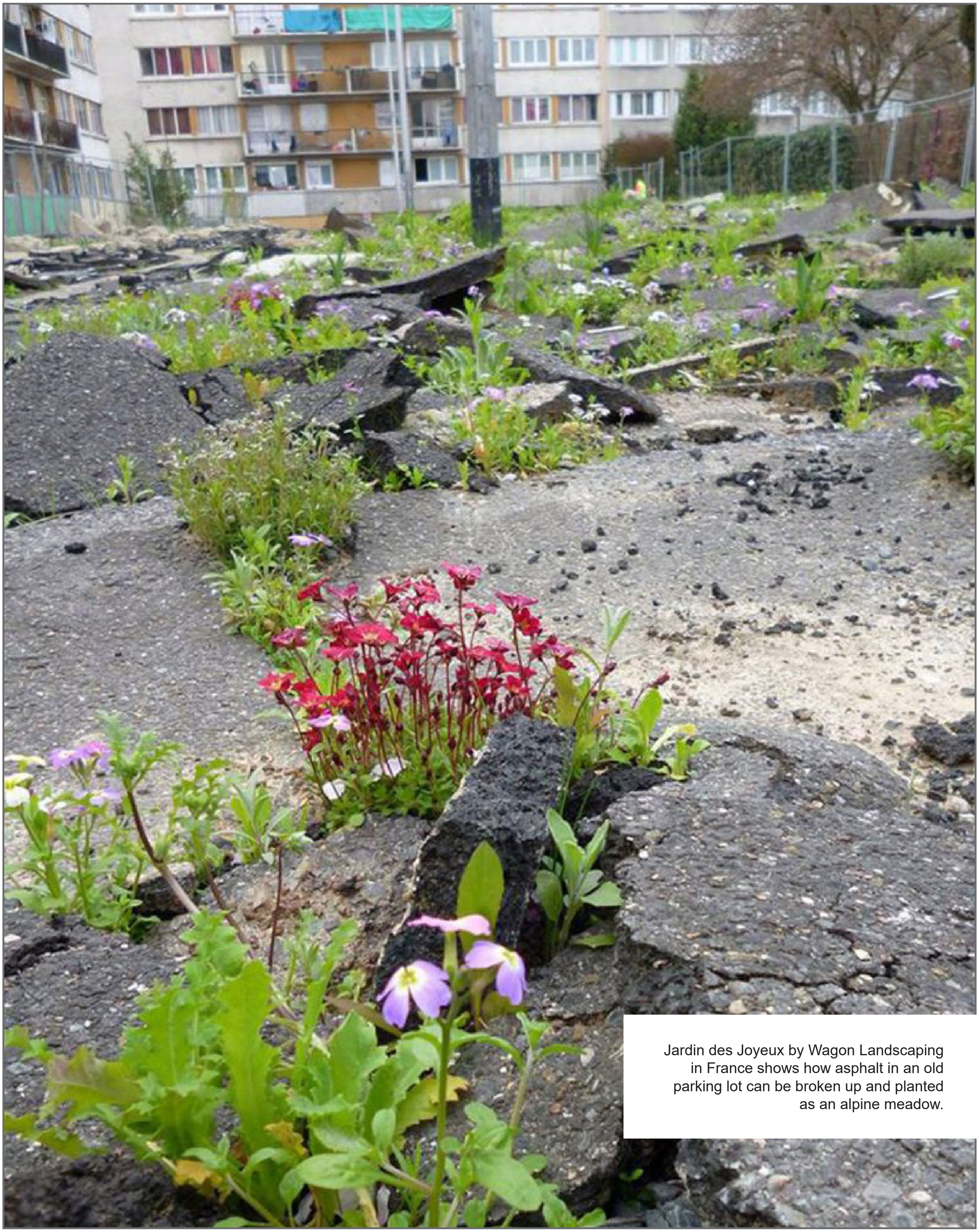
CONNECTING TO HABITAT ANALOGS

The plant communities discussed earlier offer broad stroke examples of the structural makeup of grasslands and woodlands. These general ideas can be described further by looking at specific habitats that present possible combinations of species in GRI, while working together to form an urban ecology through cohesive gradients.

A habitat analog is an urban condition which has ecological parallels to a natural area. If plant growth is possible, there is likely a natural ecosystem which echoes those urban growing conditions. The process of identifying these ecosystems aids in understanding the plant communities in order to emulate their structure, resilience, and appearance.

The most studied urban habitat analogs appear to be the rock wall - concrete relationship (Lundholm & Richardson, 2010) and the hedge row - shrubland relationship (Carlier & Moran, 2019). Both studies recognize certain aspects of urban conditions that discuss similarities to natural conditions, presenting opportunity for non-human habitat in the built world.

Whereas habitat analogs have been studied in terms of plant colonization post-urbanization, GRI is unique in that it can be specifically designed to reflect habitat. This allows for a designed plant community approach guided by the color, texture, and needs of that habitat.



Jardin des Joyeux by Wagon Landscaping in France shows how asphalt in an old parking lot can be broken up and planted as an alpine meadow.

GRI Analogs and their role in Vancouver

Vancouver's climate includes consistent rain and mild temperatures in winter months, contrasted by increasingly long periods of drought during the summer. This is conducive with two habitat analogs useful in conceptualizing plant communities in GRI.

GRI share similar hydrological conditions to wet meadows and their edges, which meet shrubland and woodland. This offers an opportunity to design GRI with these habitats in mind, following the colour and textural qualities of the planting palettes that appeal to humans, as well as the structural components that provide habitat for non-humans.

Wet Meadows

NatureServe Central Database describes the climate conditions of the "Vancouverian Freshwater Wet Meadow and Marsh" habitat to hold characteristics similar to GRI environments including tidal influences (salt inundation), freshwater pulses (periodic flooding), and the presence of sandy soils (alike to bioretention media). Dominant plant communities in the wet meadow include herbaceous species such as grasses and forbs, with some presence of low growing shrubs at the edges (NatureServe Explorer, n.d.).

> *"Grasslands have some of the highest levels of biodiversity in the world."*

Grasslands offer some of the highest levels of biodiversity in the world. In 2012, the Journal of Vegetation Science published an article titled *Plant species richness: the world records* which show that "meso-trophic, managed, semi-natural, temperate grasslands" have up to 89 species per square meter (Wilson et al.). These grasslands present similar environmental conditions to those created in a vegetated GRI practice, showing promise for using GRI to enhance biodiversity in the urban environment.

Carex and Juncus species are commonly occurring in wet meadows and have been utilized extensively in bioretention cells and swales, noted by 80% of municipal survey respondents to be one of the most effective species for high inundation zones. Connecting the structural elements of wet meadows to GRI projects such as bioswales, bioretention cells, and stormwater planters which most closely resemble these conditions can help to translate the resilience of these natural plant communities into the urban realm.

Woodlands

The "Southern Vancouverian Dry Douglas-fir – Madrone Woodland" ecosystem is characterized by "ample sun and seasonal drought" associated with south facing slopes and valleys, with quick draining rock or sandy soils. Deciduous and evergreen broadleaf trees meet a rich understory of both deciduous and evergreen shrubs, forbs, and drought tolerant grasses (NatureServe Central Databases, n.d.).

The species associated with this habitat are not particularly resilient to overland flooding, which makes them a better match for systems with piped in stormwater or those that do not involve high levels of surface flow, such as rainwater tree-trenches. The edges of this habitat meet with meadows and shrubland, suggesting potential for enhanced connection between planting design of tree-trenches, bioretention cells, bioswales, and stormwater planters.

The forest analog is currently represented through Vancouver's existing and growing urban canopy. A fuller urban ecosystem can be created by encouraging the edges of the forest (urban canopy) to extended beyond the understory to shrubland, to wet meadows.

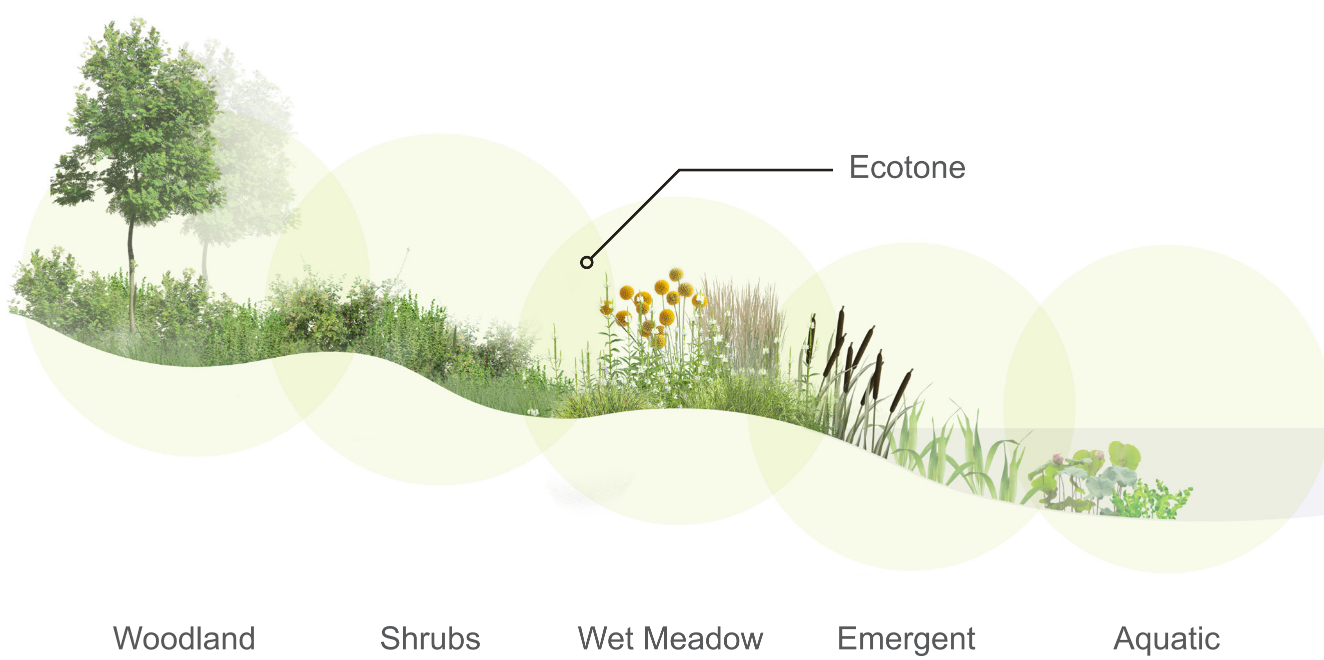
Species related to these analogs are included in Appendix B

Creation of urban ecotones

The 2016 Biodiversity Strategy identified meadows as a priority habitat in the City of Vancouver, recognizing that it represented some of the smallest areas of land coverage (48 ha) with only streams holding less of a presence (26 ha). Connecting planting design for GRI with meadow structures will contribute to a need for increased grassland species habitat. Positioning these systems across the urban grid and in relation to proposed and existing greenways, meadows, and parks has the possibility to provide "connectivity among habitat patches [which] mitigate the effects of fragmentation on biodiversity, allowing species dispersal throughout the landscape matrix" (Carlier & Moran, 2019).

An ecotone is the area of intersection of two ecosystems types. This intersection creates something called the "edge effect" where an increased amount of biodiversity occurs within this zone compared to the habitats on either side (Hedge, 2012). Urban ecotones are generally studied as the areas which intersect between city edges and natural landscape (Fors et al., 2018, Macgregor-fors et al. 2010, Puga-caballero et al., 2010), but explorations of ecotones within the urban fabric are starting to receive more focus. The VanPlay strategy specifically refers to ecotone development at Marginal Wharf at Jericho Beach, an inner-city park in Vancouver.

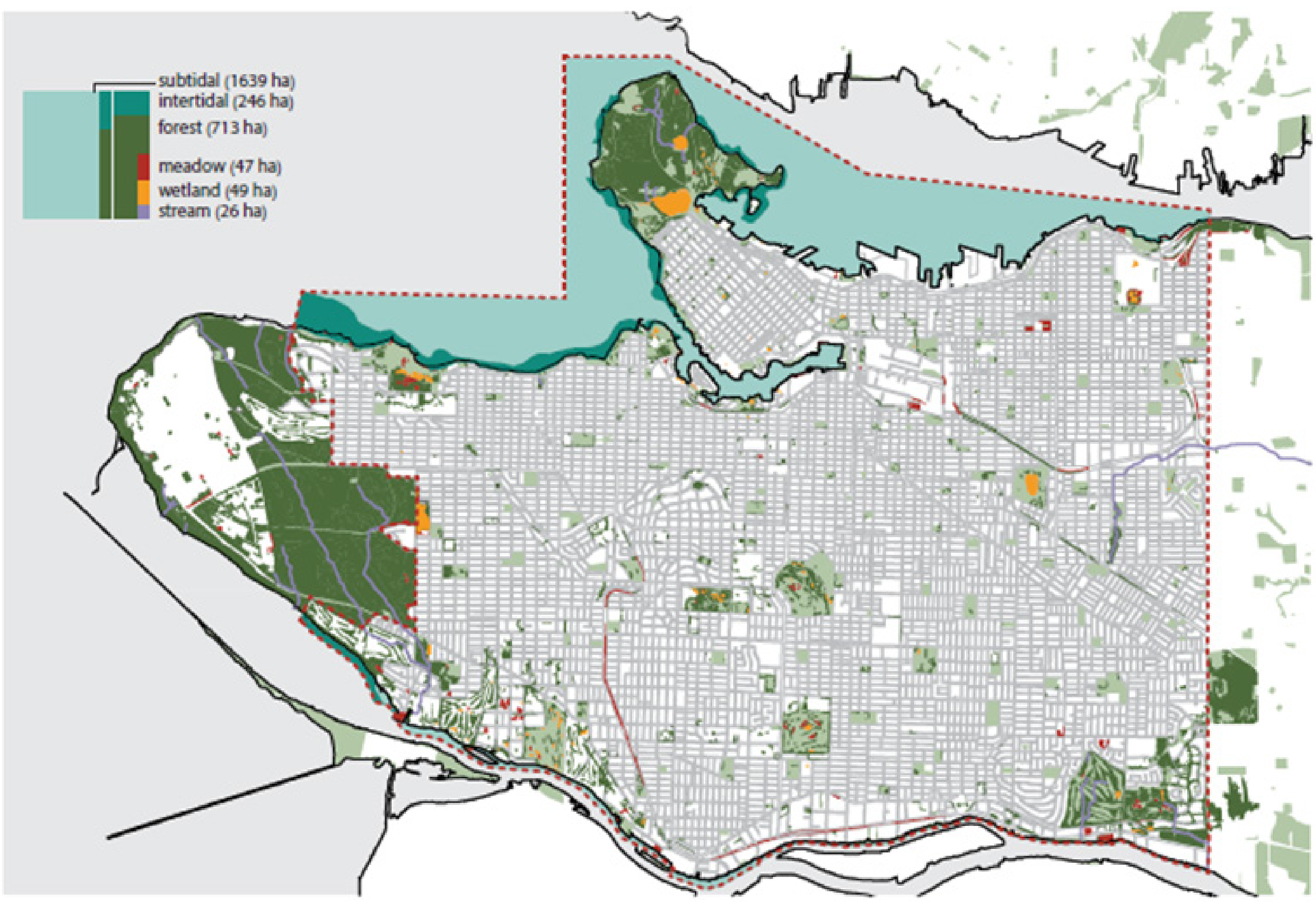
GRI systems should be considered alongside greater City planting strategies, encouraging the integration of non-GRI infrastructure plantings into the overall vision of habitat creation. An example of this is shown on a small scale using dry-beds in the Grey-to-Green case study. This attention to GRI as part of a functioning whole echoes the philosophy



of healthy plant communities and can “mitigate the effects of fragmentation on biodiversity, allowing species dispersal throughout the landscape matrix” (Carlier & Moran, 2019).

Little research has been found at the time of this study on the build out of GRI as ecotone enhancers. However, due to varying hydrological conditions which allow for GRI to encompass multiple habitat analogs, intentional planning that creates intersection zones between the urban forest and GRI shrublands and wet meadows offers potential for enhancing biodiversity. There is potential for this area to be studied further.

Distribution of priority habitats in the City of Vancouver and adjacent Areas.
Retrieved from the Biodiversity Strategy 2016



CONNECTING GRI TO BLUE-GREEN SYSTEMS

The most frequently implemented road right-of-way GRI practices in the City of Vancouver are bioswales, bioretention cells, and rainwater tree-trenches. One of the challenges of GRI is that each design must be responsive to unique site conditions such as available space, sun/shade, utility access, varying foot and vehicular traffic, infiltration capacity, pollutant loads, and drainage area. This specificity has historically led to minimal plant palettes focused on performance, and facilities that dot the urban grid without a definitive connection line.

The 63rd and Yukon project brought this connectivity potential into the forefront. Today, GRI in the City of Vancouver is being integrated into infrastructural projects such as the development of the downtown bike network with a north-south connector at Richard`s Street. Rainwater tree-trenches will be used to establish separation from vehicular traffic, improving the pedestrian experience while managing rainwater on-site and adding to the urban canopy in the downtown core.

Blue-green systems call for a wider planting palette that works to create a connected urban ecology. With ROWs accounting for 28% of land use in Vancouver the possibility for connection is great. GRI facilities can be used as tools for enhancing the connectivity of people, places, plants, and animals.

The City will be embarking upon several rehabilitation projects to revive planting and improve functionality to existing GRI in the near future. These rehabilitation projects offer an opportunity to trial and test regenerative planting theories while adding momentum to the blue-green systems vision.

While these tools serve the functional purpose of managing rainwater, creating and understanding the community narratives in which GRI are situated is important. The following descriptions imagine GRI as place-makers in the City of Vancouver. They follow principles discussed in this report such as:

- Use of the fundamental designed plant community approach.
- Planting for safety and aesthetics including maintaining sight lines and establishing tidy edges.
- Focusing on biodiversity enhancers as a main design concept.
- Guiding public perceptions of naturalized landscapes.
- Encouraging community advocacy and stewardship.
- Operating within current and future management capacity.

Urban Streams

Bioswales

Bioswales offer one of the highest opportunities for ecosystem connectivity due to their linear form, with compounding positive effects when placed across the vastness of the urban grid. They are best suited as a wet meadow habitat analog. While the sponge function of these bioswales can be carried out in small spaces such as a 2m boulevard, additional space offered by lane closures and wide-center medians create stronger habitat corridors for local pollinators.

The banks of these stream-like bioswales rise to footpaths and roadways for urban dwellers in transit while separating vehicles and pedestrians. Invertebrates and amphibians find a home here and begin to move around the city on this newfound habitat thoroughfare. Water conveyed through these systems is either soaked in on-site or directed to other GRI facilities like constructed wetlands.

These urban streams are largely herbaceous, teeming with seasonal flowers complimented by low and tall growing grasses. Some shrubs may be included around the edges, and over many years may become more dominant as banks stabilize, allowing for small trees to begin to take root. This progression may be facilitated by humans in guided succession or occur as a result of migration from other urban ecosystems.

Pocket Wetlands

A pocket wetland acts as a localized sponge or node along the blue-green network. They run the highest risk of appearing isolated in their communities. In order to address this, the planting schemes for these systems should be extended beyond the localized functional area where absorption occurs.

The pocket wetland is proportionate to the human-scale, requiring high impact planting with continual seasonal interest. The use of evergreen shrubs and grasses, and forbs with attractive winter seed heads helps to achieve this effect. The plant community approach is especially important for pocket wetlands that lack surface area. Focusing on vertical stratification and dense planting will help encourage pollinators in these condensed zones.

These are the backdrop for the new urban lifestyle that respond to the neighbourhood, morphing from wet meadows to shrublands depending on the spread of the tree canopy.

Bioretention Cells

These shapeshifters dot the urban grid with amorphous shapes that act as collector points for rainwater, humans, and pollinators. They are best suited as a wet meadow habitat analog. Often located at the end of streets as traffic bulges or taking over entire street corners, these projects offer an opportunity for people traveling on foot to sit and socialize. Community members express interest in adopting these pocket wetlands as their own, due to their small size and residential location, making it easy for a single person or small group to take on management tasks with less risk of interference from vehicular traffic.

Stormwater Planters

These are often found in places of movement with bike and vehicle traffic flanking either side, acting as connector pieces similar to the urban-stream but on a smaller scale. These systems extend the shrub/meadow edge of the gallery forest, softening the transition between hardscape and the tree canopy. Both wet meadow and woodland analogs can be explored here.

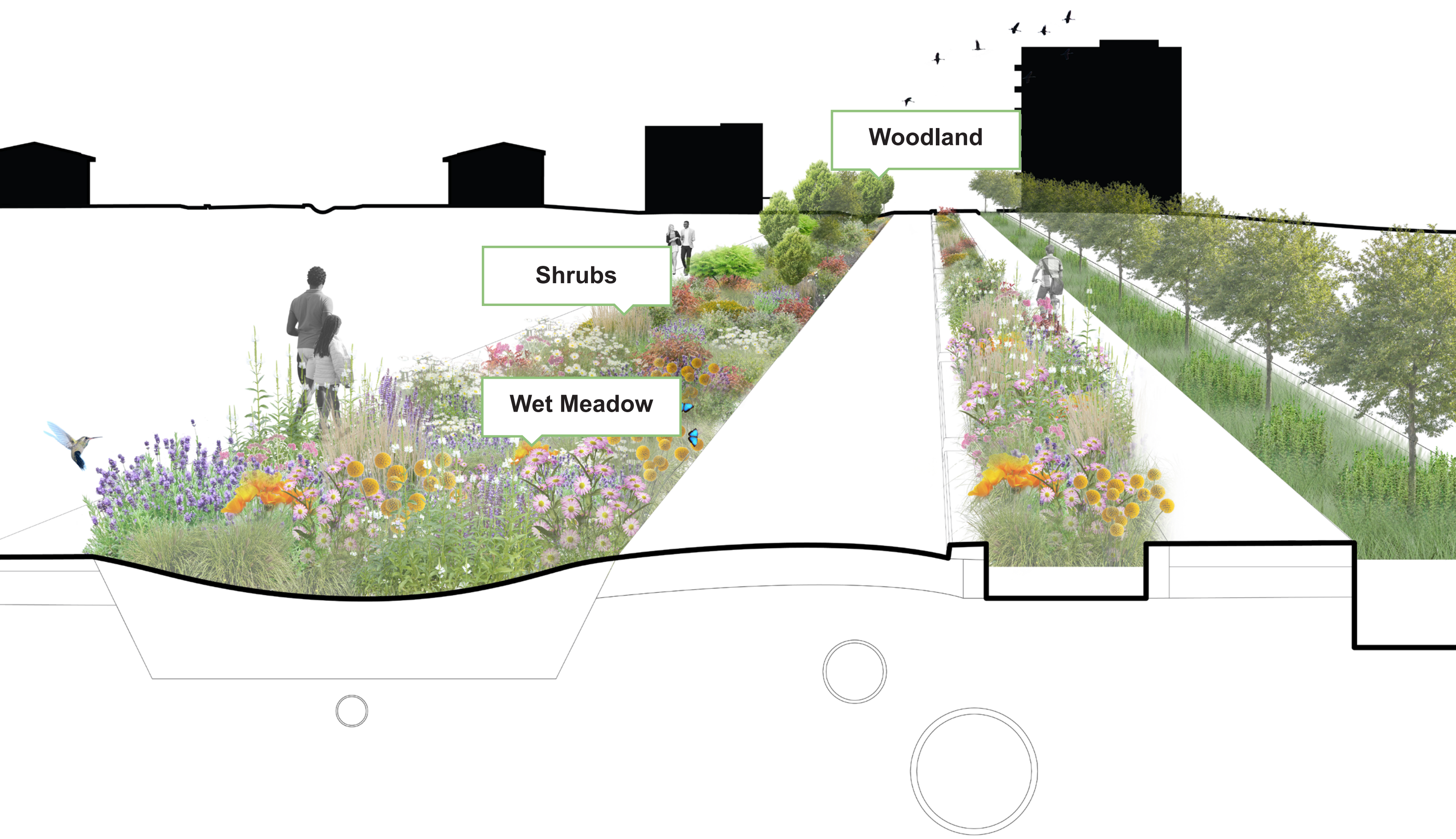
Gallery Forest

Rainwater Tree-trench

The gallery forest forms a corridor along the more densely populated urban streets where the boundary between buildings and forest is sudden, leaving little room for the otherwise expansive forest edges of shrub and meadowland. They are particularly useful in locations with challenging footprints and utility conflicts. Though contained, the gallery forest could maintain a short understory of low growing shrubs and grasses rather than turf which reflects the woodland analog. At a minimum, the understory includes planted permeable pavers which contribute to surface runoff management.

The gallery forest should accompany pocket wetlands and urban streams to extend the forest edges into shrubland and meadows. These systems should be placed with specific attention to larger ecosystems in order to establish corridors through the urban sphere. Coordination with non-GRI planting also widens the impact of the gallery forest, softening the abrupt change from canopy to sidewalk.

The highly urban context may call for formal arrangement of the understory layer, but the linearity common to the gallery forest may provide enough of a tidy edge that a naturalized scheme fits any density level. Use along medians, sidewalks, and bike paths helps to provide urban cooling while creating a pedestrian-focused experience.


Woodland
Shrubs
Wet Meadow

Next Steps

Future studies of regenerative planting strategies for GRI could include the development of decision-making tools for planting and siting of GRI. A number of decision-tree approaches have been taken, including one created by Phtyo Studio for a municipal client which aids in understanding site conditions, using generalized criteria to determine possible pre-constructed planting palettes. This, and other decision-making tools are included in Appendix C.

Though plant lists for GRI exist within the City of Vancouver, including the connection of habitat analog to those species may contribute to increase cohesion within GRI planting design.

Reporting on methods for prioritizing locations for GRI implementation with a focus on equity is a field which the City of Philadelphia has embarked upon through various mapping exercises. This would be valuable to the City of Vancouver as the attitude towards GRI continues to shift from opportunistic to visionary approaches within city planning.

Naturalized planting schemes are a new introduction into dense urban centers, and though success has been seen in using less formal designs in places like Sheffield, UK, this shift away from the formal may require additional education campaigns that help guide public perception.

The plant community approach requires horticultural expertise in order to succeed. As the momentum for GRI in the City of Vancouver grows, so does the need for team members with knowledge, passion, and vision for plants. Horticultural explorations such as evapotranspiration properties and techniques that encourage establishment such as the sowing mulch layer could be valuable to increasing functionality of GRI, and lowering construction costs, respectively.

Studies on pollinator habitat in rain gardens are underway at the University of British Columbia, led by Patrick Mooney and Melody Smale. These studies could be expanded to include ROW specific conditions in GRI that reveal new challenges and opportunities for designing for species in the blue-green network. Partnering with academic institutions to develop trials and test plots for GRI planting strategies could contribute greatly to the economies of scale.

Conclusion

ROWs are places for transition. Established *en masse* they will become the back-drop for the new urban lifestyle. This report aimed to explore the compounding effects of GRI that occur by working outwards to widen experience of typically isolated facilities. At the core lie fundamental regenerative planting design theories such as healthy plant communities, finding habitat analogs, and the application of matrix and modular matrix planting.

Truly regenerative planting design in GRI requires a meeting of current and future maintenance capacity with overall design goals. Designing in consideration of this balance will allow for more wide-spread implementation of GRI in Vancouver.

Space limitations have resulted in fragmentation in the past, but by conceptualizing each implementation as part of a larger whole, a network begins to develop that soon feels more complete from neighborhood to neighborhood.

These networks have the potential to:

- Increase community resilience by providing space for socializing that promotes travel by foot and encourages community stewardship while mitigating heat island effects.
- Establishing city-wide regenerative designs that include succession growth and management regimes within community and City capacity, allowing our green systems to grow with a changing city.
- Contribute to healthy ecosystems by providing habitat for pollinators, invertebrates of all kinds, birds and amphibians.

Appendices

Appendix A-1: Survey and Interview Participants

	Name	Position	Department	Organization
Survey	Casey Cunningham	Landscape Architect	Infrastructure Services Department	City of Portland
Interview	Nigel Dunnett	Professor of Planting Design and Vegetation Technology	Department of Landscape Architecture	University of Sheffield
Survey	Kristina Hausmanis	Project Manager, Green Streets	Transportation Services	City of Toronto
Interview	James Hitchmough	Professor of Horticultural Ecology	Department of Landscape Architecture	University of Sheffield
Survey	Timothy Linehan, Lindsay Reul, Rachel Streit	Landscape Designer	Green Stormwater Infrastructure	City of Philadelphia
Interview	Patrick Mooney	Associate Professor	School of Architecture and Landscape Architecture	University of British Columbia
Interview	Thomas Rainer	Principal	-	Phyto Studio
Survey	John Toczek	Senior Supervisor	Seattle Parks Department, Conservation Corps	City of Seattle

Appendix A-2: Survey Questions

Q1

Please provide your contact details:

Q2

What are your primary design goals when developing road right-of-way GSI planting plans? Drag and drop to list in order from MOST important to LEAST important

- Promote infiltration
- Community beautification
- Low Maintenance
- Pollinator attractor
- Incorporate native plant species
- Enhance biodiversity
- Improve water quality
- Salt tolerance
- Urban cooling
- Erosion reduction
- Flood control
- Planning for climate adaptation

Maintenance:

The following questions regard maintenance and management of planted GSI.

Q3

How would you classify the maintenance needs of your planted road right-of-way GSI overall?

a) Low level of maintenance required
b) Medium level of maintenance required
c) High level of maintenance required
d) It varies between the above
e) Other. Please describe:

Q4

Are operations and maintenance staff consulted on your planting designs?

a) Yes
b) No

Describe how this relationship impacts overall planting design:

Consider sites throughout your road right-of-way GSI facilities that require the LEAST amount of maintenance. Please answer the following questions with those sites in mind.

Q5

How frequently are the following maintenance tasks performed on sites that require the least amount of maintenance?

- Trash Removal
- Cleaning
- Pruning
- Repairing erosion damage
- Watering
- Other

Q6

How effective are these sites at achieving your design goals?

a) Extremely effective
b) Very effective
c) Moderately effective
d) Slightly effective
e) Not effective at all

Q7

How would you rate the aesthetic quality of these sites?

a) Excellent
b) Good
c) Average
d) Poor
e) Terrible

Planting Strategy:

The following questions address all road right-of-way landscape GSI facilities in your municipality, regardless of the required level of maintenance.

Q8

The image above presents examples of naturalistic and formal design strategies. Please answer this question with these in mind.

	How often do you employ this design strategy?				Where is it most appropriate to employ this design strategy?
	Often	Sometimes	Very Little	Never	Please describe below:
Naturalistic	○	○	○	○	
Formal	○	○	○	○	

Q9

Do your planting designs attempt to tie into or emulate larger landscape typologies relevant to your climate/conditions such as meadows, woodlands, forests?

- Yes
- No
- Other:

Q10

What soil medium do you use in bioretention GSI?

a) Bioretention media
b) Amended native soils
c) Native soils
d) All of the above
e) Other:

Q11

What species are most frequently used in the wettest (highest inundation) areas in your planting plans?

Q12

What species are most frequently used in the driest (lowest inundation) areas in your planting plans?

Q13

What elements have been the most successful in your planting designs?

Q14

What elements have been the least successful in your planting designs?

Q15

Have you trialed or tested any of the following planting techniques in your municipality?

- Using groundcover as mulch
- Self-seeding species
- Monocultural planting schemes
- Ready-to-lay plant mats
- Welcoming weeds and volunteer plants
- Designing with evapotranspiration in mind
- Sowing seed in-situ

Q16

If you have experimented with the strategies listed above, what were the outcomes? Is there any other innovative planting strategies you have experimented with?

Q17

Have your planting designs made an observable impact on biodiversity within your municipality? Please explain or provide an example.

Q18

Have you experienced any unexpected/unplanned benefits from your planted GSI? If so, please explain.

Q19

Are you willing to share your recommended planting list for GSI design? If so, please attach below:

Q20

If required, are you willing to participate in a short follow-up interview?

- Yes
- No

Appendix A-3: Survey Analysis

Design Goals

Almost all respondents listed aspects of technical function as the primary design goals when developing planting plans for road right-of-ways, with an emphasis on promoting infiltration. Low maintenance was included as a top priority for all respondents. Planting for pollinators, biodiversity, and community beautification were a medium to low priority for most respondents. Toronto noted design goals unique throughout the respondents, including Community beautification, Enhance biodiversity, Native plantings, Pollinator Attractor, and Low maintenance as the top 5 design goals.

Defining 'low maintenance'

Trash removal and cleaning are conducted most frequently by municipalities. Pruning was limited and mostly conducted on an as needed basis.

This begins to build a framework for how we understand the definition of low maintenance. When it comes to low maintenance GRI, planting design appears to have the least impact on overall maintenance requirements according to survey respondents. Pruning and watering requirements are limited once the establishment phase has been completed, while cleaning and trash removal appear constant. This implies that creating healthy plant communities during the establishment phase is necessary to reduce overall maintenance needs for GRI systems, and that achieving planting designs that require little pruning and watering is integral for decreasing life cycle costs considering the need for other ongoing maintenance tasks.

Natural vs. Formal

Formal plantings are generally considered for highly urbanized contexts, while naturalized landscapes are typically implemented in less populated/developed areas. One respondent indicated that size was a factor in determining naturalized vs. formal approaches, suggesting that wide-center medians were best suited for naturalized designs, while smaller areas that are integrated into the pedestrian realm were suited for formal designs.

Seattle noted that naturalized landscapes "when considered as a plant community" naturalized designs can be "effective and lower maintenance than a formal landscape" adding that maintaining formal designs such as the Swale on Yale "requires more maintenance to preserve the geometric/linear/color band appearance".

Innovative Methods

Mass/monocultural planting was met with mixed reviews, some reported success in achieving legibility of landscapes and ease of communicating maintenance, while others had experience with system-wide failure due to limited species diversity.

Groundcover as mulch faces issues of trampling and is regarded as difficult to establish.

Philadelphia has trialled and tested many methods including succession planting methods like seeding with plug overlays to encourage in-situ sowing uptake, use of self-seeding species, and experimenting with older systems to see how leaving volunteer plants in place contributes to overall aesthetic and community response. The use of container trees for planters in swales is being explored. They also conduct annual vegetation surveys and take photos from established, consistent locations "to assess the presence/absence of species and percent coverage in every GSI system to learn more about particular environments and how they influence species success."

Emulating the larger landscape

None of the respondents emulated larger landscapes in GRI projects, with some noting that size restrictions were the main deterrent. However, interest in tying GRI planting to larger landscapes was expressed as a potential opportunity for lowering maintenance needs through naturalized designs.

Common Species

Juncus, Carex and other graminoids were included as high performers for inundation areas by all respondents. In general, grasses and shrubs accounted for the majority of high-performance plants listed, many of which were native to respective locations. Flowering species were mentioned sparingly in "most commonly used" categories but were included in more extensive plant lists provided by each municipality.

Appendix B: Species Related to habitat Analogs

WET MEADOW

Grasses

- Carex obnupta
- Carex lyngbyei
- Carex mackenziei
- Leymus mollis (American Dune Grass)
- Deschampsia beringensis (Bering's tufted hair-grass)
- Deschampsia cespitosa
- Festuca rubra (red fescu)
- Molinia caerulea subsp. arundinacea (moor grass)

Forbs

- Achillea millefolium var. Borealis (Boreal yarrow)
- Cirsium rivulare (plum thistle)
- Coltha palustris (marsh marigold)
- Euphorbia palustris (marsh spurge)
- Geum rivale
- Iris sibirica Thalictrum aquilegifolium (meadow rue)
- Hemerocallis flava (Lemon Lily)
- Lychnis flos-cuculi (ragged robin)
- Filipendula ulmaria (meadow sweet)
- Trollius europaeus (globeflower)
- Veronica longifolia
- Delphinium elatum
- Angelica lucida (seacoast angelica)
- Heracleum maximum (cow parsnip)
- Succisa pratensis
- Persicaria bistorta (common bistort)
- Polemonium caeruleum (Jacob's Ladder)
- Lathyrus japonicus var. Maritimus (beach pea)
- Lupinus nootkatensis (Nootka lupine)

Shrubs

- Myrica gale
- Salix commutata
- Salix sitchensis

WOODLAND

Shrubs

- Corylus cornuta var. Californic
- Gaultheria shallon
- Holodiscus discolor
- Lonicera hispidula
- Symphoricarpos albus
- Vaccinium ovatum

Grasses

- Festuca occidentalis
- Elymus glaucus
- Bromus vulgaris are typical grass species.

Forbs

- Vicia americana
- Lathyrus nevadensis
- Sanicula crassicaulis

Hitchmough, J., Dunnett, N. (2005) Dynamic Landscape.

NatureServe Central Database (n.d.). Southern Vancouverian Dry Douglas-fir - Madrone Woodland. Accessed June 1, 2020.

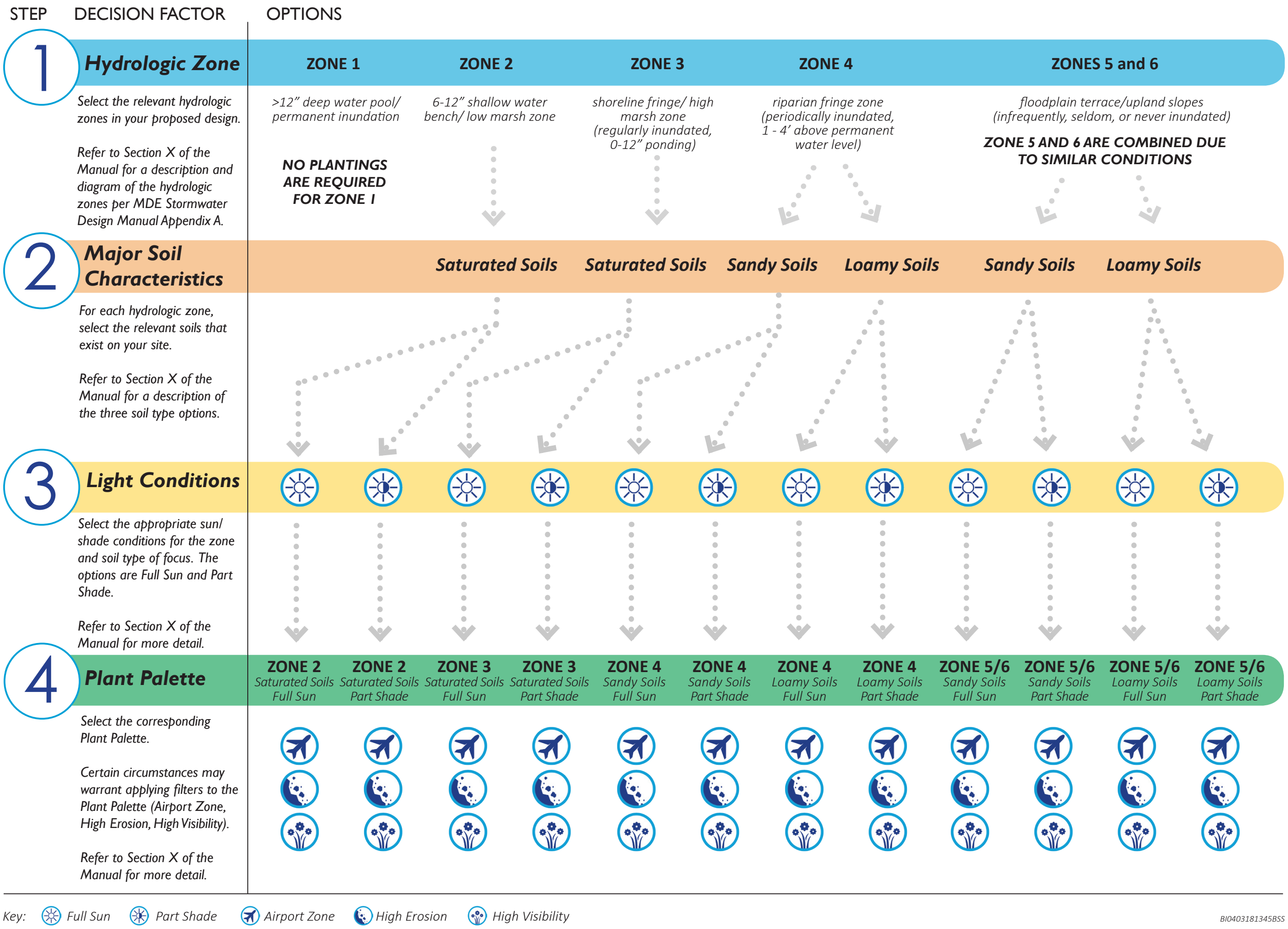
NatureServe Central Database (n.d.). Vancouverian Freshwater Wet Meadow & Marsh. Accessed June 1, 2020.

Appendix C: Decision-making tools

Provided by Thomas Rainer

Figure X

BMP Planting Palettes - Decision Matrix



Payne, E., Pham, T., Deletica, A., Hatta, B.E., Cook, P., Fletcher, D. (2018). Which species? A decision-support tool to guide plant selection in stormwater. Advances in Water Resources. Volume 113, March 2018, Pages 86-99. https://doi.org/10.1016/j.advwatres.2017.12.022

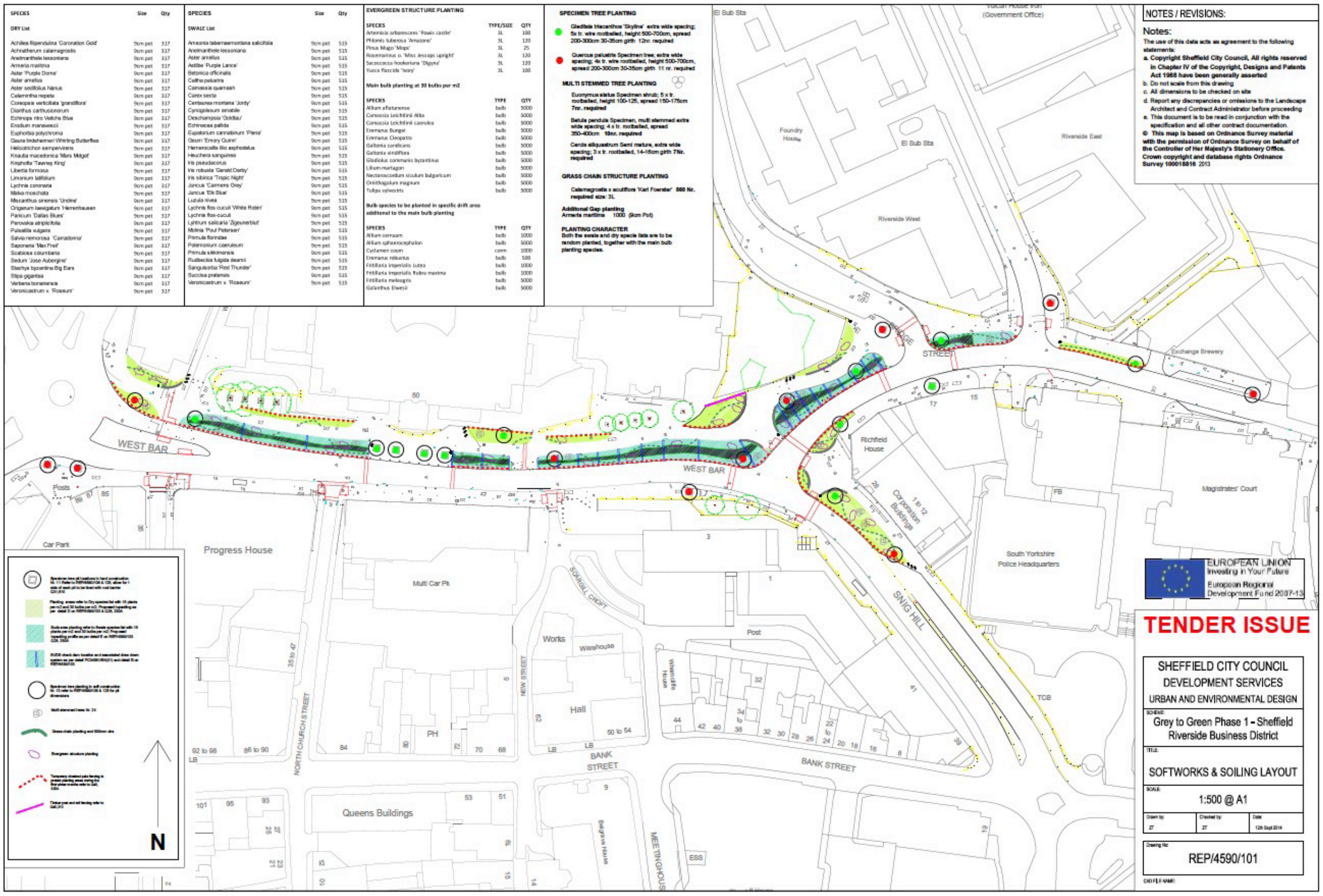
Decision support-tool – plant selection in stormwater biofiltration systems
Treatment objective: Nitrogen removal

	Plant species characteristics MORPHOLOGICAL	**Indicators**	**Proxy Indicators** (less reliable, if information or data not available)	**Expected N removal performance**	
High reliability predictors (determined from laboratory testing)	Extensive and fine root system	- High total root length - High total root surface area - High total root mass - High length of fine roots (<0.25 mm d.)	➢ Large plant size aboveground (relative to other species of same plant type)	EFFECTIVE	→ Select
	High total plant mass	- High plant biomass		EFFECTIVE	→ Select if combined with extensive roots
	Relatively high growth & above-ground biomass	- Observed high aboveground biomass & increase over time		EFFECTIVE	→ Select if combined with extensive roots
Lower reliability predictors (determined from observation only – further testing required)	Dense surface root mat	- Monocots – fibrous roots, predominance of lateral roots - Dictos – extensive lateral and fine roots from tap root	➢ Fine dense roots near-surface	EFFECTIVE	→ Consider selecting
	Soil- or sand-binding roots	- Fibrous roots, very fine and dense e.g. *Carex appressa, Juncus pallidus*	➢ Soil particles 'cemented' around root ➢ Some sedges, rushes and monocots without mycorrhizal associations ➢ Used for bank/erosion stabilisation	EFFECTIVE	→ Consider selecting
	Natural distribution – wetting/drying environments	- Distribution includes areas alongside watercourses, seasonally wet depressions but also experiences drying (not obligate wetland species)		EFFECTIVE	→ Consider selecting If combined with other key traits – extensive roots, high biomass * Select species with tolerances to extremes or specialised adaptations if biofilter subject to these conditions
	High leaf area (productive) & relatively low support mass	- High leaf area : wood or stem - High proportion photosynthetic tissue	➢ Avoid 'needle' leaves in shrubs/trees		
	Tolerance for drying, sandy soils, periodic inundation	- Recorded or observed distribution, or testing			
	Not highly specialised for stressful environments	- Not strongly adapted for: - high salt tolerance - shade tolerance - plant defence - nutrient-poor soils			
	Plant type e.g. grasses/herbs, sedges, rushes, shrubs, trees	- Range of types effective - Grasses generally medium – poor performance - Other types more variable effective – poor		EFFECTIVE - certain sedges, rushes, shrubs & trees. Less likely, but some, grasses	→ Consider selecting

	Plant species characteristics MORPHOLOGICAL	Indicators	Proxy Indicators (less reliable, if information or data not available)	Expected N removal performance	
High reliability predictors (determined from laboratory testing)	Limited, coarse root system (not extensive & fine roots)	- Low root mass, length, surface area	➢ Small plant size (for its type) ➢ Groundcover ➢ Thick roots ➢ Grows rocky environments	POOR (high reliability) →	Reject
	High proportion of support mass	- High wood : foliage ratio - Extensive belowground runners - Woody rhizomes	➢ Woody shrubs or small trees	POOR →	Reject
	Slow growth / low biomass		➢ Small biomass above-ground ➢ Low reported plant size	POOR (high reliability) →	Reject
	Predominance of thick roots	- Thick 'Noodle' roots e.g. *Dianella*		POOR (high reliability) →	Reject
	Low leaf area	- High proportion wood : leaves or stem: leaves - Low photosynthetic tissues	➢ "Needle' shaped leaves on woody plants	POOR →	Reject
	Nitrogen-fixing	- E.g. Legumes, peas - Families: Fabaceae, Casuarinaceae, - Genuses: Acacia, Hardenbergia, Senna		MEDIUM to POOR →	Reject
Lower reliability predictors Specialised adaptations to stressful environmental conditions	Very high salinity tolerance		➢ Distributed in close proximity to saline waterbodies – estuaries, lakes, coast, shallow saline groundwater	May be POOR* →	Consider rejecting, unless exposed to saline water (e.g. coast, de-icing)
	Distribution includes arid inland environments			POOR →	Consider rejecting, unless likely to experience very dry conditions
	Nutrient-poor soils	- Cluster roots e.g. *Hakea*		POOR →	Consider rejecting
	High shade tolerance	- Reported, observed or tested	➢ Dark green leaves ➢ Occur in dense understorey or rainforest ➢ Dense canopy	POOR →	Consider rejecting, unless biofilter in shaded location
	High investment in plant defence	- Slow growth - Thick leaves		POOR →	Consider rejecting
Tolerances & preferences	Low tolerance for conditions typical in biofilters: - Periodic inundation - Drought / periodic drying - Sandy soils		➢ Wetland plants (macrophytes) within frequent inundation zone ➢ Very restricted natural distribution	POOR →	Consider rejecting
	Sensitive (i.e. not hardy, adaptable)		➢ Very restricted natural distribution	POOR →	Consider rejecting

*However, some degree of plant salt tolerance can be associated with effective nitrogen removal from stormwater (Szota et al. 2015).

Appendix D: Grey-to-Green Planting Plan



DRY BEDS

BIORETENTION

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