UBC In A Changing Climate: Soft Landscape Communities Design Strategy

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Student Research Report

UBC In A Changing Climate: Soft Landscape Communities Design Strategy

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Themes: Biomimicry, Ecological Connectivity

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The team that contributed to this project:

- Laura Arango-Applied Research Coordinator, Climate Crisis in Urban Biodiversity, SEEDS Sustainability Program Manager
- Paul Pickell-Faculty of Forestry Assistant Professor of Teaching for the Master of Geomatics for Environmental Management Program
- Tara Moreau- Associate Director, Sustainability and Community Programs UBC Botanical Garden
- Liska Richer-SEEDS Sustainability Program Manager
- Penny Martyn-UBC Green Building Manager
- Jake Li-UBC Green Infrastructure Engineer

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Project Purpose, Objectives and Key Terms

Purpose

After the UBC Board of Governors endorsed the UBC Declaration of a Climate Emergency in December of 2019, there became a demand for student-led research that can inform UBC's climate action response. Drawing from the topics of biomimicry, biophilic design, ecological connectivity and mycorrhizal networks, this project will showcase tools, strategies and recommendations for modifying the green infrastructure network of the UBC Vancouver Campus. The structure and function of mycorrhizal networks will be examined to inspire UBC's approach to a resilient and sustainable campus that can adapt to the impacts of climate change. This report is targeted towards UBC Land Use Planners & Landscape Designers and students interested in urban biodiversity research.

Objectives

1. Conduct a literature review that identifies promising practices of biomimicry, biophilic design and ecological connectivity in the urban environment that includes opportunities and suggestions to improve stormwater management, air quality, and passive design.
2. Assess the current ecological connectivity of the UBC campus within the built environment, identify gaps where no connectivity exists and hot-spots where connectivity does exist. Compile this info into a web map and web scene that allows UBC Planners and Designers to understand the interaction between green and grey spaces.
3. Identify areas of low connectivity on campus, then propose solutions drawing from the practices of biomimicry, biophilic city design, and mycorrhizal networks to restore ecological connectivity
4. Propose policy recommendations that can be used to inform the Green Building Action Plan (GBAP), UBC Climate Action Plan (CAP) 2030, UBC Bird Friendly Guidelines and the United Nations Sustainable Development Goals 11 and 15 (SDGs).

Key Terms

- Green infrastructure networks
- Biodiversity and ecosystem services
- Climate change mitigation and adaptation
- Biophilia and biophilic design
- Biomimicry
- Ecological connectivity

- Nature based solutions
- Mycorrhizal networks
- Modularity

Literature review

Biomimicry

During the 3.8 billion years that life has existed on earth, nature has been busy evolving strategies to survive. The result of this period of research and development is the life that surrounds us today. Janine Benyus, the founder of the Biomimicry Institute defines biomimicry as "innovation inspired by nature." Biomimicry is a discipline that examines the structures and functions that have allowed life to flourish over the past 3.8 billion years and applies the research findings to help solve human design problems. Humanity currently faces a crisis in which we are exhausting our natural capital at an unsustainable rate. One of the practical applications of biomimicry is combining lessons from biological systems with human creativity to reconcile with nature to avoid catastrophic climate change. Humans often use heat, beat and treat methods to create materials, whereas nature uses self assembly to create materials. Humans also rely heavily on the use of toxic chemicals, whereas nature uses simple compounds like carbon as a building block for life. Nature runs on sunlight, rewards cooperation, banks on diversity, demands local expertise, and only uses the energy it needs (Benyus, 2009).

There is a growing amount of biomimicry research in the fields of architecture, design agriculture, transportation and materials chemistry. In nature everything is recycled, what works is optimized, materials are expensive and creating shape often has a low energy cost. Some landscape architects are learning from nature to create designs that synthesize the necessary components for life. The structure of a spider web is strong partially due to the number of links and the tension between those links. If a strand were to break, the fault would not propagate through the entire web because the structure of the web promotes resiliency (Pawlyn, 2019). A peacock is often characterized by its iridescent plumage. But the peacock doesn't use complex chemicals to make its colors, it manipulates light through changing the shape and structure of its feathers. Architects have learned and applied the same structural technique of manipulating light to their architectural designs. Pawlyn's report on biomimicry in architecture design emphasises that cities need to blur the line between the built and natural environment through mimicking the structures and functions of ecosystems.

To understand the core principles of biomimicry, one must understand that organisms are intimately attached to their local place. In order for the genes of a species to be passed on from one generation to hundreds of generations in the future, life focuses its energy on creating conditions that are conducive to more life. The traditional paradigm of our anthropogenic understanding of life is that competition drives evolution. Biomimicry suggests that learning from nature reveals that unity, cooperation and coexistence have a more powerful influence on survival than the force of competition. The growing discipline of biomimicry is finding that humans must embrace this new paradigm in order to live sustainably with nature. We have been surrounded by the secrets to a sustainable world, now is the time to listen, learn, and act (Benyus, 2009).

Biophilic design and sustainable, resilient cities

E.O. Wilson, one of the most influential biologists of the 21st century defines biophillia as "the innate tendency to focus on life and life-like processes" (Wilson, 1984). Building off Wilson's definition of biophilia, biophilic design is a social movement that seeks to incorporate natural elements and themes in all scales of the urban environment. From green walls, to the greening of major transportation corridors, the vision of biophilic designers is to embed cities in nature through uniting many existing fields that are examining the human connection with nature such as biomimicry. The recognition of biophilic design as a necessary component for a city has grown since 1984. Now researchers have identified the patterns, elements and benefits that encompass biophilic design. The visual and non visual patterns of biophilic design are known as "nature in the space." Whereas prospect, refuge and mystery are all common patterns of "nature of the space." Design patterns that have one degree of separation from nature are referred to as "nature analogies." The design patterns can be applied to green infrastructure in an urban area by incorporating the following principle elements: green roofs, vertical living walls, green corridors, bioswales, indoor plants, fractal patterns and natural lighting. The scientifically proven human benefits that result from these elements of biophilic design are: increased wellbeing, attention restoration, stress reduction, decreased violence and crime, improved mental health, cognitive enhancement and increased productivity (Söderlund, 2019). Embedding these principles in urban design can also lead to a vast array of environmental and economic benefits for a city. For example, the city of Brisbane, Australia has incorporated biophilic design principles in their city to create a green infrastructure network that encourages native biodiversity to thrive in the face of climate change externalities (Beatley & Newman, 2009).

Water scarcity, rising food prices and unbearable summer temperatures are all challenges that a resilient city can solve by employing the principles of biophilic design. Regulating ecosystem services of trees such as cooling through evapotranspiration and shading, stormwater management, and reduction of air pollutants can all help create resilience in an urban landscape.

The cooling and shading properties of trees also helps reduce the urban heat island effect (Marando et al., 2019). The City of New Orleans, Louisiana has degraded their riparian wetland system overtime. The degradation has directly made the city less resilient to the flooding from hurricanes and powerful storms because the riparian system is not strong enough anymore to absorb flood waters (Beatley & Newman, 2013).

A biophilic city is also a city in which the local population is actively interacting with nature. If urban residences are able to foster a caring awareness for the greenspaces near their home, then they are more likely to develop a stronger sense of place. The City of Austin, Texas has welcomed native bats back into their city. By adding this natural element to the city, the bats attract 100,000 tourists a year. Not only do the bats generate economic revenue from tourism, the bats also create a unique sense of place for the residences of Austin. Often when urban residences develop a sense of place for their local area, they are more likely to become stewards of their local natural areas. Not only does land stewardship enhance local greenspaces, it can even provide emotional resilience in times of stress. During the COVID-19 lockdown, greenspace usage in cities increased substantially (Honey-Rosés, 2020). Interacting with nature can provide solace and emotional resilience in the noise and panic of the COVID-19 lockdown.

Resilient, sustainable cities seek to re-establish a sense of place while also lowering the ecological footprint of a city and improving the quality of life for all socio-economic classes. In New York City, usage of an elevated greenway called the High Line also increased during COVID-19 lockdowns. Even though the High Line likely provided emotional resilience to the New York City residences in times of stress, the creation of the High Line in 2009 also raised the property value of the adjacent land by 35% and therefore displaced residences of lower socio-economic classes that were unable to pay the higher property taxes (Jo Black & Richards, 2020). Biophilic design is proven to create sustainable, resilient cities (Beatley & Newman, 2013), but biophilic designers also need to learn from the High Line case study that incorporating biophilic design elements in a city may indirectly result in green gentrification.

Ecological connectivity

Flora and fauna are in a constant state of change. Passive transport mechanisms such as wind and water aid in plant dispersal, whereas fauna actively swim, fly and walk in order to disperse or migrate from one habitat to another. Humans have attempted to manage the dispersal of wildlife in the past through creating protected areas labeled as “wilderness” where human activities are often restricted. Sometimes when a habitat becomes protected, the organisms in that habitat can become isolated due to habitat fragmentation of the surrounding landscape of the protected area. The fragmentation impedes the flow of genes from one population to another. Increasing ecological connectivity of an area facilitates gene flow and coexistence between humans and the natural environment (Jongman, 2019). The current literature suggests that conservation management should focus on creating ecological networks that encourage the movement of organisms (LaPoint et al., 2015). Adopting the contemporary conservation management paradigm of land sharing between humans and the surrounding environment will allow for ecological connectivity frameworks to positively influence biodiversity.

Ecological connectivity is evaluated through examining the structure and/or the functionality of an ecosystem. Structural connectivity refers to the physical configuration of a spatial habitat network and is often measured using metrics such as habitat size and distance to the closest habitat. Almost every organism on earth is influenced by the distance from one habitat patch to another. Therefore the proximity of one greenspace to another greenspace in an urban environment has a crucial impact on species dispersal and dynamics (Andersson, Örjan, 2019). There does not need to be a physical link between two habitat patches in order for functional connectivity to be measured. Functional connectivity refers to the behavioural response of an organism as it disperses throughout the surrounding environment. For example, a habitat can have high structural connectivity but low functional connectivity if there are numerous physical corridors or links associated with a habitat, but no organisms that are dispersing in or out of the habitat. Ecological connectivity is a new concept in the field of ecology, therefore limited research has been performed thus far. Ecologists do not have concrete evidence that proves distinct taxonomic groups possess functional or structural habitat preferences. No previous or current scholarly studies have successfully measured the direct influence that anthropogenic factors such as air, light and noise pollution have on wildlife in urbanized environments. The majority of the current literature on ecological connectivity focuses on tracking functional connectivity of large mammals often with VHF collars attached to measure dispersal. Few studies assess structural connectivity, and even fewer assess both structural and functional connectivity simultaneously. Ecological connectivity studies in the future are recommended to take an interdisciplinary approach to ecological connectivity through accounting for multiple, diverse sets of spatial data (LaPoint et al., 2015).

Mycorrhizal networks

In every terrestrial ecosystem on earth, mycorrhizal fungi can facilitate underground communication within a plant community. Mycelium is the thread-like fungal web that connects living tree roots below ground in the soil horizons. The mycorrhizal network can allow plants to send signals to one another and to exchange essential nutrients such as nitrogen, phosphorus, and carbon. The fungus benefits from this symbiotic relationship because the host plant supplies the mycorrhizae with sugars the fungus needs to survive through a source sink gradient from plant to fungus. Hyphae are the tips of the mycelium that the fungus can use to navigate in the soil. An endomycorrhizal/arbuscular mycorrhizal association occurs when the hyphae penetrates the root cell membrane of the host plant. The less common ectomycorrhizal association occurs when the hyphae covers the root tips of the host plant, but do not penetrate the root cell membrane (Simard et al., 2012). Most mushroom producing mycorrhizal fungi are ectomycorrhizae.

There is more carbon present in soil than carbon in our vegetation and atmosphere combined (Averill & Turner & Finzi, 2014). Trees can also store carbon in their mycorrhizal symbionts, a large portion of mycorrhizal research has focused on the role of mycorrhizae in carbon, nutrient and water cycling. It is not yet understood if mycorrhizal fungi can be manipulated to increase carbon storage in soils (Zak et al., 2019).

Suzanne Simard, a Forest Ecologist and UBC Faculty of Forestry Professor, made the discovery in 1997 that plants use these underground mycorrhizal networks to communicate with each other in a forest. The largest trees in a forest that Simard refers to as “mother trees” are hubs of abundant and diverse mycorrhizal fungi. These mother trees transfer carbon to their kin and even to other neighboring tree species through their mycorrhizal associations (Simard & Perry & Jones, 1997). Mycorrhizal fungi are agents of complex adaptive systems that can help the forest community as a whole become more resilient to anthropogenic climate change impacts such as landscape homogenization, pest outbreaks, and extreme weather events such as drought. Nutrient transfer through mycorrhizal networks can act as both a negative or positive feedback to ecosystem change. Mycorrhizae can mediate the competition between neighboring plant species (Lin et al., 2015). If all the trees in a forest are connected to a mycorrhizae and one of the trees is under attack by a beetle, the host tree can send signals to the surrounding trees in the forest community through the mycorrhizae to activate induced defense mechanisms against the beetle. Mycorrhizae also aid in plant diversity, soil water retention and even prevent leaching of nutrients from the soil horizons (Martinez-Garcia et al., 2017). The ability of mycorrhizae to increase soil water retention helps to prevent drought in many terrestrial ecosystems. Plants connected to the mycorrhizal network often perform better than plants that are unable to connect to the network. Nutrient transfer in mycorrhizal networks can act as a positive feedback mechanism that results in competitive exclusion if a plant connected to the network has a performance advantage over a plant not connected to the network (Deslippe & Simard, 2011). Mycorrhizae play a critical role in the establishment and dynamics of plants, therefore mycorrhizal fungi can be considered the central organizer of terrestrial ecosystems (Simard et al., 2012).

Modularity

In any network, the patterns among the nodes and links can be analyzed. If a network consists of groups of interconnected nodes, and each group is optimally connected to other groups in the network, then that network has a high degree of modularity. Scientists can measure the degree to which a group of nodes in a network can be decoupled then continue to interact as a network. If a shock such as a severed link cascades throughout the network resulting in collapse, then that network would have a low degree of modularity. A network with a high degree of modularity is more likely to continue operating even after a shock. A highly modular network is resilient because the network is assembled into communities of self interacting nodes. Interactions between nodes are more common within a group than between groups. Understanding the modularity of a network can help reveal how to optimize the resiliency of a network (Newman, 2006).

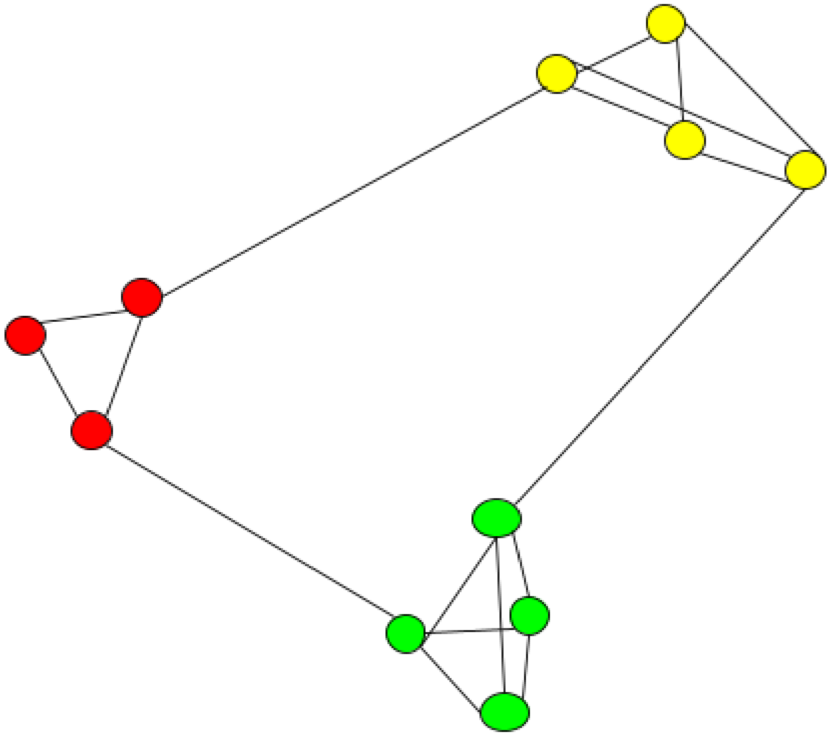


Figure 1 caption: A network with a high degree of modularity. Highly modular networks contain hubs of nodes and links in a compartmentalized group called a module, and also possess optimized connections between groups of modules.

Modularity of mycorrhizal networks

The neural network of neurons and axons in our brains is an example of a network that displays a high degree of modularity (Carvalho, 2014). The mycorrhizal fungi network is another example of a network that exhibits a high degree of modularity (Montesinos-Navarro, 2012). Older trees have more mycorrhizal fungi diversity than younger trees. The diversity of mycorrhizal fungi species associated with a host tree can be displayed as a network, then analyzed to reveal the modular pattern of plant-mycorrhizal interactions. The species diversity that leads to modularity within mycorrhizal fungi communities helps prevent disturbances in a forest community from propagating throughout the entire mycorrhizal network. If a tree were to die along with all its mycorrhizal fungi associations, the whole mycorrhizal network would not collapse because of the ability of the fungi to form strongly linked communities that can self assemble and recover after a disturbance. Mycorrhizal fungi have been busy optimizing their network structure since the symbiosis between plant and mycorrhizal fungi approximately 450 million years ago (Brundrett & Tedersoo, 2018). Mycorrhizal fungi have therefore had 450 million years to research and develop a highly evolved network structure that is resilient to disturbance. Mycorrhizal fungi are now present in every terrestrial ecosystem on earth (Simard et al., 2012).

Structural Ecological Connectivity Analysis

Link to web map and web scene tools

Please explore the Web map and Web scene tools by following the links below:

Web map: https://arcg.is/05WOzD0

Web scene: https://arcg.is/1PzHfu

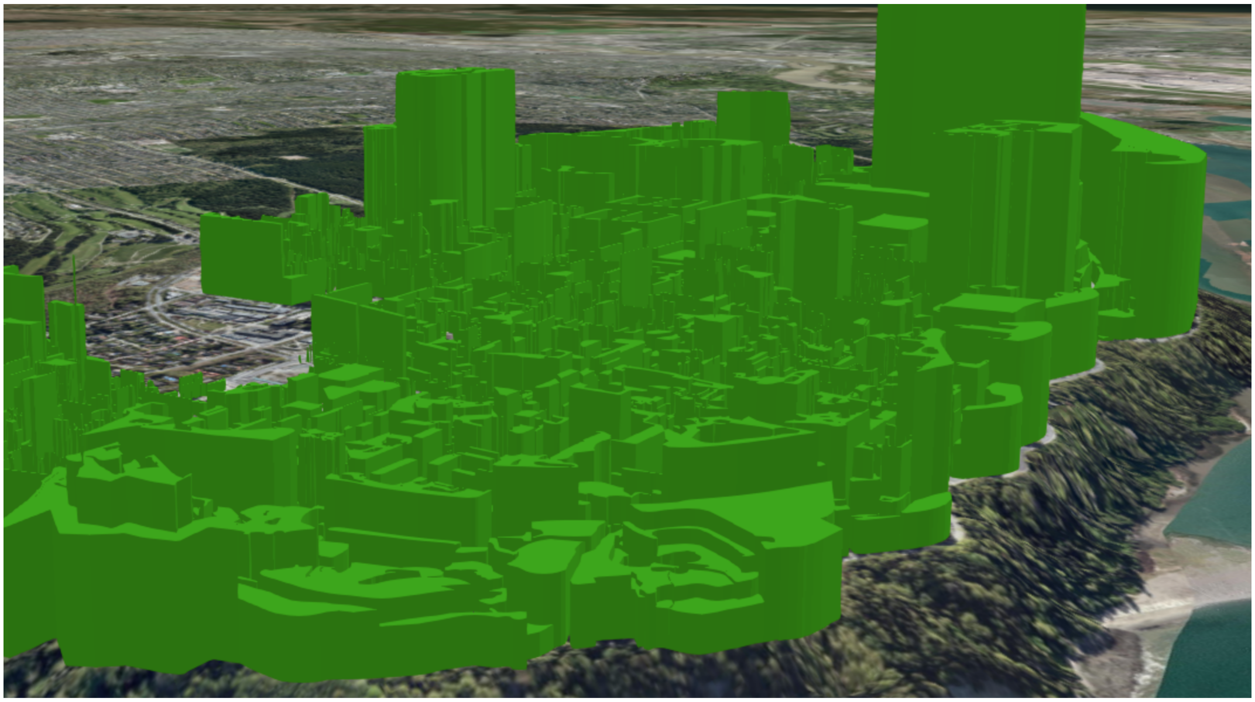


Figure 2 caption: The soft landscapes of the UBC Vancouver campus are extruded by each soft landscape's importance for ecological connectivity.

Explanation of Ecological Connectivity Web Map/Web Scene Tool

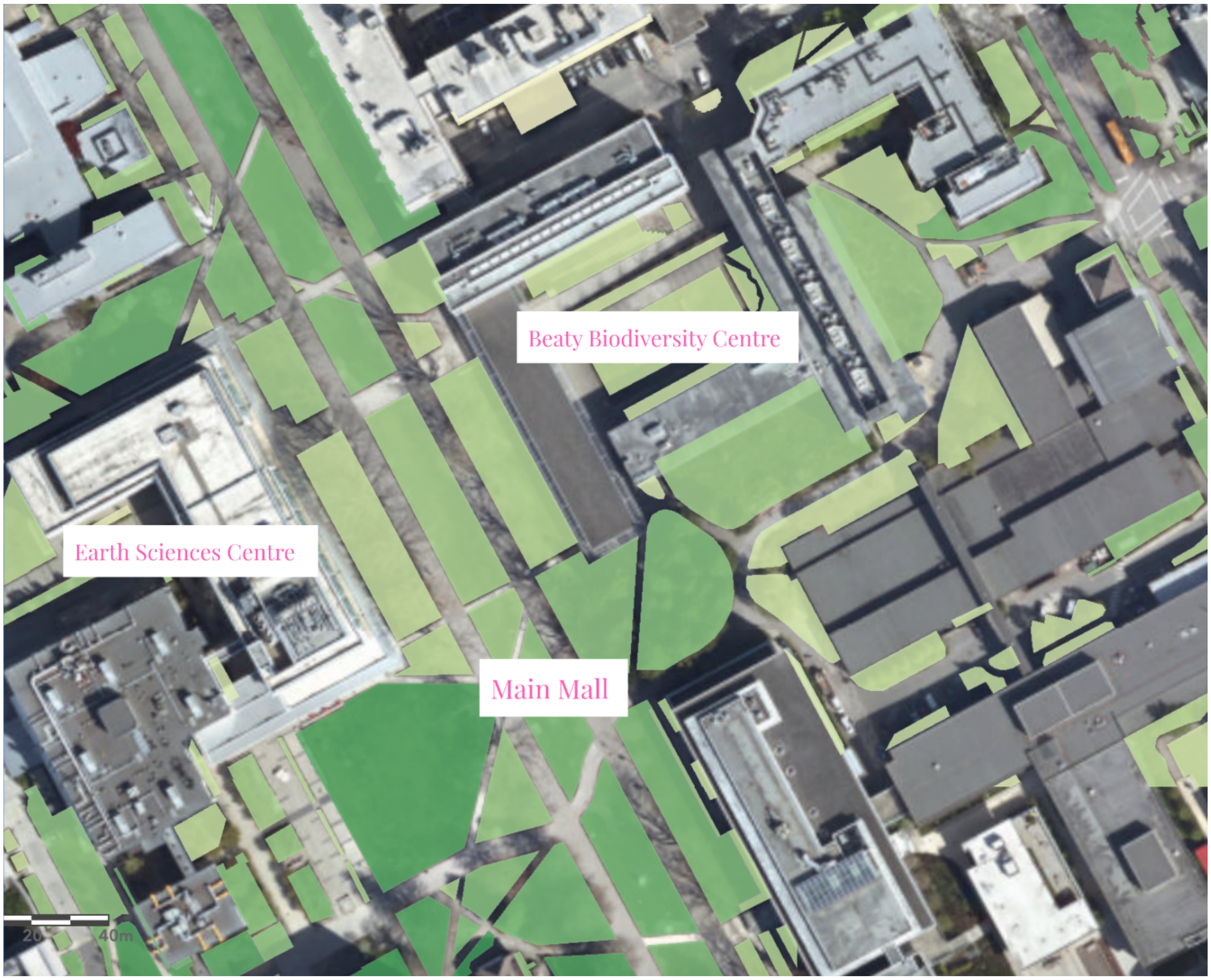


Figure 3 caption: The green polygons are soft landscapes on the UBC campus. The soft landscape polygons with darker shades of green are more likely to facilitate species dispersal.

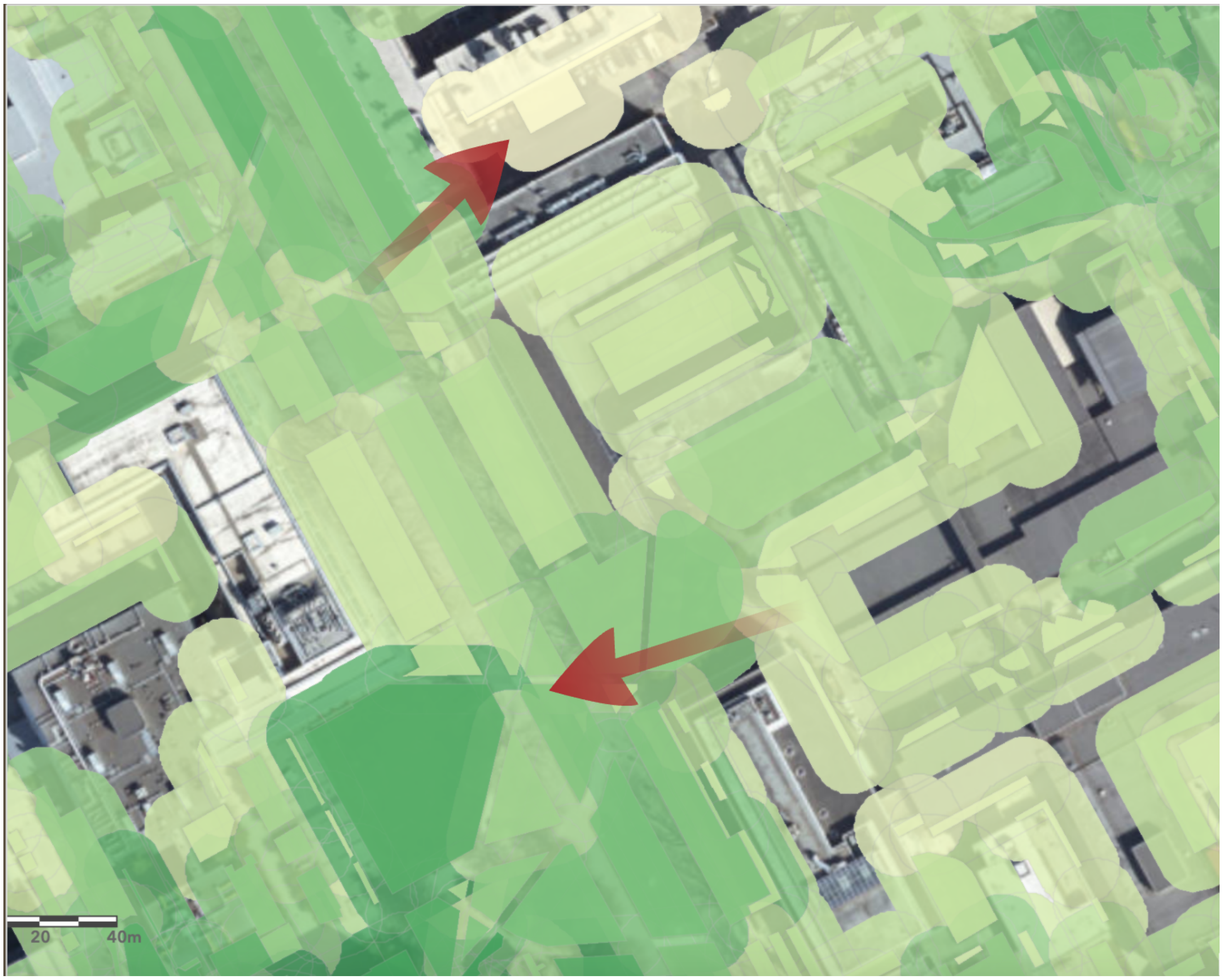


Figure 4 caption: Soft landscapes on the UBC campus buffered by 10 meters. The soft landscape buffer at the top of figure 4 has no ecological connectivity. The soft landscape near the bottom of figure 4 has high ecological connectivity. 10 meters was subjectively decided on as the buffer distance based on an estimate of the influence that the surrounding environment has on a soft landscape. Changing the buffer distance to 20 meters would increase this model of structural connectivity for each soft landscape, whereas changing the buffer distance to 5 meters would decrease the modeled structural connectivity of each soft landscape.

Figure 5 caption: Deadzones (areas in red) refer to the areas on the UBC campus where no buffers are present and are therefore areas of no ecological connectivity according to this model.

Spatial mapping tools such as arcGIS can help reveal the existing structural ecological connectivity of the UBC campus. Almost every organism on earth is influenced by the distance from one habitat patch to another (Liu et al., 2016). Therefore the proximity of one soft landscape to another soft landscape in an urban environment has a crucial impact on species dispersal and dynamics. By applying a ten meter buffer to the soft landscapes at UBC, it becomes clear that some soft landscapes possess multiple overlapping buffers, while others have no overlapping buffers such as the buffer the red arrow is pointing to at the top of figure 4. Soft landscapes with numerous overlapping buffers are symbolized in a darker shade of green, such as the soft landscape at the bottom of figure 4. The areas of the UBC campus that are 10 or more meters away from any soft landscape, shown in figure 5, are referred to as “Deadzones” in this project because these areas of extensive grey infrastructure development likely impede the ecological connectivity of the UBC campus.

Follow this link to interact with the web map: https://arcg.is/05WOzD0. If the user opens the web map and selects the layer "soft landscape with frequency and importance values", the user can navigate to the "change style" tab and project attributes titled "src_freq_1" and "importance". The src_freq_1 attribute represents the frequency of overlapping buffers for each soft landscape polygon. High values in the src_freq_1 field represent soft landscapes with numerous connections to the neighboring soft landscapes. The user can also navigate to the "filter" tab and search for BED_IDs in the web map data frame.

Explanation of "importance" attribute:

Soft landscapes with a high area measurement (m^2) are likely to have higher ecological connectivity than soft landscapes with a low area measurement. Also, a soft landscape with trees is likely to have higher ecological connectivity than a soft landscape without trees. Operating under both of these assumptions, the creator of the web map imported tree point data from the year 2013 (keep in mind that the tree point data is from 2013 and does not include the wesbrook village area, therefore the data is slightly inaccurate), and overlaid the point data with the soft landscape polygon data to obtain the number of trees within each soft landscape polygon. The area measurement (m^2) of every soft landscape polygon was also measured. The map creator exported the frequency of overlapping buffers, tree count, and soft landscape polygon area data to microsoft excel, then proceeded to calculate tree density of each soft landscape polygon. All three metrics were then scaled from zero to one. In an excel column labeled "importance", the average of the three scaled metrics (frequency, tree density, area) was calculated. The "importance" attribute is meant to be a more accurate and holistic measure of ecological connectivity because the metric accounts for the tree density and area data in addition to the frequency data. Given that models of ecological connectivity likely become more accurate if representative spatial data is added the the connectivity model, it is encouraged that students interested in adding to the web map and web scene could repeat the methodology showcased in this report to create another "importance" metric that accounts for data relevant to ecological connectivity such as functional connectivity, or tree species diversity.

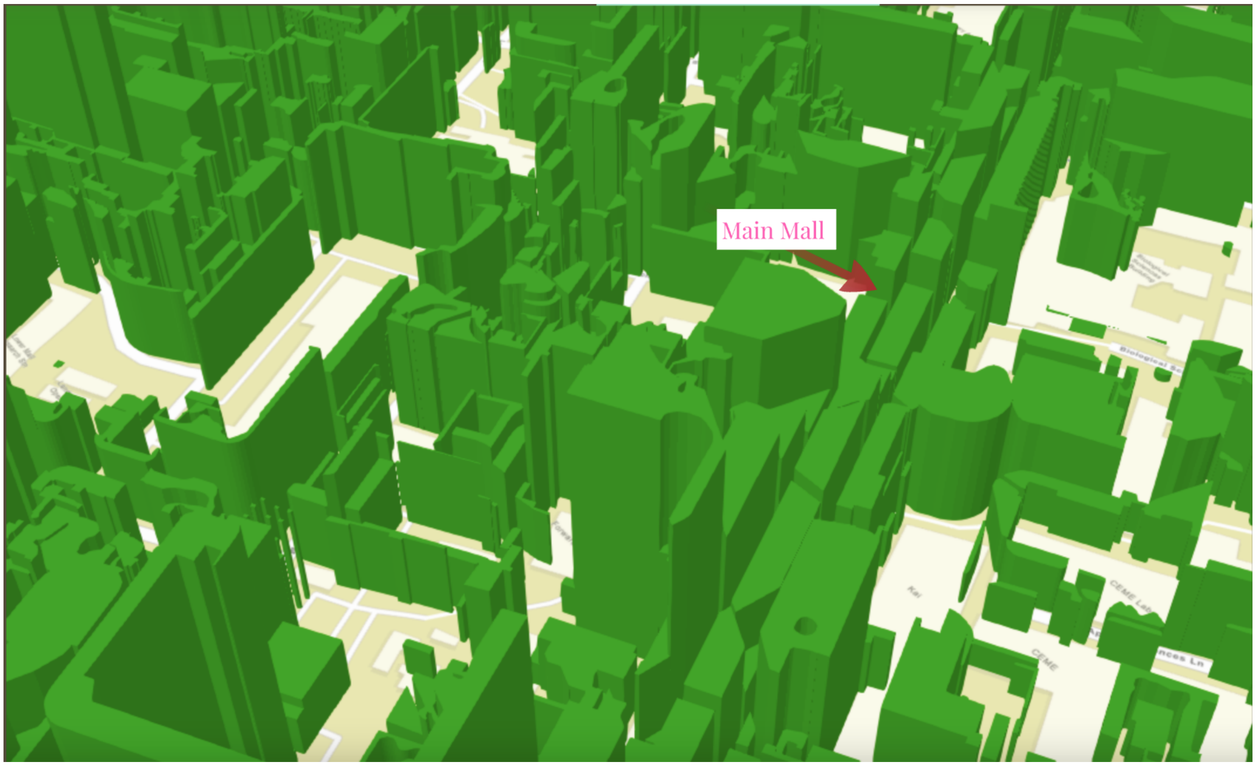


Figure 6 caption: A screenshot of the web scene tool with the map extent showing southern Main Mall. The green polygons are the soft landscape polygons extruded by their importance values. All of the importance attributes are scaled from zero to one, the polygons are extruded by kilometers so it is easier to differentiate the importance values of the soft landscape polygons in the web scene tool. Follow this link to interact with the web scene: https://arcg.is/1PzHfu

Data

Soft landscape layer obtained from Rachel Wiersma, Manager of GIS and data systems (C+CP),https://github.com/UBCGeodata/ubc-geospatial-opendata/tree/master/ubcv/landscape

University of British Columbia. Campus and Community Planning, (2013), Tree point data excluding Wesbrook village, doi:11272.1/AB2/ETO8IU

Methodology

Polygon neighbor method workflow:

1. Define projection of soft landscape data to NAD 1983 UTM Zone 10N in arcmap data frame
2. Buffer the soft landscape data by 10m
3. Open polygon neighbor tool, select landscape_buffer. In report field check OBJECT_ID and check include both sides of neighbor relationship. Check include area overlap. Run the tool
4. Open frequency tool. Select the output table from the polygon neighbor tool. Run the frequency tool on the src_OBJECT_ID column. The output table should show the number of occurrences that each src_OBJECT_ID had on an intersecting buffered polygon.
5. Refer back to the original landscape polygon shapefile. Navigate to join-->attributes from a table.. Base the join on OBJECT_ID field. Navigate to correct frequency table, and base that join on the src_OBJECT_ID of the frequency table
6. Symbolize the frequency column of the soft landscape shapefile to ensure that the data is accurate.
7. Save that landscape shapefile that includes the frequency numbers. Export the data of that shapefile to gdb.

Joining tree point data to landscape polygon data

I followed these steps from ESRI:

1. In the attribute table of the tree point shapefile, create a field called 'Count' of type 'Short Integer'.
2. Calculate the Count field equal to 1 by right-clicking the field name > Field Calculator.
3. Type the integer *1* in the white dialog area below Count = , and click OK.
4. Right-click the soft landscape polygon shapefile and click Joins and Relates > Joins. Click the drop-down list and select Join data from another layer based on spatial location.
5. Specify the point shapefile from Step 1.
6. Select the first bullet (Each polygon is given a summary of the numeric attributes...) and check the Sum box.

7. Specify an output location, and click OK.
8. A polygon shapefile with the 'Count' field indicating how many point features lie within each polygon feature is now present. This is usually named 'Sum_Count' or 'Count_'.

Scaling connectivity metrics in excel

1. Export landscape attribute table with joined frequency data to excel
2. Export landscape attribute table with spatial joined tree data to excel, then copy the column that is labeled sum_count. Copy and paste this column to the landscape polygon excel table and ensure that the Object IDs match
3. In the soft landscape frequency excel table that has tree data, create a column called tree density. For each soft landscape polygon data, tree density=tree count/area
4. Once you have area measurements, frequency data, and tree density all in the same excel sheet, you are ready to start scaling.
5. Use the excel function called descriptive statistics to identify the maximum values of shape area, frequency, and tree density
6. Take each metric and divide all the data of that metric by the maximum value of said metric. For example, the highest tree density value was 67.4840794. Therefore divide all of your tree density data by 67.4840794 to obtain the tree density scaled from 0-1.
7. Once all three metrics have been scaled, create a column labeled importance. Compute the average of scaled shape area, scaled frequency and scaled tree density. The resulting numbers in the importance column is a more holistic representation of ecological connectivity of the landscape polygons because the tree density and shape area now have an influence on the connectivity measurement of each soft landscape polygon
8. Use the table to excel function in arc map to get the excel table in arcmap
9. Join excel table to landscape polygon layer using the Object IDs
10. Now you are ready to export the attribute table to a web map/scene

Identifying areas of low connectivity

There are numerous ways that the user of the web map and web scene can identify the areas of low connectivity. The user can change the data distribution in the “symbology” tab to get a more detailed visualization of the soft landscape polygons with the lowest frequency or importance value. The user can also change the symbology of the soft landscape polygons so that the areas of low connectivity are shown in red. Explore the symbology tab in the arcscene/map to symbolize the low connectivity areas.

The “dead zones” layer in the web map and scene represent the areas on campus that are 10m or more away from the nearest soft landscape. These dead zones are areas of extensive grey infrastructure that represent where ecological connectivity is likely to be inhibited due to the lack of any soft landscapes within 10m.

If the user of the web map wants to search soft landscape polygons by BED_ID_1, the user can navigate to the filter tab, then type in the BED_ID_1 that they are looking for.

Synthesizing connectivity tool

Which soft landscape polygons have no connections to a neighboring soft landscape?

BED_ID_1:
3969
5757
649
768
12826

Which 5 soft landscape polygons have the most connections to neighboring soft landscape polygons?

BED_ID_1:
4747
13445
3125
13456
5031

Design Strategies and Recommendations

Soft Landscape Communities Proposal

UBC is interested in increasing the resiliency of the campus to climate change impacts. What can UBC learn from mycorrhizal networks that can be applied to increase the resiliency of the UBC green infrastructure network? The ecological connectivity web map and scene tool symbolizes the direct connections of each soft landscape polygon buffer using a proximity based structural ecological connectivity model. The proximity data of every source soft landscape's intersecting buffers can also be projected as a node and link network.

Figure 7 caption: The soft landscapes are projected as nodes that are proportional to soft landscape polygon shape area, and each link represents a buffer overlap. The link thickness is proportional to the buffer overlap area divided by the smaller area between the two soft landscapes in each relationship. Two sided relationships were not factored into this model. The red circles symbolize soft landscape polygons that are not linked with any surrounding soft landscape polygons.

Benjamin Scheufler, a UBC Faculty of Forestry colleague collaborated with Nick Mantegna to create figure 7. Scheufler performed a network analysis on the data generated by Mantegna's model in order to visualize the green infrastructure network of UBC as a node and link network. The main purpose of figure 7 is to help the audience think of the UBC campus soft landscapes as a network built on the frequency of soft landscape 10 m buffer overlaps. Follow this link to interact with the node and link network in web map: https://arcg.is/05WOzD0

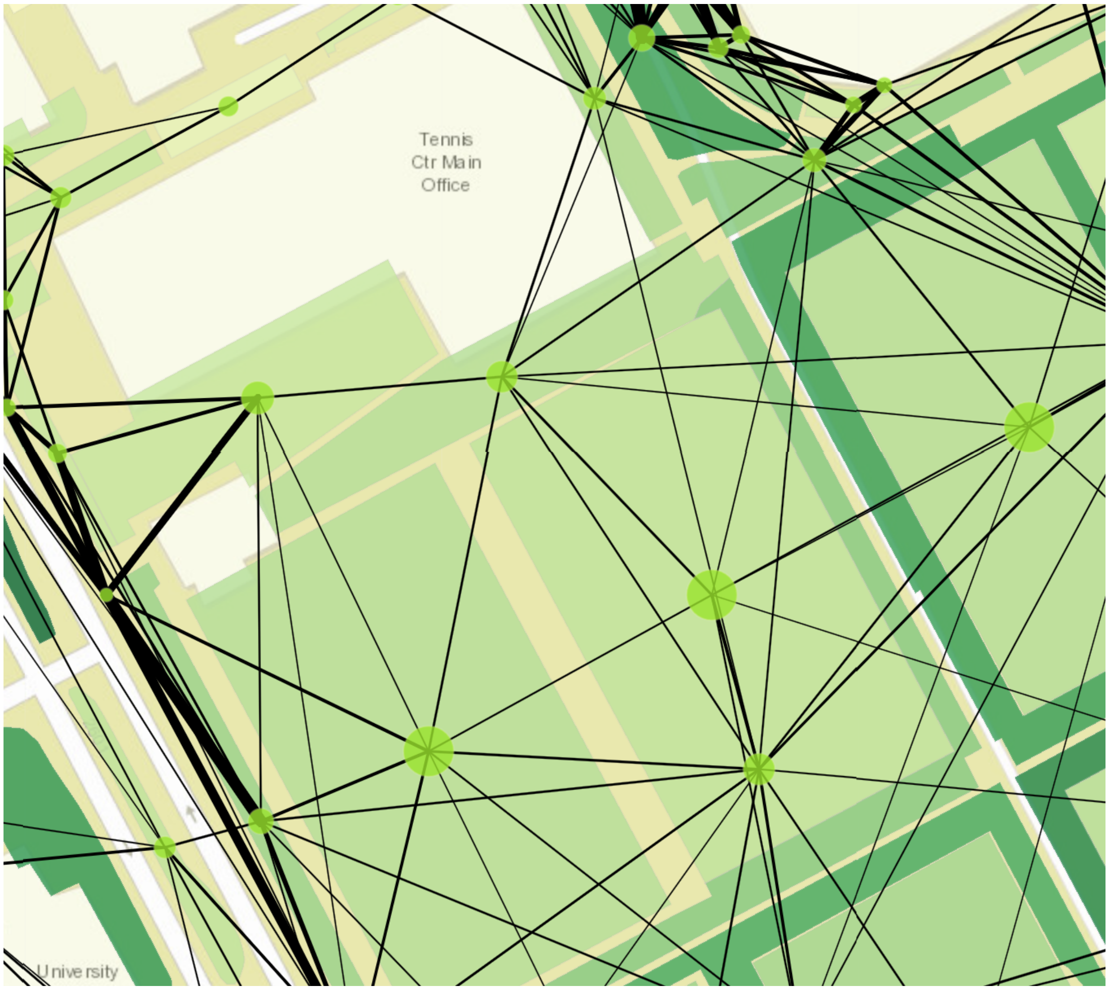


Figure 8 caption: A screenshot from the node and link web map. The network structure of the soft landscape polygons at the turf fields on campus displays a low degree of modularity.

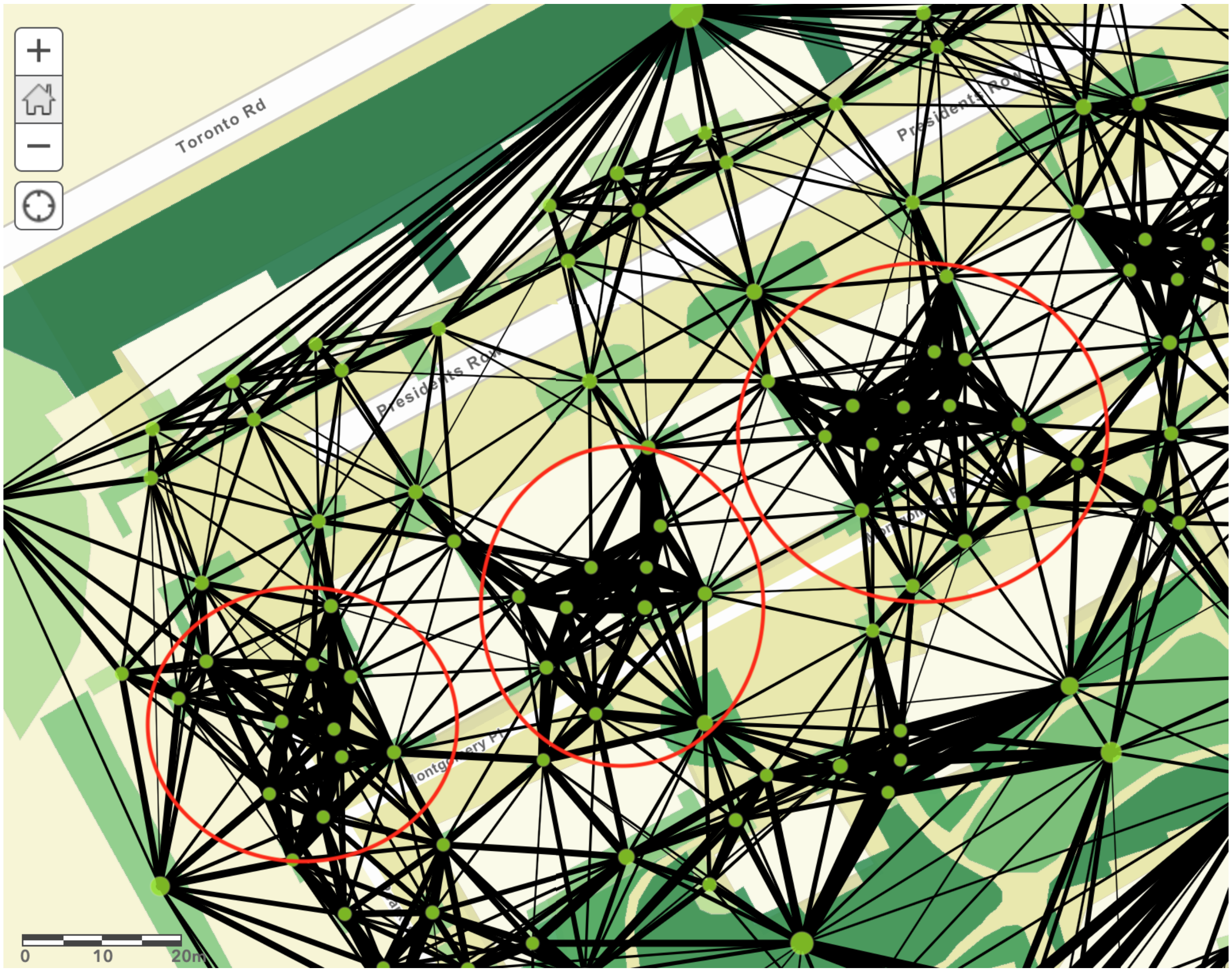


Figure 9 caption: A screenshot of the node and link web map showing an area of the East campus of UBC where the soft landscapes display a high degree of modularity. The hubs of nodes and links within the red circles are modules. See the “Modularity” section of the Literature Review for more detail.

UBC could modify the soft landscapes (nodes) so that the associated frequency values (links) mimic the modularity of a mycorrhizal network. A characteristic of a modular network is communities of self interacting modules, and each community (or module) is strung together by an optimized number of connections (Newman, 2006). Given that previous research has demonstrated that the fungal species diversity of plant-mycorrhizal interactions displays a high degree of modularity (Montesinos-Navarro, 2012), UBC could modify their green infrastructure network so that there are more modular communities of soft landscapes on campus. The soft landscape communities would mimic the modular design of a mycorrhizal network. The more links there are within soft landscape communities, the more modular the green infrastructure network can be. By implementing this soft landscape communities design strategy to areas of the UBC campus with low ecological connectivity, the UBC campus is more likely to adapt to climate change impacts as a whole because this proposed network design strategy promotes resilience within the green infrastructure network. If UBC implements this soft landscape communities design strategy, then it is more likely that the green infrastructure at UBC will be equipped to withstand local climate change impacts such as rising temperatures, extreme weather events and biodiversity loss.

Climate Emergency Response: Green Campus Design Recommendations

The following showcases the biophilic design elements that are best suited to increase the modularity, and therefore resiliency of the ecosystems at UBC. Building off the proposed soft landscape communities design strategy, these biophilic design elements can help UBC adapt to the impacts of climate change locally on campus. The planting palette for the following biophilic design elements should focus on plants grown from seed that are native in the Coastal Western Hemlock biogeoclimatic zone of British Columbia. Only 6% of the trees currently within UBC's academic core are native (UBC Urban Forest Report, 2021). Native plants should be prioritized when considering the species composition of additional soft landscapes at UBC. Native plants provide benefits such as reduced maintenance cost, soil water retention, and native plants help to facilitate conditions that are suitable for a biodiverse ecosystem (Targeted News Service, 2013).

1. Green corridors
    a. The implementation of green corridors can increase the ecological connectivity of isolated soft landscapes. Green corridors can physically link an isolated soft landscape to the nearest soft landscape.
    b. Green corridors could act as stepping stones that connect isolated soft landscape polygons to the green infrastructure network if physically linking two soft landscapes is not logistically possible.

c. Green corridors could also help encourage environmental conditions suitable for mycorrhizal fungi growth because if UBC creates more green corridors on campus, then there will be more underground room for mycorrhizal fungi to connect existing greenspaces within the UBC green infrastructure network (See “Added Benefits of Mycorrhizae at UBC” for more detail).
d. If the goal is to strengthen the resiliency of a community of soft landscapes, a green corridor could be added to an area with low modularity. The green corridor could act as an additional node with associated links that therefore increases modularity of a specified soft landscape community similar to the example in figure 11 below.
e. Green corridors are the easiest biophilic design element to implement on campus because the shape and size of a green corridor can be manipulated to fit a given area without having too high of an impact on the surrounding grey infrastructure
f. Added benefits of green corridors: reduction of the quantity of stormwater discharge, increased stream health, air quality improvements, microclimate moderations, rainwater harvesting (Chui & Ng & Savage, 2018).

2. Green roofs

The areas of the connectivity web map labeled as “dead zones” are more than 10m from the nearest soft landscape polygon, therefore these dead zones likely inhibit the dispersal of flora and fauna at UBC. Most of the dead zones are located in the campus academic core where there is a high density of grey infrastructure. Green roofs are a biophilic design element that is best suited to lower the dead zone area of the UBC campus. Buildings often act as a barrier between soft landscape communities. The implementation of green roofs could therefore act as a crucial stepping stone for linking soft landscapes that were previously isolated by the presence of buildings. UBC Planners and Designers should consider the deadzones that are covering the largest land area as having the highest deadzone area minimization priority.

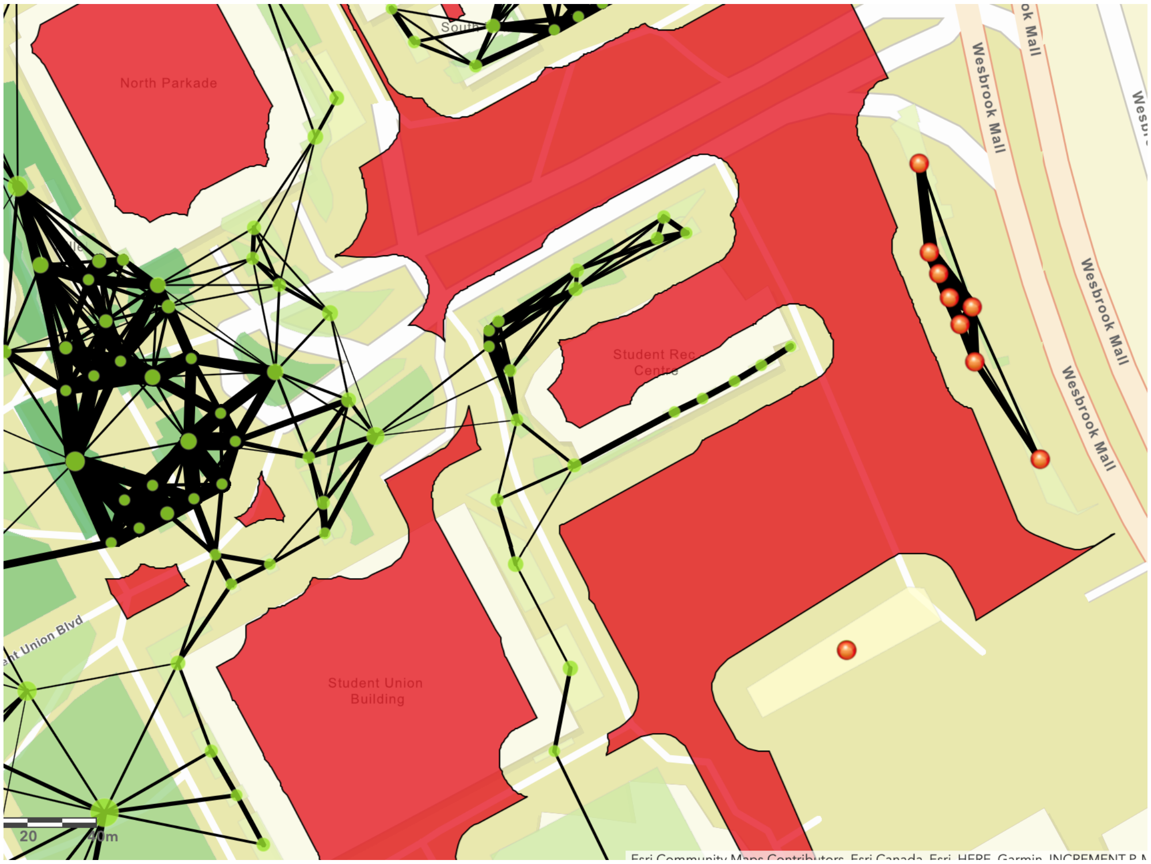
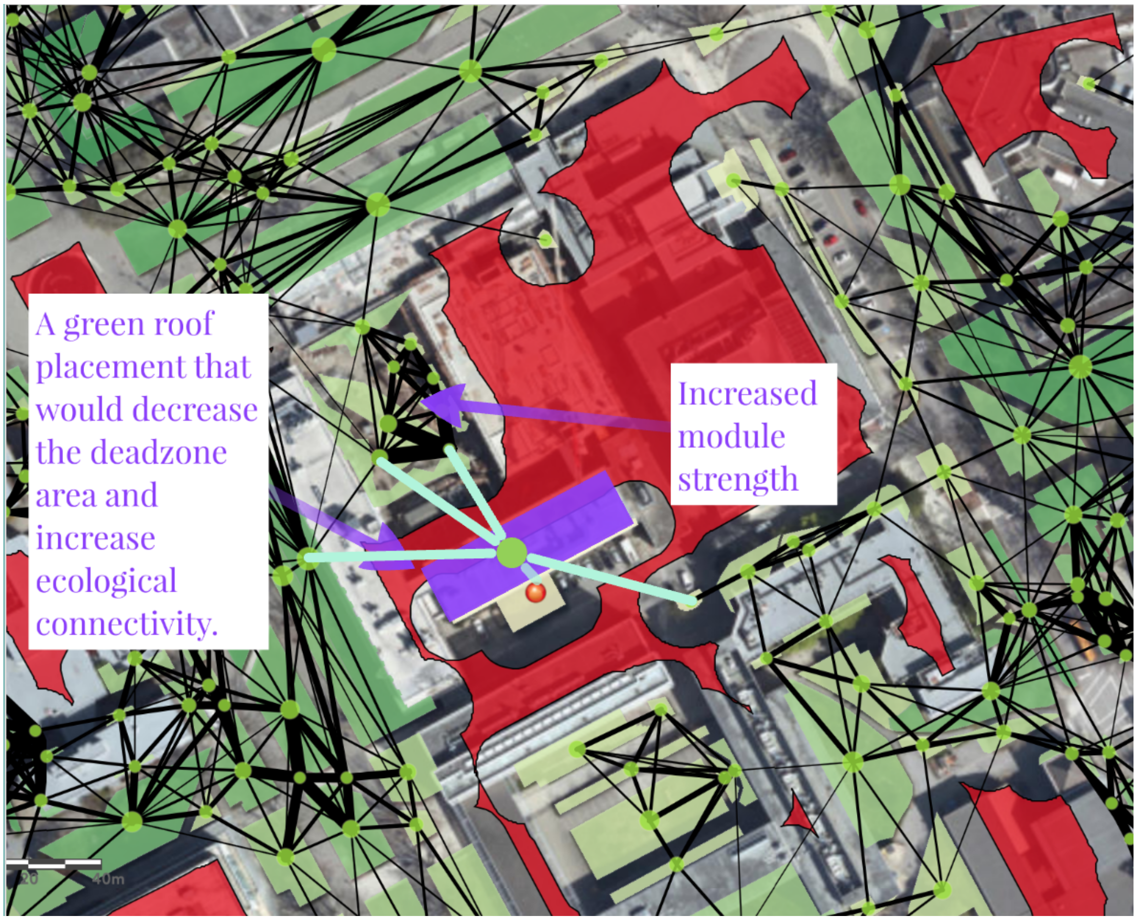


Figure 10 caption: One of the largest deadzone areas on campus is located near the UBC student recreation centre. Implementing a green roof in this area could connect the isolated soft landscape polygons (red dots) to the broader green infrastructure network.


A green roof placement that would decrease the deadzone area and increase ecological connectivity.

Increased module strength

Figure 11 caption: An example of the ecological connectivity benefits that could result from implementing a green roof on top of one of the Biological Sciences Buildings.

3. Green walls

If there is a building with a green roof that has soft landscapes on at least two sides of the building, then green walls could act to connect the adjacent soft landscapes to the green roof habitat. A direct connection of vegetation between soft landscapes on the ground and green roofs would facilitate the movement of organisms from the ground to the roof. The species composition of the green wall is not relevant to this project. The most important factor for creating green walls is encouraging the growth of life that may already be trying to climb up a wall such as vines climbing a green facade.

Green campus design recommendations that likely require further research

1. Wildlife corridor

Wildlife such as coyotes need to travel across Southwest Marine Drive to get to and from the forest habitats near Wreck Beach. UBC could construct a wildlife corridor above or below Southwest Marine Drive. The wildlife corridor would increase the functional and structural ecological connectivity, mitigate the risk of cars colliding with wildlife, and reduce habitat fragmentation of the UBC campus because the wildlife corridor will provide a direct pathway for wildlife dispersal. In the Bow Valley of Banff National Park, the construction of a wildlife corridor greatly reduced wildlife-vehicle collisions, and also increased ecological connectivity of the Bow Valley area (Graveland, 2019).

2. Soil corridors

If there is not room above ground to implement a green corridor, UBC could experiment with underground corridors that connect existing soft landscapes belowground. Assuming space is available below ground, then soil corridors could help conserve soil on campus and also may create more room for tree roots and mycorrhizal fungi to grow. Soil cages could be installed underground to help prevent soil compaction and to create room for a soil corridor.

Added Benefits of Mycorrhizae at UBC

The greenspaces in urban areas have become increasingly fragmented overtime due to grey infrastructure development pressures. The trees in these fragmented urban landscapes have fewer mycorrhizal associations than trees in a forest ecosystem (Bainard et al., 2011). Mycorrhizal fungi can provide numerous ecosystem services for urban environments including the following:

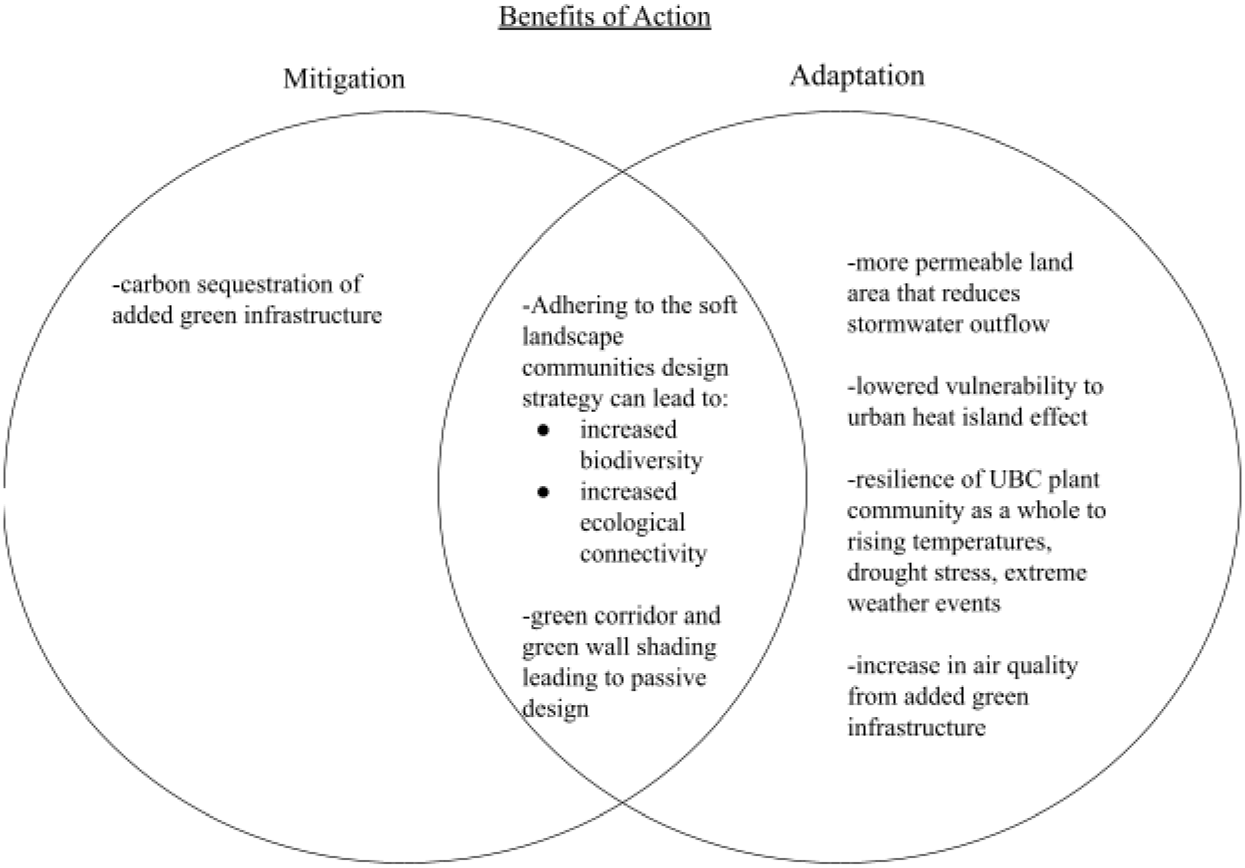
1. Regulating Ecosystem Service: Stormwater management:

In a forest mycorrhizal fungi play a crucial role in drought resistance and soil water uptake (Palacios & Winfrey, 2021). In an urban environment such as UBC, mycorrhizae could be inoculated to green infrastructure vegetation with the goal of improving stormwater uptake. Khalvati et al. found that inoculating barley plants with mycorrhizal fungi increased soil water uptake (Khalvati et al., 2005). Mycorrhizal fungi inoculation may help increase plant physiological activity and soil water retention, but more research is needed to quantify the benefits of mycorrhizal fungi inoculation in urban environments (Fini & Frangi & Amoroso, 2011). An alternative to mycorrhizal inoculation is to grow plants that are known to possess an abundance of mycorrhizal associations. These plants are more likely to uptake water and therefore reduce the volume of water entering stormwater drainage systems if they are able to establish abundant fungal symbionts. If UBC approaches stormwater management by investing in nature based solutions such as mycorrhizal fungi for soil water uptake through green infrastructure such as bioswales or rain gardens, then UBC is less likely to need to pay for a stormwater management facility.

2. Biodiversity Resiliency

Mycorrhizae can influence the level of competition between neighboring plant species (Lin et al., 2015). By mediating underground communication in a plant community, mycorrhizae play a fundamental role in ensuring that the biodiversity of an ecosystem is in balance. Plants that are able to communicate with one another are more likely to create conditions suitable for a biodiverse ecosystem, especially in urban environments. The trees in urban ecosystems possess fewer mycorrhizal associations than trees in a forest, therefore many trees in urban environments are unable to perform the beneficial communication that a tree is adapted to having. The fundamental influence that mycorrhizae have on plant to plant communication helps to organize the biodiversity of an ecosystem. Green roofs are a biophilic design element that would benefit from the introduction of mycorrhizae. The available literature on mycorrhizal fungi suggests that the drought resistance, plant diversity, and carbon sequestration of a green roof could all increase due to the presence of mycorrhizae (John et al., 2017). Green walls would facilitate a pathway for mycorrhizal networks to move from soft landscapes on the ground to the soil on a green roof, therefore green walls are likely to influence the abundance of mycorrhizal fungi on a green roof.

Benefits towards climate change mitigation and adaptation venn diagram



-carbon sequestration of added green infrastructure

-Adhering to the soft landscape communities design strategy can lead to:

- increased biodiversity
- increased ecological connectivity

-green corridor and green wall shading leading to passive design

-more permeable land area that reduces stormwater outflow

-lowered vulnerability to urban heat island effect

-resilience of UBC plant community as a whole to rising temperatures, drought stress, extreme weather events

-increase in air quality from added green infrastructure

Policy Alignment-Local to Global Jurisdictions

The soft landscape communities design strategy proposed in this report can be integrated to existing policies on campus and beyond. The following highlights plans and policies for consideration.

UBC

Green Building Action Plan (GBAP)

The 2018 Green Building Action Plan (GBAP) is structured around eight component areas that guide the report: Health and Welbeing, Climate Adaptability, Quality, Materials & Resources, Place & Experience, Water, Biodiversity, and Energy. Health and Welbeing, Climate Adaptability, and Biodiversity are all emerging component areas that still require foundational work (GBAP, 2020), therefore substantial remaining progress is needed. The upcoming GBAP seeks to incorporate climate adaptive design strategies to sustainable design policy at UBC. The findings outlined in this project align with the GBAP's demand for campus design strategies that can also contribute to UBC's emerging Climate Action Plan. A crucial piece of UBC's GBAP Climate Adaptation component area is to modify buildings and landscapes so that they are resilient to rising temperatures, increased frequency of extreme weather events and also provide co-benefits of the biodiversity and water component areas. Adhering to the soft landscape communities design strategy and associated recommendations proposed in this report will help UBC meet its GBAP climate adaptation goals. One of the benefits of viewing the web map tools linked in this project is the ability to identify which areas impede the ecological connectivity of the UBC campus. These areas of extensive grey infrastructure that limit ecological connectivity are referred to as "deadzones" in this report. Green roof bylaws on campus are more likely to be strengthened if UBC recognizes the importance of decreasing the dead zone area to make progress towards Biodiversity and Climate Adaptation component areas of the GBAP.

UBC has a history of flooding due to crumbling stormwater detention tanks and outfall facilities, therefore the emerging GBAP is interested in novel nature based solutions to stormwater management on campus. Green infrastructure such as bioswales, rain gardens, green walls, green roofs and green corridors are examples of biophilic design elements that help mitigate the stormwater discharge of the UBC campus. By utilizing green infrastructure to increase the modularity of soft landscape communities on campus, UBC could become more on track to meet multiple GBAP goals within the Water, Biodiversity and Climate Adaptation component areas. As outlined in a SEEDS report titled “Green Corridor/Green Infrastructure at UBC,” the benefits of a green infrastructure approach to stormwater management include: “stormwater cleansing, reducing stormwater runoff quantities, enhancing sense of place, adding and re-linking habitat, improving stream health, moderate microclimate and reducing GHG.” It is also suggested in the report that soft landscapes with more biodiversity likely intercept and retain more stormwater runoff than soft landscapes with less biodiversity (Ossola et al., 2015). The biodiversity component area in the emerging GBAP could include the added benefit of increased stormwater retention when landscapes on campus are modified to enhance biodiversity. The ability of mycorrhizal fungi to mediate plant species interactions and therefore have an influence on spatial complexity of a landscape provides an incentive for UBC to increase the abundance of mycorrhizal fungi on campus. Given that UBC is interested in exploring alternative stormwater management strategies, mycorrhizae could be researched as a mechanism that supports progress towards the GBAP component goals of Water, Climate Adaptation, and Biodiversity.

An increase in the resiliency of the UBC campus to climate change impacts is a key objective of the emerging GBAP. One of the Biodiversity component goals is to develop highly functioning landscapes at the building and site scales that facilitate a biodiverse campus. By applying a soft landscape communities design strategy to the green infrastructure at UBC, the ecological connectivity of the soft landscapes on campus will increase. The ecological functioning of these soft landscape community greenspaces will also increase as a result because the network design of the soft landscapes will promote resilience to climate change stressors within the green infrastructure network that is visualized in this report. The emerging UBC Resiliency Initiative could benefit from incorporating the design strategies and recommendations presented in this report to the Initiative's vision. The added benefits of increasing the abundance of mycorrhizal fungi also could encourage resilience within the landscapes at UBC because plants are more drought resistant when mycorrhizal fungi associations are present in the soil horizons. A previous SEEDS report titled “Enhancing Green Networks and Fabrics” featured a section by a Faculty of Forestry Graduate student, Eva Snyder, titled “Climate Resiliency in the Urban Landscape.” In the section, Snyder discusses the potential drought resistance benefits that may arise if UBC were to experiment with restoring the symbiotic fungi associations of the vegetation on campus. The idea of learning from mycorrhizal fungi to frame climate change resilience strategies in an urban landscape is quickly gaining recognition within communities of biophilic designers. For thousands of years First Nation communities have told stories about how everything is connected. Now is the time to listen, learn, and integrate traditional ecological knowledge to UBC policies.

Incorporating the proposed soft landscape communities design strategy to the upcoming GBAP provides co-benefits that align with the Health and Welbeing component area. In addition to providing stormwater management benefits, green infrastructure also provides cultural ecosystem services for UBC. The benefits of exposure to greenspaces such as attention restoration, well being, and mental health are now clear in the scientific literature (Söderlund, 2019). This SEEDS report has focused on what we can learn from mycorrhizal fungi that can be applied to policy alignment at UBC. The themes that we can draw from the relationship between mycorrhizal fungi and their plant symbionts include reciprocity, collaboration and mutualism. UBC could look to mycorrhizal fungi as an inspiration for the collaboration that is needed to glue together the interacting components of our institution's shared vision of a sustainable university campus.

Key Recommendation

- Enhancing biodiversity resilience, stormwater management and climate adaptation can be achieved by implementing biophilic design elements such as green corridors, and green roofs to areas on the UBC campus that display a low degree of network modularity.

Climate Action Plan 2030 (CAP 2030)

The 2020 Climate Action Plan focused on climate change mitigation tactics to reduce GHG emissions of UBC campus operations. Considering that green corridors and green walls are likely placed adjacent to buildings, these biophilic design elements could contribute to passive design. The CAP 2020 focused on action areas regarding existing buildings as well new buildings. The shading from green corridors and green walls can result in energy savings for new and existing buildings of the UBC campus. The added green infrastructure needed to design modular soft landscape communities would increase carbon sequestration of the UBC campus. With that being said, the design strategies and recommendations showcased in this report have more benefits for climate change adaptation compared to mitigation. There is not enough land area on the UBC campus for vegetation to have a sizable influence on Canada's carbon sequestration targets. There is only one mention of climate change adaptation in CAP 2020. The upcoming CAP 2030 could seek to focus a section of the report on climate change adaptation strategies for the UBC campus because a synergistic combination of mitigation and adaptation is needed if UBC is to effectively respond to climate change. A variety of climate adaptation tactics are possible for UBC such as creating ecological networks on campus that promote the movement of organisms. In CAP 2030, the benefits of green roofs and green walls could be highlighted as a living lab adaptation tactic that supplements CAP 2030. The potential for mycorrhizal fungi to improve green roof functioning could also be examined as part of the campus as a living lab initiative.

Key recommendations:

- Incorporate passive design that accounts for both climate mitigation and adaptation-consider the energy savings for shading of green corridors and green walls, as well as the increased connectivity that results from these biophilic design elements
- Increase urban forest cover for the purpose of mitigating the impacts of the urban heat island effect
- Reduce habitat fragmentation on campus by creating modular ecological networks with green corridors and green roofs that promote the movement of organisms so that UBC is more adapted to local climate change impacts

Bird Friendly Design Guidelines

UBC has previously implemented novel building design strategies to reduce the frequency of bird collisions on the walls of buildings. Bird friendly glass is a common solution that UBC has previously employed to reduce bird collisions. In this project, green walls are presented as a biophilic design element with the purpose of providing a direct vegetated pathway from a soft landscape up to a green roof. Green facades which grow from the ground, and living walls which grow directly from the wall are the two most common types of green walls. A co-benefit of green walls is that they can help reduce the frequency of bird collisions if designed properly (Bird Friendly Building Design, 2019). An added benefit is that green walls (as well as green roofs) also can provide nesting sites, shelter, and food for birds that interact with the UBC campus. Green walls can be implemented as a method for helping to reduce bird collisions at UBC.

Key Recommendations:

- Design green walls that climb from a soft landscape and up onto a green roof so that bird are less likely to collide with walls
- The decision of implementing a green wall is highly dependent on the context of the surrounding environment, therefore a green facade or living wall could be created in areas of the campus where it is easiest given the local context

Metro Vancouver

City of Surrey Green Infrastructure Network

The “City of Surrey Ecosystem Management Study” performed an in depth analysis of the Surrey green infrastructure network in 2011. The study proposed a framework for managing Surrey’s ecosystems that promotes ecological connectivity of all the green infrastructure within the city limits. The City of Surrey based the proposed design of their green infrastructure network with three principles in mind:

1. Preserving large core habitat areas (“Hubs”).
2. Ensuring connectivity between habitat areas (“Corridors”).
3. Providing a diversity of habitat features throughout the City (“Sites”).

This SEEDS report referenced Surrey’s Ecosystem Management Study to create the framework proposed in this report. The Surrey study did not incorporate biomimicry, or visualize the green infrastructure as a node link network. In addition to contributing to UBC’s Climate Action Plan, the City of Surrey could also apply the frameworks that are proposed in this SEEDS report to the City of Surrey’s next Ecosystem Management Study.

Climate 2050 Strategic Framework

Metro Vancouver released their Climate 2050 Strategic Framework in 2018. The report goes over the guiding principles for Metro Vancouver’s climate action plan. The soft landscape communities design strategy proposed in this report could be implemented within climate adaptation frameworks of the next draft of Metro Vancouver’s strategic climate framework. Ecological connectivity has also been explored by the City of Vancouver. Through measuring functional connectivity of three animal species, the City of Vancouver found that the Pacific wren (*Troglodytes pacificus*) has the highest connectivity, the Townsend's vole (*Microtus townsendii*) has the lowest connectivity, and the Douglas squirrel (*Tamiasciurus douglasii*) connectivity is in between the Pacific wren and Townsend's vole.

Provincial

Climate Preparedness and Adaptation

The province of British Columbia is currently developing a Climate Preparedness and Adaptation Strategy. The report has not been published as of now, but it is likely that resilience will be a key consideration for adaptation strategies. The soft landscape communities design strategy could have a place within British Columbia's climate adaptation plan for metropolitan areas that possess networks of soft landscapes.

National

Canada's Climate Change Adaptation Platform

Canada's Climate Change Adaptation Platform is a federal initiative to create climate adaptation priorities. Key actors such as Federal Departments and Agencies, Indigenous Organizations, Provincial and Territorial Governments, National and Regional Organizations/Associations all collaborate to make decision support tools with the desired outcome of increasing the capacity for actions toward climate adaptation. The web map in this report could be featured as a tool to help decision makers identify areas of high and low ecological connectivity in Canadian urban areas. Urban greenspace networks can be strengthened for climate adaptation through implementing a soft landscape communities design strategy.

United Nations

Sustainable Development Goals (SDGs)

"Goal 11: Make Cities and human settlements inclusive, safe, resilient and sustainable"

The soft landscape communities design strategy proposed in this paper promotes a resilient green infrastructure network. Increasing the resilience of the green infrastructure network can help UBC adapt to climate change stressors such as rising temperatures, extreme weather events and biodiversity loss. Creating more soft landscape communities on the UBC campus will help the institution make progress towards the UN SDG 11 locally on campus.

"Goal 15: Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forest, combat desertification, and halt and reverse land degradation and halt biodiversity loss."

Mycorrhizal fungi play a key role in ensuring that the biodiversity of an ecosystem is in balance. By increasing the abundance of mycorrhizae on campus, UBC could help prevent biodiversity loss. Mother trees are hubs of diverse mycorrhizal fungi. These hubs therefore play a crucial role in maintaining the biodiversity of an ecosystem. The central role that mother trees play in facilitating a resilient ecosystem increases the incentive to conserve the remaining mother tree on the UBC campus. The health of soil on campus is also decreasing rapidly with the trend of sprawling grey infrastructure growth. By proposing soil corridors as a method to increase ecological connectivity on campus, soils are more likely to be conserved if their importance for ecological connectivity and mycorrhizae is recognized and valued. If UBC is to meet UN SDG 15, then policy is needed to conserve mothers trees and soil on campus.

UN Framework Convention on Climate Change (UNFCCC)

Since the creation of the UNFCCC in 1994, the organization has focused on climate change mitigation tactics for industrialized countries. Recently the UNFCCC created the Adaptation Committee (AC) with the purpose of incorporating climate change adaptation strategies to the UNFCCC as a whole. The members of the Adaptation Committee could benefit from learning about the soft landscape communities design strategy proposed in this report.

Future Research Questions-Campus as A Living Lab

Can mycorrhizal fungi be manipulated to help maximize belowground carbon storage or sequestration?

What are the measurable benefits of increasing the abundance of mycorrhizal fungi in urban environments?

Can increasing the abundance of mycorrhizae in the soil horizons have a measurable positive impact on the biodiversity or the soil water retention of a greenspace?

Given that UBC is interested in exploring alternative water management strategies, can mycorrhizae be researched as a mechanism that supports progress towards the GBAP component goals of Water, Climate Adaptation, and Biodiversity?

In a GIS, what is an optimized buffer distance of soft landscapes that accounts for dispersal ranges of flora and fauna?

Sensitivity analysis-What patterns can we deduct from changing the buffer distance of the soft landscape node and link network?

Potential layers to add to the web map tools that make the ecological connectivity metric more accurate: Biodiversity? Functional connectivity?

Wildlife corridors and soil corridors listed in the previous section: “Green campus design recommendations that likely require further research”

Can the lifecycle cost of mycorrhizal fungi vs. stormwater management facility be compared?

What are the short and long-term costs of installing and maintaining green campus designs such as green walls?

Key Takeaways

- Greenspaces on campus are full of diverse and interacting species that should be managed at a community scale.
- Increasing soft landscape cover in large deadzone areas helps to increase ecological connectivity
- Biodiverse greenspaces that are connected as a green infrastructure network can help UBC adapt to a changing climate
- Learning from the modular design of mycorrhizal fungi species diversity and applying a modular design to the green infrastructure network at UBC can result in a climate resilient campus that is more equipped to adapt to climate change if urban forest cover is preserved and increased.

Glossary

Soft landscape-Any plant or collection of plants in a defined area

Soft landscape polygon-Any soft landscape that has been identified, then projected as a polygon in a Geographic Information System (GIS)

Greenspace-An area of vegetation in an urban environment that has recreational and/or aesthetic value

Green infrastructure-Natural features such as trees, shrubs, and soil that are specifically designed to fulfill a stormwater management objective.

Bioswale-An area of vegetation that receives stormwater runoff and filters pollutants

Green corridor-A thin strip of soft landscape that facilitates the movement of wildlife

Green wall-Vegetation growing from a vertical surface such as wall

Wildlife corridor-A habitat area that provides a link between wildlife populations that were previously separated due to human activities

Buffer (GIS)- An output polygon drawn with a specified distance around a line, point, or polygon

Resiliency-the ability of a person or material to recover after a disruptive event

Ecosystem services-the benefits that humans receive from natural systems

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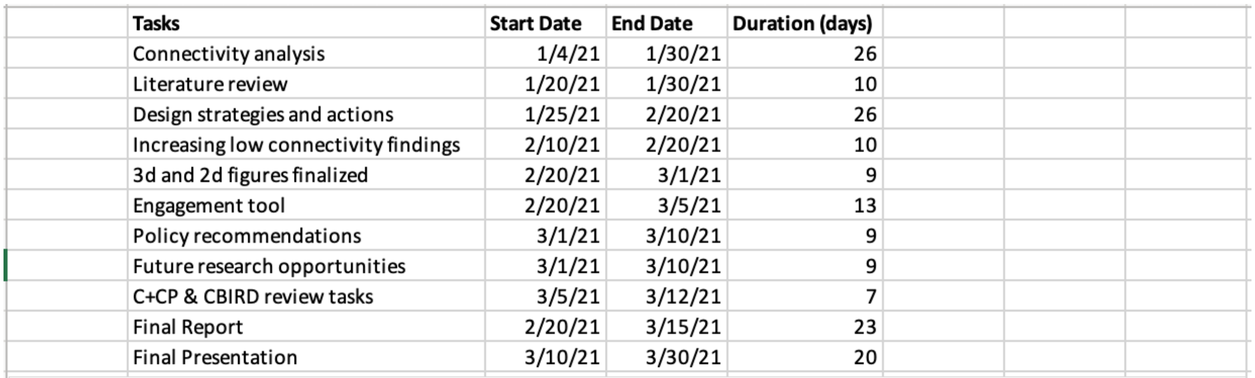
Appendix

Gantt Chart / Timeline



Tasks	Start Date	End Date	Duration (days)
Connectivity analysis	1/4/21	1/30/21	26
Literature review	1/20/21	1/30/21	10
Design strategies and actions	1/25/21	2/20/21	26
Increasing low connectivity findings	2/10/21	2/20/21	10
3d and 2d figures finalized	2/20/21	3/1/21	9
Engagement tool	2/20/21	3/5/21	13
Policy recommendations	3/1/21	3/10/21	9
Future research opportunities	3/1/21	3/10/21	9
C+CP & CBIRD review tasks	3/5/21	3/12/21	7
Final Report	2/20/21	3/15/21	23
Final Presentation	3/10/21	3/30/21	20