Biodiversity-Led Green Infrastructure in a Changing Climate

by

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# Approval

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Abstract

The south coast region of British Columbia, and the neighboring Pacific Northwest US states, Oregon and Washington, are dominated by coastal, marine, freshwater, high alpine, and forest ecosystems. This rich biodiversity has significant social, environmental, and economic value, and includes a unique range of flora and fauna. Development of ecological networks at the regional scale is being globally advocated for as a strategy to responding to growing concern regarding the declining biodiversity while building resilience to climate change. The purpose of this report is to investigate the intersection of the global loss of biodiversity and climate change adaptation planning, and specifically answer the question; what is the best management practice for developing green infrastructure networks as a climate change response that also benefits biodiversity? The research is based on publications on green infrastructure and the growing body of work on advancing nature-based solutions to climate change; it was also guided by the expert opinion provided by an interdisciplinary panel with expertise in the field of green infrastructure. The report provides case-study analyses at various scales, the Yellowstone to Yukon initiative, Chicago Metropolitan area, and the U.S. Army Corps of Engineers’ Engineering With Nature program. These case studies highlight ways of identifying and effectively communicating the benefits to biodiversity of green infrastructure implementation, when using an ecosystem and biodiversity perspective. The findings from this study are synthesized into five broad recommendations for governments in the Pacific Northwest region, particularly highlighting the benefits to be achieved through interdisciplinary engagement and coordinated policy-formulation among various governmental agencies.
**Keywords:** Biodiversity; Climate change adaptation; Green infrastructure; Regional government; Low carbon resilience; Nature-based solutions
Dedication

To Steve.
Acknowledgements

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Executive Summary

The world is witnessing dangerous and unprecedented biodiversity loss at a scale and pace hundreds of times faster than normal (Díaz et al., 2019). This phenomenon is considered by many to have potentially greater impact than the effects of climate change on its own (Ceballos et al., 2015). However, these two global phenomena are not distinct. Climate change, further exacerbated by human-driven habitat loss, unsustainable land and water use, pollution, and urbanization, is wiping out biodiversity around the globe by altering, fragmenting, and shifting habitats and forcing species to migrate (Littlefield et al., 2019; O’Riordan, 2009; Krosby et al., 2010; Shanley et al., 2015). Likewise, ecosystem loss is fueling climate change and its impacts in multiple ways. For example, habitat loss and soil degradation release soil and forest carbon into the atmosphere and reduce potential for carbon absorption, and ecosystem loss exacerbates urban heat and flood impacts (Edmondson et al., 2014).

Meanwhile, nature-based climate change adaptation solutions, such as green infrastructure, are taking hold worldwide as low carbon, economical urban planning approaches with multiple benefits, from climate resilience to human health and wellness to robust property values. However, planning and implementation of these nature-based solutions and protection and restoration of ecosystems and species are largely being approached separately, resulting in missed opportunities to enhance biodiversity while gaining larger-scale benefits from green infrastructure (Salomaa et al., 2017).

The south coast region of British Columbia, and the neighboring Pacific Northwest US states, Oregon and Washington, are dominated by coastal, marine, freshwater, high alpine, and forest ecosystems. This rich biodiversity has significant social, environmental, and economic value (O’Riordan, 2009), and includes a unique range of flora and fauna, such as large carnivores, old-growth forests, important bird areas on the Pacific Fly, and a variety of invertebrate and marine species.

This research report is derived from my contributions to the second phase of the Adaptation to Climate Change Team’s (ACT) work studying the potential for green infrastructure approaches as a nature-based solution to climate change. The research intends to answer the question: what is the best management practice for developing
green infrastructure networks as a climate change response that also benefits biodiversity at a strategic level? This research is based on the findings from a facilitated workshop and a focus group that engaged with a diverse range of professionals working in the field of green infrastructure and nature-based solutions to climate change. Results of these stakeholder engagement sessions are available separately and are directly incorporated into this report, alongside an extensive literature review and case study analysis of green infrastructure and planning and implementing nature-based solutions.

The literature review consisted of recent publications on green infrastructure and the growing work in advancing nature-based solutions to climate change. The report also provides three case studies at various scales to communicate the benefits to biodiversity when taking an ecosystem approach to green infrastructure implementation.

Biodiversity-led green infrastructure represents the intersection between two types of regional planning: that which reduces the impacts of a changing climate and that which responds to the global mass extinction of species and loss of biodiversity. The results of this work identify five policy recommendations for regional governments to advance biodiversity-led green infrastructure as a nature-based solution to climate change.

**Recommendation 1:** Develop a regional biodiversity-led green infrastructure planning process through interdisciplinary engagement.

**Recommendation 2:** Incorporate biodiversity-led green infrastructure as a goal in regional growth strategies.

**Recommendation 3:** Coordinate with policies relating to housing, densification, land use, and transportation to articulate co-benefits.

**Recommendation 4:** Coordinate planning to include existing green infrastructure, initiatives responding to climate change threats to species, and other habitat-connectivity initiatives.

**Recommendation 5:** Co-develop policies, standards, targets, and reporting strategies with municipalities to employ biodiversity-led green infrastructure across jurisdictional boundaries.
Chapter 1. Introduction

Climate change is causing, and will increasingly drive, complex challenges in the form of increased flooding, heatwaves, sea level rise, droughts, and other extreme weather events and their side effects such as wildfires, while stressing ecosystems and adding new impacts such as climate-driven species migration (Demuzere et al., 2014; Krosby et al., 2010). Governments, professional practitioners, and communities are faced with the need to both reduce emissions and adapt to these changes while building resilience, as well as respond to the global decline in biodiversity and the increasing rate of species extinction (Matthews, et al., 2015; Díaz et al., 2019).

Most decision-making processes require structured and long-term approaches to planning and risk management, resulting in barriers in responding to climate change. Climate change responses should be adaptable and accommodate uncertainty (Matthews et al., 2015). Past policy approaches have valued the economy over the environment using cost-benefit analyses, resulting in path dependent and vulnerable systems designed with single, siloed purposes in mind (Matthews et al., 2015). As a result, economic growth has come at a significant cost to the environment resulting in habitat degradation and loss, and a global decline in biodiversity (Díaz et al., 2019).

Ecosystems provide an essential part of the climate change solution, helping to buffer against and reduce the impacts of floods, heat, and other extreme weather events, absorb and filter greenhouse gases, nourish biodiversity, and foster human health and well-being (Díaz et al., 2019). However, development- and climate change–based factors have resulted in the disruption of ecosystem flows and species migration, which is particularly problematic at a regional scale (Díaz et al., 2019). In particular, human influences since the Industrial Revolution have resulted in a rate of species loss and ecosystem degradation now being referred to as dangerous and unprecedent (Díaz et al., 2019). Since 1900, native species in major land-based habits have fallen by 20%; since 1970, invasive alien species have risen by 70%. Around the world, 40% of amphibian species, 33% of reef-forming corals, and 33% of all marine mammals are considered threatened (Díaz et al., 2019). Although the rate and scale to which
biodiversity is declining varies across the globe, research states that all ecosystems are threatened if no action is taken (Ceballos, et al., 2017). This has serious implications for human well-being; for instance, when urbanization causes the degradation of ecosystems and the services they provide, this impacts the physical, psychological, and economic well-being of communities (Beatley, 2016). Specifically, notable findings from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) summary of its global assessment on biodiversity and ecosystem services note, “land degradation has reduced the productivity of 23% of the global land surface, up to US$577 billion in annual global crops are at risk from pollinator loss and 100-300 million people are at increased risk of floods and hurricanes because of loss of coastal habitats and protection (Díaz et al., 2019).”

In light of these challenges, it is crucial to consider the fact that collaborative, regionally-integrated urban planning and ecosystem management practices have the potential to restore, protect, and maintain ecosystem health, while reducing emissions and building climate resilience, an approach known as low carbon resilience (LCR). LCR means integrating the two streams of climate action – mitigation and adaptation – in order to produce responses to climate change that build resilience while reducing emissions (Harford & Raftis, 2018). Government support for climate action–oriented policies is growing at the municipal, provincial, and federal level; however, equally urgent planning is also required to prioritize strategic protection of key habitats and reversal of the loss of biodiversity. Enabling species to adapt to climate change by moving across the landscape as temperature, habitat, and food availability changes will require connecting fragmented landscapes through networks and matrices of protected corridors and green spaces (Krosby et al., 2010). As urban communities struggle to adapt to climate change and reduce emissions, development and pollution will continue to put pressure on the natural environment. As a result, protecting and restoring ecosystems will become increasingly vital to the well-being of humans and wildlife alike (Campbell et al., 2009).

Green infrastructure has the potential to be a useful approach to provide habitat for species that are either being displaced due to urbanization (Meerow & Newell, 2017) and/or experiencing climate change-induced range shifts (Matthews et al., 2015). The definition of green infrastructure provided by Metro Vancouver’s Connecting the Dots: Regional Green Infrastructure Network Resource Guide (2015) is used in this report: the
natural vegetation, soils, water and bioengineered solutions that collectively provide society with a broad array of products and services for healthy living.

Simply employing green infrastructure does not guarantee improved biodiversity presence and health; however, taking a detailed biodiversity-led, multifunctional approach can maximize ecosystem service provision and reduce the impact urban growth has on biodiversity loss while achieving multiple co-benefits (Connop et al., 2016).

This report discusses the growth in adoption of green infrastructure as a nature-based solution to climate change in the Pacific Northwest (PNW), with specific attention to two areas: the benefits green infrastructure may have for biodiversity if planned strategically, and the role urban areas can play in limiting biodiversity\(^1\) loss while building LCR to the impacts of climate change. By addressing these two areas, this research responds to the question of how can green infrastructure planning at the regional scale respond to the nexus of these two global phenomena?

Although biodiversity-led green infrastructure is an emerging approach, regional planning can draw on existing and emerging research and practices focused on ecosystem connectivity, nature-based solutions to climate change, low-impact development, urban greening, natural asset management, and low carbon resilience (Harford & Raftis, 2018).

1.1 Research Methods

This project was guided by inputs provided through a panel of experts working in the field of planning and implementation of solutions pertaining to green infrastructure and climate change adaptation. This panel included representatives from NGO’s, local, regional, and Indigenous governments, as well as urban planners, biologists, lawyers,

\(^1\) For the purposes of this report, the definition of biological diversity provided by the Convention on Biological Diversity will be used synonymously with biodiversity, i.e., “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Convention on Biological Diversity, 1992).”
and natural resource managers. The Executive Director of ACT, Ms. Deborah Harford, was responsible for organizing three working group sessions of the expert panel. The objective of these sessions was to explore the intersection between climate change, species extinction and the role green infrastructure plays in responding to both crises. The experts served as guides in the research process, providing research material and ideas towards the kinds of case studies that would be useful to express the role green infrastructure plays in responding to the two crises.

As the intersection between biodiversity loss and climate change is an emerging field, and green infrastructure programs are generally still in pilot stages in urban areas, it was determined by the expert panel that producing an exploratory research document that highlights the wide variety of green infrastructure applications would be useful in that green infrastructure, depending on the context, can serve a range of solutions. The idea to explore how green infrastructure has been applied to provide habitat connectivity, ecosystem services, and human health benefits was the result of the three expert panel meetings. The literature review as a result was based on exploring these key themes and provided a framework for conducting the review.

Two common theses arose from the expert working group meetings: biodiversity benefits are often not reported; and, due to species’ migration patterns, a regional approach is required in planning. According to the inputs provided by the experts, biodiversity is often not reported on in the monitoring and evaluation of a green infrastructure interventions. Often green infrastructure if reported on, is evaluated on its benefits to a single species, making a survey of case studies to highlight the biodiversity benefits difficult. Additionally, there is a growing understanding of how species migration patterns are changing and habitats themselves are shifting due to climate change. It means that for green infrastructure to benefit both biodiversity loss and climate change, a regional approach to planning and implementing is essential. The Pacific Northwest, and more specifically the corridor between Metro Vancouver, Metropolitan Area of Seattle, and the Metropolitan Area of Portland was identified as a useful eco-region in considering what an ecosystem approach to planning at the regional scale would look like.

Taking an ecosystem approach to green infrastructure planning is the second phase of a three-phase biodiversity-led green infrastructure planning project for ACT.
The first phase considered the transboundary application of green infrastructure in the Still Creek Watershed between Vancouver and Burnaby, British Columbia. The research outcomes of phase one established that there is an interest in exploring how species can benefit from green infrastructure. The second phase, represented in this report, has established the regional context for green infrastructure planning in the Pacific Northwest. In order to develop appropriate recommendations, the experts utilized their experience working in the Metro Vancouver context to provide recommendations targeted specifically at regional governments. As a result, future research on how green infrastructure in Metro Vancouver can be aligned with regional planning bodies in Washington and Oregon has been established. The cross-border integration of green infrastructure planning is anticipated to be the third phase in the biodiversity-led green infrastructure project facilitated by ACT, which is beyond the scope of this research report.
Chapter 2. The Biodiversity Crisis

Biological diversity is organized based on three attributes,

- composition (habitat type, species present, and genetic diversity within species),
- structure (physical characteristics such as size, or ecological structure),
- function (ecological and evolutionary processes effecting life such as natural disturbances) (Biodiversity BC, 2007a).

A combination of human influences—such as land use and land cover change and pollution beginning during the Industrial Revolution (circa 1750–1850)—has led to an alarming rate of global species extinction, a phenomenon that some scientists are now referring to as the sixth mass extinction (see Figure 1). Vertebrate losses over the last century are approximately 100 times higher than the previous century’s rate (Ceballos et al., 2015). Data on invertebrates and most marine species are less available (Ceballos et al., 2017). This unprecedented influence by humans on earth’s systems, especially since the 1950s, has led many scientists to assert that we have left the relatively stable geological epoch of the Holocene and have now entered the Anthropocene, an epoch defined as a great acceleration of change to many earth systems caused by human intervention (Ceballos et al., 2017).

![Figure 1. Graph describing a highly conservative (left) and conservative (right) estimate of global species extinction rates over time, indicated a steep increase in species loss beginning in the Industrial Revolution (Ceballos et al., 2015).](image)
The global trend toward species decline in population size, range, and genetic diversity can be attributed to a number of complex processes with combined impacts, such as pollution, introduction of invasive species, overexploitation of species, fragmentation of landscapes, and climate change (Solamaa et al., 2017). Specifically in Canada, areas with the highest levels of urban development and regions with the most intensive agriculture are also where the greatest number of species at risk are located (Coristine et al., 2018). Vancouver in particular is home to 100 of the 249 at-risk species in British Columbia alone (Semeniuk, 2019). A decline in species diversity and population has a myriad of impacts, from reducing ecosystem services to affecting the enjoyment and health benefits citizens receive from spending time in natural areas (Beatley, 2016). Unlike some of the impacts associated with climate change, land use and land cover change, and pollution, the loss of species to extinction cannot be reversed (Ceballos et al., 2017). The introduction of alien and invasive species can cause significant negative impacts on local species as well. It is well established, for example, that one invasive pathogen, *Batrachochytrium dendrobatidis*, will threaten approximately 400 amphibians worldwide (Díaz et al., 2019).

The relationship between temperature and habitat has always been a significant driver for species migration, either seasonally or throughout variations in historic average temperatures (Littlefield et al., 2019). Due to climate change, temperatures are expected to rise at a pace beyond that which species are able to adapt to; furthermore, many species will face physical barriers due to habitat fragmentation and urban sprawl as climate-driven migration forces them to move (Krosby et al., 2010). There is a general expectation that species in certain habitats would need to shift a particular distance—in elevation and/or latitude—to continue to experience similar temperatures to those they are adapted to, as local climatic conditions change (García-Valdés et al., 2015).

Although trends are evident, there is difficulty in planning for or around shifts in species range since there will likely be differences in responses for individual species (Chen et al., 2011). Habitat fragmentation will have differing impacts as well; some species may be able to shift their ranges from protected patches of habitat or natural areas to other suitable environments, while others’ mobility may be limited due to infrastructure in urban areas of major road networks (García-Valdés et al., 2015).
Research suggests that locating high-risk areas or high-risk species that may not survive without protected corridors between conservation areas could result in the strategic location of protected areas in order to maintain habitat connectivity (Robillard et al., 2015). Protected areas established to secure climate corridors that enable species to migrate are called *climate refugia* (Rose & Burton, 2011).

To create effective climate refugia, protected areas and corridors should be large and within close proximity in order to reduce the impacts of rapid changes in climate and ease species into new habitats. At the same time, defining and monitoring alien or invasive species will become increasingly difficult as the climate changes, so efforts need to begin as early as possible in order to establish baselines for assessment of future species migration (Robillard et al., 2015).

Definitions guiding establishment of connectivity will also consider both the structural and functional aspects of the refugia. Functional aspects are more difficult to define and quantify, while the structure can be easily measured in size and proximity to other relevant spaces, and can be monitored and measured using aerial photographs and spatial planning (Solamaa et al., 2017). The functional aspects of climate refugia are likely to require consistent monitoring and evaluation, using sets of site-specific indicators that consider the complex, dynamic relationship between the built and natural environment to evaluate the health of refugia (Su et al., 2010).
Chapter 3. Conflicting Land Use Pressures in the Pacific Northwest

Data from 2012 suggest that over half of the world’s population already reside in cities and 95% of population increases over the next five decades will occur in urban areas (Coles et al., 2012). Human population trends in North America reflect this pattern; populations are expanding into urban and suburban landscapes, with both the United States and Canada housing approximately 80% of their residents in urban areas (Statistics Canada, 2014; United States Census Bureau, 2010). This trend has created enormous demand for land and resources to sustain growing populations in cities. The combined pressures of low-density housing, automobile dependency in suburban development, and high-density, concrete-and-asphalt-dominated urban centres are resulting in significant ecosystem loss and degradation as cities expand (Biodiversity BC, 2007b).

High-density development in existing urban footprints can also result in significant per capita resource demand and land use conflicts with natural ecosystems. Domestic water use requirements can strain aquifers and other forms of natural storage; food demand requires additional water use and land conversion for agricultural purposes; urban demand for consumer materials depletes additional resources around the globe; waste requires significant landfill storage; automobile use results in disruptive land use requirements for vehicle-based infrastructure; and energy demand causes additional land use and resource concerns. Coupled with population growth, this demand for resources and land can put exorbitant pressure on natural resources, especially at the nexus of water, food, energy, and biodiversity (O’Riordan & Sandford, 2015).
The Pacific Northwest (PNW) region exemplifies these increasing resource and land pressures due to rapid growth in both urban and peri-urban areas. The PNW region is defined by three large, growing metropolitan areas: Seattle Metropolitan Area, Portland Metropolitan Area, and Metro Vancouver. Population growth in this region has been roughly twice the respective countries’ national rates since 1990, with populations in the metropolitan areas of Portland, Seattle and Vancouver more than doubling in number since 1965 (Davis & Schaub, 2005). Despite containing only 17% of the Cascadian land mass—southwestern BC, western Washington and western Oregon—the corridor between these cities contains approximately 80% of the population of the PNW (CascadiaNow!, 2014). The US and Canadian governments have deemed the area spanning Vancouver to Portland an emerging megaregion due to its intertwined

*Figure 2. Three major metropolitan areas of the Pacific Northwest (PNW) indicating urban growth surrounding Portland, Seattle, and Vancouver (Wikipedia, 2019).*
economic and transportation systems, transboundary ecosystems, and shared natural resources (CascadiaNow!, 2014).

The PNW region has maintained a level of economic, environmental, and social cohesion, partly due to the influence of several regional and collaborative governing bodies, such as the Pacific North West Economic Region and the Pacific Coast Collaborative. Targeted ecosystem health and climate strategies have been adopted in various parts of the region (Rice, 2014), such as the North Cascadia Adaptation Partnership, which focuses on the forested and mountainous ecosystems of the Cascades (Raymond et al., 2013), and the partnership between the two federal governments—represented in the US by the United States Environmental Protection Agency and in Canada by Environment and Climate Change Canada—on collaborative marine ecosystem studies of the Salish Sea (United States Environmental Protection Agency (USEPA), 2017).

The growing metropolitan areas of the Cascadia region—Vancouver, Seattle, and Portland—reflect the habitat fragmentation and loss of ecosystems, which, along with climate change and urban growth, are contributing to human and species-related impacts around the world. However, all three urban areas are beginning to adopt green infrastructure approaches within their jurisdictions due to increasing understanding of the benefits of nature-based solutions.

3.1 Biodiversity and Habitat Shifts in the PNW

Climate change is altering the distribution of species in time and space, known as range shifts (Alig & Mercer, 2011). In general, amphibians, birds, and mammals are migrating from their current habitats and converging through the PNW corridor (see Figure 6) (The Nature Conservancy, 2017). In the Pacific region, the loss of biodiversity has been attributed to habitat loss, overexploitation, fragmentation, pollution, invasive species and disease, and climate change (WWF, 2018). Climate change-specific impacts—such as increasing freshwater temperatures, melting glaciers, and land cover changes—are having cascading effects on both marine and terrestrial species.
Monitoring of the Pacific region, for example, has shown a 14% decline since 1970 in populations of species that rely on freshwater ecosystems (WWF-Canada, 2017).

Figure 3. This is a screen capture from The Nature Conservancy’s graphic depicting the directions mammals, birds, and amphibians will move in order to reach new, appropriate habitats under projected climate change (The Nature Conservancy, 2017).

The structure and function of ecosystems within the PNW are being altered through climate change-driven shifts in the geographic ranges of many flora and fauna. This creates further challenges for conservation efforts as species communities, including those currently within protected areas, begin to cross jurisdictional and park boundaries (Johnston et al., 2012). Projected trends show that higher-elevation mammal species will experience significant loss in the size of their geographic ranges as temperatures increase, as they have limited room to migrate higher (Johnston et al., 2012). Species that are incapable of relocating or adapting to local changes fast enough to match the pace of the shifting climate are highly susceptible to local extinctions (Littlefield et al., 2019), while some species are more likely to respond—or have already been identified as responding—to local climatic changes more rapidly than previously thought and faster than management strategies themselves are changing (Díaz et al.,
2019). The compositions of biological communities in the PNW region are likely to change quite significantly due to these range shifts and local extinctions that are being either driven or exacerbated by climate change (Mauger et al., 2015). Importantly for this report, species with habitats within close proximity to urban areas are particularly vulnerable to local climatic changes and are often not given a priority in land use decisions that may impact their presence, richness, and abundance (Rastandeh et al., 2018). The following section briefly describes land use pressures in the three growing PNW metropolitan areas, Metro Vancouver, Seattle Metropolitan area, and Portland Metropolitan area.

3.2 Metro Vancouver

![Figure 4](image-url). A Map of Metro Vancouver’s general urban land use areas which presents the isolated patches of protected green spaces in the darkest green colour (Metro Vancouver, 2018a).

Metro Vancouver is home to 2.5 million people and is projected to grow to over 3.5 million people by 2050. The region contains 21 municipalities, an electoral area, and a First Nation government. The city of Vancouver is currently the most populous at roughly 700,000 residents, followed closely by the city of Surrey (Metro Vancouver, 2018a). The Metro Vancouver region is biologically diverse; however, urban growth is creating implications for the surrounding natural ecosystems and the biodiversity it supports (Metro Vancouver, 2018b).
Boundary Bay in the southwestern part of the region, for example, makes up part of a rich ecosystem that is vital to many migratory and wintering water birds in Canada. This Important Bird and Biodiversity Area (IBA) supports the movement of numerous species of bird populations, including the northern pintail, the western sandpiper, and the great blue heron, as well as significant numbers of barn owls (Important Bird Areas Canada, n.d.). The major threats to this ecosystem are said to be habitat degradation, fragmentation, and ultimately permanent loss (Important Bird Areas Canada, n.d.). The main cause of these threats can be attributed to the overlap of the IBA with Metro Vancouver; the IBA is therefore subject to the ecological consequences of urban development (Important Bird Areas Canada, n.d.). Water contamination and runoff from urban, industrial, and agricultural activities greatly affect the quality of habitats in the region, which is an integral stop along the Pacific flyway for many bird species. Aquatic and terrestrial habitats supporting other species in the region are also impacted by urban growth and climate change, such as the Salish Sea orcas (Cox, 2018), barn owls (Hindmarch et al., 2014), and salmon species (Davis & Schaub, 2005).

3.3 Seattle Metropolitan Area

Figure 5. A map of proposed land uses in Puget Sound from 2012, showing the variety of land uses surrounding the growing Seattle metropolitan area and the greater Puget Sound region.
According to US census data in 2014–2015, Seattle was one of the top five fastest growing cities in the United States. Other cities within King County, of which Seattle is the largest, are also growing at significant rates (Balk, 2016). Urban sources of pollution, and coastal modifications such as seawalls and piers, have resulted in drastic changes to the habitats in shallow environments along the coast of Puget Sound, which many species depend on. Shallow ecosystems are extremely important as they act as nurseries for some species by facilitating the survival and development of many juvenile fish (Munsch et al., 2014).

For example, Pacific salmon—highly valued in the PNW both culturally and economically—are one of the key species affected by shoreline modifications and urbanizing watersheds, since they often keep near to the shore during their migration to and from rivers, in their journey to the ocean. The waterfront area of downtown Seattle and the metropolitan region is a location of significant urbanization causing physical, biological, and chemical degradation to salmon habitat (Spromberg & Scholz, 2011).
3.4 Portland Metropolitan Area

Portland is the largest city in its metropolitan region, which has a population of roughly 2.5 million people and contains five counties in Oregon and two counties in Washington (Njus, 2019). Portland is widely recognized as one of the most environmentally-conscious cities in North America (Biophilic Cities, 2017). Stormwater in Portland, as is typical in all urban areas, causes significant environmental impacts as it acts as a conveyor of a number of pollutants. Pollutants such as fertilizers, pesticides, animal waste, and chemicals from automobiles enter habitats of species resulting in degradation and unhealthy ecosystems (City of Portland, 2004). Portland has responded to its identified stormwater problems by implementing a Green Streets initiative designed to reduce stormwater issues and improve ecological health by absorbing precipitation and floodwater at source (Biophilic Cities, 2017; City of Portland, 2019). The initiative includes strategies to improve and incorporate streetscape vegetation, and to identify unused urban space that can be converted into parkland (City of Portland, 2019). It is supported by various policy tools, including a watershed-scale management plan.
stormwater management manual, Green Street policy, city building eco-roof policy, and a Green Street inventory (City of Portland, 2019b). The city also contains over 4,000 hectares of public parks, one of the highest parks-per-capita ratios in the United States. The park system includes important wildlife areas, such as Forest Park, a regionally connected urban forest reserve, and Oaks Bottom Wildlife Refuge, which also functions as an urban migratory bird park (City of Portland, 1999).

3.5 Impacts on Biodiversity in Major PNW Ecosystems

Changes in local climate affect habitats in a number of ways, which result in added pressure on species to adapt or migrate (Rose & Burton, 2011). The PNW is home to an array of environments, which accounts for the rich biodiversity of the region, including forested, coastal, and riparian ecosystems (O’Riordan, 2009). Cities and major metropolitan areas within the PNW are expanding rapidly and putting pressure on surrounding ecosystems. As a result, species now and in the future will be impacted by the degradation and fragmentation of these ecosystems. The following section highlights three dominant ecosystems and the combined implications for them of a changing climate and continued conflicting land use pressures.

3.5.1 Forested Ecosystems

The distribution, growth, and function of forested ecosystems in the PNW will be affected by climate change and land use pressures in several ways, many of which are already evident. For instance, the health of these ecosystems will be threatened by disturbances such as large increases in fire, disease, insect outbreaks, and natural resource management decisions (Peterson St-Laurent et al., 2018 and Snover et al., 2013). Although forested ecosystems are directly impacted by climate change through alterations to ecosystem markers such as tree species distribution and productivity, the

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2 For the purpose of this research an ecosystem is defined as “A dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit. An ecosystem includes all living things (plants, animals and organisms) in a given area, as well as their interactions with each other, and with their non-living environments (weather, earth, sun, soil, climate, atmosphere). Each organism in an ecosystem has a role to play and contributes to maintaining the health and productivity of an ecosystem (United Nations Water, 2019).
indirect impacts through disturbances will be largely responsible for the changes in structure and function of forested ecosystems in the region (Snover et al., 2013). The productivity of forested ecosystems will be impacted due to changes in local temperature and water availability, accompanied by a reduction in carbon sequestration capacity due to increasing disturbances (Snover et al., 2013).

3.5.2 Coastal Ecosystems

Coastal ecosystems are important to many species in the PNW. Climate change impacts such as saltwater intrusion, erosion, introduction of invasive species, and sea level rise are likely to result in loss of crucial habitats for PNW species (Seabloom et al., 2013). Low-lying areas such as tidal flats, coastal wetlands, and beaches are restricted in their ability to migrate further upslope, making them and the species they support highly vulnerable to coastal erosion and sea level rise (Dalton et al., 2013). Upland habitats are also exposed to storm surges and extreme tide events as erosion along coasts occurs. Beaches, for example, are already experiencing high levels of erosion as the frequency of storm surges increases and sea levels rise damaging buildings and coastal infrastructure (Dalton et al., 2013). Saltwater inundation is also projected to convert coastal freshwater swamp and marsh habitats to salt or transitional marshes. These changes have serious implications for the habitats of many associated species, such as forage fish and shore birds (Dalton et al., 2013).

3.5.3 Riparian Ecosystems

Since riparian ecosystems are heavily reliant on consistent seasonal water levels, climate change and pollution is likely to have significant implications on stream flow and seasonal water temperatures, and water quality (Poffz et al., 2011). Impacts such as droughts, floods, and increasing water temperatures will highly influence the physical and biological compositions of riparian ecosystems. For example, climate change is likely to result in vegetation shifts and allow invasive species to outcompete the native species as they become less adapted to the new conditions (Poff et al., 2011). In addition, pollution from urban areas carried to receiving waters through stormwater runoff is impacting both species and ecosystem health (Peter et al., 2018). Not only will these ecosystems be affected by climate change and pollution, but the ecosystem services they provide—such as water purification and flood protection, will also be
significantly hindered, impacting urban areas in the PNW that currently benefit from these services (Shanley et al., 2015).
Chapter 4. Nature-Based Solutions to Climate Change

*Adaptation* in the context of climate change means planning for responses to the unpredictable and uncertain impacts of a changing climate and to adjust systems in order to avoid harm (Intergovernmental Panel on Climate Change (IPCC), 2014). There is a general understanding of what impacts can be expected based on climate models and observations of trends; however, there is uncertainty of the scale and magnitude of those changes when considering specific locations (Matthews *et al.*, 2015). The application of nature-based solutions (NBS) such as green infrastructure approaches as part of a climate change adaptation strategy can and should benefit biodiversity while building resilience in urban areas.

This is a practical solution, schematically illustrated as the biophysical capacity of green infrastructure in Figure 7 (Matthews *et al.*, 2015). The capacity for green infrastructure as a climate change adaptation response is expressed as a combination of the biophysical capacity of the infrastructure and the socio-political feasibility of its implementation. It means that the extent to which a green infrastructure intervention can perform effectively is based on the capacity of its natural features (biophysical capability) combined with factors such as political will, public knowledge, and available finances (socio-political feasibility). These two overarching factors are further influenced by species characteristics and societal characteristics, respectively; each also has its own spatial limits, which may or may not completely overlap. Nature’s influence, or agency, will also affect design, planning and management decisions about the structure and configuration of green infrastructure. The schematic posits that eventually the biophysical capability and the socio-political feasibility, coupled with climate influences or climate agency, will shape the green infrastructure’s success as an adaptive response (Mathews *et al.*, 2015).

Site-specific green infrastructure approaches have been identified as a mechanism for adapting urban areas to the impacts caused by climate change, such as increasing heat, altered precipitation patterns, and health concerns, as well as increasing energy efficiency and reducing emissions (Connop *et al.*, 2016). The complex multifunctionality of green infrastructure can cause confusion between practitioners,
since it can be implemented to solve multiple problems related to climate change in ways that challenge the traditional structures of local governments and roles of professionals (Sussams et al., 2015). For example, green infrastructure can be seen as a form of capital as it relates to natural asset management, and as a risk buffer as it relates to climate change adaptation (Matthews et al., 2015). The definition of green infrastructure provided by Metro Vancouver’s Connecting the Dots: Regional Green Infrastructure Network Resource Guide (2015) provides useful insight into one interpretation of green infrastructure and its applications:

*Green infrastructure* is the natural vegetation, soils, water and bioengineered solutions that collectively provide society with a broad array of products and services for healthy living. Natural areas such as forests, wetlands and floodplains, and engineered systems like bioswales and rain gardens conserve natural resources and mitigate negative environmental effects, benefiting both people and wildlife. When green infrastructure is connected as part of a larger framework, a green infrastructure network is created.
Nature-based solutions (NBS) literature is increasingly being published in the context of climate change adaptation, particularly in countries within the European Union (Snäll et al., 2016). The NBS approach to adaptation highlights multiple benefits to urban areas through the linkages between scientific programs, nature conservation, and on-the-ground applications (Escobedo et al., 2019). There is a growing understanding, reflected through NBS literature, that protecting and enhancing natural areas can have co-benefits, such as enhancing the livability of dense urban areas, alleviating some of the pressures of poverty, reducing environmental degradation, and mitigating the impacts of climate change (Escobedo et al., 2019). However, when applications of NBS only focus on ecosystem service protection, there is potential to miss opportunities to develop holistic biodiversity conservation strategies that incorporate the above-mentioned co-benefits. Provisioning services, for example, are likely to be given priority.
since they are more easily translated into economic benefits, which may result in a narrow view of an NBS (Salomaa et al., 2017). As the economic benefits of biodiversity are not easily expressed or are less understood, biodiversity is often not considered in adaptation solutions (Salomaa et al., 2017).

In order to manage biodiversity and ecosystem health in urban areas, municipalities are looking toward establishing green infrastructure networks with the intention of making urban areas healthier and more livable (Escobedo et al., 2019). Species-rich communities have been identified as healthier and more resilient, and able to maintain their integrity better than those that are less diverse (Strachan et al., 2016). Likewise, the health of an ecosystem plays a vital role in the quality of the ecosystem services it can provide, such as water filtration, pollinator species habitat, air quality, stormwater management, extreme heat reduction and shading, and carbon sequestration (The University of British Columbia, 2016). Green infrastructure networks in the urban context are established by protecting and connecting natural open and/or undeveloped spaces to restore fragmented ecosystems (Hostetler et al., 2011). Linking green infrastructure networks with concerns associated with biodiversity survival has the potential to reduce pressure on sensitive ecosystems and species in urban areas and play an important role in survival as species’ ranges shift in response to climate change (Connop et al., 2016).

However, the inclusion of biodiversity protection or restoration in urban areas is not often considered in planning for green infrastructure approaches (Salomaa et al., 2017). Including such concepts in the decision-making process changes the dialogue by requiring consideration of how the NBS may benefit ecosystems a solution is connected to (Cortinovis & Geneletti, 2018).

In addition to the benefits to climate change adaptation, NBS applications such as green infrastructure have the potential not only to build resilience but also reduce emissions and as such are considered to be LCR best practice (Harford & Raftis, 2018). Evidence suggests that certain green infrastructure approaches to stormwater management can reduce local emissions through reduced need for pumping and filtering as well as provision of localized cooling, reducing the need for air conditioning (Casal-Campos et al., 2013). They can also extend the life and capacity of grey infrastructure solutions, reducing pressure from extreme precipitation as well as the need for
emissions-intensive replacements (Vineyard et al., 2015). There is also a growing research body on the carbon storage capacity of green infrastructure approaches, where rain gardens and other strategies can have significant carbon absorbing and storage capacity, depending on their size and vegetation type (Spatari et al., 2010).

4.1 Green Infrastructure in the Pacific Northwest

A systems approach to designing and implementing green infrastructure in the PNW requires an inclusive approach that engages the expertise of planners, biologists, architects, engineers, landscape architects, accountants, and decision-makers to design, implement, and manage more resilient ecosystems with benefits for both humans and other species. As noted above, well-designed green infrastructure has inherent multifunctional benefits as it provides environmental, social, and economic ecosystem services (Connop et al., 2016).

The implementation of green infrastructure in the PNW has already been proven to benefit biodiversity in urban ecosystems. In one example, green infrastructure’s effectiveness has been monitored and evaluated by the consistent return of salmon populations after decades of absence in the Still Creek watershed in Metro Vancouver, as well as growing insect populations in the area surrounding the creek (O’Riordan, 2009). Organizations such as Salmon-Safe offer certifications for private landowners and municipalities adopting land-use decisions that reduce the impacts of development on riparian areas and subsequently salmon habitat, and also make an effort to enhance those natural systems. To date, Salmon-Safe has certified over 95,000 acres of farm and urban land in the PNW and California (Salmon-Safe, 2019), which represents a relatively miniscule fraction of salmon habitats and related watersheds.

In another example, the City of Portland offers discounts on their city utility bills to homeowners who build rain gardens on their property as an on-site stormwater management approach (City of Portland, 2019). Similar stormwater management programs exist in Washington State, where Washington State University and Stewardship Partners are leading a campaign to install 12,000 rain gardens in the Puget Sound region, which would capture an estimated 160 million gallons of runoff.
It is evident through these examples that municipalities play a crucial role in land management and urban planning and therefore have a responsibility to plan for conservation and enhancement of green infrastructure at the regional scale (Rodríguez-Loinaz et al., 2018).
Chapter 5. Can Green Infrastructure Benefit Biodiversity?

Green infrastructure has the potential to provide habitat for species that are either losing habitat due to urbanization (Meerow & Newell, 2017) or experiencing range shifts due to climate change (Matthews et al., 2015). In general, it is difficult to establish an understanding of the benefits to biodiversity from green infrastructure approaches since reporting is often site- and species-specific (Rastandeh et al., 2018). However, benefits specifically to biodiversity cannot be assumed through the implementation or protection of NBS without strategic consideration of biodiversity health as a key component of the solution (Connop et al., 2016). For example, planting a single tree species to increase canopy cover in an urban area may provide habitat for birds and some insects, but without considering connectivity to ground-dwelling species and to other natural areas, the system or network will not maximize the potential for biodiversity (Connop et al., 2016). Applications of green infrastructure that prioritize the protection or planting of one species can also result in unintended consequences, such as attracting and spreading pests (Goddard et al., 2010).

A biodiversity-led approach to green infrastructure – that is, taking an “ecosystem approach” to protecting, enhancing, and connecting existing green spaces in urban areas through corridors of green infrastructure – has the potential to benefit biodiversity while adapting to climate change (Connop et al., 2016). Corridors of green infrastructure are planned based on ecosystem boundaries, instead of municipal boundaries. This approach incorporates best practices in the prioritization of species migration corridors, nature-based solutions to climate change, low-impact development, urban greening, and natural asset management.

Measuring or attempting to quantify the benefits to biodiversity from implementing green infrastructure is difficult for two reasons. First, in urban areas there are a number of pressures which impact species to varying degrees, and species’ ability to adapt to change also varies (Su et al., 2010). Pressures such as urban development, pollution, and climate change all combine to make urban areas difficult places for species and ecosystems to not only survive but also to thrive. Second, when measuring biodiversity at the scale in which green infrastructure is most often implemented—for
example, bioswales, rain gardens, green roofs, pollinator gardens, green transportation corridors, and/or the protection of natural areas—there are often no useful baseline data or simple-to-use metrics that can identify whether or not a design has “maximized” the potential for biodiversity (Secretariat of the Convention on Biological Diversity, 2012).

Nevertheless, there are a number of examples of the implementation of green infrastructure that have demonstrated creation of healthy habitats, even where biodiversity was not the primary focus of the projects. By using indicators such as those below from The Government of Queensland, Australia to measure ecosystem health, it is possible to plan for green infrastructure approaches that will benefit biodiversity in the urban context despite the pressures presented by development and climate change.

Indicators of a healthy ecosystem (The State of Queensland, 2018):

1. Physio-chemical indicators: water temperature and salinity, soil nutrients, prevalence of chemicals in both water and soils (e.g., insecticides, herbicides)
2. Biological indicators: diversity of species (population sizes, distribution, and growth rates)
3. Habitat indicators: size, continuity, amount of shade, species composition (range of sexes and ages), erosion or degradation
4. Flow indicators: the ability of water to travel through a system and for species to travel in and out

The relationships and interactions between healthy ecosystem indicators can be used to help guide the design process of individual green infrastructure projects, and help practitioners understand how individual sites fit into ecosystem networks (Cortinovis & Geneletti, 2018). In a healthy and productive ecosystem, all components work together, therefore the physio-chemical, habitat, and flow indicators must be considered in planning for biodiversity survival.

To analyze the benefits of green infrastructure to biodiversity, it is important to understand that a combination of factors in design, location, and structure of systems are at play. Taking the indicators of a healthy ecosystem shown above as an example (The State of Queensland, 2018), we can start to develop strategies and considerations
that are useful for estimating how and where green infrastructure is most likely to result in benefits to biodiversity. By applying a biodiversity-led green infrastructure approach, urban ecosystems are likely to respond more positively to local challenges such as extreme heat events, flooding, and air pollution (Connop et al., 2016). Due to the threats on biodiversity globally, priority consideration should be given to biodiversity when implementing green infrastructure in order to maximize their potential.

There is growing acceptance of green infrastructure approaches by a diverse range of interest groups, including health professionals, biologists, landscape architects, planners, and engineers (Sussams et al., 2015). This uptake is resulting in a patchwork of uncoordinated green infrastructure projects and disconnected green and protected spaces been urban and peri-urban areas (Tzoulas et al., 2007). Designing green infrastructure as a method to enhance the connectivity of existing green spaces, improve the provision of ecosystem services, and advance health benefits are three common approaches in developing green infrastructure. This report proposes that, in order to implement green infrastructure networks that fulfill the maximum potential to both increase resilience in urban areas and provide healthy and biodiverse habitats, green infrastructure planning must be conducted in the context of ecosystems as a whole. The following section provides three useful case studies ranging in scale and scope, offering evidence to support planning of green infrastructure to support biodiversity.

5.1 Planning Green Infrastructure to Enhance Connectivity

Some degree of connectivity is important for all species. When taking an ecosystem approach to the development of green infrastructure, considering the network as a whole will likely benefit all species (Pinho et al., 2016). Using green infrastructure to enhance or protect the connectivity between established natural spaces will therefore benefit biodiversity. There is a proven correlation between the location of a protected natural area and the availability of space—a corridor—for species to travel to another area and enhancement of biodiversity health (Rudd et al., 2002). As climatic conditions change and habitats begin to shift, corridors will likely provide crucial spaces for species capable of shifting ranges.
Transboundary efforts to predict habitat modification and species migration are becoming more common. These models attempt to determine a species’ path of least resistance from habitat to habitat to determine how they might move in the future (McGuire et al., 2016). Examples of this kind of predictive modeling include the Washington-British Columbia Transboundary Climate-Connectivity Project and work by Andrew Shirk at the University of Washington’s Climate Impacts Group (CIG). The CIG is in the process of developing a mapping tool, to be completed by 2020, to demonstrate spatial priorities of species in a changing climate. The tool is expected to account for landscape integrity, connectivity, land facets, and topoclimatic diversity. By identifying climate corridors that will be needed to facilitate species migration, emphasis on protecting certain areas between current and future habitats using green infrastructure can reduce the pressure on species in a changing climate (Shirk, et al., webinar, July 25, 2018).
Connecting natural areas within peri-urban or rural areas using green infrastructure corridors is the current predominant strategy used by much of Europe (Snäll et al., 2016), and the development of ecological networks has been advocated globally as a means of alleviating the ecological impacts of habitat fragmentation (O’Riordan, 2009). These green corridors can benefit urban communities by providing them with green space, meeting areas, and walking/biking routes throughout a city (City of Coquitlam, 2002). Similarly, they benefit non-human species by providing more natural spaces as well as transportation routes between larger areas of habitat throughout urban areas (O’Riordan, 2009). For example, urban gardens can act as important connections between natural areas such as parks and protected areas for some species. Biodiverse gardens can combine to contribute to a larger natural system by providing some necessary habitats and minimizing isolation (Goddard et al., 2010).

In order to manage biodiversity and ecosystem health in urban areas, municipalities could look toward establishing green infrastructure networks by protecting and connecting natural open and undeveloped spaces in order to restore fragmented ecosystems (Hostetler et al., 2011). The following discussion of the Yellowstone to
Yukon Initiative shows how considering the connectivity of protected natural areas by using green infrastructure planning has benefits for biodiversity at the regional scale.

5.1.1 Yellowstone to Yukon, North America

At the regional scale, the Yellowstone to Yukon Conservation Initiative (Y2Y) works with a variety of environmental groups, municipalities, private landowners, and Indigenous communities to ensure migration corridors are protected and when possible enhanced. The initiative’s work spans two territories (Yukon and the Northwest Territories), two provinces (Alberta and British Columbia), and five states (Washington, Oregon, Idaho, Wyoming, and Montana). This equates to an area roughly 1.2 million kilometers squared and extending 3,200 km along the Rocky Mountains (Mattson et al., 2011). Y2Y advocates for land use decisions within the area to take an ecological and landscape-scale approach to management (Yellowstone to Yukon Conservation Initiative (Y2Y), 2019). The Y2Y vision statement encompasses the symbiotic relationship between humans and other species that is required to maintain the natural heritage of the unique corridor; Y2Y is “an interconnected system of wild lands and waters stretching from Yellowstone to Yukon, harmonizing the needs of people with those of nature (Y2Y, 2019).” Y2Y is considered one of the world’s premier “large landscape” conservation initiatives, providing a framework for other regions (Chester, 2015).
Public engagement and long-term planning have been identified as useful tools in locating priority areas for protection to ensure migration corridors remain intact. Tracking and monitoring of Grizzly bear movement with stakeholder engagement and community support has for example allowed for land acquisition along migration corridors to maintain connectivity (Locke & Francis, 2012). This integrated strategy of science and public engagement is required in order to apply conservation and restoration at the landscape scale (Locke & Francis, 2012).

Municipal growth plans are a vital piece to the regional conservation puzzle within the Y2Y corridor. Municipalities have the political, economic, and legal authority to make decisions and create incentives for development that can assist in the protection of migration corridors through their jurisdiction (Aengst, 1999). Municipalities within the Y2Y network, such as the Town of Canmore, have adopted land use planning strategies that embrace their position within a migration corridor, and conduct on-going engagement.
with the community as well as planners, engineers, biologists, and other decision-makers to ensure space for wildlife is not inhibited by development. Examples of green infrastructure like wildlife overpasses along the Trans-Canada Highway ensure the protection and connection of habitats within municipal boundaries are maintained, and also help to serve as a visual aid to educate the public about species migration, increasing both human and wildlife safety (Town of Canmore, 2013).

Although not located directly within the Y2Y initiative area, The City of Edmonton has also adopted urban planning practices that focus on biodiversity and ecosystem health at the regional scale. The boundaries of YZY shown in Figure 10 are described by Wilcox (1998) as permeable and not a sharp delineation based on a single ecoregion or any ecological difference. So, although Edmonton is not located within the Y2Y ‘boundaries,’ it is still useful to consider how migration corridors are managed within close proximity to the YZY area. The adoption of the *Natural Connections* integrated conservation plan by the City of Edmonton as an outcomes-based ecological network strategy that includes specific strategies for biodiversity, community engagement, conservation of natural features, and green infrastructure are complementary to those of the neighboring Y2Y initiative (Beatley, 2016). Edmonton is also a member of the Biophilic Cities network, which promotes the connection and integration of green spaces to protect and enhance habitats throughout the urban and peri-urban environments (Beatley, 2016). The city uses the Biophilic Cities approach to planning by considering the geographic location of the city along the North Saskatchewan River and recognizing the important corridor the river represents for the migration of species as well as uses for the community. Importantly, the city identifies connectivity as a key component in increasing the adaptive capacity of ecosystems as the local climate changes (Beatley, 2016).

Initiatives such as Y2Y, or City of Canmore and the City of Edmonton’s ecologically focused programs are examples of regional planning with a focus on protecting and enhancing ecosystem connectivity that additionally benefit human populations. As local climates change and species migration patterns shift, ensuring there is available space to accommodate these new patterns is one way to protect species and support healthy ecosystems. Approaches such as these require a regional focus and cooperation with a wide variety of knowledge holders. The mountain ranges within this north-south network have served as refugia for species for centuries,
considerably so following colonial occupation of North America (Chester, 2015). The health of this eco-region hinges on the protection, preservation and on-going efforts to reconnect habitat patches in order for species to migrate freely.

5.2 Planning Green Infrastructure to Improve Provision of Ecosystem Services

![Green infrastructure diagram](image)

*Figure 11. Green infrastructure as it relates to both the natural and built environment, illustrating how their interconnections can enhance ecosystem service delivery (Metro Vancouver, 2015).*

Nature-based responses to climate change can address several interrelated issues simultaneously, including urban growth, biodiversity decline, and species migration (European Commission, Directorate-General for Research and Innovation (EC), 2015). Some of these benefits are intrinsically valuable to the ecosystem services all species rely on. Ecosystem service-based climate change adaptation responses offer an adaptive way to address climate change impacts that are low cost, efficient, and sustainable (Ballesteros-Canovas et al., 2017). As a result, there is growing support for green infrastructure approaches that act to enhance ecosystem services. In order to successfully employ these techniques, there is a need to develop system approaches that combine technology, business, finance, governance, regulation, and social
innovation. They also involve working beyond “silos” and engaging with others across disciplines and sectors, as well as systematically involving all stakeholders, including citizens (EC, 2015).

Climate change threatens all four categories of ecosystem services—regulating, provisioning, supporting, and cultural—that are essential to reducing greenhouse gases and preparing for climate change impacts (Boyle & Nichol, 2017). Creation and preservation of green infrastructure provides an effective ecosystem-based response to capture these services. As noted, healthy and connected ecosystems are more resilient to the impacts of climate change (Connop et al., 2016). The following example of the U.S. Army Corps of Engineers’ (USACE) Engineering With Nature approach shows how the implementation of green infrastructure as a nature-based response to climate change to enhance ecosystem services can have benefits for biodiversity while providing solutions to needed environmental problems.

5.2.3 Engineering With Nature, U.S. Army Corp of Engineers

The Engineering with Nature (EWN) guiding principles created by the USACE are holistic, collaborative, cost-effective, socially responsible, innovative, and adaptive (Engineering With Nature, 2018). The EWN program was initiated by the USACE in 2010, and were established by a team of scientists and engineers to be an “intentional alignment of natural and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaboration (Engineering With Nature, 2018).” EWN develops guidance and practical methods to incorporating ecosystem approaches to infrastructure development that are sustainable and resilient. The USACE is responsible for a wide variety of engineered systems including shoreline protection, engineered wetlands, reef rehabilitation and dredging. Traditional forms of dredging can be considerably impactful on the environment which is why the USACE is increasing their use of EWN principles in future projects (Szimanski et al., 2019).

Dredging is a common practice used in rivers globally, in some cases to enhance navigation capabilities (Habersack et al., 2016). To-date this practice has had wide ranging impacts on river hydrology and riparian habitats. There is a growing understanding of the economic, social, and ecological benefits in finding new practices
that protect the ecosystem services rivers provide while minimizing the loss of biodiversity in river habitats (Habersack et al., 2016). In order to develop sustainable dredging practices, efforts to couple scientific knowledge with community and local knowledge are proving to reach both engineering and socioecological goals (Abeyth-Evans, 2018). In a comparative analysis between dredging technique using EWN principles and traditional dredged shoreline material placement practices, it was determined that through collaborative engagement and communication with stakeholders, there is often added ecological, economic, and social benefits that come at no additional cost when using EWN principles (Szimanski et al., 2019).

The Atchafalaya River is an important waterway that is heavily used for the transportation of goods from the Gulf of Mexico to inland communities in Louisiana. It is common for waterways in southern Louisiana to require periodic dredging to remain navigable (Berkowitz et al., 2016). The Horseshoe Bend Island project (see Figure 12) for example demonstrates how using the EWN principles in planning and implementing a dredging project can support the ecosystem service delivery of a river island (Suedel et
By using a multi-factor ecological assessment that considered geomorphic evolution, ecosystem classification and distribution, floral communities, bird species, aquatic invertebrates, soils and biogeochemical activity, and hydrodynamic and sediment transport processes, the USACE were able to identify the benefits of using natural features and materials instead of traditional grey infrastructure techniques to protect navigation capabilities. The project resulted in habitat for floral and avian species, and aquatic invertebrates (Suedel et al., 2015). The island became nesting ground for native wading birds, such as the tricolored heron, snowy egret, and ibis. It also enhanced habitat quality for species of insects and the growth of wetlands and forested wetlands. Ecosystem services such as the filtration of water and sequestering of other nutrients increasing downstream water quality have also been observed (Suedel et al., 2015). The project’s success has been acknowledged through winning a number of awards, including the Dredging and Port Construction, Working, Building, or Engineering with Nature Award in 2017 which recognizes projects that preserve or promote wildlife, reduction of air emissions, water quality, treatment of soils/sediments, community engagement, and sustainability (Engineering With Nature, 2018).

The ecosystem services provided by natural and protected places, and projects using green infrastructure or nature-based practices are valuable in that they, amongst other functions, protect coast lines, enhance air and water quality, and can provide similar functions as engineered infrastructure. The protection and enhancement of these services when planned strategically with an effort to include both scientific knowledge with community engagement, can provide wide ranging ecological, social, and economic benefits. FEMA for example estimates that for every dollar spent on preserving wetlands and other natural defenses will save four dollars in the long run (Texas General Land Office, 2014).
5.3 Planning Green Infrastructure to Advance Health Benefits

Interaction with natural spaces has been identified as beneficial to both the physical and mental health of humans (Beatley, 2016). There is a growing suite of literature that has indicated benefits to humans as their proximity to nature increases. This is particularly important in urban areas; as cities grow and densify, the likelihood of losing natural spaces increases (Rawcliffe et al., 2019). Whether an individual's proximity to nature increases the likelihood of participating in physical activity or by simply viewing and interacting with natural systems, exposure to natural areas has benefits for human health (see Figure 13) (Maas et al., 2009).

This is crucially important as human health impacts associated with climate change, such as asthma and heat stress, are likely to be both caused and exacerbated by the increase in frequency and intensity of extreme weather events (Maas et al., 2009). Mental health is also an important consideration since it is not only crucial to wellness but can be a precursor to other health issues, especially those associated with sedentary lifestyles. There is a growing understanding of the mental health benefits to

Figure 13. Health and well-being benefits from parks and protected areas identified by Scotland’s national overview of the health and well-being benefits from parks and protected areas. It is important to note that everyday contact with nature is needed to realize health benefits (Rawcliffe et al., 2019).
proximity and contact with green space in urban areas (Vujcic et al., 2017). Access to public spaces for example promotes physical activity, provides a space for interactions and relaxation, and offers a reprieve from stressful urban lives, all of which are beneficial for mental health (Nutsford et al., 2013).

Partnerships between health practitioners and environmental planners to develop strategies to benefit human health using green infrastructure are growing (Rawcliffe et al., 2019). For example, research on the “urban nature diet” shows that exposure to natural areas and interactions with a variety of species has a number of health benefits and is one way to promote the human health benefits of proximity to nature. It uses an approach similar to other public health advisory initiatives (e.g., Canada’s food guide) to present the importance of exposure to natural areas. Traveling long distances for a “single serving” of nature will not suffice, just as a single serving of vegetables per day does not make for a healthy diet (Beatley, 2016). The following example of the Chicago Metropolitan Area’s approach to regional planning of green infrastructure networks shows how by considering the benefits to human health biodiversity can also benefit.

5.3.1 Chicago Metropolitan Area, Illinois

A major heat wave in the Chicago area in 1995 caused over 700 excess deaths in a one-week period, demonstrating the significance of extreme weather event impacts on people living in urban areas (Hayhoe et al., 2010). Protecting and enhancing green space is particularly important in the Chicago areas as a regional analysis of surface temperatures in Chicago showed that hardscapes and areas with high and medium intensity development were five to six degrees Fahrenheit warmer than the regional average. This is significant in that as of 2012, impervious surfaces covered roughly 556,000 acres of the region which is equivalent to 8% of the total Chicago Metropolitan area (Chicago Metropolitan Agency for Planning (CMAP), 2014). Biodiversity conservation, protection and enhancement began in the Chicago region in the early 1990’s with the organization of a variety of university groups, government agencies, community groups, and private interests to create Chicago Wilderness (Retzlaff, 2007). The group is considered one of the first regional scale conservation groups to focus on biodiversity at the urban regional scale. The group created the Chicago Wilderness Biodiversity Recovery Plan which is described as a useful example in how collaborative planning can be used even for a topic so broad as biodiversity planning (Retzlaff, 2007).
In 2014, the metropolitan region of Chicago published its regional growth strategy, \textit{GO TO 2040}. The strategy was developed to ensure that growth in the region included a focus on the environment, equity, and other sustainable development principles. In addition, the strategy identifies the benefits of implementing green infrastructure as part of its network approach (CMAP, 2014). A regional green infrastructure network is described by the Chicago Metropolitan Area as “interconnected natural areas make up the region’s green infrastructure network and provide important conservation landscapes for high-quality ecosystems.” Providing a policy framework for future regional growth plans link the benefits of planning green infrastructure strategically, incorporating all scales of green infrastructure; regional, community, and site scale. By incorporating all scales of green infrastructure in one framework the region is working to enhance recreational space, habitats, increase air quality, reduce flood risks, and promote groundwater recharge (CMAP, n.d.).

The regional growth plan aims to increase conservation of green, open spaces from 250,000 acres (2010), to 400,000 acres by 2040. At the community scale this translates to providing all residents with four acres of park space per 1,000 people (CMAP, n.d.). In addition to protecting and enhancing access to open spaces, the regional strategy aims to connect natural spaces with green infrastructure interventions such as greenway planning and best management practices in stormwater management. The \textit{GO TO 2040} plan also calls for 1,348 total miles of greenway across the region by 2040 (CMAP, n.d.).
Figure 14. The green infrastructure network design indicates the use of corridors of green space connecting larger green protected areas in Chicago Metropolitan Area. This core, hub, corridor, and link design facilitates the movement of species between large protected natural areas while providing green spaces for residents of the region (CMAP, n.d.).

Green infrastructure is identified within this plan as being beneficial to the health of both the environment and humans. In the Chicago region, the urban heat island effect and air pollution are of growing concern to human health. Increasing canopy cover will not only reduce local temperatures but also the demand for energy, which is likely to increase in the future (CMAP, 2014). Although the GO TO 2040 plan has a greater focus on the use of green infrastructure approaches to increase livability for humans, it also identified potential benefits to non-human species through the development of protected corridors to support their migration through the region due to climate change (CMAP, 2014).

To date, initiatives such as Chicago’s Green Roofs Program, Green Alleys Chicago, Green Streets Chicago, and the Sustainable Backyards program has increased green space and naturalized areas across the city. For example, as of 2014, the Chicago Green Roofs program has supported the installation of over 5.5 million square feet of green roof vegetation within Chicago city limits, including on its’ own City Hall. In addition, the Green Streets Chicago program, which specifically identifies the usefulness of street trees in reducing the urban heat island effect, enabled the planting of over
70,000 street trees between 1994 and 2014. This increase in canopy cover offers reprieve for humans and other species during extreme heat events (City of Chicago, 2014).

The health benefits of green infrastructure are wide ranging and in the case of Chicago, where urban heat island effects are of particular concern, play a vital role in increasing the livability of heavily urbanized areas. Green roofs in Chicago have been recorded as reducing daytime peak rooftop temperatures by over 3 degrees Celsius (Sharma et al., 2016). Initiatives that promote the implementation of interventions of green roofs are significant in that they can increase energy efficiency and provide cooling capacity, however the strategic coupling of green roofs with a connected network of green spaces will have significantly more cooling capacity in urban areas (Sharma et al., 2016).
Chapter 6. Conclusion

Canada’s most heavily settled areas and regions—the south coast of British Columbia, southern Prairies, and southern Ontario—have the greatest concentration of at-risk species and the lowest percentage of protected space (Coristine et al., 2018). Urgent planning is required to prioritize the protection of key habitats and address the loss of biodiversity in tandem with climate change adaptation (Díaz et al., 2019). The degradation of ecosystems and the services they provide caused by urbanization also impacts the physical, psychological, and economic well-being of communities (Beatley, 2016). Designing future development within urban areas to work with instead of against nature has been identified as a multifunctional adaptation measure which can help to reduce the impacts of climate change. Green infrastructure that is designed to respond with climate change considerations, reflects multifunctionality when input from a variety of professionals across disciplines is included (Sussams et al., 2015). Urban green spaces play a critical role in conserving biodiversity, protecting water resources, reducing urban heat, and sequestering carbon. Municipalities and regional governments therefore play a crucial role in land management and have a responsibility to contribute to planning for conservation and enhancement of green infrastructure at the regional scale (Rodríguez-Loinaz et al., 2018).

Employing green infrastructure and other nature-based approaches to sustainable urban development has the potential to provide a cost-effective response to both the climate crisis and the global decline in biodiversity (Díaz et al., 2019). The IPBES summary of its global assessment report on biodiversity and ecosystem services notes that “nature-based solutions can be cost-effective for meeting the Sustainable Development Goals in cities, which are crucial for global sustainability (Díaz et al., 2019).” In addition, the development of ecological networks at the regional scale has been globally advocated for to alleviate the ecological impacts of urban development while building resilience to climate change (O’Riordan, 2009). Through an evaluation of the three case studies, a review of available literature, and engagement with an expert panel of green infrastructure practitioners, it is evident that biodiversity benefits when green infrastructure is:
1. designed to protect natural area corridors and patches for species migration between larger protected natural areas;  
2. used to enhance the ecosystem services natural areas provide; and,  
3. used to make urban areas healthier places for humans to live in.

Green infrastructure is already proving increasingly popular as a nature-based solution to climate change impacts in urban areas. Simply employing green infrastructure however does not guarantee improved biodiversity health, but by taking a detailed, multifunctionality-focused approach to its planning can maximize ecosystem service provision and help reduce the impact of urban growth on biodiversity loss (Connop et al., 2016). Maximizing the potential for biodiversity benefits includes a protection of habitats and planning green infrastructure networks at the regional scale.

6.1 Challenges in Implementation

The successful implementation of biodiversity-led green infrastructure as a climate change adaptation response will likely face a number of challenges. Planning and cooperation will be required at the watershed, river basin, and other ecosystem-levels where jurisdictional and cultural boundaries do not overlap completely. In addition to on-going engagement between community groups, private land owners, special interest groups, and between layers of government, there are four challenge areas that stood out from this research:

- useful baseline data is often not available regarding biodiversity health;  
- developing a business case is problematic as placing a monetary value on some benefits can be difficult;  
- institutional and human resource capacity is limited for effective implementation across complex state, federal, provincial, municipal, and cultural boarders; and  
- views among different interest groups are often divergent and can often be in conflict, making achieving consensus on approaches difficult.
While considering these challenges, this research has identified a set of recommendations that can alleviate some of these challenges in order to successfully implement biodiversity-led green infrastructure in a changing climate.

### 6.2 Recommendations

Adopting green infrastructure networks at the regional scale with an intentional focus on protecting biodiversity and increasing ecosystem health has been identified as a successful approach to limiting urban development impacts on biodiversity, while simultaneously adapting to climate change and providing multiple co-benefits (Connop et al., 2016). The IPBES recommends five interventions that will generate the transformational change necessary to reduce the degradation of land and the decline of global biodiversity (Díaz et al., 2019):

1. develop incentives and build capacity,
2. develop cross-sectoral cooperation,
3. take pre-emptive action,
4. apply decision-making strategies in the context of resilience and uncertainty, and
5. develop and implement environmental laws.

Municipalities and governments of the PNW, along with regional district staff, could work together to consider how existing plans, strategies, and resources can be coordinated and updated in order to implement strategies that employ nature-based solutions to climate change. The following existing regional governance resources are examples for how Metro Vancouver should be utilized to establish a biodiversity-led green infrastructure network at the regional scale that advances low carbon resilience while supporting biodiversity survival in a changing climate. Other regional governments in the PNW could use similar plans and strategies within their jurisdiction to integrate green infrastructure planning with existing policies.

Metro Vancouver’s regional growth strategy, *Metro Vancouver 2040: Shaping Our Future*, includes Goal 3: Protect the Environment and Respond to Climate Change Impacts. Within this goal, Strategy 3.1: Protect conservation and recreation lands, and
3.2: Protect and enhance natural features and their connectivity, specifically identify the role Metro Vancouver plays in the protection and enhancement of natural areas while responding to the impacts of climate change (Metro Vancouver, 2017). However, the opportunity to respond to the intersection between climate change and the decline of biodiversity is missed if the regional government does not explicitly acknowledge the potential of biodiversity-led green infrastructure as a natural solution to the two problems.

Similarly, the *Climate 2050 Strategic Framework* outlines ten issue areas where climate change is likely to pose a threat to communities in the region. These issue areas—such as nature and ecosystems, infrastructure, human health and well-being, and buildings—all identify climate change challenges that could be addressed by employing biodiversity-led green infrastructure (Metro Vancouver, 2018b). For example, when planned strategically, biodiversity-led green infrastructure approaches could enhance and protect natural areas; reduce pressure on stormwater infrastructure during heavy rainfall events; increase air quality and improve residents’ access to green space, benefiting physical and mental health; and lower emissions by reducing the need for some energy-intensive cooling systems.

The “*Connecting the Dots: Regional Green Infrastructure Network Resource Guide*” provides advice and information to member municipalities on where and how to develop green infrastructure networks in the Metro Vancouver region (Metro Vancouver, 2015). This document is useful for its recommendations, yet ecosystems—especially those in transboundary areas—continue to be degraded due to a lack of mandated policies for the production of green infrastructure with specific considerations of biodiversity and climate change adaptation.

Finally, Metro Vancouver’s *Ecological Health Framework* has already identified the five key challenges in developing and implementing a regional green infrastructure strategy. The challenges identified are climate change, connectivity and habitat loss, environmental contamination, invasive species, and data gaps in baseline information on species (Metro Vancouver, 2018c). Addressing these challenges will protect biodiversity and build resilience to climate change in Metro Vancouver.
By reviewing literature on green infrastructure and nature-based solutions to climate change, conducting case study analysis, and engaging with experts in the field of green infrastructure planning and implementation, I have compiled five recommendations to advance biodiversity-led green infrastructure at the regional scale that complement the interventions described above in the IPBES report (Díaz et al., 2019).

**Recommendation 1:** Develop a regional biodiversity-led green infrastructure planning process through interdisciplinary engagement with professional sectors, rural and peri-urban communities, local community groups, First Nations, and non-Indigenous governments.

**Recommendation 2:** Incorporate biodiversity-led green infrastructure as a goal in regional growth strategy updates and provide members with support to develop regional context statements that facilitate cooperation across municipal boundaries.

**Recommendation 3:** Coordinate with policies relating to housing, densification, land use, and transportation to articulate co-benefits and to complement and facilitate the development of a regional biodiversity-led green infrastructure network.

**Recommendation 4:** Coordinate planning to include existing green infrastructure, initiatives responding to climate change threats to species, and other habitat-connectivity initiatives in the Pacific Northwest, in order to capture macro-scale benefits and promote landscape connectivity.

**Recommendation 5:** Co-develop policies, standards, targets, and reporting strategies with members to employ biodiversity-led green infrastructure across jurisdictional boundaries in areas such as stormwater and water quality, land use, and development.
References


