SFU ACT Adaptation to Climate Change Team

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Background Report: **Biodiversity-Led Green Infrastructure in a Changing Climate**

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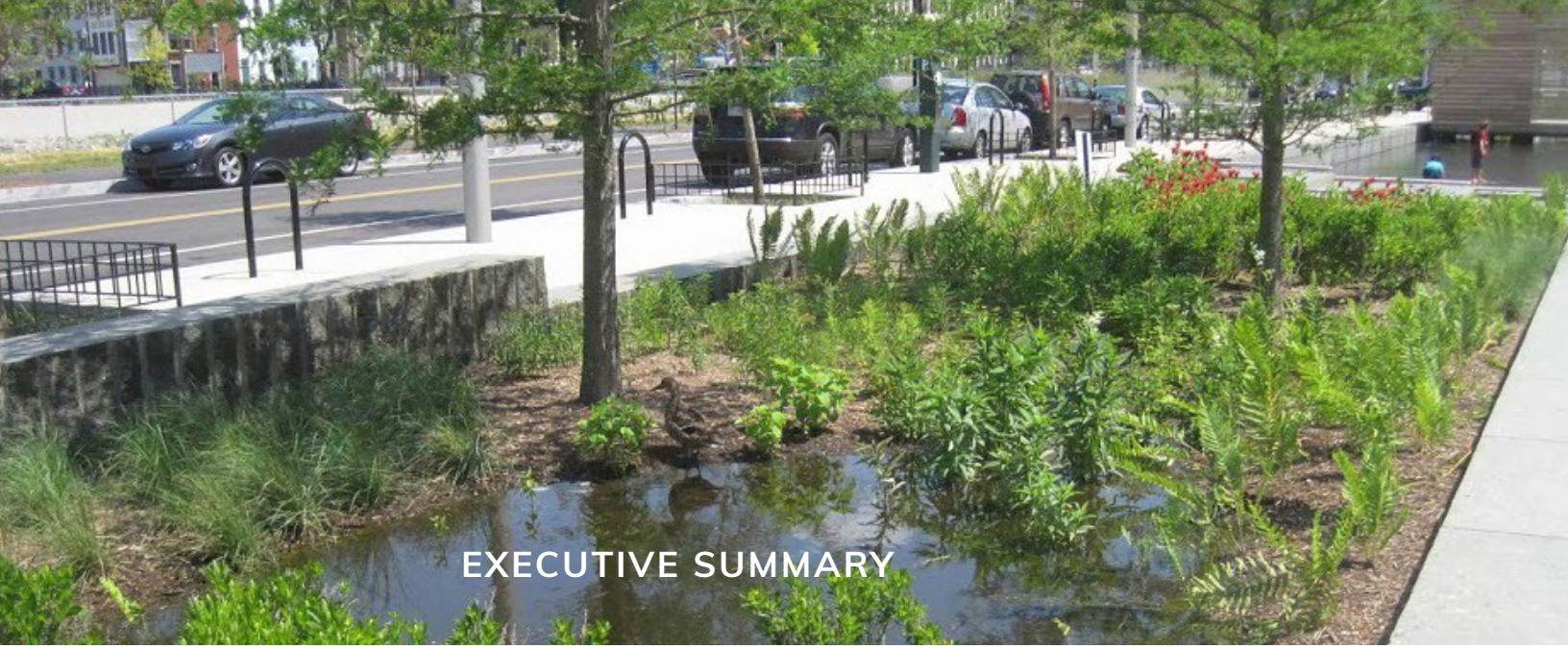


EXECUTIVE SUMMARY

This background report is the culmination of the second phase of ACT's work studying the potential for green infrastructure approaches as nature-based solutions to climate change. The second phase included facilitating a workshop and a focus group that engaged with a diverse range of professionals across sectors working in the field of green infrastructure and natural assets as well as climate solutions. Results of these stakeholder engagement sessions are available separately and also incorporated into this report, which provides the results of an extensive literature review of green infrastructure and nature-based solutions. The report also provides seven brief case studies at various scales designed to communicate the benefits to biodiversity that can be achieved by taking an ecosystem approach to green infrastructure implementation.

The world is witnessing the sixth mass extinction, with biodiversity loss occurring at a scale and pace hundreds of times faster than normal.[1] This phenomenon is considered by many to have potentially greater impact than the effects of climate change on its own;[2] however, these two global crises are inextricably linked. Climate change, in addition to 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.[3,4,5,6] Meanwhile, ecosystem loss is fuelling 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 sequestration, and ecosystem loss exacerbates urban heat and flood impacts,[7] which are also associated with increased emissions.

Uptake of nature-based climate change adaptation solutions, such as green infrastructure, is taking hold worldwide as these approaches emerge as low carbon, economical responses with multiple benefits for climate resilience, human health and wellness, and property values. However, planning and implementation of nature-based solutions, and the conservation and restoration of ecosystems and species, are largely being approached separately, resulting in missed opportunities to help biodiversity

survive in a changing climate while gaining larger-scale low carbon resilience benefits from green infrastructure.[8]

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. In order to maximize the potential benefits of biodiversity-led green infrastructure and avoid building in additional risks and vulnerabilities, it is essential to respond at a regional scale with approaches that include transboundary cooperation and engagement with a wide variety of professional practitioners and knowledge holders.

This approach has great relevance for the south coast region of British Columbia, and the neighboring Pacific Northwest US states, Oregon and Washington, which are home to ecozones dominated by coastal, marine, freshwater, high alpine, and forest ecosystems. This rich biodiversity has significant social, environmental, and economic value,[9] and includes a unique range of flora and fauna, such as large carnivores, old-growth forests, and ungulates. The region also preserves important stopovers on the Pacific flyway for millions of migratory birds. Many cities in the Pacific Northwest are considering green infrastructure approaches, and could benefit species survival through strategic regional planning in this regard.

The results of this work identify three key steps to advancing biodiversity-led green infrastructure in the Pacific Northwest as a nature-based solution to climate change: 1. convene an interdisciplinary community of practice, 2. consider how a regional green infrastructure approach aligns with other regional strategies, and 3. consider linkages to peri-urban and rural areas.

INTRODUCTION

Climate change is causing, and will increasingly drive, complex challenges in the form of 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.[10,11] Governments, professional practitioners, and community residents 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.[12,13]

Due to uncertainty associated with the rate and scale of climate change and its impacts, it is necessary to ensure that responses are adaptable.[14] Past policy approaches have valued the economy over the environment, resulting in path-dependent, vulnerable systems designed with single, siloed purposes in mind.[15] 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.[16]

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.[17] 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.[18] In particular, human influences since the Industrial Revolution have resulted in a rate of species loss and ecosystem degradation now being referred to as the sixth mass extinction.[19] Since 1900, native species in major land-based habitats 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 threatened.[20] Although the rate and scale at which biodiversity is declining varies across the globe, research states that all ecosystems are threatened if no action is taken.[21] 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.[22] Notable findings from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)' summary of its global assessment report on biodiversity and ecosystem services state that "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."[23]

In light of these challenges, it is crucial to consider the possibility that regionally-integrated urban planning and ecosystem management practices have the potential to restore, protect, and maintain ecosystem health, while providing reducing emissions and building climate resilience, an approach known as low carbon resilience (LCR). 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.[24] As urban communities struggle to adapt to climate change and reduce emissions, while development and pollution continue to put pressure on the natural environment, protecting and restoring ecosystems will become increasingly vital to the well-being of humans and wildlife alike.[25]

Green infrastructure has the potential to be a useful tool to provide habitat for species that are either being displaced due to urbanization[26] and/or experiencing climate change-induced range shifts.[27] The definition for green infrastructure provided by Metro Vancouver's *Connecting the Dots: Regional Green Infrastructure Network Resource Guide* (2015)[28] 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, multi-functional approach can maximize ecosystem service provision and reduce the impact urban growth has on biodiversity loss while achieving multiple co-benefits.[29]

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 loss while building LCR to the impacts of climate change. 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."[30]

Although biodiversity-led green infrastructure is an emerging approach, it is clear that 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.[31] The research for this project was informed by the work of experts specializing in climate change adaptation, local, regional, and Indigenous government, urban planning, and biology. Key themes and insights were developed through a workshop, a focus group, and a national webinar with professional practitioners, government representatives, NGOs and researchers.

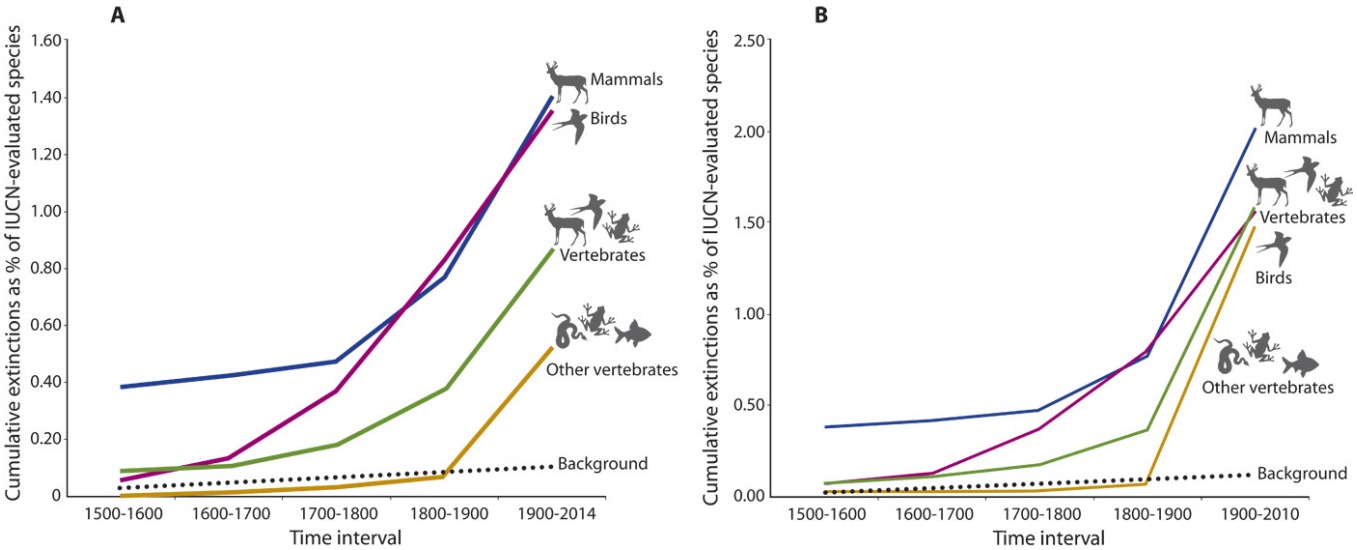
THE BIODIVERSITY CRISIS

Biodiversity is organized at various levels, including:

- species level (different kinds of organisms found on Earth),
- population level (individuals of a specific species within a region),
- community level (all populations within a region), and
- ecosystem level (a biological community in which organisms interact with the physical environment).[32]

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 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;[33] however, data on invertebrates and most marine species are less available.[34] This unprecedented influence by humans on the 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 entered the Anthropocene, an epoch defined as a great acceleration of change to many earth systems caused by human intervention.[35]

Figure 1. **Graph describing a highly conservative (left) and conservative (right) estimate of global species extinction rates over time.[36]**



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.[37] 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.[38] Metro Vancouver, for instance, is home to 100 of the 249 federally-listed species at risk found in British Columbia.[39] 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.[40] 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.[41] The introduction of alien and invasive species can cause significant negative

impacts on local species. For example, one invasive pathogen, *Batrachochytrium dendrobatidis*, threatens approximately 400 amphibians worldwide.[42]

The relationship between temperature and habitat has always been a significant driver for species migration, either seasonally or throughout variations in historic temperature.[43] Due to climate change, temperatures are expected to rise at a pace beyond that to which species are able to adapt; furthermore, many species will face physical barriers due to habitat fragmentation and urban sprawl as climate-driven migration forces them to move.[44] There is a general expectation that species in certain habitats will 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.[45] Although such 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.[46]

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.[47] Research suggests that identifying 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.[48] Protected areas established to secure climate corridors that enable species to migrate are called *climate refugia*.[49] To create effective climate refugia, protected areas and corridors should be large and within close proximity to one another 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.[50]

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.[51] 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.[52]

LAND AND RESOURCE PRESSURES IN THE PACIFIC NORTHWEST

Data from 2012 suggest that over half of the world's population already resides in cities and 95% of population increases over the next five decades will occur in urban areas.[53] 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.[54, 55] This trend is creating 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.[56]

Figure 2. **Three major metropolitan areas of the Pacific Northwest: the Portland and Seattle Metropolitan Areas and Metro Vancouver.[58]**

High-density development in existing urban footprints can also result in significant per capita resource demand and land use conflicts. 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 resources around the globe; waste requires significant landfill storage; automobile use results in large-scale land use requirements for vehicle-based infrastructure; and energy demand causes additional land use and resource pressures. Coupled with population growth, this exploding level of demand for resources and land is putting exorbitant pressure on natural resources, especially at the nexus of water, food, energy, and biodiversity.[57]

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 contains three large, growing metropolitan areas: the Portland Metropolitan Area, the Seattle 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.[59] 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.[60] The US and Canadian governments have deemed the area spanning Vancouver to Portland an emerging megaregion due to its intertwined economic and transportation systems, transboundary ecosystems, and shared natural resources.[61]

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 NorthWest Economic Region and the Pacific Coast Collaborative. Targeted ecosystem health and climate strategies have been adopted in various parts of the region,[62] such as the North Cascadia Adaptation Partnership, which focuses on the forested and mountainous ecosystems of the Cascades,[63] 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.[64]

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

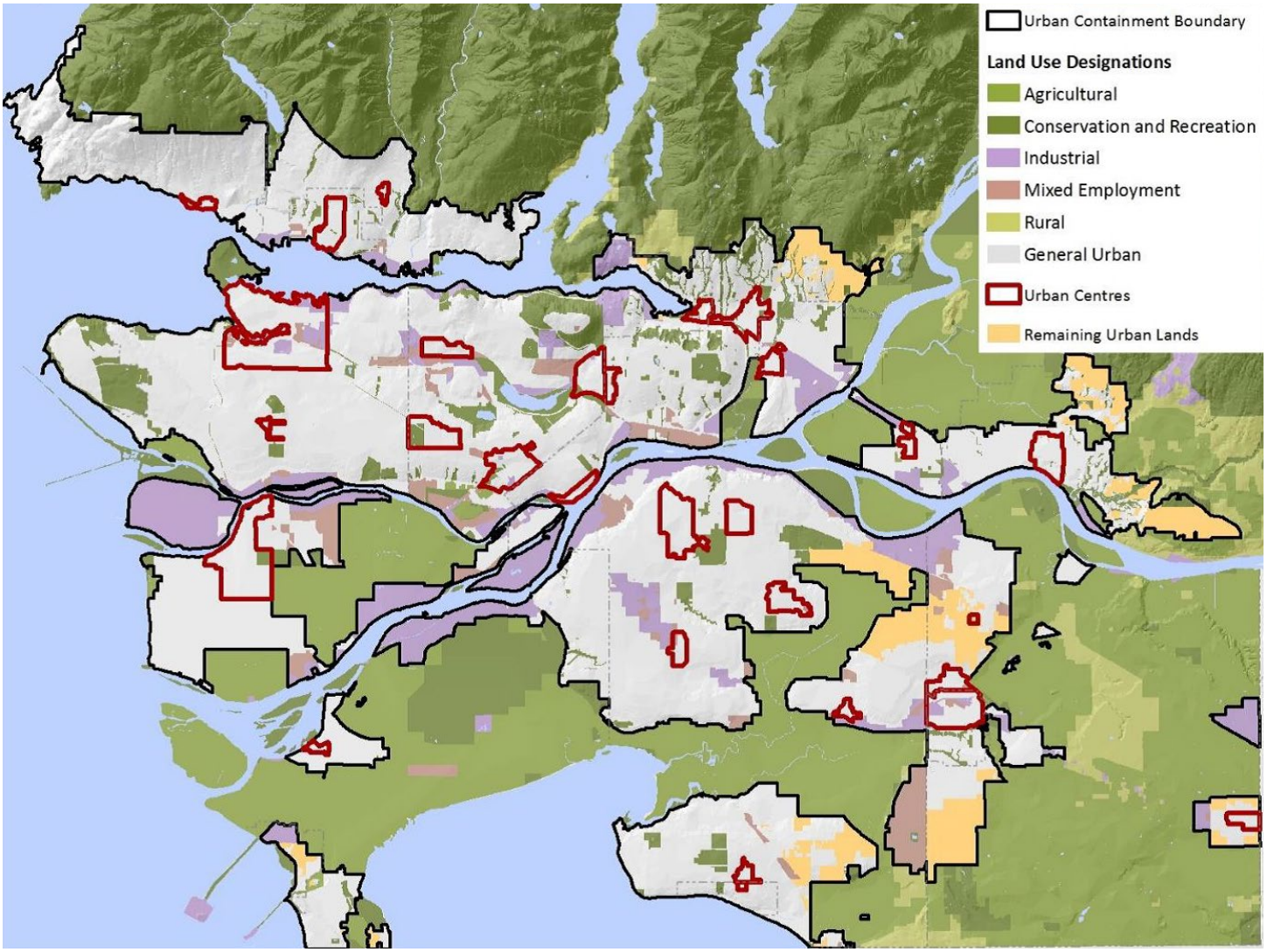
human- and species-related impacts around the world. However, all three urban areas are beginning to adopt green infrastructure approaches within their jurisdictions, due to increasing understanding of the benefits of nature-based solutions to climate change and other impacts. The following section briefly describes each metropolitan area, and provides context for the application of green infrastructure approaches.

Metro Vancouver

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.[66] The Metro Vancouver region is biologically diverse; however, urban growth is creating implications for the surrounding natural ecosystems and the biodiversity it supports.[67]

For example, Boundary Bay, in the southwestern part of the region, 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.[68] The major threats to this ecosystem are cited as habitat degradation, fragmentation, and ultimately permanent loss.[69] 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

Figure 3. **A Map of Metro Vancouver's urban land use areas.[65]**

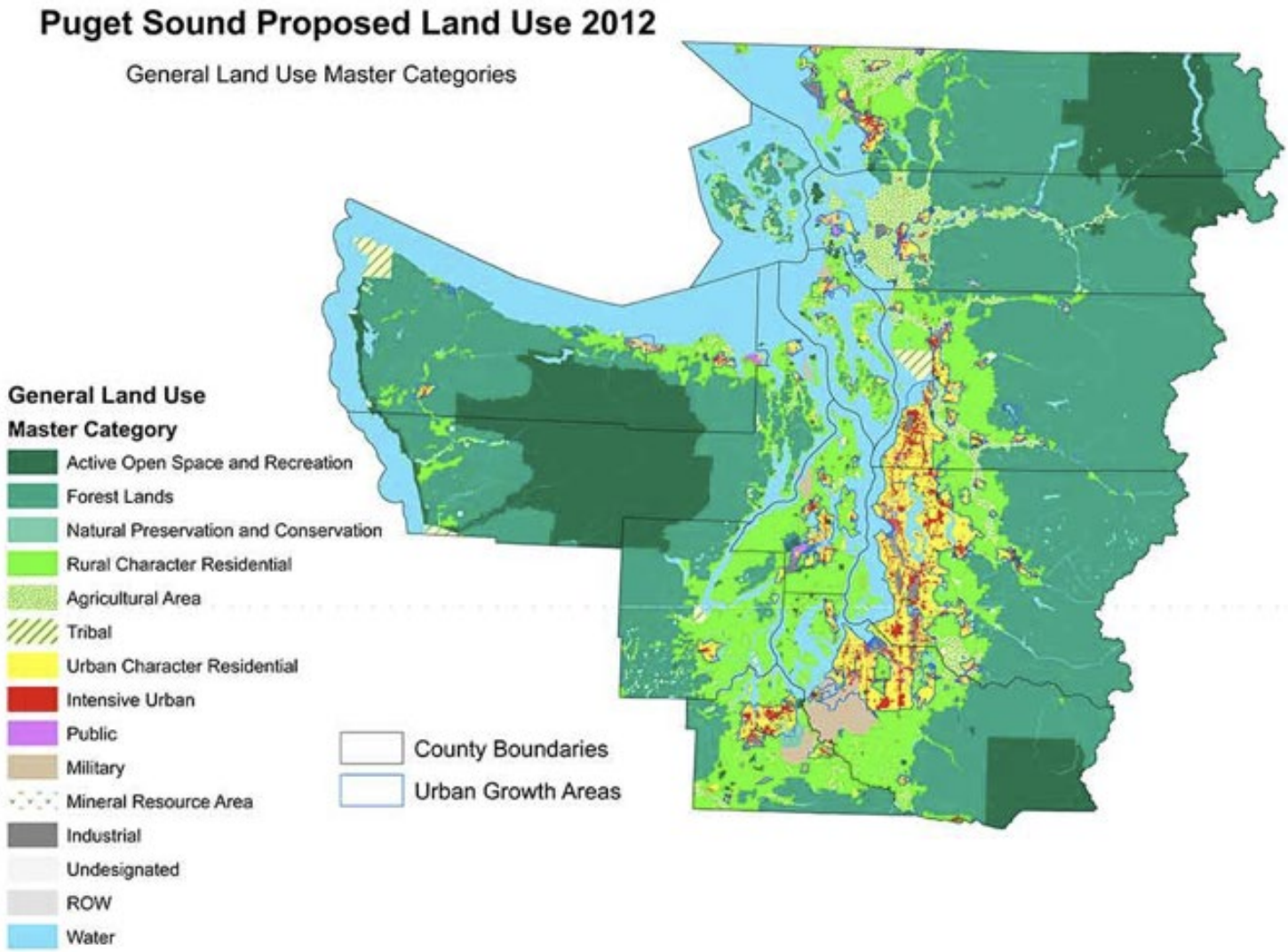


of urban development.[70] Water contamination and runoff from urban, industrial, and agricultural activities greatly affect the quality of habitats in the region, which is an integral stop along the Pacific flyway for many bird species. Aquatic and terrestrial habitats supporting other species in the region are also impacted by urban growth and climate change, affecting wildlife such as the Salish Sea orcas,[71] barn owls,[72] and salmon species.[73]

Seattle Metropolitan Area

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.[75] 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, on which many species depend. These shallow ecosystems act as nurseries for some species by facilitating the survival and development of many juvenile fish.[76] For example, Pacific salmon, which are 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.[77]

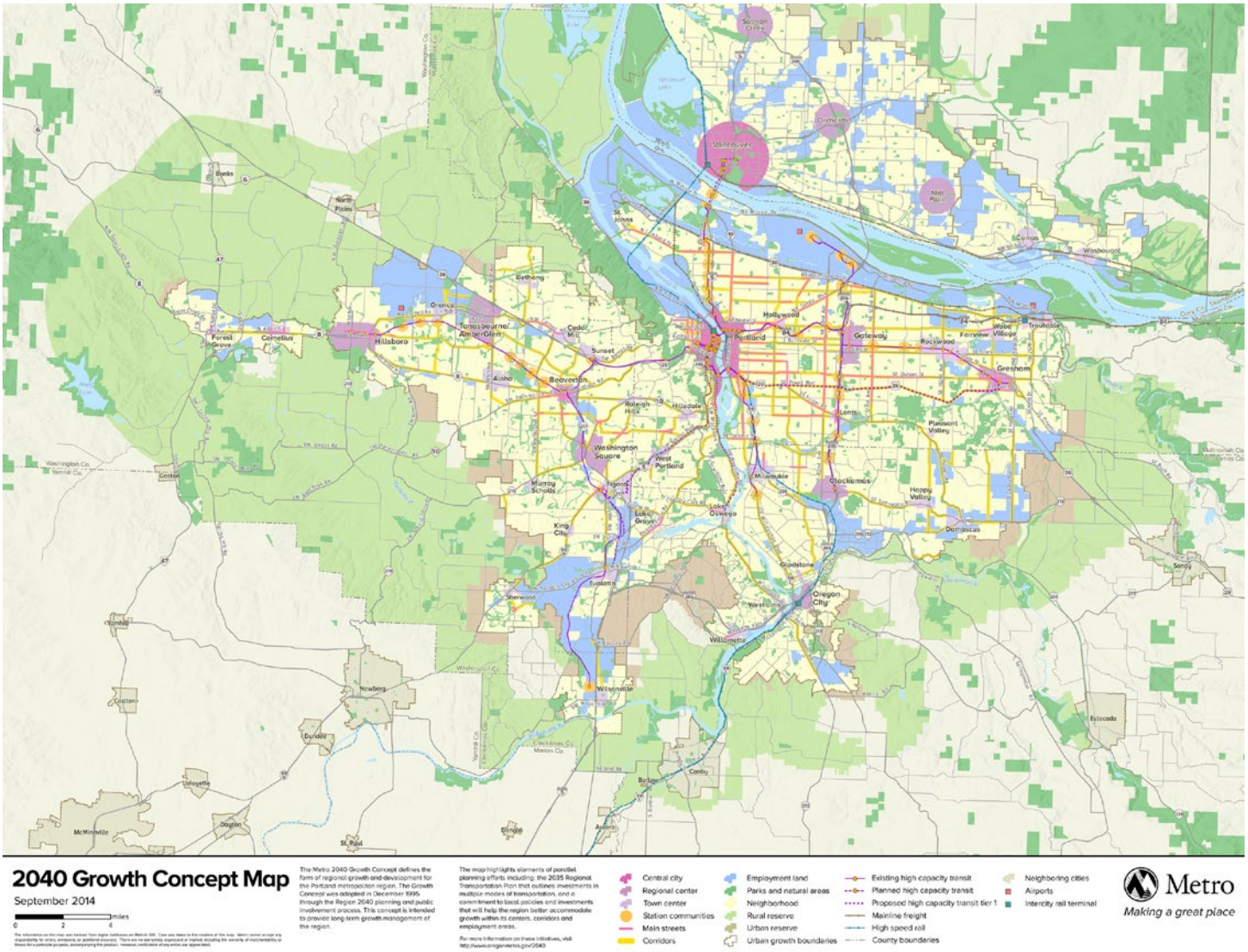
Figure 4. **A map of proposed land uses in Puget Sound from 2012, showing the variety of land uses surrounding the growing Seattle metropolitan area.[74]**



Portland Metropolitan Area

Portland is the largest city in its metro region, which has a population of roughly 2.5 million people and contains five counties in Oregon and two counties in Washington.[79] Portland is widely recognized as one of the most environmentally-conscious cities in North America.[80] Stormwater in Portland, as in all urban areas, causes significant environmental impacts as it acts as a conveyor of a number of pollutants, such as fertilizers, pesticides, animal waste, and chemicals from automobiles, which enter habitats of species as run-off, resulting in degradation and unhealthy ecosystems.[81] Portland has responded to these problems by implementing a Green Streets initiative designed to reduce stormwater issues and improve ecological health by absorbing precipitation and floodwater at source.[82,83] The initiative includes strategies to improve and incorporate streetscape vegetation, and to identify unused urban space that can be converted into parkland.[84] 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.[85] 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.[86]

Figure 5. **The 2040 growth concept map for the Portland metropolitan area, which provides visual evidence of the impact of a growing metropolitan area.[78]**

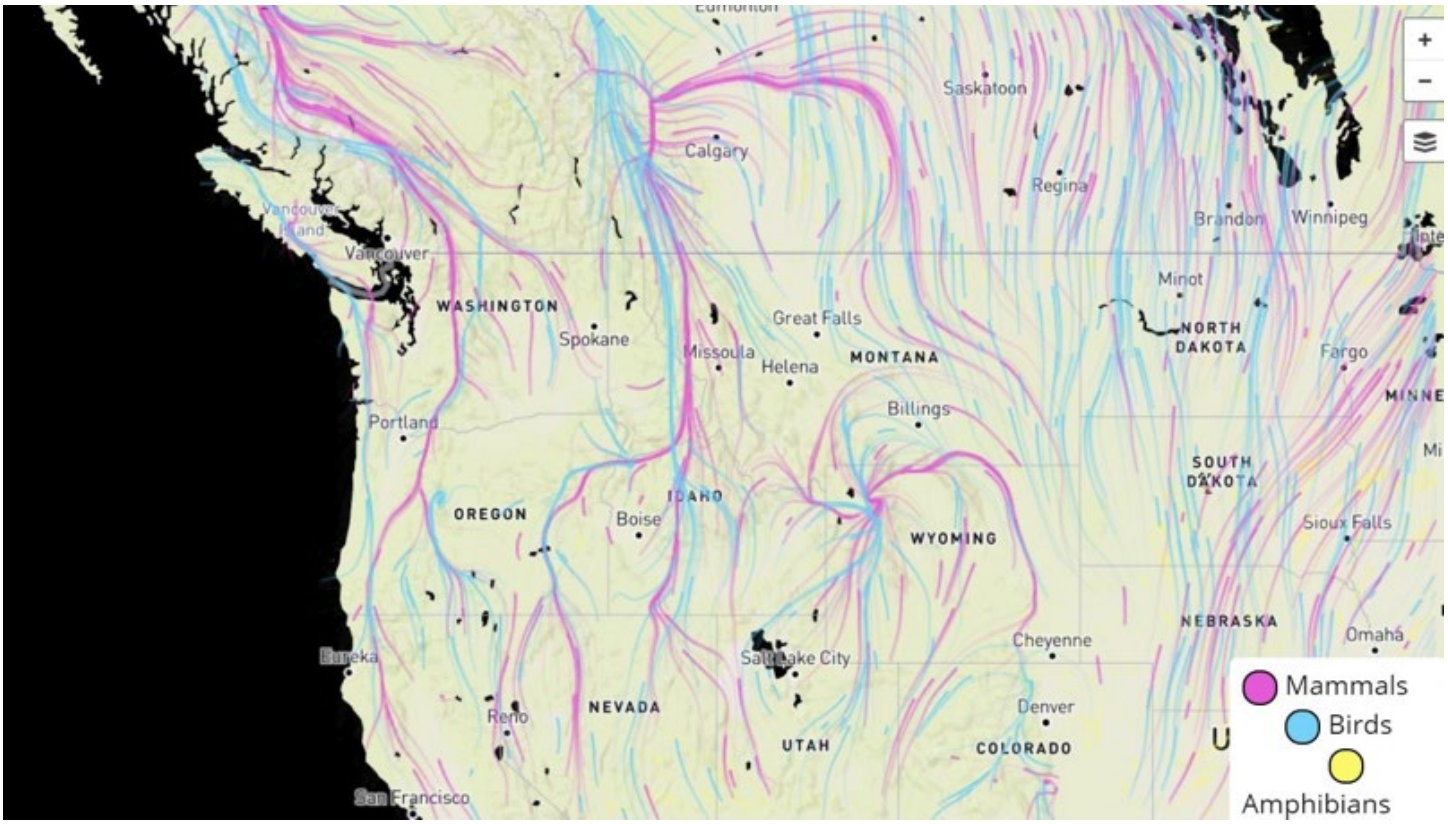


Biodiversity and Habitat Shifts in the PNW

Climate change is altering the distribution of species in time and space, known as range shifts.[87] In general, amphibians, birds, and mammals are migrating from their current habitats and converging through the PNW corridor (see Figure 6).[88] In the Pacific region, the loss of biodiversity has been attributed to habitat loss, overexploitation fragmentation, pollution, invasive species and disease, and climate change.[89] 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.[90]

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, which are themselves shifting but are not yet being updated.[92] Projected trends show that higher-elevation mammal species will experience significant losses in the size of their geographic ranges as temperatures increase, as they have limited room to migrate higher.[93] Species that are not capable of relocating or adapting to local changes fast enough to match the pace of the shifting climate are highly susceptible to extinction,[94] 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.[95] 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.[96] Importantly for the context of this report, species with habitats in urban areas are particularly vulnerable to local climatic changes, and are often not given priority in land use decisions that may impact their presence, richness, and abundance.[97]

Figure 6. **Estimated pathways of mammals, birds, and amphibians migrating under projected climate change.[91]**



Impacts on Biodiversity in Major PNW Ecosystems

Changes in climate affect habitats in a number of ways, resulting in added pressure on species to adapt or migrate.[98] The PNW is home to an array of environments, which accounts for the rich biodiversity of the region, including forested, coastal, and riparian ecosystems.[99] The following section highlights these three major ecosystems and the implications for them of a changing climate.

Forested Ecosystems

The distribution, growth, and function of forested ecosystems in the PNW will be affected by climate change 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, and insect outbreaks.[101] Although forested ecosystems are directly impacted by climate change through alterations to ecosystem markers such as tree species distribution and productivity, the indirect impacts through disturbances will be largely responsible for the changes in structure and function of forested ecosystems in the region.[102] The productivity of forested ecosystems will be impacted due to changes in local temperature and water availability, accompanied by a potential reduction in carbon sequestration capacity due to increasing disturbances,[103] requiring increasing attention to strategic species management to assist establishment of low carbon resilience (LCR).

Coastal Ecosystems

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.[104] 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.[105] Upland habitats are also exposed to storm surges, extreme tide events and erosion along coastlines. Beaches, for example, are already experiencing high levels of erosion as the frequency of storm surges increases and sea levels rise.[106] Saltwater inundation is 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.[107]

Riparian Ecosystems

Since riparian ecosystems are heavily reliant on consistent seasonal water levels, climate change is likely to have significant implications due to its effects on stream flow and seasonal water temperatures.[108] Impacts such as droughts, floods, and increasing heat will highly influence the physical and biological compositions of riparian ecosystems. For example, climate change is likely to result in vegetation shifts and also allow invasive species to outcompete native species

Definition of an ecosystem

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.[100]

as they become less adapted to the new conditions.[109] Not only will these ecosystems be affected by climate change, but the ecosystem services they provide—such as water purification and flood protection—will also be significantly affected, impacting urban areas in the PNW that currently benefit from these services.[110]

NATURE-BASED SOLUTIONS TO CLIMATE CHANGE

Adaptation in the context of climate change means planning for responses to the impacts of a changing climate and to adjust systems in order to avoid harm.[111] There is a general understanding of impacts that can be expected based on climate models and observations of trends; however, there is uncertainty around the scale, magnitude and pace of these changes in specific locations.[112] The application of nature-based solutions 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, illustrated in Figure 7, which demonstrates the biophysical capacity of green infrastructure.[113]

Site-specific green infrastructure approaches have been identified as a mechanism for adapting urban areas to climate change impacts such as increasing heat, altered precipitation patterns, and health concerns, as well as increasing energy efficiency and reducing emissions.[114] The complex multi-functionality 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 professions.[115] For example, green infrastructure can be seen as a form of capital as it relates to natural asset management, and as a risk buffer

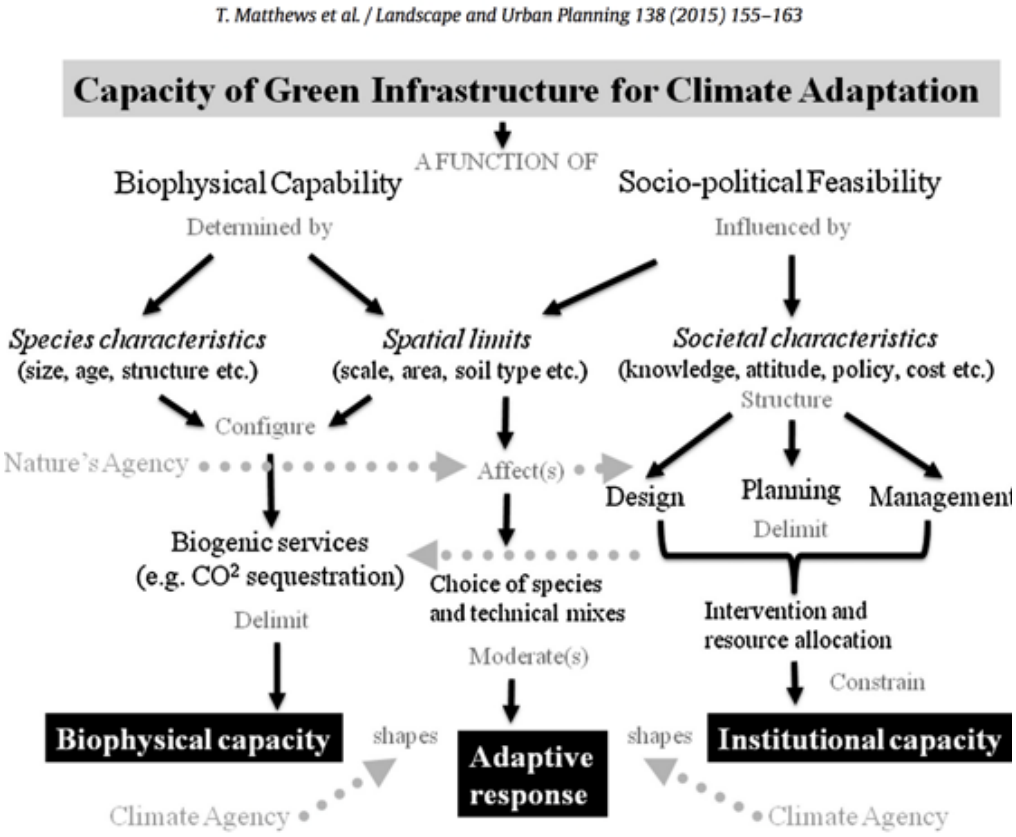


Figure 7. The capacity of green infrastructure to contribute to climate adaptation presented in a flow chart. The image presents the complex relationship between socio-political feasibility and the biophysical capability considerations required to maximize the capacity of green infrastructure as an adaptive response.[118]

as it relates to climate change adaptation.[116] The definition of *green infrastructure* provided by Metro Vancouver's *Connecting the Dots: Regional Green Infrastructure Network Resource Guide* (2015)[117] 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.[119] The NBS approach to adaptation highlights multiple benefits to urban areas through the linkages between scientific programs, nature conservation, and on-the-ground applications.[120] There is a growing understanding 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.[121] 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.[122] As the economic benefits of biodiversity are not easily expressed biodiversity is often not considered in adaptation solutions.[123]

The conservation of urban biodiversity is a complex and growing focus in urban planning and growth management (see Figure 8). 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.[124] Species-rich communities, i.e., those that are higher in biodiversity, have been identified as healthier and able to maintain their integrity better than those that are less diverse, making them more resilient to climate change.[125] Likewise, the health of an ecosystem plays a vital role in the quality of the ecosystem services provided, such as water filtration, pollinator habitat, air quality, stormwater management, extreme heat reduction and shading, and carbon sequestration.[126] Natural water filtration and mitigation of urban heat both contribute to reduced need for emissions-intensive processes.

Green infrastructure networks in the urban context can be established by protecting and connecting natural open and/or undeveloped spaces to restore fragmented ecosystems.[127] Linking green infrastructure networks in order to address concerns associated with the sixth mass extinction and biodiversity survival therefore 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.[128] However, the inclusion of biodiversity protection or restoration in urban areas is seldom a priority in consideration of and planning for green infrastructure approaches,[129] and adding this to the decision-making process changes the dialogue by requiring consideration of how NBS may benefit existing ecosystems in a changing climate.[130]

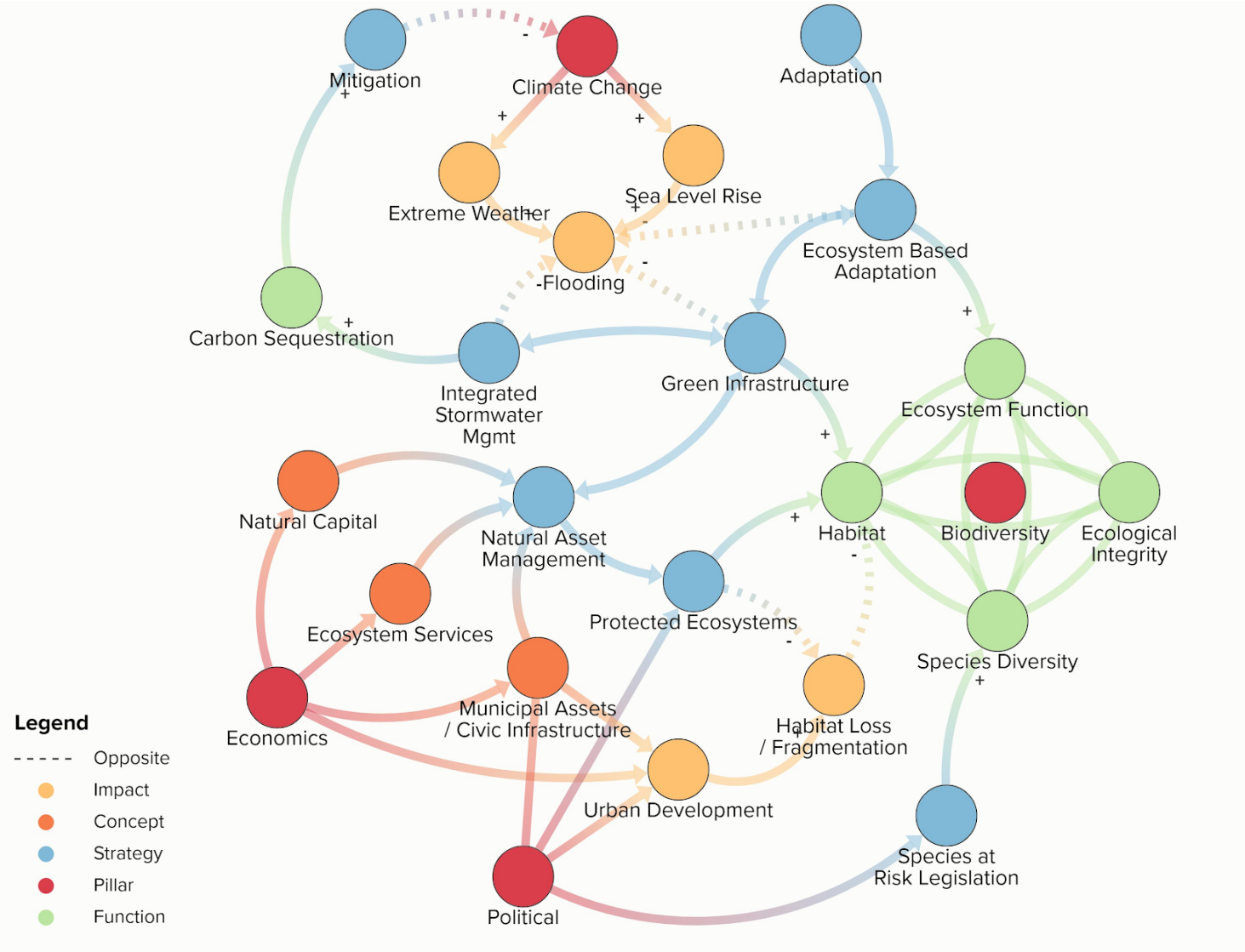


Figure 8. **Systems map describing the relationship between biodiversity, climate change, and green infrastructure. The arrows indicate influences and the (+) and (-) indicate enhancements and reductions. Please note: numerous emissions reduction benefits, in addition to carbon sequestration, can be gained through employment of green infrastructure solutions, and these could be added to future iterations of this model (Straker, 2019).**

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 can help achieve low carbon resilience (LCR).[131] Green infrastructure approaches to stormwater management can reduce emissions through reduced need for pumping and filtering as well as provision of localized cooling, reducing the need for air conditioning.[132] They can also extend the life and capacity of grey infrastructure solutions, reducing pressure from climate change-driven extreme precipitation events as well as the need for emissions-intensive replacements, as concrete, for instance, has a high level of embodied emissions.[133] There is also a growing research body on the carbon storage capacity of green infrastructure approaches such as rain gardens and green roofs, which tends to be dependent on their size and vegetation type.[134]

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.[135]

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 demonstrated by the consistent annual return of spawning salmon after decades of absence in the Still Creek watershed in Metro Vancouver, as well as growing insect populations in the area surrounding the creek.[136] 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.[137]

In another example, the City of Portland offers discounts on its city utility bills to homeowners who build rain gardens on their property as an on-site stormwater management approach.[138] 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.[139] It is evident through these examples that municipalities play a crucial role in land management and urban planning and therefore have an important role to play in planning green infrastructure at the regional scale.[140]

LESSONS LEARNED FROM PHASE 1: STILL CREEK STUDY

In May 2017, ACT finalized the results of a year-long case study on transboundary municipal ecosystem governance in Still Creek, a riparian ecosystem that crosses the boundary between the cities of Burnaby and Vancouver in British Columbia, Canada.[141] Successful municipal transboundary ecosystem governance in Still Creek has led to many benefits, including the return of spawning salmon after decades of pollution and neglect. This case study illuminated several key considerations that have transferability to broader ecosystems across the PNW region:

1. ***Land use legacy challenges.*** The presence of urban landscapes and the infrastructure that connects them presents a barrier to protecting ecosystems, requiring creative solutions to better accommodate natural systems.

2. ***Government and public awareness issues.*** Residents may not have education in nor experience with ecological concepts, and therefore may not be inclined to value the protection of ecosystems and biodiversity. Without improved public awareness and understanding, government agencies are unlikely to feel public support for conserving and restoring ecosystems.

3. ***The importance of management and jurisdiction.*** Ecosystems are often under the jurisdictional control of multiple entities, and ecological health can fall between administrative cracks due to siloed institutional mandates, goals, and enabling legislation. Jurisdictions may not have ownership nor feel responsibility for the entire ecosystem, and some jurisdictions may be reluctant to collaborate on projects if

they do not perceive a direct benefit. Also, some decisions that affect ecosystem health are made at the federal and provincial levels of government, outside the control of municipal planners and decision-makers that operate in local governments. This issue is complicated further in the trans-national context.

4. ***Collaboration and partnerships.*** Managing ecosystems that cross multiple jurisdictions requires communication, collaboration, and partnership among a range of government entities, as well as public, private, non-profit, and academic institutions. Collaboration provides opportunities to develop new policies focused on ecosystem health and to explore knowledge and cost-sharing options. Partnerships provide opportunities to incorporate additional perspectives and innovative ideas, which can generate more diverse and holistic solutions than a lone entity might be able to provide on its own.

5. ***Establish a formal collaborative entity.*** A collaborative entity or formalized partnership structure is vital for the long-term co-operation involved in managing ecosystems that cross political boundaries. A collaborative entity can encourage participation from multiple municipalities, Indigenous governments, regional government, provincial/state and federal governments, academic institutions, and local organizations.

6. ***Public input.*** Widespread public support for a plan can result in higher likelihood of its approval. Public engagement on policies and plans related to ecosystem health improves the potential for incorporation of local knowledge into the planning process, awareness raising within the community, and development of widespread support for policies and plans. Ensuring meaningful grassroots participation is present from the outset of planning processes and throughout implementation is therefore helpful to ensure the long-term feasibility of a plan.

7. ***Access innovative sources of funding.*** Funding is necessary for the conservation and restoration of urban ecosystems, yet many municipalities face infrastructure funding deficits and lack a steady funding stream dedicated to ecosystem health or climate change resiliency. However, municipalities that are prepared with plans and objectives can be opportunistic with funding and creative with existing policy tools. Ecosystems that cross jurisdictional boundaries may have more potential funding partners, particularly if the ecosystem services and values are acknowledged and well characterized. Municipalities can combine funding from various sources, including innovative use of taxes and levies, private property owners and developers, and grants from other levels of government and private agencies. Urban redevelopment also provides opportunities for rezoning and development requirements that can improve environmental conditions on privately owned property. Municipalities can require or incentivize developers to restore vegetation, increase setbacks, or protect environmental features during development, relying on various regulatory powers.

CAN GREEN INFRASTRUCTURE BENEFIT BIODIVERSITY?

Green infrastructure has the potential to provide habitat for species that are either losing habitat due to urbanization[142] or experiencing range shifts due to climate

change.[143] In general, it is difficult to establish a general understanding of the benefits to biodiversity from green infrastructure approaches, since reporting is often site- and species-specific;[144] furthermore, these benefits cannot be assumed through the implementation or protection of NBS without strategic consideration of biodiversity health as a key component of the solution.[145] 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 intervention will not maximize the potential for biodiversity.[146] 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 and increasing vulnerability.[147]

A biodiversity-led approach to green infrastructure, i.e., taking an "ecosystem approach" to protecting, enhancing, creating and connecting green spaces in urban areas through corridors and matrices of green infrastructure, has the potential to benefit biodiversity while adapting to climate change.[148] Corridors of green infrastructure should be planned based on ecosystem boundaries rather than 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.[149] 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.[150] Nevertheless, there are a number of examples of 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 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:[151]

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

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.[152] 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,[153] 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.[154] Due to the threats to biodiversity globally, priority consideration should be given to species health when implementing green infrastructure in order to maximize its potential.

There is growing acceptance and uptake of green infrastructure approaches by a diverse range of practitioners, including health professionals, biologists, landscape architects, planners, and engineers, resulting in a patchwork of largely uncoordinated green infrastructure projects within eco-regions. 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.

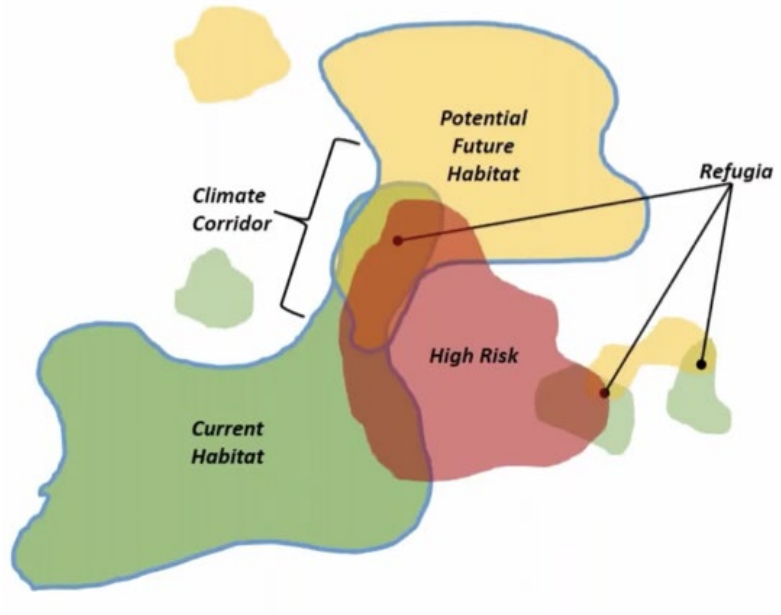


Figure 9. **Spatial priorities when planning for climate refugia in a changing climate (Shirk, Watkins, & Vynne, webinar, July 25, 2018).**

Planning Green Infrastructure to Enhance Connectivity

Some degree of connectivity is important for the health and survival of almost all species. When taking an ecosystem approach to the development of green infrastructure, and using it to enhance or protect the connectivity between established natural spaces, considering the network as a whole will likely benefit the majority of species.[155] There is a 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.[156] 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. Examples of this kind of predictive modeling include the Washington-British Columbia Transboundary Climate-Connectivity Project and work by the University of Washington's Climate Impacts Group (CIG). The CIG is developing a mapping tool, to be completed by 2020, to demonstrate spatial priorities of species in a changing climate. The tool accounts for landscape integrity, connectivity, land facets, and topoclimatic diversity. By identifying climate corridors that will be needed to facilitate species migration, emphasis can be placed on protecting certain areas between current and future habitats through using green infrastructure to reduce pressure on species in a changing climate (Shirk, Watkins, & Vynne, webinar, July 25, 2018).

Connecting natural areas within peri-urban or rural areas using green infrastructure corridors is the predominant strategy used by much of Europe,[158] and the development

of ecological networks has been advocated for globally as a means of alleviating the ecological impacts of habitat fragmentation.[159] These green corridors can benefit urban communities by providing them with green space, meeting areas, and walking/biking routes throughout a city.[160] Similarly, they benefit non-human species by providing more natural areas as well as transportation routes between larger areas of habitat throughout the city.[161] For example, urban gardens can act as important connections between natural areas such as parks and protected areas. Biodiverse gardens can combine to contribute to a larger natural system by providing some necessary habitats and minimizing isolation.[162]

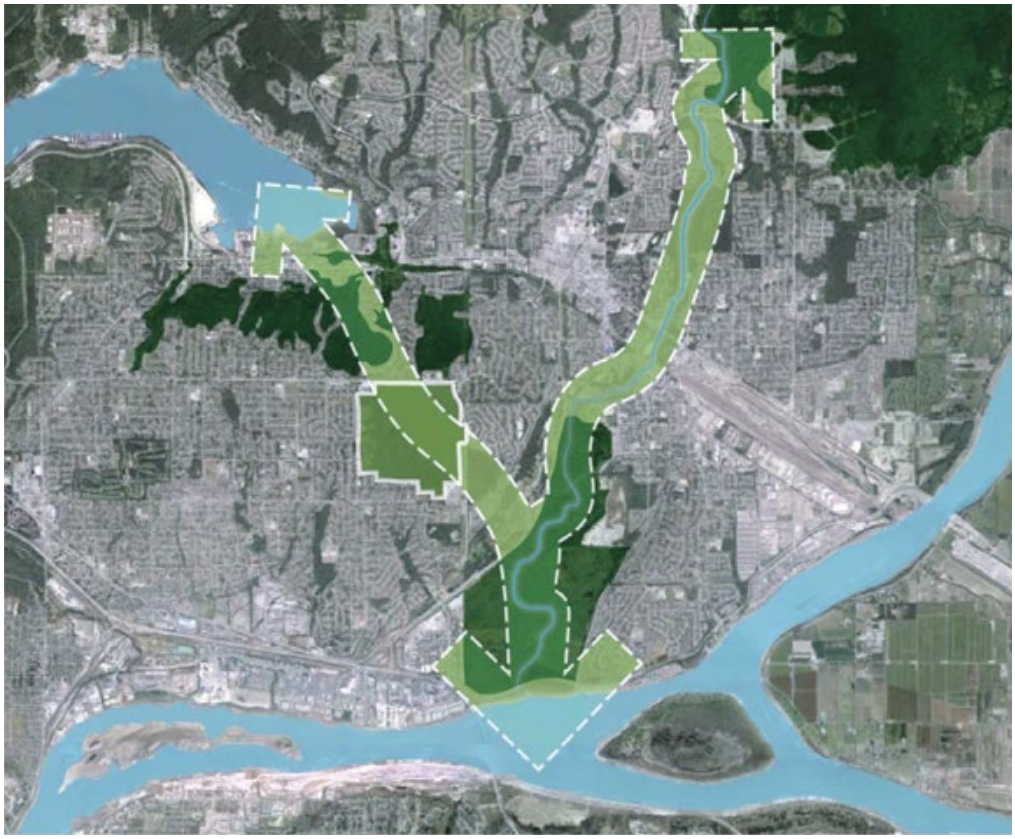


Figure 10. **Wildlife management corridors in Coquitlam, British Columbia show how species may use or travel through an urban environment in order to reach the ecosystem conditions they require to survive.[157]**

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.[163] The following examples illustrate ways considering the connectivity of protected natural areas by using green infrastructure planning could have benefits for biodiversity at the regional scale.

Yellowstone to Yukon, North America

The Yellowstone to Yukon Conservation Initiative (Y2Y) works with a variety of environmental groups, municipalities, private landowners, and Indigenous communities to ensure the protection of large-scale migration corridors. 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), advocating for land use decisions within the area to take an ecological and landscape-scale approach to management.[164] 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 have engaged with the community as well as planners,

engineers, biologists, and other decision-makers to ensure space for wildlife is not inhibited by development. Examples 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.[165]

Edmonton, Alberta

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 is an example of urban planning practices with a focus on biodiversity and ecosystem health that are growing across Canada at the municipal and regional scales.[166] Edmonton is a member of the Biophilic Cities network, which promotes the connection and integration of green spaces to protect and enhance habitats throughout urban and peri-urban environments.[167] 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.[168]

Planning Green Infrastructure to Improve Provision of Ecosystem Services

NBS responses to climate change can address several interrelated issues simultaneously, including urban growth, biodiversity decline, and species migration.[170] Some of these benefits are intrinsically valuable to the ecosystem services on which all species rely. Ecosystem service-based climate change adaptation responses offer an adaptive way to address climate change impacts that are low cost, efficient, and sustainable.[171] As a result, there is growing support for green infrastructure approaches in urban areas

Figure 11. **Green infrastructure as it relates to both the natural and built environment, illustrating how their interconnections can enhance ecosystem service delivery.[169]**

that act to enhance ecosystem services. In order to successfully employ these techniques, there is a prior need to develop system approaches that combine technology, business, finance, governance, regulation, and social innovation. This also involves working beyond silos and engaging across disciplines and sectors, as well as systematically involving all stakeholders, including citizens.[172]

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.[173] 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.[174] The following examples show how the implementation of green infrastructure as a nature-based response to climate change to enhance ecosystem services can have benefits for biodiversity.

Still Creek, Vancouver-Burnaby, British Columbia

The Still Creek watershed crosses the municipal boundary between the Cities of Vancouver and Burnaby, British Columbia. Still Creek had been impacted for decades by heavy urbanization and industrialization, resulting in extensive ecosystem pollution and degradation and loss of habitat. However, the potential for Still Creek to provide provisioning, regulating, habitat, and cultural services was largely restored by strategic actions on the part of both municipal governments as well as community groups and local businesses. Green infrastructure approaches such as stream daylighting and connecting habitats made this possible. The two municipalities worked together to restore the habitat around the creek, resulting in benefits for water quality and overall ecosystem health, in particular the annual return of salmon to spawn in the creek system since 2012, after decades of absence. The enhancement of ecosystem services includes improved stormwater management, more habitat for species, and natural spaces for the community to enjoy.[175]

Kanaka Creek, Maple Ridge, British Columbia

Kanaka Creek Watershed Stewardship Centre is located in the Kanaka Creek Regional Park of Metro Vancouver. Kanaka Creek is a tributary of the south Fraser River and is thus important habitat for salmon and other species in the south coast region of British Columbia. The Kanaka Creek Watershed Stewardship Centre provides an example of effective consideration of ecosystem services in design and building processes designed to reduce the impact of development within a watershed.[176] The concept of green infrastructure was employed in the Centre's consideration of ecosystem health and services throughout the design process and construction. The Centre and surrounding campus use a roof-to-creek concept to ensure the ecosystem services the creek provides are not inhibited by the building's location, and that stormwater falling within the park replenishes the creek at a rate and quality that will continue to provide healthy habitat for species and maintain high levels of ecosystem services and biodiversity. This design concept spans the entire footprint of the centre using a network of channels, ponds, and native plant species, resulting in rainwater being retained and slowly draining into the creek.[177] The benefits to biodiversity are evident in the planting of a variety of native species and the high quality of water entering the creek with benefits for salmon and other species that live in the Kanaka Creek ecosystem.

Atchafalaya River, Louisiana

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. The Horseshoe Bend Island project was designed to demonstrate how dredged material can be used to support the natural development of a river island. 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 US Army Corps of Engineers were able to identify the benefits of using natural features and materials instead of traditional grey infrastructure techniques. By using the *Engineering with Nature* guiding principles created by the Army Corps of Engineers—which are holistic, collaborative, cost-effective, socially responsible, innovative, and adaptive[178]—the project resulted in habitat for floral species and avian and aquatic invertebrates.[179] The island became a nesting ground for native wading birds, such as the tricolored heron, snowy egret, and ibis. It also enhanced habitat quality for insects and contributed to 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.[180]

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.[182] 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.[183] 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.[184]

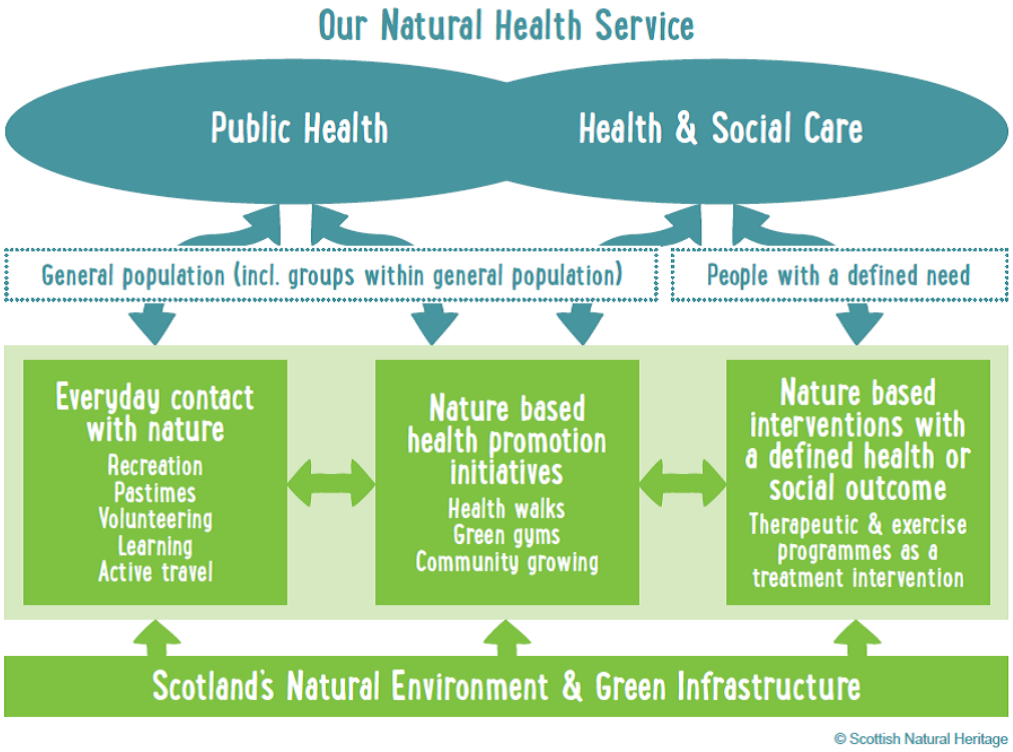


Figure 12. **Health and well-being from parks and protected areas identified in Scotland's national overview. Everyday contact with nature is needed to realize health benefits.[181]**

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.[185] There is a growing understanding of the mental health benefits to proximity and contact with green space in urban areas, which is also an important consideration since mental health is not only crucial to wellness but when compromised can become a precursor to other health issues, especially those associated with sedentary lifestyles.[186] Access to green spaces 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.[187]

Partnerships between health practitioners and environmental planners to develop strategies to benefit human health using green infrastructure are growing.[188] For example, research on the "urban nature diet" shows that exposure to natural areas and interactions with a variety of species have a number of health benefits. 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.[189] The following are examples of how green infrastructure designed for human health benefits has also benefited biodiversity.

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.[190] In 2014, the metropolitan region of Chicago published its regional growth strategy, *GO TO 2040*. Developed to ensure that growth in the region included a focus on the environment, equity, and other sustainable development principles, the strategy identifies the benefits of implementing green infrastructure strategies as part of its network approach. 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.[191] 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.[192]

Edinburgh, Scotland

Edinburgh's city council and local authority have placed human health and well-being at the forefront of their urban green space planning. As initiatives within the city are proposed, the city council considers them on the basis of their ability to provide green space that will benefit human health. Examples such as brownfield sites being redeveloped as green spaces or for planting fruit trees show the benefits to the community and human health of the establishment of green infrastructure in urban areas.[193] In terms of biodiversity benefits, the City of Edinburgh has adopted an approach that considers shifting some parts of their existing green network, which is managed through their Green Belt policy, to more natural areas. Through developing a biodiversity action plan, the city is able to identify locations that can be left to return to a natural state, generating benefits to biodiversity but also cost savings to the city due to lower maintenance requirements.[194] Edinburgh's green infrastructure strategy is focused on community engagement, with equitable access to green space at its core. By

establishing linkages between the biodiversity action plan and the Green Belt policy, the city is able to implement plans and actions that result in green infrastructure benefiting human health and biodiversity simultaneously.[195]

CONCLUSION

Canada's most heavily settled areas and regions with intensive agriculture—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.[196] Urgent planning is required to prioritize the protection of key habitats and address the loss of biodiversity in tandem with climate change adaptation.[197] The degradation of ecosystems and the services they provide caused by urbanization also impacts the physical, psychological, and economic well-being of communities.[198]

Designing future development within urban areas to work with instead of against nature has been identified as a multifunctional climate change adaptation measure which can help to reduce the impacts of climate change. Green infrastructure that is designed to respond to climate change considerations reflects multifunctionality when input from a variety of professionals across disciplines is included.[199] Urban green spaces play a critical role in conserving biodiversity, protecting water resources, reducing heat, sequestering carbon, and even supplying a portion of the food consumed in urban areas. Municipalities 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.[200]

Employing green infrastructure and other nature-based approaches to sustainable urban development has the potential to provide a cost-effective response to both aspects of the climate crisis and the global decline in biodiversity.[201] 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."[202] 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.[203] Through an evaluation of case studies and a survey of the available literature, it is evident that biodiversity benefits when green infrastructure is:

1. Designed to guard natural area corridors and patches for species migration between larger protected natural areas.
2. Used to enhance the ecosystem services natural areas provide to urban environments.
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 does not guarantee improved biodiversity health, but taking a detailed, multifunctional approach to its planning can maximize ecosystem service provision and help reduce the impact of urban growth on biodiversity loss.[204] In order to maximize the potential for biodiversity benefits, and slow the sixth mass extinction, we must plan green infrastructure in urban areas strategically, with biodiversity health as one of the priorities.

NEXT STEPS

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.[205] The IPBES recommends five interventions that will generate the transformational change necessary to reduce the degradation of land and the decline in global biodiversity: 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.[206]

Through stakeholder engagement in a workshop, focus group, and a review of literature on green infrastructure and nature-based solutions to climate change, three steps were identified that can help to advance biodiversity-led green infrastructure at the regional scale that complement the interventions described above in the IPBES report:

1. **Convene an interdisciplinary community of practice.**
   An interdisciplinary community of practice is required to advance a regional approach to biodiversity-led green infrastructure networks. This community of practice should include Indigenous and non-Indigenous governments, the private sector, professional practitioners, non-governmental organizations, and academics. Adapting urban areas to the impacts of climate change while also enhancing biodiversity requires collaboration across the public and private realm and among various knowledge holders and practitioners, such as biologists, landscape architects, engineers, planners, accountants, community members, neighbourhood associations, health practitioners, and teachers.

2. **Consider how a regional approach aligns with other regional strategies.**
   Advancing a biodiversity-led green infrastructure approach requires considering how associated concepts may already be reflected in existing strategies, such as official community plans, regional growth strategies, and climate action strategies. Concepts that are relevant to a regional approach—such as green space protection or enhancement, greenhouse gas emissions reduction, active transportation, stormwater management, and climate change adaptation—are likely to have been considered to some extent in existing strategies, and finding opportunities to integrate these actions can facilitate the adoption of a biodiversity-led green infrastructure strategy.

3. **Consider linkages to peri-urban and rural areas.**
   Ecosystems and habitat boundaries rarely align with jurisdictional boundaries. An ecosystem approach will help identify areas where cooperation across jurisdictional boundaries will protect and enhance migration corridors that species are likely to use as the climate changes. Decision-making at a scale that is outside the jurisdiction of regional government will require working with neighbouring regions, as well as the agriculture and forestry industries, to both advance the concept of biodiversity-led green infrastructure and prioritize potential species migration corridors in urban areas.

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ACT Adaptation to Climate Change Team

ACT (the Adaptation to Climate Change Team) in the Faculty of Environment at SFU brings leading experts from around the world together with industry, community, and government decision-makers to explore the risks posed by top-of-mind climate change issues and to identify opportunities for sustainable adaptation.

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