Climate Change and Urban Nature

Opportunities, Solutions, and Risks

CENTRAL PARK CONSERVANCY

Natural Areas Conservancy

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Illustrations: created by Elena Kakoshina

The Natural Areas Conservancy
Founded in 2012, the Natural Areas Conservancy (NAC) is a nonprofit organization devoted to restoring and conserving New York City's 20,000 acres of forests and wetlands in close partnership with the New York City Department of Parks and Recreation. NAC is also dedicated to ensuring urban natural areas are protected and managed in the face of climate change.

Yale School of the Environment
Yale School of the Environment is leading the world toward a sustainable future with cutting-edge research, teaching, and public engagement on society's evolving and urgent environmental challenges. Yale School of the Environment is focused on the most significant threats to a sustainable future including climate change and the increasing stresses on our natural resources.

Central Park Conservancy
The Central Park Conservancy aims to preserve and celebrate Central Park as a sanctuary from the pace and pressures of city life, enhancing the enjoyment and wellbeing of all. The Central Park Climate Lab also aims to work with cities across the United States to advance and implement urban park strategies to mitigate and adapt to climate change and understand how these greenspaces could be used to create more resilient futures.

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Natural Areas Conservancy
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DELTA

Climate Change and Urban Nature

Opportunities, Solutions, and Risks

What is in this report?

With more frequent extreme weather events and higher average temperatures, there is a clear need to address the impacts of climate change. These impacts are especially high risks for urban areas as these landscapes already experience higher temperatures and risk of flooding due to large amounts of impervious surface. Further, with the majority of people living within urban landscapes and a growing influx of urban residents, the climate related problems faced by urban residents represent a challenge to a significant portion of the global population.

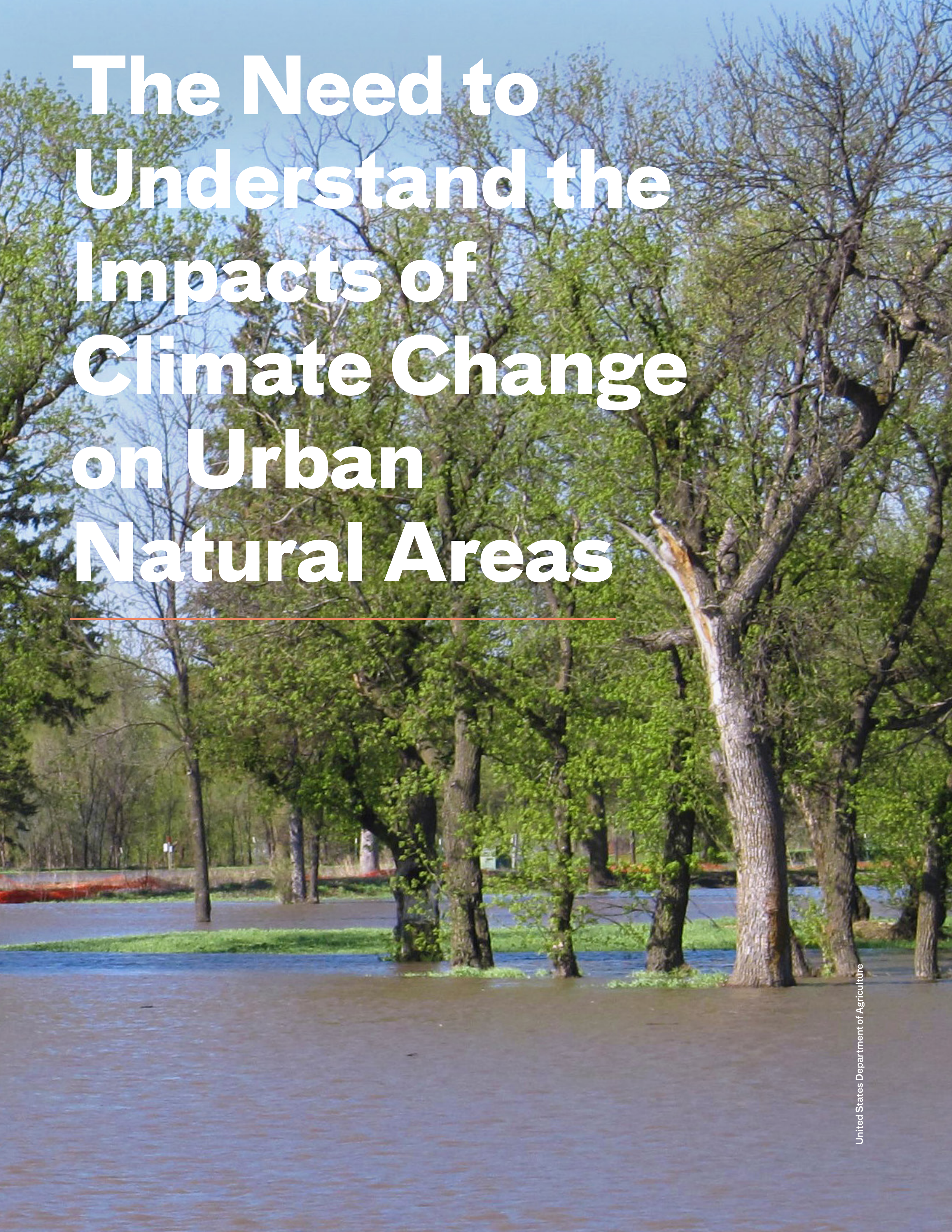
However, a potential solution to many of the challenges posed by climate change already exists within many cities. Urban natural areas provide a multitude of environmental benefits from mitigating stormwater runoff to reducing local temperatures. Despite the many benefits of urban natural areas, these spaces are often overlooked when it comes to landscape planning and budgetary allocation. As a result, a valuable set of tools for mitigating climate change are often under maintained and underfunded. The lack of attention also increases the risk that climate change negatively impacts and damages these natural areas, reducing potential climate solutions and further exacerbating impacts of climate change.

With this report, we aim to highlight the potential climate adapting and mitigating impacts of urban natural areas as well as identify climate related risks to these natural areas. We acknowledge that the intersection of climate change and urbanization is complex and one report is unlikely to capture all of the different interactions within urban landscapes. Additionally, many reports explore how urban greenspace is integral to the sustainable design of cities. However, this report will serve as a resource specifically addressing the role of urban nature in the context of climate change. We also present explicit examples both of how urban nature can reduce climate impacts as well as how city governments and organizations are protecting urban nature from climate change. We recognize cities exist within a complex social governance framework so we focus on the direct impacts and opportunities.

We hope that this can serve as a resource and roadmap for ourselves and those within the urban natural areas community.

Contents

The Need to Understand the Impacts of Climate Change on Urban Natural Areas



United States Department of Agriculture

Climate change poses a significant risk to human health and has wide-ranging negative impacts.[1] Increasing global temperatures result in more frequent and intense heat-related illnesses and deaths, especially among vulnerable populations.[2,3] *Climate change* is broadly characterized by long-term shifts in weather patterns.[4] Over the past century, scientists and observers have noted changes in global temperatures and atmospheric gas levels, largely attributable to the industrial revolution. The conversion of natural land into agricultural and urban landscapes stands out as one of the primary drivers of climate change; in countries like the United States, urbanized land accounts for ~10% of total landcover and houses over 80% of the population.[5–8] The rapid expansion of cities, accompanied by the reduction of natural areas, increased energy consumption, and transportation emissions, poses a global risk with urban areas producing up to 75% of all greenhouse gas emissions. However, urban residents may face unique challenges as they become more disconnected from nature and confront the compounding impacts of climate change.[9–11] Risks associated with climate change are particularly impactful for urban residents as many major urban centers are in coastal locations; urban areas are also often much hotter than surrounding rural areas due to large amounts of impervious surfaces.[12,13]

Residents of New York City attend a march calling for action to stop the impacts of climate change.
Mathias Wasik

Climate Change and Urban Landscapes

Urban landscapes present unique challenges when it comes to climate change. Due to the large amount of paved and other impervious surfaces, urban areas tend to be significantly hotter than the surrounding rural regions, an effect known as the *Urban heat island*.[13,14] The dense infrastructure, concrete, and asphalt surfaces in urban environments absorb and retain heat, creating localized hotspots that are often associated with lower-income areas and areas with high proportions of non-white residents.[15–17] These elevated temperatures exacerbate the health risks for urban residents, increase energy demands for cooling, and disrupt ecosystems through increased physiological stressors and the introduction of non-native species.[18,19] Additionally, stormwater management poses a crucial challenge for urban areas. As impervious surfaces replace natural vegetation, the ability of urban landscapes to absorb and filter rainwater is reduced, resulting in increased runoff, which can lead to flooding, erosion, and water pollution.[20,21] The increased severity of storms associated with climate change can also lead to flooding from coastal storm surges, which is exacerbated by increased sea level rise resulting from polar ice melt.[22,23] These negative impacts are of particular concern as most of the world's population live in urban areas, with urban centers becoming more densely populated each year; as people continue to move to urban areas, the expansion of these urban areas can, in turn, exacerbate negative climate impacts.[24–26]

Natural areas within urban landscapes play a vital role in mitigating the impacts of climate change. They provide essential ecosystem services, such as carbon sequestration, air purification, and temperature regulation.[27–29] Trees and vegetation reduce the urban heat island effect by providing shade and evaporative cooling.[30,31] However, these urban natural areas are not immune to the adverse effects of climate change. Rising temperatures and shifts in precipitation patterns can lead to heat stress, drought, and increased vulnerability to pests and diseases in these ecosystems. Changes in water availability and sea-level rise pose risks to wetlands, rivers, and coastal areas, affecting their ecological functioning.[8,31] Extreme weather events can cause flooding, erosion, and habitat loss, further impacting the resilience of these natural areas. It is crucial to recognize the vulnerability of urban natural

A riparian area embedded within an urban landscape.
Natural Areas Conservancy

A restoration project promoting the growth of riparian vegetation in the city of Austin, Texas.
Larry D. Moore

areas to climate change and prioritize their conservation and restoration.[27] By preserving and enhancing these areas, cities can strengthen their capacity to withstand climate change impacts, while also reaping the benefits of improved air quality, recreation, mental health support, and community connection.[28,33] Effective urban planning and sustainable design practices can ensure the integration and protection of natural areas, creating healthier and more resilient urban environments for both people and nature.

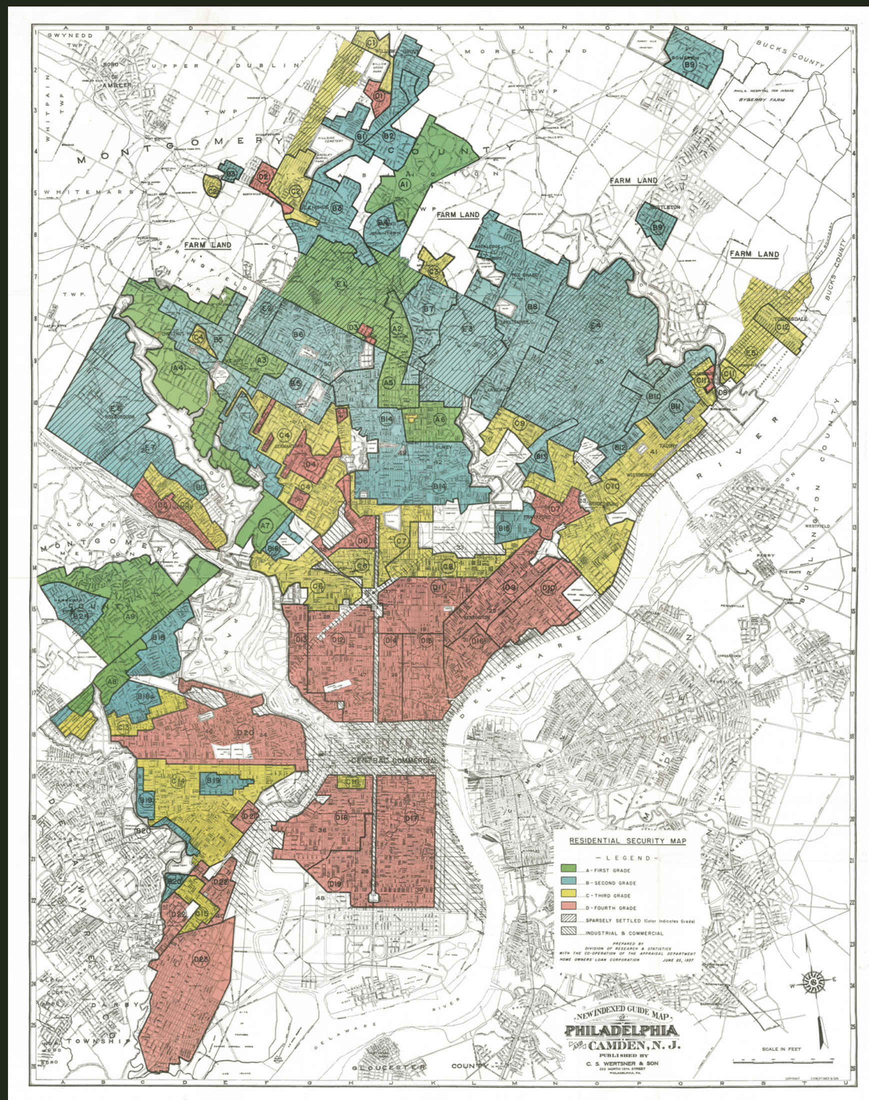
As the impacts of climate change continue to increase, the risk to urban residents grows. However, we still lack key data necessary to understand how best to mitigate the impacts of climate change both within cities and globally. Particularly, we need more data on how natural areas function within these urban landscapes as bastions of climate resilience. While there is growing focus on the importance of urban greenspaces, there is limited focus on the importance of natural areas within cities.[34,35] This lack of focus excludes large portions of greenscapes within cities which may have some of the largest impacts on climate change. For example, in New York City, over approximately 12% of the total land is natural area and this landcover serves to cool the city, absorb stormwater, provide habitat for local species, and provide biocultural services for residents.[36] However, the natural areas within cities are not uniformly distributed and, therefore, the services that natural areas provide are not equally beneficial to all residents.[37–39] Additionally, public funding for the management and care of natural areas has typically lagged relative to other areas of urban park and green space maintenance and operations. Unlike many other features of urban park systems, natural areas that lack proactive management and care, facing the threat of complete degradation and loss. The urgency of this moment requires dedicated advocacy to push decision makers to prioritize investing in the management, restoration, and care of urban natural areas as a key climate mitigation and job creation strategy for our cities. Thus, the study and investment in urban natural areas is not only a part of a larger climate solution but also an avenue to creating more equitable and just cities.

As we delve further into this report, we will explore various topics that shed light on the unique challenges faced by urban natural areas. We will differentiate between urban natural areas and managed greenspaces, investigating the implications of increased heat on these vital green spaces. Additionally, we will examine how altered hydrological patterns and increased runoff affect urban natural areas, emphasizing the importance of effective stormwater management. Furthermore, we will delve into the consequences of biodiversity loss and the spread of invasive species resulting from climate change, and their potential ramifications on the resilience and function of urban natural areas. By understanding these interconnected aspects, we can develop strategies to mitigate the impact of climate change on urban ecosystems and ensure a sustainable and vibrant future for our cities and the natural areas within them.

Case Study
Climate Change and Urban Residents

The majority of the world's population live within urban landscapes, and by 2050, it is projected that 68% of the world's population will live within urban landscapes.[40] In the United States, 80.0% of residents live in urban areas, according to the 2020 Census.[41] Over the last two hundred years, as people have migrated to urban centers, many residents have faced negative consequences associated with pollution and overcrowding.[42,43] As early as 1899, physicians in areas like New York City called for the incorporation of natural features such as trees as potential solutions to increased levels of heat and pollution associated with urbanization.[44] As climate change exacerbates many of the threats associated with urban living, it is critical to understand how urban residents are impacted and how nature-based solutions may reduce risks and inequities in urban environments.

In many urban contexts, it is not uncommon for marginalized communities to reside in areas with inadequate green spaces, resulting in higher levels of air pollution and heat. Further compounding this issue, these groups often have less access to adaptive resources, such as air conditioning or healthcare services, enhancing their vulnerability to heat-related illnesses. The driving force behind many of these inequities are the legacies of racial policies such as redlining, which prevented investment in greenspaces such as parks in areas with high proportions of non-white residents.[38,45] In order to combat these legacies, there needs to be emphasis placed on investing in the management and development of natural areas throughout cities. Further, local governments and organizations should focus on funding research and initiatives that explore how natural areas can be tools to mitigate environmental inequities.



1937 Home Owners' Loan Corporation "redlining" map classifying neighborhoods in the Philadelphia area by "riskiness" preventing residents of D (red) and C (yellow) areas from securing property loans.

United States Government

It is crucial that these initiatives are not merely top-down, but involve active participation from the affected communities. Their lived experiences and local knowledge can offer invaluable insights into crafting effective and sustainable solutions. Involving these communities in decision-making processes can foster a sense of ownership and empowerment while also ensuring that the solutions implemented are culturally appropriate and relevant. Thus, tackling the uneven impacts of climate change calls for a paradigm shift towards more inclusive, equitable, and participatory climate action.

Urban Natural Areas vs. Landscaped Greenspaces

Urban natural areas, including forests, wetlands, grasslands, and streams, exhibit significant differences from managed urban green spaces such as landscaped lawns in terms of their ecological characteristics and management approaches.[46,47] While both can occur in parkland, natural areas are primarily composed of native plant and animal species that have evolved and adapted to the local environment over time, resulting in higher biodiversity and habitat creation for various wildlife species.[29,48] *[See the invasive species section below for details on how natural areas are impacted by non-native species].* In contrast, managed urban green spaces are intentionally designed and landscaped, often featuring a limited range of plant species and sometimes incorporating non-native ornamental plants.[47,49]

Furthermore, urban natural areas often disproportionately contribute to ecological processes and services when compared to other types of green spaces. They help regulate the local climate, absorb and purify water, support nutrient cycling, and provide natural flood protection.[50,51] These areas also play a crucial role in maintaining biodiversity and supporting the overall health of ecosystems.[29] In contrast, managed urban green spaces may not possess the same level of ecological functioning, although they do offer recreational and aesthetic benefits.[46,47]

The management practices employed in these two types of urban spaces also vary. Urban natural areas require minimal human intervention, as they are self-regulating systems.[52] Efforts are focused on conserving and protecting these areas from encroachment and degradation.[50] On the other hand, managed urban green spaces are actively maintained and modified through human intervention.[52] Regular mowing, planting, irrigation, and pest control measures are undertaken to ensure desired aesthetics and functionality.[46]

Accessibility and use differ between urban natural areas and managed urban green spaces. On a national scale, urban natural areas often have limited accessibility, prioritizing conservation, and preservation.[50] In urban landscapes, natural areas may have designated trails or viewing points to balance safeguarding natural habitats with allowing residents access to nature.[53] Conversely, managed urban green spaces like parks are designed with recreational activities in mind. They provide open spaces for sports, picnics, gatherings, and other social events, meeting the needs and desires of urban residents for outdoor leisure and relaxation.[29,49]

Central Park in New York City is one of the largest and most well known urban parks. It contains both natural areas such as the North Woods, as well as landscaped features such as Sheep Meadow.

Alfred Hutter

Managed greenspaces, such as parks, can contribute to mitigating the impacts of climate change through various mechanisms. Firstly, parks serve as carbon sinks by supporting the growth of trees and vegetation that absorb and store carbon dioxide from the atmosphere. This helps offset greenhouse gas emissions and combat global warming.[54,55] Additionally, managed greenspaces can help regulate urban temperatures by providing shade and cooling effects, thereby mitigating the urban heat island effect and reducing energy consumption for cooling.[56,57] Furthermore, parks can support stormwater management by acting as natural infiltration areas, reducing runoff and the risk of flooding and may also be designed to include bioswales that take advantage of landscaping to capture water.[58,59] While managed greenspaces have these climate mitigation benefits, they may be less effective than natural areas due to their typically smaller size, limited biodiversity, and intentional management practices. Natural areas, such as forests and wetlands, possess more extensive ecosystems, higher biodiversity, and self-regulating mechanisms that make them more effective in capturing carbon, regulating temperature, and managing water.[59,60] Nonetheless, managed greenspaces like parks still play a valuable role in urban climate change mitigation efforts and provide additional benefits for recreation and community well-being.

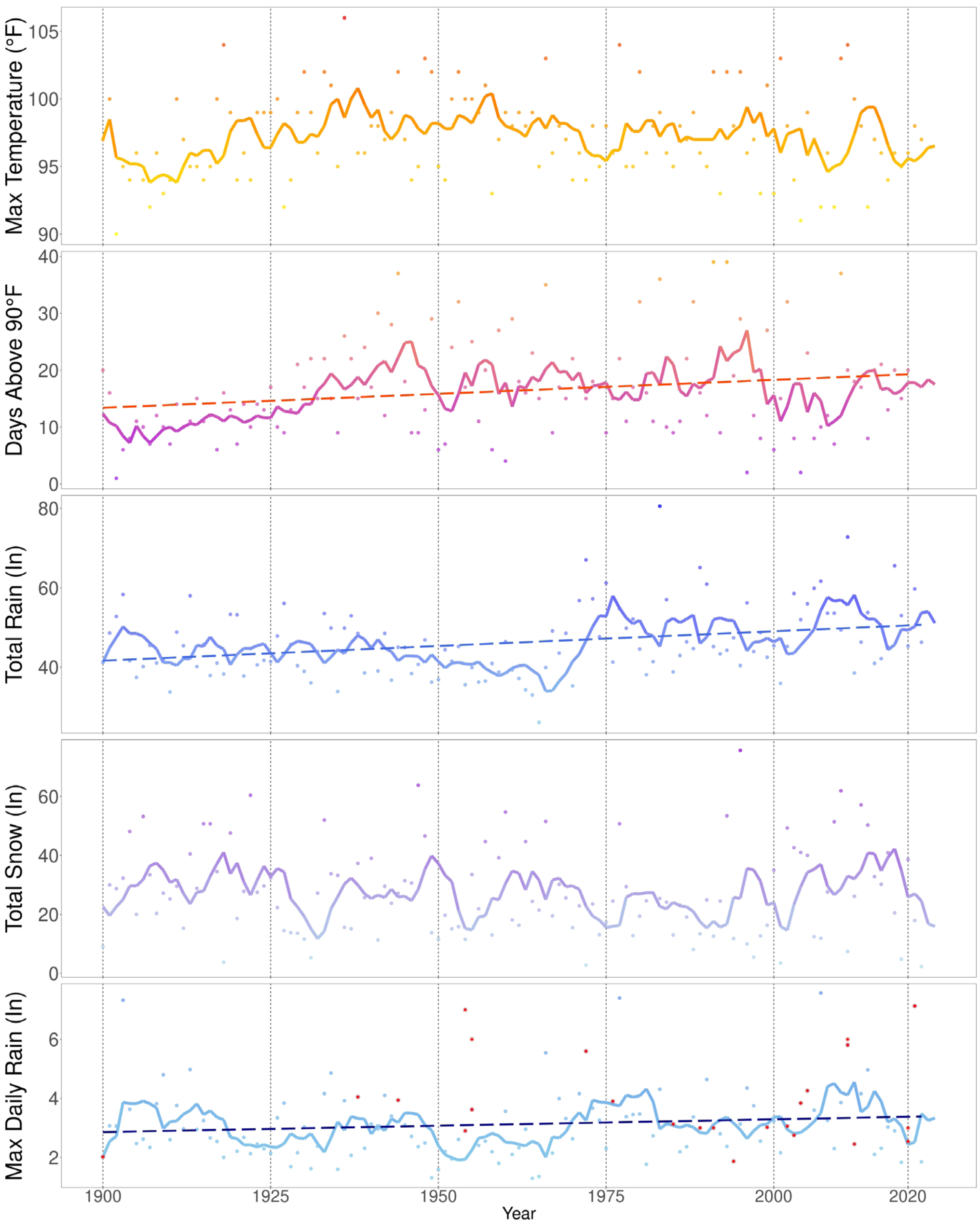
In conclusion, urban natural areas and managed urban green spaces represent distinct approaches to urban land use. While natural areas maximize conservation and protection of ecosystems, managed green spaces maximize human recreational and social needs while still providing some greenery in urban environments. Both types of spaces contribute to the well-being and livability of cities, albeit with different emphases and functions.

An illustration highlighting differences between landscaped greenspaces and natural areas.
Elena Kakoshina

Urban Natural Areas
Greenspaces or other areas managed primarily for ecological function / value. Often include trails for walking and hiking but may have limited additional amenities.

Landscaped Urban Greenspaces
Areas of greenspace that are managed primarily for aesthetic and recreational purposes with vegetation as a dominant cover type. Often include areas of highly maintained grasses or lawns. Often include multiple amenities such as benches, bathrooms, ball fields, and water fountains.

100 Years of Climate Data in New York City



While global temperatures have increased, the maximum temperature recorded in New York City has not significantly changed over time.

Although the maximum recorded temperature has not significantly changed over the last 100 years, the number and frequency of heat waves has steadily increased since 1900.

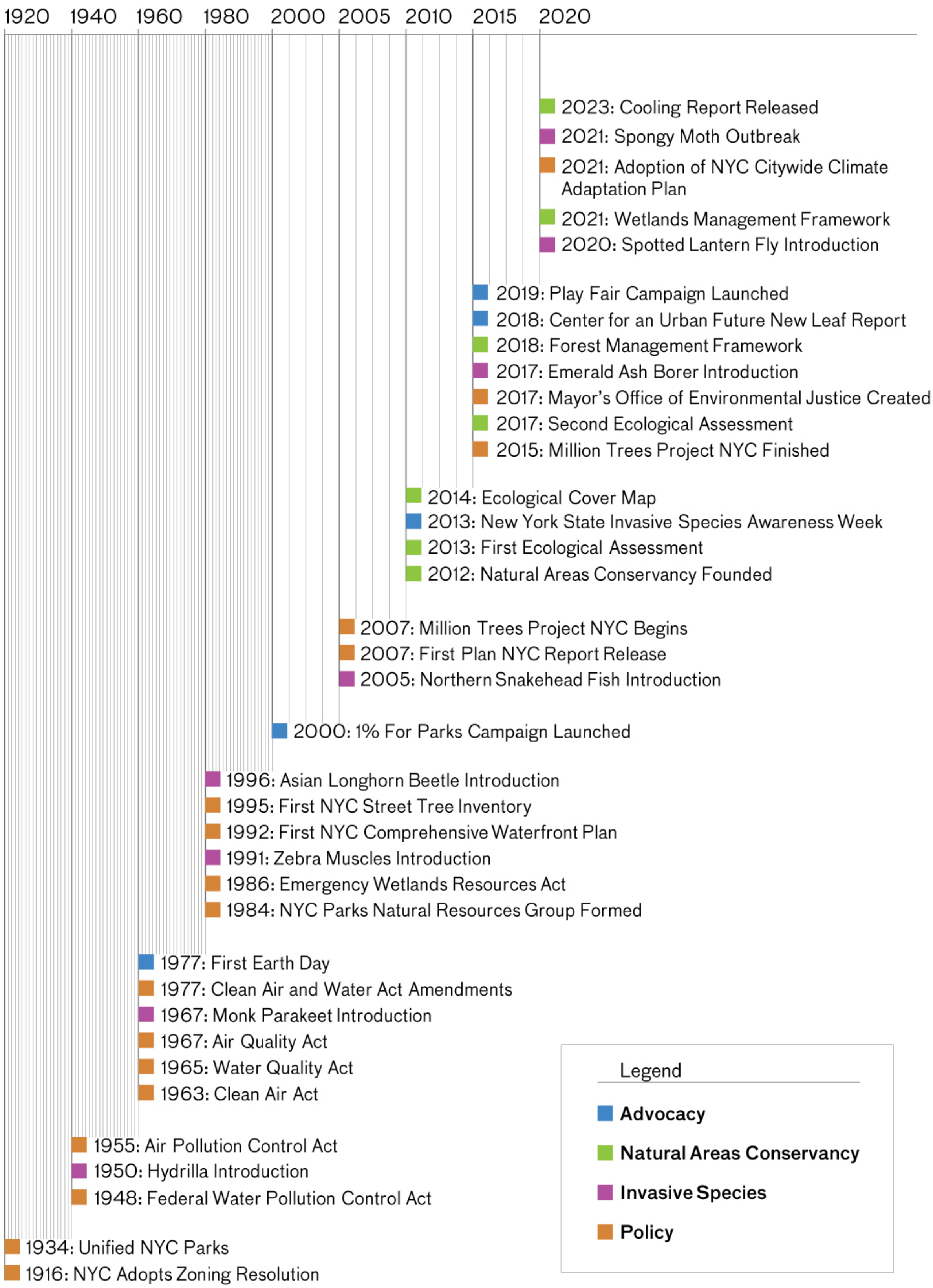
The increased frequency of flooding in New York City corresponds with an increase in total rainfall recorded per year. Prior to 1950, there were no recorded years with over 65 inches of rain, after 1950, there have been ten years with over 65 inches of rain

The total snowfall recorded in New York City has not significantly changed since initial recording began. However, yearly snowfall is highly variable and total snowfall recorded has decreased consistently since 2017.

The frequency of severe storms has steadily increased since 1900 and as a result the maximum amount of rain recorded in a single day has also increased. Correspondingly, the number of fatal storms in New York City (noted in red) has also increased.

For each figure, the recorded climatic variable for a given year is shown as a point while the 10 year rolling average is shown as a solid line. If there is a significant relationship between year and climatic variable, the trendline is shown as a dashed line. All data collected from the National Oceanic and Atmospheric Administration weather monitoring station in Central Park.

100 Years of Climate Policy, Advocacy, and Species Introductions in New York City



Increased Temperature

Broad street in Philadelphia contains almost no vegetation and high amounts of impervious surface, contributing to the urban heat island effect.
Peter Alt

Global Temperature Increases

The global temperature increase, a primary indicator of climate change, is largely attributed to the greenhouse gas effect. Greenhouse gases, such as carbon dioxide, methane, and nitrous oxide, are released into the atmosphere through human activities, including deforestation, burning fossil fuels, and industrial processes. These gases trap heat from the sun, preventing it from escaping back into space and thus causing the Earth’s average temperature to rise. This phenomenon, known as the greenhouse effect, is natural and necessary for life on Earth; however, the excessive accumulation of these gases due to anthropogenic activities has led to an enhanced greenhouse effect, resulting in global warming.[61–63]

Climate models play a crucial role in understanding and projecting future global temperatures. These models are complex mathematical representations of the Earth's climate system, incorporating various factors such as atmospheric conditions, ocean currents, and land surfaces. They are used to simulate and study the interactions between these components and their collective impact on the Earth's climate. Current climate models consistently project that if greenhouse gas emissions continue unabated, global temperatures will continue to rise throughout the 21st century. The Intergovernmental Panel on Climate Change (IPCC) estimates that by 2100, the global mean surface temperature could increase by 1.5 to 4.5 degrees Celsius, depending on the emission scenario.[4,64,65]

Positive feedback loops further exacerbate global temperature increases. These are processes that, once triggered, can amplify the initial warming effect. For instance, as global temperatures rise, polar ice melts, reducing the Earth's albedo (the amount of sunlight reflected back into space) and causing the oceans and land to absorb more heat, which in turn leads to further warming and ice melt. Another example is the release of methane, a potent greenhouse gas, from thawing permafrost. As the Earth warms, permafrost thaws, releasing stored methane into the atmosphere and further enhancing the greenhouse effect. These feedback loops, if not mitigated, could lead to a runaway climate change scenario, where the warming becomes self-sustaining and irreversible.[66,67]

Urban Heat Island

The urban heat island effect is a significant consequence of land-use change, deforestation, and the conversion of grasslands to urban landscapes. As natural vegetation is replaced by concrete and asphalt, the ability of these areas to absorb and store carbon dioxide is diminished, contributing to the greenhouse effect and global warming.[68,69] Furthermore, the removal of trees and other vegetation eliminates their cooling effect, which is achieved through the process of evapotranspiration. This process, where water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants, can significantly reduce local temperatures.[68,70]

Impervious surfaces, such as concrete and asphalt, contribute to higher temperatures in urban areas. These materials absorb a significant amount of solar radiation and re-emit it as heat, a process known as radiative heating. This results in higher surface and air temperatures in urban areas compared to surrounding rural areas.[13,30,68] Moreover, impervious surfaces prevent the infiltration of water, reducing the availability of moisture for evapotranspiration and further increasing local temperatures.[68,71]

The Urban Heat Island as a Proxy for Climate Change

Hotter average temperatures in urban areas can serve as a surrogate for understanding the impacts of global temperature rises due to climate change. Urban areas often experience more extreme temperature increases than the global average, providing a glimpse into the potential future impacts of climate change on temperature.[13,70] Furthermore, the urban heat island effect can exacerbate the impacts of heatwaves, which are expected to become more frequent and intense with climate change, posing significant risks to human health and urban infrastructure.[72,72] As such, the higher temperatures of urban areas may provide insights into how ecosystems will respond globally to higher temperatures.

Research Highlight

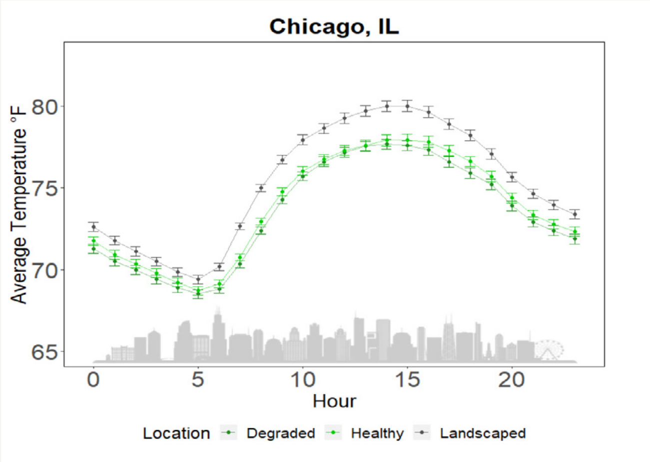
Why Some Natural Areas are Cooler than Others

Background: During the summer of 2022, the Natural Areas Conservancy collaborated with partners from 12 U.S. cities that are part of the Forests in Cities network, a coalition of urban forested natural areas professionals from across the U.S., to conduct a study investigating the cooling potential of urban forest ecosystems. This highlight utilizes data collected from air temperature sensors deployed in both Austin, Texas, and Chicago, Illinois, during the summer of 2022. In each city, three sites were selected. Within each site, a healthy natural area, a degraded natural area, and a landscaped area or street tree was selected within close proximity of each other (<1 mile). A HOBO sensor was placed at each location, and air temperature was recorded every 5 minutes continuously. For more information, see the full Cooling Cities Report.

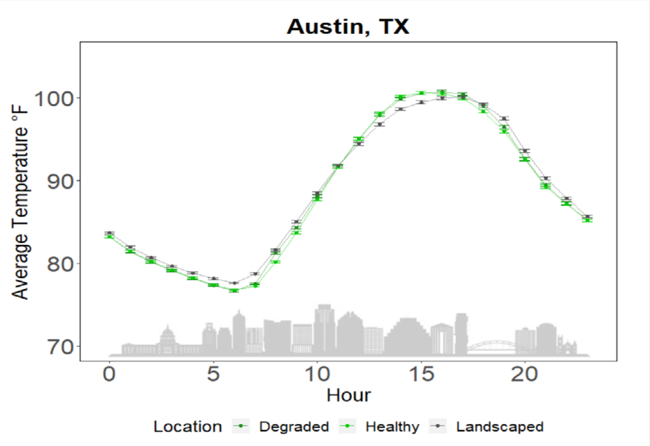
Result: In general, natural areas were significantly cooler than landscaped areas. During the month of July in Chicago, Illinois, average temperatures in both healthy and degraded natural areas were consistently lower than their corresponding landscaped counterpart. However, during the same time period in Austin, Texas, temperatures in natural areas initially were cooler than landscaped areas during the start of the day, but landscaped areas became cooler than natural areas during the hottest portion of the day.

The Importance of Local and Global Context: Why are natural areas in Chicago and Austin cooling differently when compared to landscaped areas? Although the closed canopy of forests can provide cooling through shade and evapotranspiration, the canopy can also trap air, and dense forests can limit wind flow.[56,80] The increase in local heat can be compounded by different levels of humidity, as drier air warms and cools more quickly than wetter air.

Implications: While natural areas can provide cooler local climates, their overall impact depends on both the surrounding urban context as well as their latitude, plant composition, and time of year. As such, natural areas' cooling capacities and other ecosystem services are context specific. Thus, some natural areas will experience higher than average temperatures putting the plants and animals within them at greater risk of heat related disease and mortality. We emphasize the importance of further studies to better understand the heterogeneous cooling dynamics within larger urban natural areas.



Throughout the day, landscaped areas in Chicago, Illinois were consistently hotter than both degraded and healthy natural areas.



Although natural areas were cooler than landscaped spaces early in the day, by approximately 2pm, temperatures in both healthy and natural areas exceeded temperatures in landscaped areas".

Research Highlight

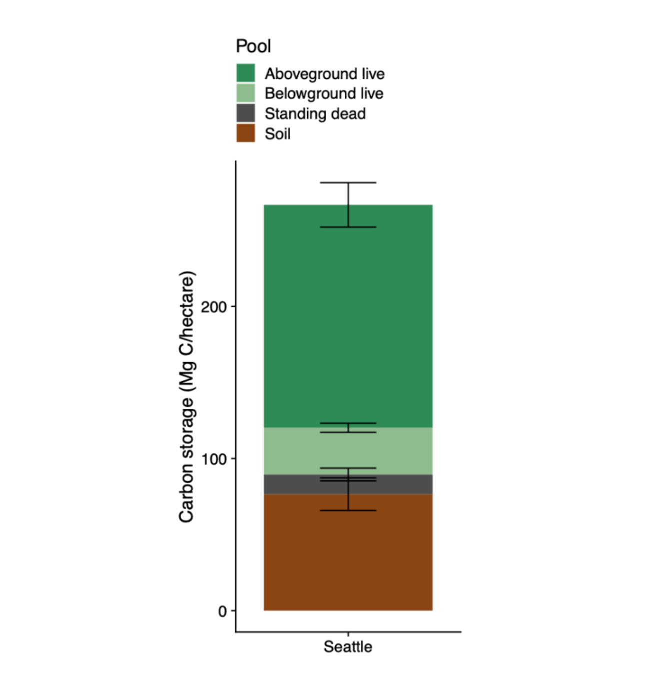
Carbon Capture by Urban Forested Natural Areas in Seattle, WA

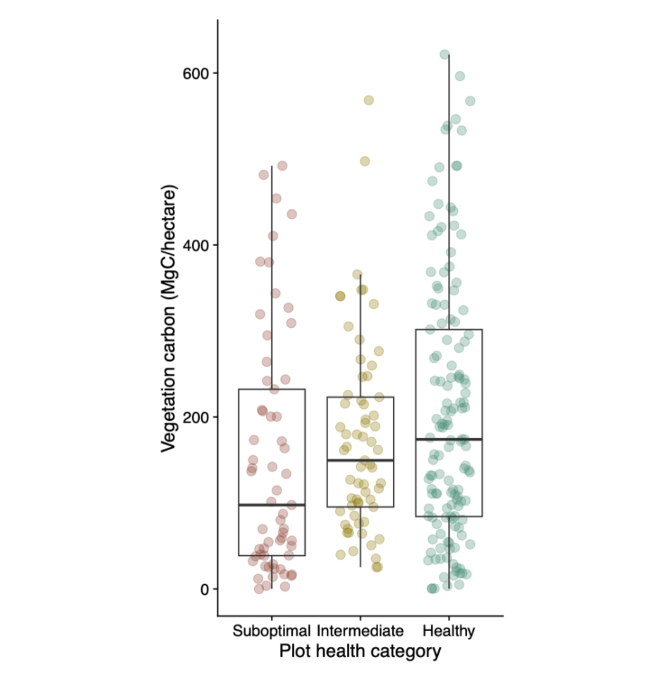
Background: Urban forests provide an attractive option for cities looking to mitigate and adapt to climate change; however, they are often overlooked in forest carbon accounting, which means that most cities cannot quantify the climate benefits of their urban natural areas. Seattle, also known as "the Emerald City" for its abundant, year-round green spaces, contains numerous parks and natural areas. In an effort to better characterize the benefits of the forested natural areas, over 5700 trees have been measured at 270 plots in 71 of these parks. Data has also been collected on the species of trees present, whether those trees are native to Washington state, and the carbon stored in the top 30 cm of soil.

Results: Forested natural areas in Seattle store on average 267 Mg C per hectare (or about 107 Mg C per acre). This carbon is found primarily in the live, aboveground parts of the trees, but belowground carbon (including roots and soil) also contribute significantly. Although these forests are subject to the combined stressors of an urban environment and climate change, this is a similar amount of carbon per area that is stored by rural forests in Washington state.

The natural areas forests of Seattle are dominated by native tree species, including *Acer macrophyllum* (big leaf maple), *Alnus rubra* (red alder), *Populous balsamifera* (Black cottonwood), *Thuja plicata* (Western redcedar) and *Psuedotsuga menziesii* (Douglas fir). In fact, about 70 % of the woody vegetation in forest natural areas is native to Washington state. Common trees that are not native include *Ilex aquifolium* (English holly), *Prunus laurocerasus* (cherry laurel), and *Prunus avium* (bird cherry). These non-native trees tend to be smaller than the local native species; thus, healthy forested natural areas (areas that contain more native canopy species) store, on average 42% more carbon than suboptimal areas dominated by non-native species. In fact, although only 70% of the individual trees in Seattle's natural area forests are native, these trees store nearly 97% of the vegetation carbon.

Implications: Although forested natural areas do not cover large areas, and thus the total carbon storage potential is limited, Seattle illustrates that forested natural areas are carbon-rich ecosystems and havens for native tree species. Despite local pressures, they are dominated by native trees and can store similar amounts of carbon as rural forests on a per area basis. This research also highlights the importance of monitoring and management in these areas, as healthier forests with more native species provide more of a carbon storage benefit than invaded forests.

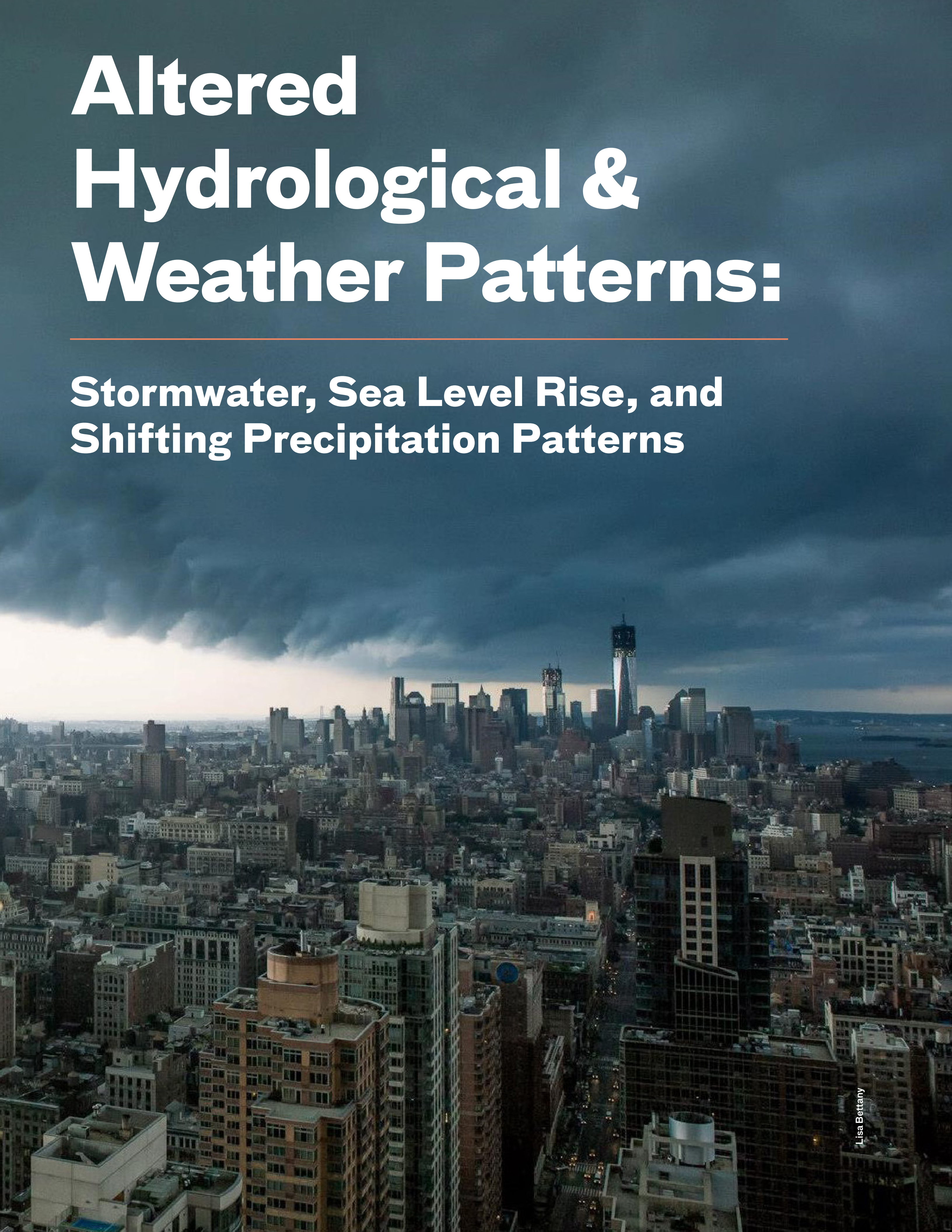




In Seattle, the majority of carbon in natural areas is stored in above ground live biomass. Additionally, healthy plots contain more total carbon on average than plots with suboptimal or intermediate health.

Altered Hydrological & Weather Patterns:

Stormwater, Sea Level Rise, and Shifting Precipitation Patterns



Lisa Bettany

Flooding & Storms

Increased Storm Severity

As global temperatures rise, warmer air holds more moisture, leading to an increase in atmospheric water vapor. The increase in atmospheric water vapor leads to more intense precipitation events, with a higher likelihood of heavy rainfall and severe storm and wind events.[81] In recent years, storms that were forecast to occur only once every thousand or every hundred years have become more common, forcing a reevaluation of many flooding models.[82,83] Within urban landscapes, high levels of impervious surface, often coupled with lower levels of draining and sewer outfall systems, create areas especially at risk of flooding from excess rainfall.[83,84] As a consequence, natural areas within urban landscapes are likely to experience high levels of flooding. Flooding can negatively impact natural areas by drowning vegetation, contributing to soil erosion, and, in large-scale flooding events, create landslides and wash-out events that remove large portions of natural areas.

Storm Surges, Coastal Flooding, and Sea Level Rise

Another source of flooding caused by climate change is an increase in storm surge events, exacerbated by rising sea levels.[23,85,86] As global temperatures warm, the melting of land-based ice combined with thermal expansion of seawater contribute to average sea levels rising. Some coastal areas are further put at risk as melting land-based ice shifts the weight distribution of tectonic plates causing localized coastal sinking.[23] During storm events, seawater can be pushed inland and flood coastal regions, leading to saltwater intrusion of natural areas that surround coastal wetlands, rivers, streams, and marshes.[22,85] Storm surges can also remove large amounts of sediments and coastal dunes when they recede, putting coastal areas at greater risk of flooding in future events.[87] Loss of sediment and higher sea levels also result in less suitable habitat for coastal vegetation leading to the loss of biomass which can further destabilize sediment and the coast.

A street is closed due to high water levels from storm surge after Hurricane Ian.

Altered Snaps

A large street tree knocked over during Hurricane Sandy causes damage to a parked car.
Natural Areas Conservancy

Impacts of Larger and More Frequent Storms

Climate change is resulting in more frequent and more severe storm events, which can negatively impact urban natural areas. Wind events such as hurricanes, cyclones, microbursts, and intense lightning storms are becoming more frequent and are also occurring in areas not historically associated with these events. Strong winds can cause widespread damage to trees and other vegetation and within urban landscapes, wind often gets funneled due to the vertical nature of cities causing higher concentrations of wind at windbreaks such as natural areas. This wind can uproot trees, break branches, and lead to the loss of vegetation and biodiversity in natural areas.

Additionally, climate change also results in heavier snowfall events and earlier snowmelt. Heavy snow accumulation can weigh down and break tree branches and alter the canopy structure of natural areas. Rapid snowmelt can also lead to soil erosion and nutrient leaching, negatively impacting the health and composition of urban natural areas.

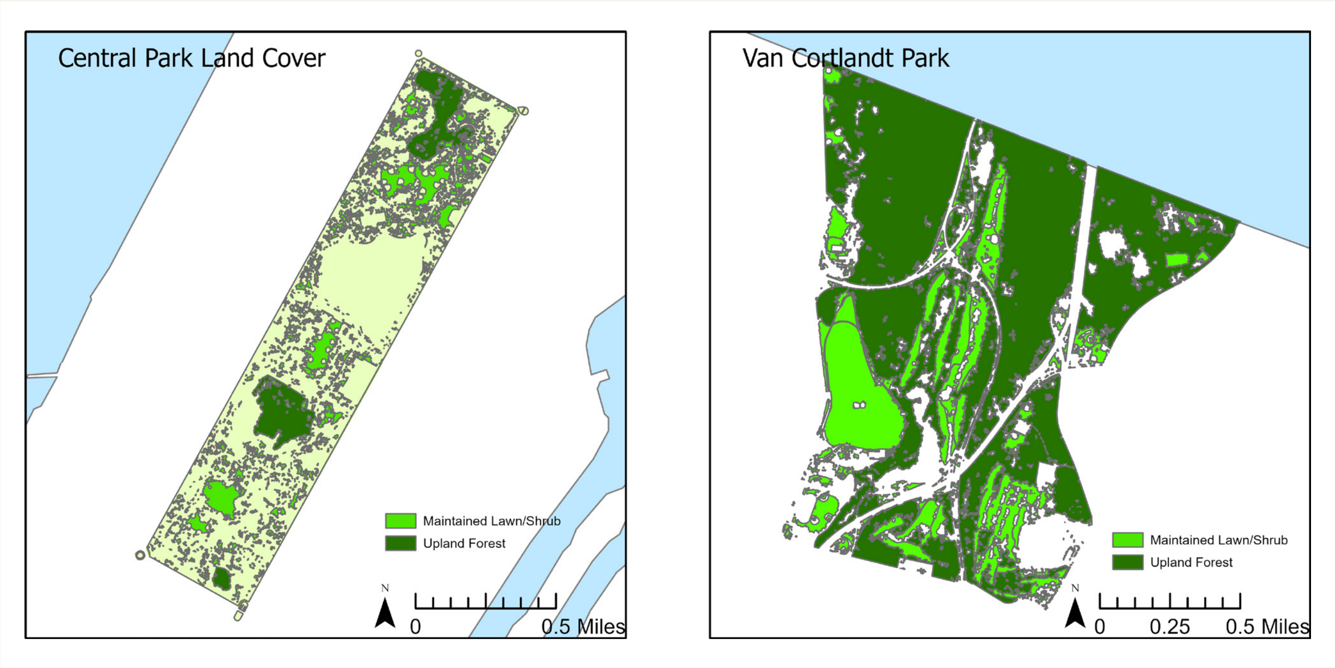
Increased Drought and Shift in Wet/Dry Seasonality

Climate change is projected to significantly alter the patterns of wet and dry seasons, leading to increased droughts and floods. According to some studies, an average increase in temperature (~2°C) and precipitation (~6%) is expected by 2050 to 2079.[88] This increase in precipitation would result in a 10% increase in streamflow during flood periods, while an 8% decrease could lead to a 60% reduction in flow during dry periods. Droughts are anticipated to become more frequent and prolonged, particularly in highland regions, while wet periods will be less frequent but of greater duration and intensity. These changes point to future challenges, such as water deficits in the dry season and increased streamflow during the wet season, necessitating strategic adaptation to climate change.

The alterations in wet and dry seasons due to climate change have profound implications for urban areas and natural environments. Changes in rainfall patterns can lead to extreme weather events, affecting hydrological regimes and impacting water resources. Droughts can severely alter river water quality and aquatic ecosystems, while increased rainfall can cause floods and landslides. These natural disasters not only affect the population and economic development but also increase vulnerability. Additionally, land use changes and climate change affect hydrological processes such as evapotranspiration, interception, and infiltration, altering surface and groundwater flows. The availability of water resources is further strained by population growth, emphasizing the need for effective adaptation policies in both developed and developing countries.

Research Highlight

Stormwater Retention in Urban Greenspaces by Covertype in New York City



A comparison in the land cover composition in Central Park and Van Cortlandt Park. The large amount of upland forest in Van Cortlandt Park provides high stormwater retention compared to the open lawns of Central Park.

Background: With the increased likelihood of extreme rainfall (often called 'cloud burst') and severe storm events, cities are considering how to prioritize pervious land uses that allow for stormwater retention. In New York City, events like Hurricane Ida, which brought 3.15 inches of rain in a single hour to Central Park and caused inland flooding across the city, underscore the risk of extreme weather. As pervious surfaces, urban green spaces, including managed greenspaces and natural areas, provide stormwater retention benefits by allowing soil infiltration, uptake through vegetation, and rainfall interception through canopy.

We leveraged the Natural Capital Project's InVEST open source Urban Stormwater Retention Model to look at how much stormwater two large urban parks in New York City, Central Park in Manhattan and Van Cortlandt Park in the Bronx, retain over an average year. We looked at the land cover composition of the two parks and compared the performance of upland forests and maintained lawns or shrubs within the parks. The InVEST model calculates annual stormwater retention by using annual runoff coefficients for each land use land cover type, soil hydrologic group, and annual precipitation to estimate stormwater retention in a given area.

Results: Forests have a denser canopy to intercept more rainfall, higher soil infiltration rates, and a higher density of trees to uptake water than maintained lawn.

Using the InVEST model, we found that, on average, an acre of Van Cortlandt Park annually retains about 1,723.36 m^3/y, where on average, an acre of Central Park retains about 1,441 m^3/y.[1] Van Cortlandt retains more water per acre annually then Central Park because it has a larger proportion of upland forest (59.36%) than Central Park (8.53%).

The Importance of Local and Global Context: Van Cortlandt Park is a largely forested park in the north Bronx, whereas Central Park is a heavily used park in Manhattan that is used for recreation and global tourism. Central Park was also built on soil that is marked by rocky outcrops, clay-like, and shallow, all of which may influence lower annual retention per acre.

Implications: Restoring and expanding natural forested areas in urban parks provides added stormwater retention benefits. Urban planners and park managers can work to expand natural areas, where appropriate, to maximize benefits.

1. U.S. Department of Agriculture, Forest Service. 2020. Urban forest systems and green stormwater infrastructure. FS–1146. Washington, DC. 23

Case Study

Riparian Restoration to Reduce Flood Risks in Houston, Texas

Image of Buffalo Bayou in Houston, Texas highlighting the use of green infrastructure to reduce flood impacts.
Michael Barera

Context: Houston's rapid development, population growth, and changing land cover, combined with its low elevation and dense urban bayous, make it vulnerable. Extreme weather events have become more frequent and intense. The city's Climate Action Plan focuses on mitigating climate risk through greenhouse gas reductions. Houston's forested natural areas, despite the presence of invasive species, are a significant asset for resilience. These areas provide numerous ecosystem services, including carbon storage, energy savings, air quality improvement, and stormwater management.

Riparian Restoration Initiative: Within the City of Houston's comprehensive Climate Action Plan, the Riparian Restoration Initiative aims to restore or create riparian buffers in 70 parks, resulting in the restoration of over 1,000 acres of habitat and the planting of 200,000 native trees. Integrating forestry initiatives into the Climate Action Plan was a significant strategic step. In less than two years, the city restored forested riparian buffers in four parks, resulting in 20 acres of restored land and the planting of 6,000 native trees. Five more sites have been funded for restoration in 2020. The project primarily used funding from grants as well as specifically allocated funds for planting trees within the city.

Key Strategies and Results

1. *Integration into the Climate Action Plan:* Instead of trying to establish a completely new project, the Riparian Restoration Initiative was incorporated into an already existing Climate Action Plan.

2. *Rapid Action:* Although the overall project is highly ambitious, the city of Houston began implementing parts of the initiative quickly and garnered the support of both local partners and volunteers to rehabilitate land in four parks in the first two years.

3. *Securing Future Funding:* The program has secured funding for the restoration of an additional five sites in 2020. The targeted acreage and number of trees for these upcoming projects are expected to double the achievements of the previous projects.

Broader Climate Context: The City of Houston, given its unique set of natural and developmental challenges, is particularly vulnerable to the impacts of climate change. Rapid urban development, population growth, and changing land cover, combined with its inherent low elevation and dense urban bayous, have heightened its susceptibility. Extreme weather events, including record-setting droughts and high-profile flooding incidents, have intensified in frequency and severity over the years. In response to these challenges, particularly in the aftermath of Hurricane Harvey, the city launched a comprehensive Climate Action Plan. This plan emphasizes the mitigation of climate risks primarily through the reduction of greenhouse gases. The broader climate context of this paper underscores the urgent need for integrated and proactive strategies, like the Riparian Restoration Initiative, to bolster the city's resilience against the escalating threats of climate change.

Adapted from Bowers et al. 2020

Case Study

Built vs. Natural Coastal Resilience

Context: In May 2014, RAND Corporation and BuroHappold Engineering Cities group conducted a two-phase effort to explore how Jamaica Bay in New York City, New York, could help reduce future flood risk, improve water quality, and enhance ecological restoration. The integrated approach to planning considers the complex interplay between ecological, hydrological, and human systems, all of which are affected by climate change. The report considered two distinct plans to manage the space to improve coastal resilience.

Concept 1: Barrier and Restoration

Summary: Concept 1 represents a combination of hard infrastructure (storm surge barrier) and ecological restoration (marsh islands and perimeter). It aims to explore the potential benefits and challenges of integrating a significant engineering intervention with nature-based restoration efforts. The concept aligns with broader goals of building resilience in Jamaica Bay, considering factors like sea-level rise, storm surges, and ecological integrity.

Components

Storm Surge Barrier: The central feature of Concept 1 is a proposed storm surge barrier across Jamaica Bay Inlet. The specific details regarding the frequency or flood elevation threshold for closure for the surge barrier were not presented in the report, as an Operation Plan would come later in the planning process.

Marsh Island and Perimeter Restoration: Along with the barrier, Concept 1 includes restoration projects focused on the marsh islands and the perimeter of the Bay. The most current footprints for restoration sites were obtained from USACE and the New York City Department of Parks and Recreation (NYCDPR).

Inlet Narrowing Lever: The concept retains the inlet narrowing lever (Lever 9) to explore its implications.

Implications

Land Changes: Concept 1 leads to changes in land gain and loss, with patterns of loss similar to the Future Without Action (FWOA) scenario.

Integration with Other Projects: The concept includes proposed structures from the New York City Office of Recovery and Resiliency (ORR) Raised Shoreline project, adding to the perimeter restoration.

Concept 2: Narrowing and Wetlands

Summary: Concept 2 represents a more ecologically focused approach to managing Jamaica Bay, emphasizing nature-based solutions and maximizing restoration opportunities. It seeks to enhance the natural landscape through a combination of inlet narrowing and extensive marsh island and perimeter restoration. The concept aligns with broader goals of ecological integrity, resilience, and adaptation to climate change, reflecting a commitment to sustainable and nature-oriented planning

Components

Nature-Based Narrowing: Instead of a barrier with gates, Concept 2 proposes a nature-based narrowing for the Rockaway Inlet. The specifics of this design were outside the scope of the report, but the narrowing was modeled through an assumed build-out of land by Manhattan Beach and south of Floyd Bennett Field.

Maximized Marsh Island Restoration: The concept seeks to maximize ecosystem restoration in and around the Bay. It includes a significant investment in marsh island restoration, returning all of the marsh islands to their 1974 footprints.

Perimeter and Additional Restoration Sites: All Concept 1 restoration sites and Raised Shoreline sites were included in Concept 2. Additional restoration sites included Shellbank Creek, Marine Park, North 40, Four Sparrow, Mill Basin, Bergen Beach, McGuire Fields, and others.

Implications

Land Gains and Habitat Retention: Concept 2 leads to significant land gains in a configuration closer to the 1974 marsh island footprint. The habitat retained in 50 years is notably greater with this concept, especially in the Mid climate scenario.

Inlet Narrowing Impact: The inlet narrowing is assumed to achieve a vertical elevation sufficient to counteract High scenario sea-level rise (SLR) during the period of analysis, meaning that none of this area is lost even under the High scenario simulation.

Adapted from Building Resilience in an Urban Coastal Environment report by Fischbach et al. 2018 https://www.rand.org/content/dam/rand/pubs/research_reports/RR2100/RR2193/RAND_RR2193.pdf

Photo of Jamaica by Bjoertvedt
Wikimedia commons

Case Study

The Decline of Western Red Cedar Across Urban Areas

Western Red Cedar *(Thuja plicata)* commonly found throughout urban areas in the Pacific Northwest of the United States as a result of its unique combination of adaptability and aesthetic appeal. This resilient tree tolerates shade, thrives in moist conditions, and survives compacted urban soil. Its shallow root system minimizes damage to sidewalks and foundations, making it a popular choice for streetside planting. Additionally, its attractive reddish-brown bark and aromatic foliage add beauty and character to urban landscapes. Western Red Cedar also offers practical benefits, including air filtration, shade provision, and erosion control. The tree also plays an important role in providing habitat to a diverse array of wildlife. However, in recent years, Western Red Cedar populations have dramatically declined throughout urban areas.

Large western red cedars growing in a residential neighborhood.
Sairus Patel

Climate Change Poses Multiple Threats to Western Red Cedar (WRC)

1. *Heat Stress:* With rising temperatures, WRC faces increased heat stress. Their shallow root systems struggle to access deeper, cooler water sources, leading to dehydration and stunted growth. This makes them particularly vulnerable during hot, dry summers, which are becoming increasingly common due to climate change.

2. *Drought:* WRC thrives in cool, moist environments. However, changing precipitation patterns are leading to more frequent and severe droughts, further exacerbating their water stress. Droughts weaken trees, making them susceptible to pests and diseases, ultimately leading to decline and mortality.

3. *Pests and Diseases:* Warmer temperatures and reduced water availability create ideal conditions for the spread of pests and diseases that can devastate WRC populations. These threats are further amplified by the fragmentation of urban habitats, which limits the ability of trees to disperse and escape infection.

A Call to Action

1. *Planting diverse, climate-resilient trees:* Diversifying urban forests with species better adapted to hotter, drier conditions can help mitigate the impacts of climate change.

2. *Protecting existing trees:* Prioritizing the protection of mature WRC trees through proper management practices, including regular watering and pest control, is essential.

3. *Restoring natural habitats:* Restoring degraded natural areas by planting native species and improving soil health can create more resilient ecosystems and support the survival of WRC populations.

4. *Community involvement:* Engaging communities in tree planting initiatives, educational programs, and citizen science projects can foster awareness and encourage participation in conservation efforts.

Conclusion

The case of Western Red Cedar serves as a stark reminder of the devastating impact climate change can have on our urban forests. By taking proactive measures to protect and restore these vital ecosystems, we can ensure that future generations can continue to enjoy the beauty and benefits of these majestic trees.

It is imperative to act now to protect and restore urban natural areas, ensuring that these vital ecosystems continue to thrive in the face of a changing climate. Only through collaborative efforts can we safeguard the future of our cities and the natural wonders they hold.

Research Highlight

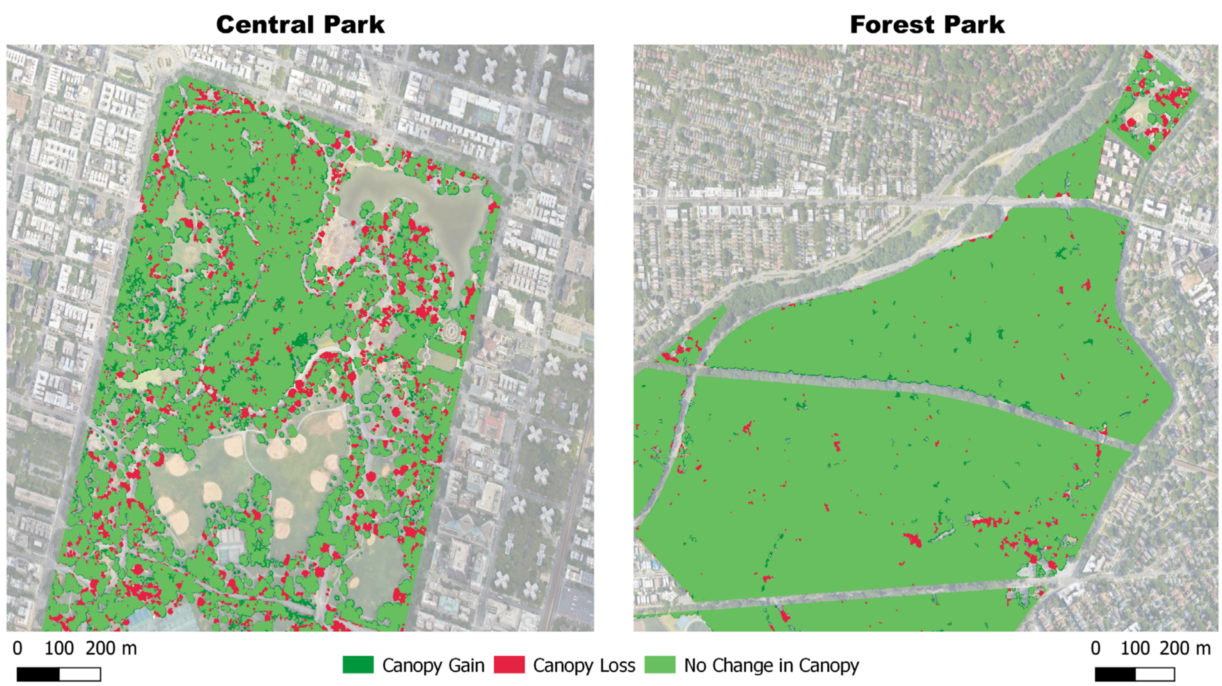
Natural Areas’ Resilience to Canopy Loss

Background: Over the past 50 years, increased urbanization resulted in a decline in tree canopy across urban areas, especially around the fringes as urban areas expand. Within urban areas, often green spaces that are not protected are replaced by built infrastructure which also contributes to the overall decline in canopy. However, development is not the only cause of canopy loss in urban landscapes; one of the most prominent is the increased frequency and severity of storms associated with climate change. High winds, heavy rainfall, and flooding can cause widespread tree damage and mortality, particularly for street trees and those isolated in parks. These isolated trees are often planted in shallow, compacted soils, making them more susceptible to windthrow and root damage during extreme weather events. In contrast, trees in forests and natural areas tend to be more resilient to the impacts of climate change. They benefit from a deeper root system and the protection of surrounding vegetation, which helps to mitigate wind and water damage.

To explore the extent to which canopy in urban natural areas may be more resilient to loss than trees outside of these natural areas, canopy change data from derived from LiDAR comparing tree canopy in 2010 and 2017 were compared to LiDAR based land cover classifications to identify what type of land cover, natural vs. street trees, experienced more loss over the 7 year period.

Result: Overall, natural areas showed significantly lower loss of canopy over with many natural areas gaining canopy cover while most loss of canopy occurred in highly landscaped areas or on street trees. Although we cannot directly attribute the loss of canopy to climate related events, the overall pattern emphasizes the increased resilience of natural areas compared to street trees.

Implications: This highlights the inherent ecological strengths of urban natural areas that enable better adaptation to and mitigation of climate-related stresses. As such, these areas can serve as vital components in urban planning strategies aimed at combating climate change. Although it is not always possible to expand or establish new urban natural areas, ensuring that natural areas maintain protection and are not developed can provide resilient sources of ecosystem services including air purification, carbon capture and urban cooling. By prioritizing the conservation and enhancement of these natural areas, urban planners and policymakers can create more resilient urban ecosystems, better equipped to withstand the challenges posed by a changing climate. This approach not only preserves biodiversity but also contributes significantly to the overall well-being and environmental health of urban populations.



Canopy loss within parks, seen in red, is often found on the edge of natural areas or along paths. In contrast, canopy gain, seen in dark green, is often seen in the core of natural areas or larger stands of forest.

Biodiversity Loss & Invasive Species Spread

City of Portland Government

Biodiversity Loss & Climate Migration

Habitat Fragmentation

Urbanization is a primary driver of habitat fragmentation, a process where continuous natural landscapes are broken into isolated patches. As cities expand, roads, buildings, and other infrastructure developments dissect and encroach upon natural areas, creating barriers that separate wildlife populations.[82,83] These fragmented habitats often lack the ecological integrity of undisturbed areas, leading to reduced biodiversity and the disruption of ecological processes. The isolation can hinder the movement and genetic exchange of species, making populations more vulnerable to local extinction.[83] Urbanization-induced fragmentation is particularly concerning in regions with high biodiversity, where the loss of habitat connectivity can have profound ecological consequences.[84]

Climate change further exacerbates habitat fragmentation by altering the distribution and suitability of natural habitats. As temperature and precipitation patterns shift, species may be forced to migrate to new areas that match their ecological requirements.[85] However, fragmented landscapes can impede this movement, trapping species in unsuitable or shrinking habitats.[86] Additionally, climate change can lead to more frequent and severe weather events, such as storms and droughts, which can further degrade fragmented habitats. The combined effects of climate change and existing fragmentation create a complex and dynamic challenge for conservation, demanding adaptive strategies that consider both current landscape configurations and future climatic uncertainties.

Shifting Species Ranges

Climate change is causing significant shifts in species ranges as temperature, precipitation, and other climatic factors change, altering the suitability of habitats. Species are moving poleward or to higher elevations in search of cooler temperatures and more favorable conditions.[87] In urban landscapes, these shifts can have complex impacts on natural areas. For instance, native species that are adapted to local conditions may be pushed out, while invasive species that thrive in the altered climate may become established. This can lead to changes in community composition and ecosystem functioning, potentially reducing biodiversity and the ecological services that natural areas provide, such as pollination, water purification, and climate regulation.[88,89] The dynamic interplay between climate change and urban ecosystems requires careful monitoring and adaptive management to preserve the integrity and benefits of natural areas within cities.

Increase in Invasive Species & Pest Prevalence

Climate change is facilitating the spread of non-native and invasive species, as well as increasing the presence of pest species, with notable consequences for urban greenspaces. Warmer temperatures, altered precipitation patterns, and increased atmospheric carbon dioxide levels can create conditions that favor certain invasive plants, insects, and other organisms, allowing them to outcompete native species.[90] In urban greenspaces, these changes can lead to a loss of native biodiversity and disrupt ecological balances. For example, invasive plants may dominate landscapes, altering soil chemistry and hydrology, while pest species such as mosquitoes and ticks may proliferate, posing health risks to humans and wildlife.[91, 92] The altered species composition can reduce the aesthetic, recreational, and ecological value of urban greenspaces, demanding new management strategies that consider the complex interactions between climate change, species invasions, and urban ecology.

White-tailed deer are commonly found throughout urban areas and can negatively impact natural areas.
Chesapeake Bay Program

Case Study

White Tailed Deer Management in Urban Forests

Context
High population densities of white-tailed deer lead to the overbrowsing of vegetation which in turn results in limited tree regeneration. Further, by decreasing the understory vegetative density, white-tailed deer also can increase the prevalence of non-native plant species94.

As white-tailed deer alter the vegetative community composition in forests, they can exacerbate the impacts of climate change, specifically through limiting carbon sequestration and altering forest biodiversity. Further, white-tailed deer often thrive in altered landscapes with high human population densities so the negative impacts of white-tailed deer can compound with other anthropogenic impacts.[95]

Management of White-tailed Deer in Eagle Creek Park
White-tailed deer became overabundant in Eagle Creek Park, Indianapolis, Indiana, during the late 1990s.Monitoring studies conducted between 2003 and 2013 showed heavy to severe browse damage within the park, necessitating proactive management of the deer population.

The goal of the ECP deer management program was to establish a sustainable relationship between biological diversity and habitat structure. Nighttime sharpshooting was chosen as the safe, effective, and humane option to reduce deer overabundance. A public information meeting was held, and despite some opposition, the reduction proceeded with legal support.

Implementation
The first reduction in November 2014 removed 148 deer, followed by sharpshooters removing an additional 101 deer in January 2015. To date, 585 deer have been removed, and more than 18,000 pounds of venison have been donated to the local food bank. Funding and support were provided by various departments and organizations.

Key Results
- Habitat recovery began with a harvest per square mile between 12–16 deer.
- Two species on the statewide watch list, goldenseal and ginseng, increased in abundance.
- Significant browse damage continues to hamper restoration efforts in reforestation plots.

Broader Climate Context
The overabundance of deer led to a decrease in native vegetation and an increase in invasive species, disrupting the ecological balance. The management strategies implemented at ECP can serve as a model for other urban areas facing similar challenges. In the face of climate change, maintaining biodiversity and healthy ecosystems is crucial for resilience and sustainability. The article underscores the importance of research, monitoring, and community engagement in achieving these goals, all of which are vital in the broader context of climate change adaptation and mitigation. *For more details, see: Howard et al. 2020.*[96]

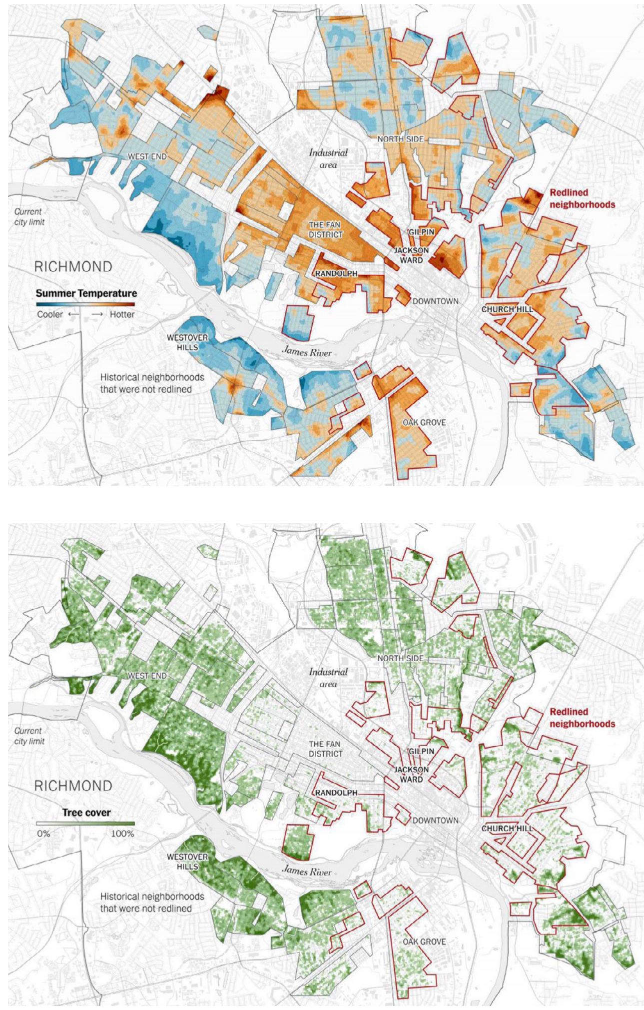
Climate Change and Environmental Equity

Natural Areas Conservancy

Climate change is not only a global environmental crisis but also a social justice issue. The impacts of climate change are disproportionately felt by marginalized and vulnerable communities, often exacerbating existing inequalities.[96,97] Environmental equity refers to the fair distribution of environmental benefits and burdens, ensuring that no group bears an undue share of negative environmental consequences. However, the reality is often far from equitable, with low-income and minority communities facing greater exposure to pollution, extreme weather events, and other environmental hazards. This disparity reflects a complex interplay of socio-economic factors, policy decisions, and historical legacies.

In many urban landscapes, a lack of access to greenspace is a striking manifestation of environmental inequity. Historically, urban planning and zoning practices have often marginalized certain communities, limiting their access to parks and natural areas.[98] These decisions, rooted in racial and economic discrimination, have lasting impacts, leading to environmental injustices that persist today. The absence of greenspace not only deprives communities of recreational and aesthetic benefits but also essential ecosystem services such as air purification, temperature regulation, and mental well-being.

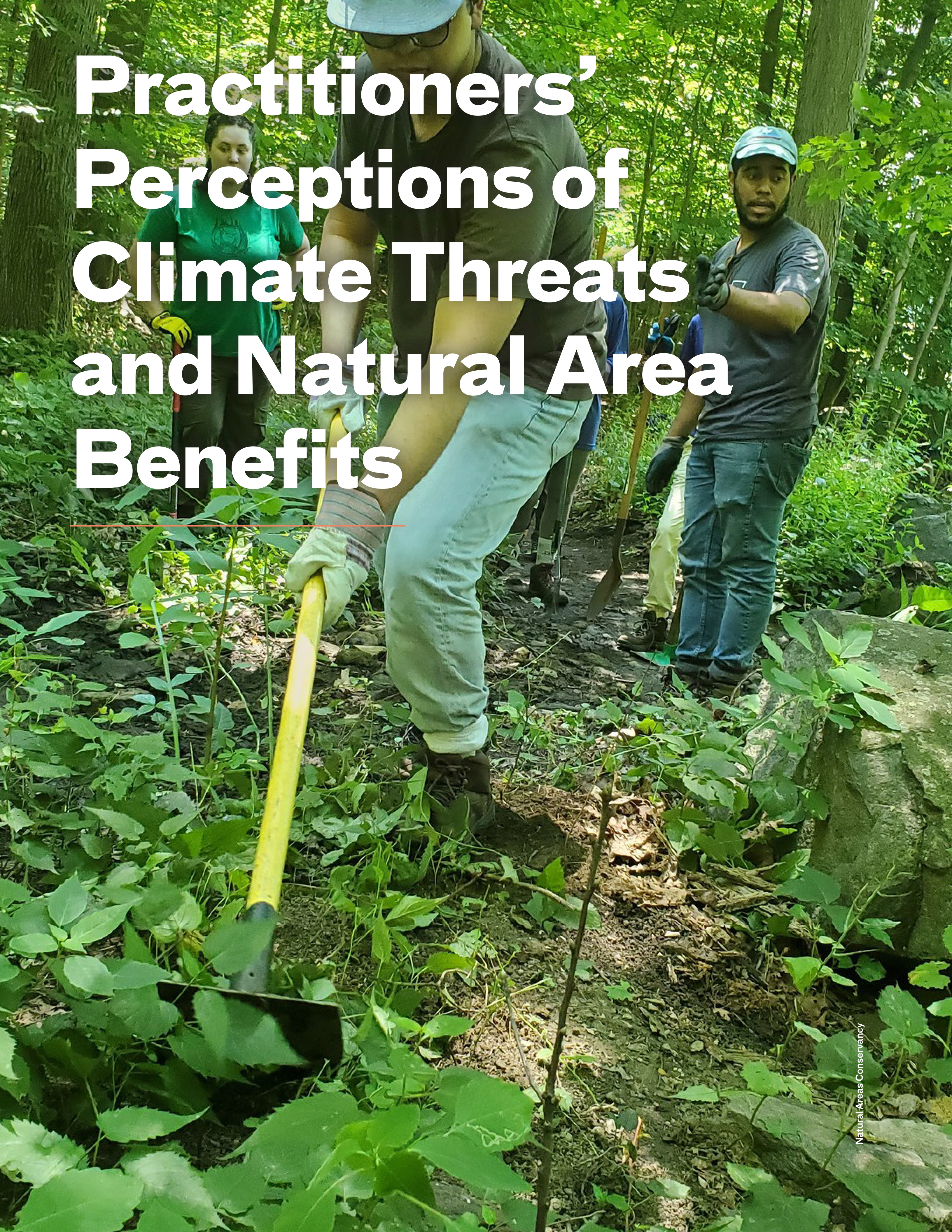
Natural areas within cities can be part of the solution to environmental inequity. By prioritizing the creation and maintenance of parks, gardens, wetlands, and forests in underserved areas, cities can begin to redress historical imbalances.[99] These natural spaces provide opportunities for physical activity, social interaction, and connection to nature, contributing to overall community health and well-being. Moreover, they offer tangible environmental benefits, such as improved air quality, water retention, and urban cooling, which can be particularly valuable in mitigating the effects of climate change in vulnerable communities.



Formerly redlined areas are associated with increased temperatures and decreased tree cover.

University of Richmond Atlas of Prejudice

Practitioners' Perceptions of Climate Threats and Natural Area Benefits



Natural Areas Conservancy

Forest in Cities Network

Forest in Cities Network

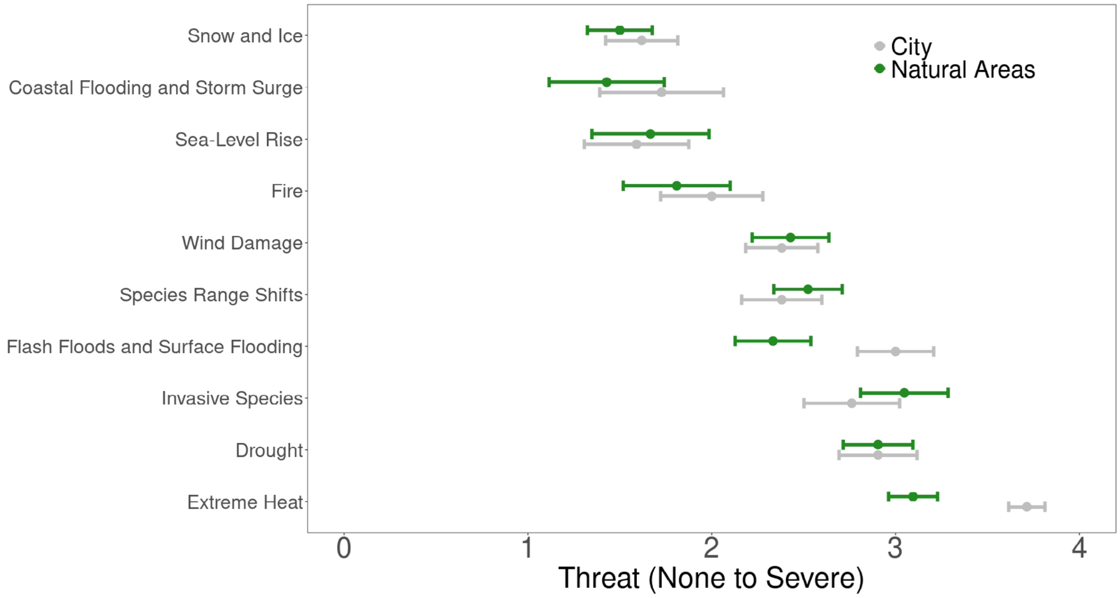
The Forest in Cities (FiC) Network was created in 2019 to promote and advance healthy forested natural areas in cities across America through science, management, partnership, and communications. Since it was founded, 19 cities have joined the organization representing metropolitan regions from across the United States. Members of the network include researchers, practitioners, and advocates and their deep knowledge of their city's natural areas provide invaluable insights on best practices for managing these landscapes.

Members of the Forest in Cities Network in Miami for their annual meeting.

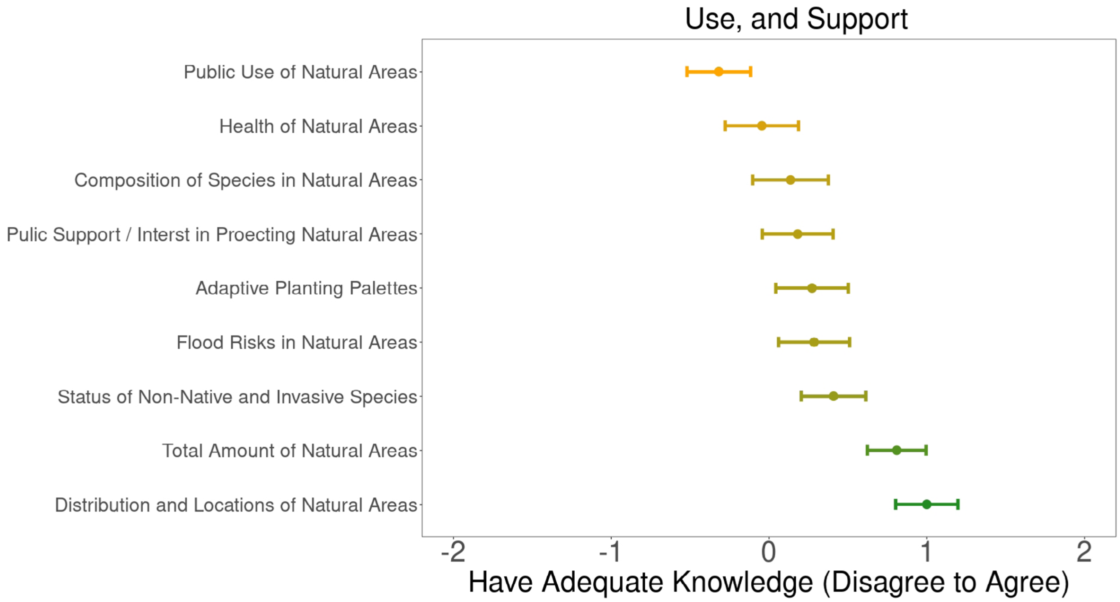
Natural Areas Conservancy

Understanding Climate Threats

Members of the FiC Network were asked to rank specific climate related threats to their cities as a whole as well as the natural areas within their cities. By highlighting where threats overlap for people and natural areas, practitioners, planners, and policymakers can find common ground and develop strategies to protect both cities and their natural areas.



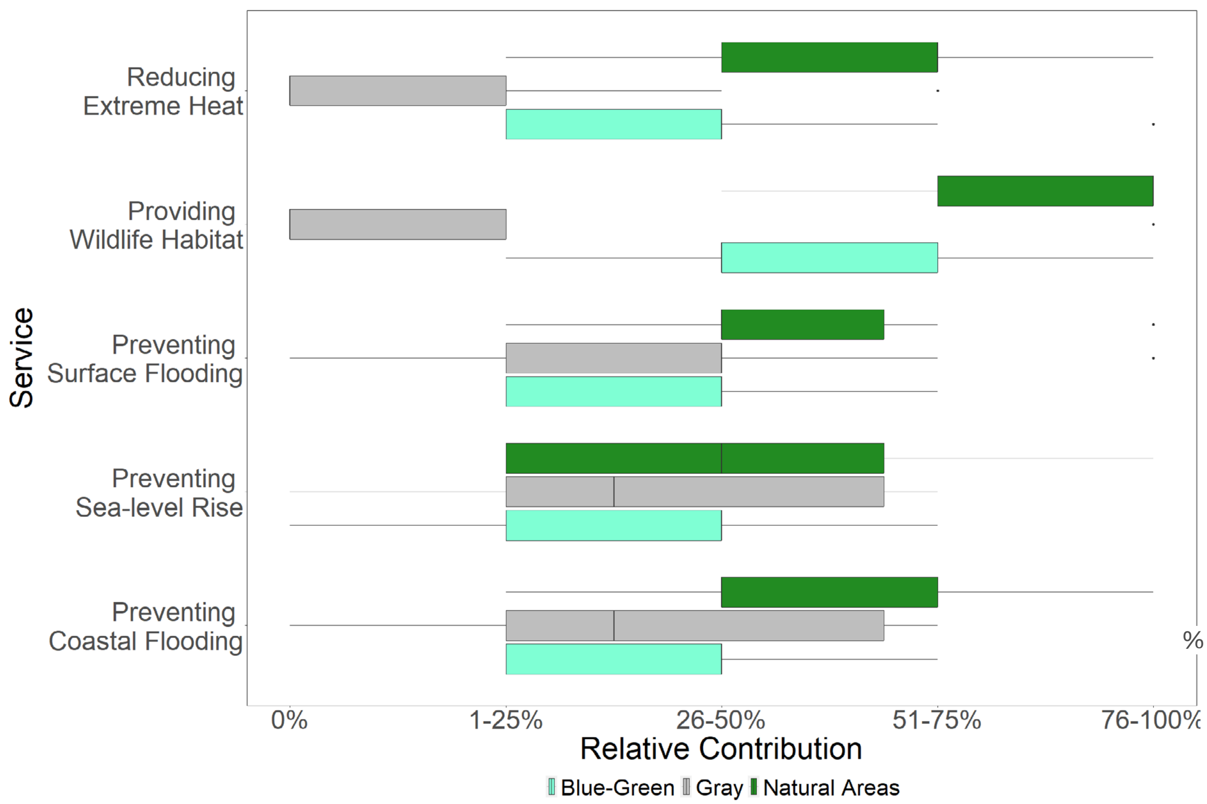
FiC Members consistently reported extreme heat as the largest threat to both their cities (gray) and natural areas in their cities (green). In contrast, ground flooding was seen as a lesser threat to natural areas than to cities, their people, and their infrastructure. Scores represent an increasing threat level with "Not a threat at all (0)" to "A severe threat (4)."



FiC members reported that they needed more information about how people are utilizing natural areas. They also reported that, on average, they agreed that they knew where the majority of natural areas in their cities were located but this knowledge could be increased or better mapped.

Services Provided by Natural Areas

As cities look for solutions to climate related challenges, it is important to recognize that natural areas are already providing benefits and helping cities adapt to climate change. FiC members consistently reported that natural areas were already contributing to key climate adapting services and in many cases were contributing the majority of specific services such as reducing extreme heat.



FiC members were asked to assess how much of a specific climate adapting service different infrastructure provided within a city. On average, natural areas were reported as providing a higher relative contribution than other infrastructure across cities.

Future Opportunities and Needs

Synthesis and Application

Layers from Natural Area Conservancy's Ecological Cover Map highlight the various greenspaces through New York City.
Natural Areas Conservancy

Synthesis

Urban natural area mapping and identification: Combining remote sensing techniques, such as satellite imagery, with the on-the-ground expertise of practitioners offers a promising approach to uniformly mapping urban natural areas. Satellite imagery provides a comprehensive and up-to-date overview of the urban landscape, identifying green spaces and natural habitats that might be overlooked or underappreciated. When this data is coupled with the nuanced, local knowledge of practitioners—who understand the unique characteristics and definitions of natural areas in their respective cities—it enables the creation of more accurate and universally applicable maps. This harmonized approach not only facilitates better management of these areas by providing a clear, consistent picture of their extent and condition but also enhances communication and collaboration among practitioners across different cities. By establishing a common language and framework for identifying and classifying urban natural areas, this strategy can lead to more effective conservation efforts, policy development, and public engagement in urban environmental stewardship.

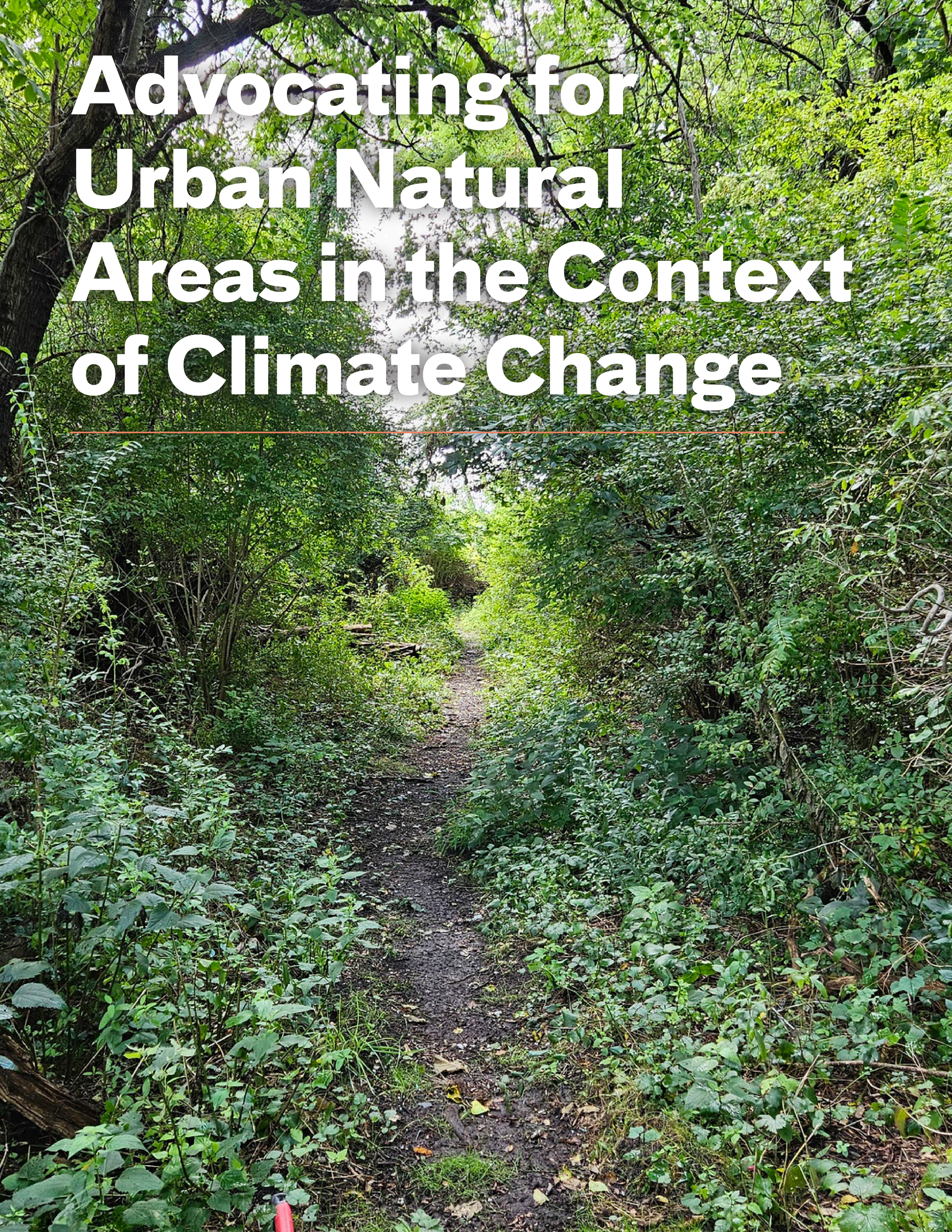
Utilization of historic sampling efforts to predict future change: Historical data from conservancies plays a pivotal role in understanding the change of urban natural areas over time, particularly in relation to climate change. By analyzing records and observations from past decades, conservationists and researchers can track changes in vegetation, wildlife populations, and ecosystem health within these urban green spaces. This data is invaluable in identifying patterns and trends, such as shifts in species distribution, changes in blooming periods, or alterations in land use, which are often driven by climate change-related events like increased temperatures or altered precipitation patterns. Understanding these historical changes enables scientists and urban planners to predict how these areas might continue to evolve under future climate scenarios. This foresight is crucial for developing adaptive management strategies that anticipate and mitigate the impacts of climate change, ensuring the resilience and sustainability of urban natural areas. By leveraging past insights, we can better protect these vital green spaces for future generations, enhancing the overall ecological health and livability of urban environments.

Application

Integrating urban natural areas into climate resilience plans through funding: Integrating the maintenance and protection of urban natural areas into city budgets, policies, and plans is essential for adapting to climate change effectively. These areas are critical for mitigating the impacts of climate change, such as extreme heat, air pollution, and flooding, by providing natural cooling, carbon sequestration, and stormwater management. Cities should allocate sufficient funds for the preservation and enhancement of these green spaces, ensuring they are included in urban planning and development strategies. Policies should be developed to protect existing natural areas from urban encroachment and degradation, and to encourage the creation of new green spaces, particularly in underserved neighborhoods. This integration necessitates a collaborative approach, involving multiple sectors and stakeholders, including city planners, environmental scientists, community groups, and policymakers. By prioritizing urban natural areas in their strategic planning, cities can create healthier, more sustainable, and climate-resilient urban environments for current and future generations.

Increased awareness and opportunity for stewardship: Increasing urban residents' awareness of urban natural areas is crucial, particularly in the context of climate change, as it fosters a sense of stewardship and connection to these vital ecosystems. Awareness leads to appreciation and understanding of the multifaceted benefits these areas provide, such as improving air quality, reducing urban heat islands, and enhancing mental and physical well-being. Educated and engaged citizens are more likely to support and participate in conservation efforts, policy-making, and sustainable practices that protect and nurture these spaces. Moreover, in an era where climate change poses significant challenges to urban environments, an informed public can be instrumental in advocating for and adopting green initiatives that contribute to urban resilience and sustainability. This collective awareness and action are essential for ensuring the long-term health and viability of urban natural areas, making them integral to the ecological and social fabric of cities.

Advocating for Urban Natural Areas in the Context of Climate Change



Urban Nature Needs Your Help!

Urban natural areas are indispensable in the context of cities adapting to climate change, serving as vital ecosystems that enhance urban resilience. These areas provide crucial services such as carbon sequestration, temperature regulation, and stormwater management, directly countering the adverse effects of climate change. Their role in maintaining biodiversity and offering recreational and mental health benefits to urban populations further underscores their importance. However, the continuous evolution of climate change presents new challenges, making ongoing research and funding for these areas critical. By investing in the study and conservation of urban natural areas, cities can not only better understand and mitigate the impacts of climate change but also ensure these spaces continue to thrive as integral, vibrant parts of urban life. This commitment is essential for fostering sustainable, resilient urban communities in the face of an ever-changing global climate.

Call to Action

The time to act is now. We must recognize the critical role urban natural areas play in mitigating and adapting to climate change, promoting biodiversity, and enhancing the well-being of our communities. By protecting, managing, and studying these vital spaces, we can create more sustainable and resilient cities for generations to come. Let us embrace the challenge and ensure that these vital and unique components of our cities continue to persist and thrive. Your actions can help:

- **Contact your elected officials and request additional funding for natural areas in your city.**
- **Volunteer for stewardship opportunities to protect and restore natural areas.**
- **Visit your local natural areas and post about it on social media. Show local leaders and politicians that these natural areas are important to you!**

Natural Areas Conservancy Staff and volunteers work to remove invasive species and clear trails to increase access to natural areas.
Natural Areas Conservancy.

Appendix A: Climate Risks, Adaptation, and Mitigation

Increased Temperature

Risks

Increased Temperatures and Evaporation Rates

Increasing heat associated with climate change can heighten the susceptibility of trees and other plants to drought stress. Higher temperatures lead to increased evaporation rates and reduced water availability, which can result in plant mortality and diminished overall forest health.[73–75] Increased temperatures can also cause the build-up of dead and dry vegetation making forests and grasslands more susceptible to fire.

In wetland ecosystems, rising temperatures can intensify evaporation rates and alter precipitation patterns, leading to reduced water availability. Lower water levels can disrupt the hydrological balance, degrade wetland habitats, and potentially result in the loss of unique plant and animal species that depend on these fragile ecosystems.

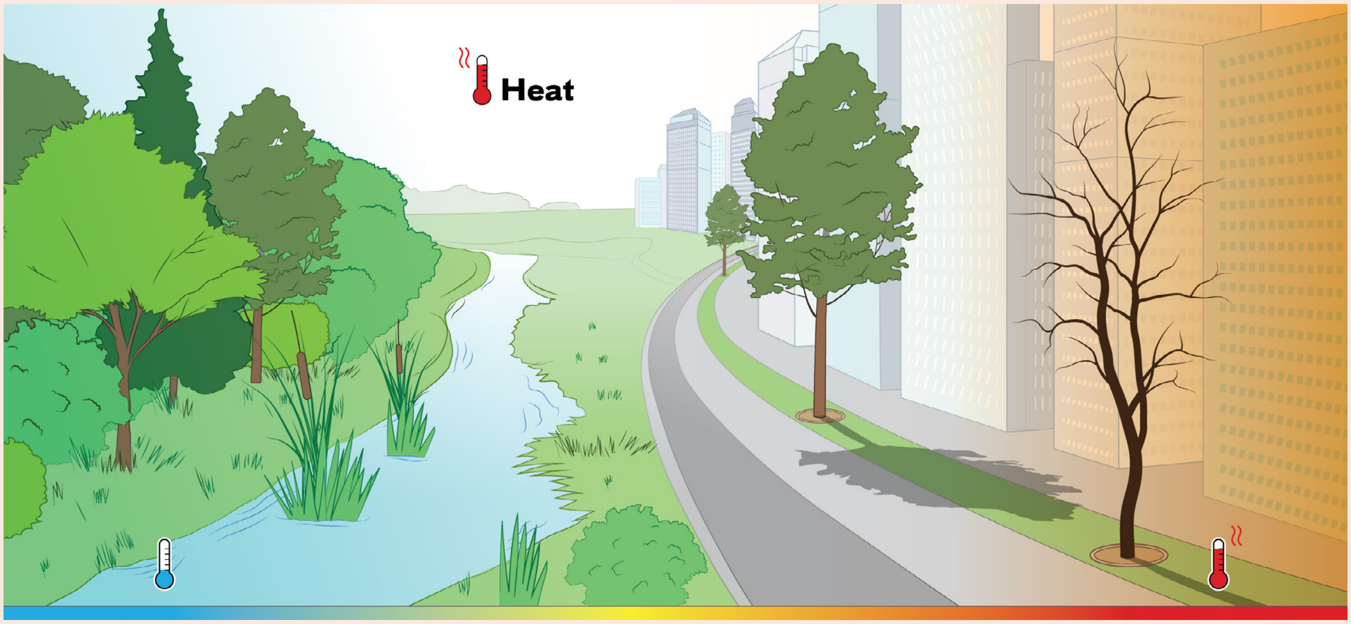
Change in Water Availability

Higher temperatures lead to accelerated snowmelt and reduced water availability, negatively impacting the water levels and flow patterns in riparian zones. These changes disrupt the unique ecological dynamics of riparian ecosystems, affecting the availability of habitat, nutrient cycling, and species composition, thereby posing a risk to the overall resilience and functioning of these critical transitional zones between land and water. In salt marshes, the reduction in water can also increase the salinity within the remaining water, putting local wildlife populations at risk.

Shifts in Species Composition and Increase in Non-Native Species

See Biodiversity Loss & Invasive Species Spread, page 28

The elevated temperatures associated with climate change present selective pressures on grassland communities, favoring the establishment and dominance of heat-tolerant species, thereby posing a potential threat to biodiversity and the delicate ecological interactions intrinsic to the grassland ecosystem.[76,77] Additionally, heatwaves can exacerbate the occurrence of pests and diseases, posing another significant threat to urban forests as weakened trees become more vulnerable to infestations and infections.[78,79]



Urban natural areas provide cooling benefits through both shade and evapotranspiration and can be several degrees cooler than adjacent built environments.

Elena S.

Adaptation & Mitigation

Shade & Evapotranspiration: Cooling of Local Microclimates

Urban forests can directly reduce local temperatures by providing shade. The vegetation within natural areas also undergoes evapotranspiration, a process associated with photosynthesis. As plants absorb carbon dioxide from the air, they release water vapor through evaporation, which cools the surrounding areas. Trees particularly contribute to cooling through evapotranspiration as they are able to pull water from deep in the ground.[30,31] It is important to note that while most plants contribute to localized cooling in this way, some drought and heat-tolerant species, especially many grasses, undergo a modified method of photosynthesis in order to limit water loss, and thus, not all plants equally contribute toward evapotranspiration driven cooling.

Evaporative cooling benefits are also abundant in urban riparian areas and wetlands due to the presence of bodies of water.[73] The standing bodies of water within these ecosystems provide natural cooling through evaporation and can reduce local temperatures. The water in these systems also requires a large amount of energy to heat or cool, providing more stable local climates. The strategic placement of urban riparian areas can facilitate natural ventilation and air circulation, further aiding in heat reduction and improving the overall microclimate of urban environments.

Carbon Sequestration

As plants undergo photosynthesis and growth, they absorb carbon dioxide from the air and turn it into biomass. In forest ecosystems, much of the carbon is stored within the trunks and branches of trees, which can sequester it for hundreds of years due to the long lifespan of trees.[54] Wetlands also store carbon for long periods of time through the formation of peat. Peat forms when vegetation in wetlands die; most of the biomass does not decompose and release carbon due to the limited amount of oxygen in the water and water-logged soils.

Solar Absorption

The impervious surfaces within urban landscapes, especially pavement and blacktop, absorb solar rays and store the heat energy, which then radiates outward, warming the area and causing the urban heat island effect. Forest canopy intercepts solar radiation, preventing the ground from warming; vegetation also absorbs solar energy, limiting its local warming effects.[66] Water within wetlands and riparian areas also reflects solar radiation, contributing to local cooling effects.

Often urban areas flood during storm events because stormwater can not be absorbed due to the large amounts of pavement and buildings. Natural areas provide an inlet for stormwater to be absorbed and captured.

Elena S.

Altered Hydrological & Weather Patterns—
Stormwater, Sea Level Rise, and Shifting Precipitation Patterns

Risks

Canopy Destruction

Stronger storms, bearing heavy winds and torrential rains, can cause substantial damage to forest canopies by breaking branches and uprooting entire trees.[23] This destruction not only alters the structure of the forest but also affects the microclimate within the canopy, impacting plant and animal species that depend on this unique habitat. Increased flooding, often exacerbated by urbanization where natural water flow is impeded by buildings and infrastructure, can further contribute to forest degradation. Floodwaters may submerge the root systems, leading to tree stress or death and erosion of the soil, which undermines the stability of the remaining trees.

Soil Erosion

Torrential rainfalls and strong winds associated with storms can remove the topsoil layer, which is rich in essential nutrients and organic matter. In forested areas, this erosion undermines tree stability and hampers growth, as the trees lose the vital soil required for anchorage and nourishment. In wetlands, soil erosion can alter the hydrology and sediment balance, thereby affecting the native flora and fauna that are specially adapted to those unique conditions.[21,52] Grasslands, too, suffer from the loss of topsoil, leading to the degradation of the land, reduced plant growth, and consequent declines in the species that depend on these habitats. The cumulative effect of soil erosion on these diverse ecosystems within urban landscapes impairs their ecological function, threatens biodiversity, and can lead to a loss of the natural barriers and buffers that these areas provide against further climate extremes.

Habitat Loss

Severe storms in urban natural areas can have profound negative impacts on wildlife, leading to loss of biodiversity. Intense winds, heavy rainfall, and flooding can physically damage or destroy nests, dens, and other critical wildlife shelters, leaving animals exposed and vulnerable.[22,86] Such destruction can fragment habitats, disrupting movement and breeding patterns, and isolating populations, leading to a loss of genetic diversity. Flooding may also alter the chemical composition and temperature of water bodies, impacting aquatic life, especially as stormwater from urban infrastructure enters natural systems. In addition, the sudden and drastic changes in environmental conditions brought on by severe storms can cause immediate stress to animals and plants, impacting their behavior, reproduction, and survival. These disturbances in urban ecosystems can lead to an imbalance in species interactions and result in the loss of species that are less resilient to such extreme events. Over time, these changes can contribute to a reduction in overall biodiversity, diminishing the ecological richness and functionality of urban natural areas.[88] Therefore, the adverse effects of severe storms emphasize the need for strategic planning and management to enhance the resilience of wildlife habitats in cities.

Adaptation & Mitigation

Windbreaks

The presence of trees and dense vegetation in natural areas serves as a physical barrier that disrupts the flow of wind, slowing down its velocity as it passes through the foliage and branches. This reduction in wind speed diminishes the force exerted on buildings and other urban structures, thus lowering the risk of damage during intense storms. Additionally, the windbreak effect contributes to a decrease in wind-chill during colder months, enhancing the microclimate and comfort level within the urban area. By acting as a buffer against harsh weather conditions, natural areas play a significant role in mitigating the adverse effects of severe storms, showcasing the vital importance of preserving and incorporating green spaces into the urban landscape. Their protective function further emphasizes the need for thoughtful planning and management to maintain and leverage these natural assets for the resilience and well-being of city environments.

Walkways along a river become unusable after a large storm.
Pointillist

Soil Stabilization

The vegetation found in wetlands, forests, and grasslands plays an essential role in stabilizing soil and preventing soil erosion, a function that's vital to maintaining the ecological balance within a city. The root systems of plants, trees, and grasses create a complex network that binds the soil together, enhancing its resistance to the erosive forces of wind and water.[82] In wetlands, plants like reeds and sedges not only hold the soil in place but also slow down the flow of water, reducing its erosive power. In forests, the canopy intercepts rainfall, and the roots create channels that facilitate water absorption, minimizing surface runoff. Grasslands, with their dense root mats, act as a protective barrier against both wind and water erosion. These vegetative features act synergistically in urban settings to maintain soil integrity, support biodiversity, and provide a buffer against the loss of valuable topsoil. In doing so, they contribute to the overall resilience and sustainability of urban landscapes, preserving the multifunctionality and aesthetic appeal of natural areas within the city.

Water Infiltration

Natural areas within urban landscapes serve as important mechanisms for managing water, thereby mitigating the risks associated with flooding and excessive water runoff. Given the prevalence of impervious surfaces in urban environments, these green spaces provide essential opportunities for water to infiltrate the soil and be effectively managed. Among these natural areas, forests, grasslands, and wetlands each contribute uniquely to this process. Forests serve a dual role by intercepting and slowing rainfall, allowing water to gradually percolate into the soil where it can be retained by the trees' complex root systems. Grasslands often contain dense mats of root networks which efficiently absorb rainwater, reducing surface runoff. Additionally, wetlands act as natural reservoirs, capable of storing significant amounts of standing water. This stored water is then released slowly into the soil over time, preventing sudden surges in water levels. Consequently, the combined effects of vegetation absorption and wetland water storage not only safeguard against flooding but also contribute to sustained soil moisture and urban resilience to extreme weather events.[76]

Impacts of Larger and More Frequent Storms & Increased Drought

Under extreme drought conditions, soil can dry and crack. This dry soil not only is inhospitable to most vegetation but also has a reduced capacity to absorb water.
Kyle Powys Whyte

Risks

Vegetation Loss

Increased droughts pose a significant threat to urban vegetation, which provides essential ecosystem services that make cities more livable. As urban areas continue to expand, the vegetation cover is rapidly changing, and drought conditions can exacerbate the decline in green cover. During droughts, the lack of water availability can lead to reductions in green cover in many cities, impacting the ecological quality of the urban area. The loss of vegetation not only diminishes the aesthetic appeal but also affects key ecosystem services such as temperature regulation and the availability of green space for recreation. In some urban areas, initiatives to create new parks and gardens or construct vegetated buildings may counteract this trend, but maintaining and expanding urban vegetation cover in the face of increasing droughts remains a critical challenge for the well-being of urban populations.[89]

Wildfires

Climate change is contributing to an increased frequency of wildfires by creating hotter and drier conditions, which make forests and other vegetation more susceptible to ignition.[90] These altered weather patterns, including prolonged droughts and heatwaves, create an environment where wildfires can ignite more easily and spread more rapidly.[91] In urban areas, wildfires pose a significant threat to infrastructure, property, and human lives. The encroachment of urban development into wildland areas creates a complex interface where fire can easily spread between natural and built environments. Moreover, the smoke and pollutants from wildfires can degrade air quality, leading to health issues for urban residents. In natural areas within cities, wildfires can devastate ecosystems, destroying habitats and threatening local flora and fauna. The loss of these natural spaces not only impacts biodiversity but also diminishes the ecological services they provide, such as air and water purification, climate regulation, and recreational opportunities. The interplay between climate change, wildfires, and urban-natural interfaces thus presents a multifaceted challenge that requires comprehensive planning and management to mitigate risks and preserve both human and ecological well-being.

Adaptation & Mitigation

Water Retention

Natural areas within cities play a vital role in increasing water retention, thereby contributing to flood control and groundwater recharge. Wetlands, in particular, act as natural sponges, absorbing and storing excess water during heavy rainfall, and slowly releasing it over time, reducing the risk of flooding and erosion.[92] Forested areas, with their complex root systems and soil structures, enhance water infiltration and storage in the soil, preventing rapid runoff and allowing for the gradual replenishment of groundwater supplies.[93] The vegetation in both wetlands and forests also aids in filtering pollutants, improving water quality. Urban planners and environmentalists are recognizing the importance of preserving and integrating these natural areas into urban landscapes, as they offer sustainable solutions to water management challenges. By mimicking nature's way of handling water, cities can create resilient systems that not only enhance water retention but also provide ecological, recreational, and aesthetic benefits to the community.

Biodiversity Loss & Invasive Species Spread

Risks

Non-Native and Invasive Species Spread

Non-native species can cause significant damage and alteration to natural spaces within urban landscapes. When introduced into new environments, these species often lack natural predators and competitors, allowing them to proliferate unchecked.[93] They can outcompete and displace native species, leading to reduced biodiversity and changes in community composition. For example, invasive plants may alter soil chemistry, hydrology, and nutrient cycling, disrupting established ecological processes and relationships.[75] Invasive animals, such as rodents or insects, can prey on native species or introduce new diseases, further destabilizing the ecosystem. The alteration of natural spaces by non-native species not only impacts the ecological integrity of urban landscapes but can also reduce their aesthetic, recreational, and educational value. Managing and mitigating the impacts of non-native species in urban natural areas requires ongoing monitoring, public awareness, and coordinated efforts across different sectors and jurisdictions.

Increased Disease and Pests

Climate change and urbanization are converging to increase the spread of diseases and pests in urban landscapes, creating complex public health challenges. Warmer temperatures and altered precipitation patterns associated with climate change can create favorable conditions for the proliferation of vectors such as mosquitoes and ticks, which transmit diseases like malaria, dengue, and Lyme disease.[42] Urbanization compounds this risk by providing abundant breeding sites for these vectors in the form of standing water in urban infrastructure, such as stormwater systems and artificial containers. Increased human density in urban areas also facilitates the spread of contagious diseases and can attract pest species like rodents, which may carry pathogens.[104]

Spotted Lantern Flies have invaded many cities in the Eastern United States.
Cbaile19

The combination of climate change and urbanization thus creates a multifaceted challenge, intertwining ecological, social, and infrastructural factors that demand integrated and adaptive strategies for disease and pest management in urban landscapes.

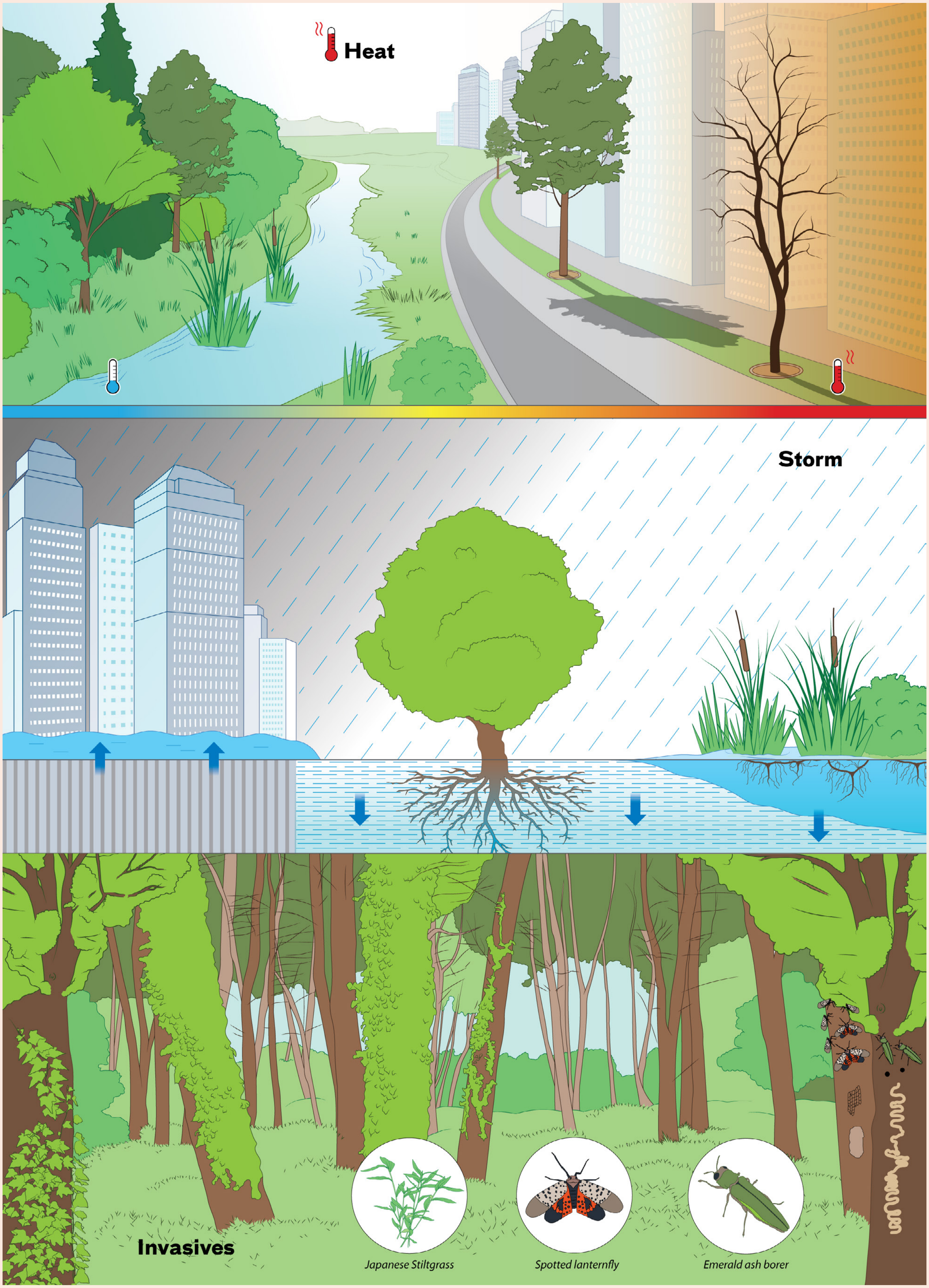
Species Loss

Rising temperatures, altered precipitation patterns, and increased frequency of extreme weather events can create conditions that are inhospitable for certain species, particularly those with specialized habitat requirements or narrow climatic tolerances.[87] In natural areas, these changes can disrupt ecological relationships, leading to mismatches in species interactions such as pollination and predation. In urban landscapes, where habitats are often more fragmented and isolated, species may have limited ability to migrate to more suitable conditions, exacerbating their vulnerability to climate-induced stresses.[9,29] The loss of species in both natural and urban contexts not only diminishes biodiversity but also affects ecosystem functioning, resilience, and the provision of essential services such as water purification, soil fertility, and disease regulation. The complex interplay between climate change and species survival underscores the urgent need for adaptive conservation strategies that consider the unique challenges and opportunities in different landscape contexts.

Adaptation & Mitigation

Resilient Systems

Natural areas often exhibit greater resilience to invasive species compared to more disturbed or managed landscapes, and there are several reasons for this phenomenon. In undisturbed natural ecosystems, native species have evolved together over time, forming complex relationships and dependencies that create a balanced and stable community.[87] This ecological complexity can make it more difficult for invasive species to establish and spread, as they may encounter competition, predation, or other biotic resistance that limits their success. Furthermore, natural areas often have greater biodiversity, which has been shown to enhance ecosystem stability and resistance to invasion.[9] In contrast, human-altered landscapes, such as urban greenspaces, may lack this ecological integrity and diversity, making them more susceptible to invasions. The inherent resilience of natural areas underscores the importance of preserving and restoring these ecosystems as a strategy for managing invasive species and maintaining ecological health.



Climate Change Impacts and Urban Natural Areas" Add the caption below the image, "Urban natural areas are often cooler than the built environment that surrounds them (top) and have the ability to absorb vast amounts of storm water (middle). However, without management, these natural areas are susceptible to invasive species and can lose many of the benefits they provide (bottom).

Elena S.

Appendix B: Ecosystem Specific Impacts

Forested Ecosystems

Climate Adaptation and Mitigation Impacts

Urban forests play a vital role in mitigating the impacts of climate change. As carbon sinks, they absorb and store carbon dioxide from the atmosphere, helping to reduce greenhouse gas emissions and combat global warming.[97] Through the process of photosynthesis, urban forests also release oxygen and improve air quality, mitigating the effects of urban heat islands and reducing energy consumption by providing shade and cooling.[98] Additionally, urban forests can help manage stormwater runoff, preventing flooding and protecting water quality.[97] Their presence in cities enhances biodiversity, providing habitats for various species and promoting ecological resilience.[99] By acting as green lungs in urban environments, urban forests contribute to climate change mitigation while simultaneously enhancing the overall well-being and livability of cities.

Climate Risks

However, urban forests themselves are not immune to the risks posed by climate change. Rising temperatures, altered precipitation patterns, and extreme weather events associated with climate change can impact the health and survival of urban trees. Heat stress, drought, increased pest and disease pressure, and changes in water availability can weaken or kill trees.[73] Urban forests may also face challenges due to shifting climatic conditions, as some tree species may become less suited to the new environmental conditions or more vulnerable to invasive species. Furthermore, increased frequency and intensity of storms can lead to tree damage and uprooting, posing risks to human safety and infrastructure. These climate-related risks underscore the importance of proactive management and planning to enhance the resilience and adaptability of urban forests in the face of a changing climate.

Grasslands

Climate Adaptation & Mitigation Impacts

Natural grasslands, such as prairies and meadows, can mitigate climate change by acting as carbon sinks, reducing solar radiation, and providing vital habitat for plant and animal species. Grassland ecosystems act as carbon sinks by sequestering and storing carbon dioxide from the atmosphere both above ground and through the extensive root systems of grasses.[100] Their perennial nature allows for long-term carbon storage. In some biomes, due to grasslands' resilience to drought and fire, and the fact they can store the majority of their carbon underground, grasslands can be more reliable carbon sinks than forests.[101] Grasslands also contribute to temperature regulation by reflecting sunlight and reducing heat absorption thereby helping to reduce the urban heat island effect.[13,70] Moreover, these ecosystems play a crucial role in stormwater management, as their permeable soils facilitate water infiltration, reducing runoff and preventing soil erosion.[70] Additionally, these open grassy landscapes support biodiversity and provide habitats for a variety of plant and animal species, enhancing ecosystem resilience. The conservation of urban grasslands is of particular importance because grassland is often the first type of land-cover developed for urbanization and as such, there has been a dramatic reduction in global grasslands.[102,103] The resilience and capacity of natural grasslands to sequester carbon, regulate temperatures, and manage stormwater make them valuable assets in the fight against climate change.

Climate Risks

However, natural grasslands face risks and challenges due to climate change. Rising temperatures and altered precipitation patterns can result in extended drought periods, impacting the growth and vitality of grasses which also reduces the ability of grasslands to sequester carbon and maintain their ecological functions.[104,105] Extreme weather events, including intense storms or prolonged heatwaves, can cause soil erosion and disrupt grassland ecosystems.[106] Climate change may also facilitate the encroachment of invasive plant species or disrupt the delicate balance between grasses and other flora and fauna within grassland habitats.

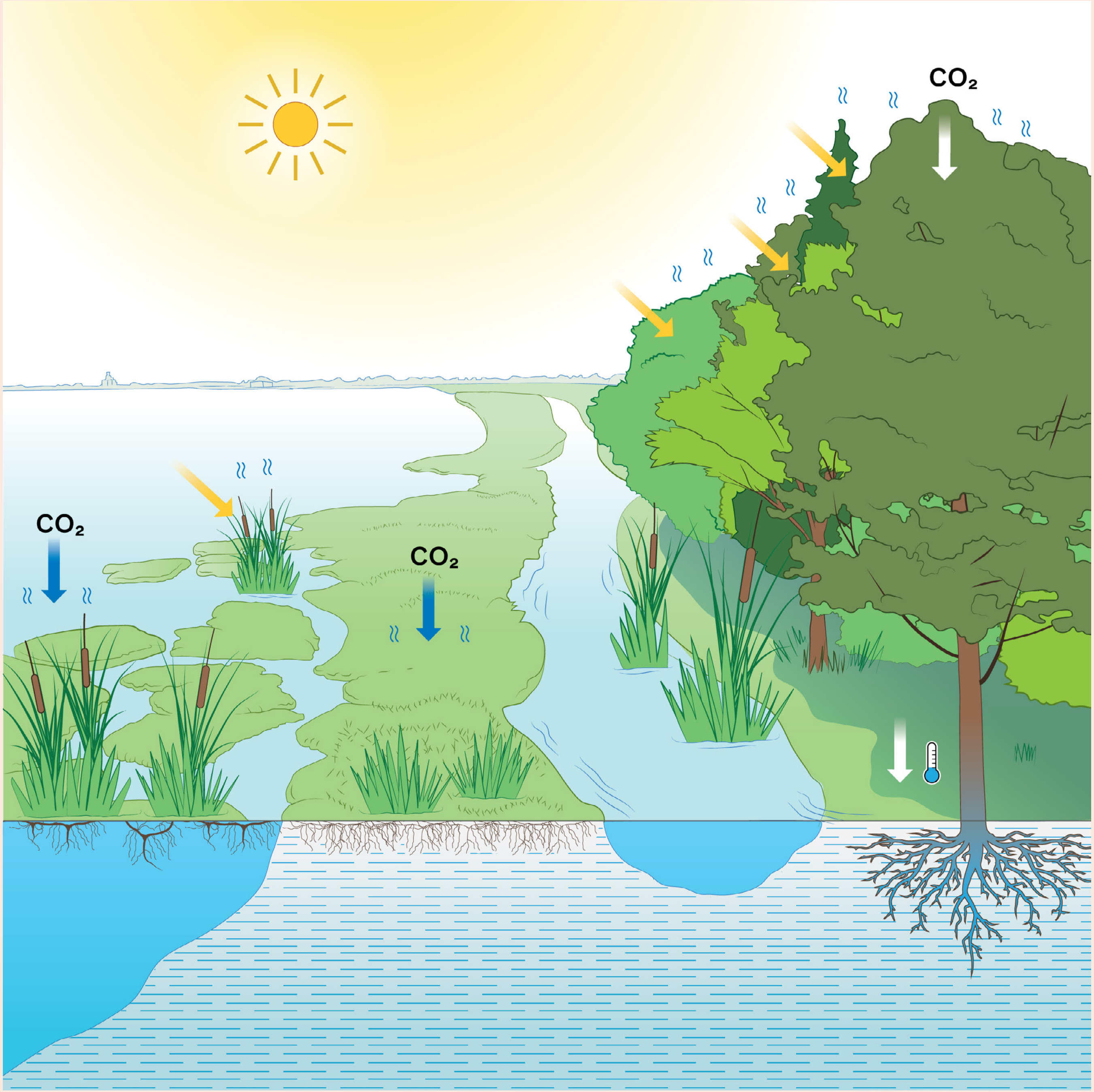
Riparian Areas

Climate Adaptation & Mitigation Impacts

Urban riparian areas, such as rivers, streams, and wetlands, act as natural buffers against flooding by absorbing and storing excess rainfall, reducing the risk of inundation in urban areas.[107,108] These areas help regulate water flow, preventing erosion and protecting water quality by filtering pollutants and sediments. Riparian vegetation, including trees and plants, helps sequester carbon dioxide from the atmosphere, mitigating greenhouse gas emissions.[108] Moreover, urban riparian areas provide habitat for a variety of species, enhancing biodiversity and supporting ecological resilience in urban environments. Their presence offers recreational opportunities, improves air quality, and contributes to the overall well-being and aesthetic appeal of cities.

Climate Risks

However, urban riparian areas also face several risks as a result of climate change. Rising temperatures and altered precipitation patterns can lead to changes in water availability and flow regimes, affecting the health and functionality of riparian ecosystems.[109] Increased frequency and intensity of storms can result in erosion, habitat destruction, and the loss of riparian vegetation. Additionally, sea-level rise poses a significant threat



The benefits of natural areas vary by type and composition. While wetlands may store more stormwater than forests, forests can provide cooling and carbon capture that may be more limited in these wetlands. Understanding the gradient of services provided by urban natural areas is key to correctly implementing them in climate adaptation strategies.

Elena S.

to urban riparian areas located along coastal regions, increasing the risk of saltwater intrusion and compromising freshwater resources.[109,110] These climate-related risks highlight the need for proactive management and restoration efforts to protect and enhance the resilience of urban riparian areas in the face of a changing climate.

Freshwater Wetlands

Climate Adaptation & Mitigation Impacts

Due to the amount of water contained in urban freshwater marshes, they serve a unique role in mitigating the impacts of climate change. These wetland ecosystems act as natural carbon sinks, absorbing and storing carbon dioxide from the atmosphere, by both sequestering carbon dioxide and within the water as well as the vegetation in the system.[111,112] Freshwater marshes also aid in flood control by absorbing excess rainfall and stormwater, mitigating the risk of urban flooding.[113] Freshwater wetlands also act as natural filters, purifying water by trapping pollutants and sediments, thus improving water quality and providing lower energy intensive water treatment options.[114,115] Additionally, urban freshwater marshes contribute to local biodiversity by providing habitat for a wide variety of species which depend upon both the terrestrial and aquatic nature of wetlands as well as the unique microhabitats they provide.[116,117] Wetlands are of particular importance to species such as amphibians and macroinvertebrates that rely on vernal ponds to develop in the absence of predators.[118]

Climate Risks

Urban freshwater marshes are particularly at risk to the impacts of climate change due to the delicate nature of nutrient influx and outflux most marshes experience.[85] Rising temperatures and altered precipitation patterns can disrupt the hydrology of these ecosystems, leading to changes in water availability, prolonged droughts, or increased flooding events. Although much of the vegetation in freshwater marshes is adapted to varying water levels, extreme highs and lows can still prove fatal.[119,120] Additionally, sea-level rise poses a significant threat to coastal urban freshwater marshes, leading to saltwater intrusion and coastal erosion.[119] The increased frequency and intensity of storms associated with climate change can also lead to physical damage and erosion of marshes, further compromising their ecological functions and resilience.[121,122]

Saltwater Marshes

Climate Adaptation & Mitigation Impacts

Urban saltwater marshes, also known as coastal or tidal marshes, can help mitigate the impact of climate change by providing buffers to storm surges and reduce the impacts of coastal flooding. Like other natural areas, saltwater marshes act as natural carbon sinks, trapping and storing carbon dioxide from the atmosphere but they play a unique role in providing protection against coastal erosion and storm surges, acting as a buffer between land and sea.[121,122] Through their dense vegetation and intricate root systems, saltwater marshes stabilize shorelines, reduce wave energy, and help mitigate the impacts of sea-level rise.[123] Furthermore, these marshes provide critical habitats for a diverse range of plant and animal species, contributing to biodiversity conservation and supporting the overall resilience of coastal ecosystems.[123,124] By serving as natural barriers and habitats, urban saltwater marshes provide multiple benefits to both the environment and nearby human communities.

Climate Risks

However, urban saltwater marshes face several risks as a result of climate change. Rising sea levels pose the most significant threat to these marshes, leading to increased saltwater intrusion and subsequent loss of vegetation.[110] As saltwater encroaches further into marshes, it can cause shifts in plant communities and impact the overall health and functioning of the ecosystem.[125,126] In a contrasting effect, changing climate conditions may alter the availability of freshwater inputs to the marshes, impacting the delicate balance of salinity levels and affecting the survival of specialized plant and animal species. Additionally, the increased frequency and intensity of storms associated with climate change can result in erosion, habitat loss, and damage to saltwater marshes.[22,122,127] Extreme weather events, such as hurricanes or tropical storms, can exacerbate these risks, causing significant damage to marshes and potentially disrupting their ecological functions and resilience. Salt marshes are often especially at risk to climate change in urban landscapes due to the hardscape edges of urbanized areas. As sea level rises, the urban edge prevents marsh retreat resulting in coastal squeeze and the potential loss of the marsh.[128,129]

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