Climate Change and Cities

Second Assessment Report of the Urban Climate Change Research Network

SUMMARY FOR CITY LEADERS

ARC3.2

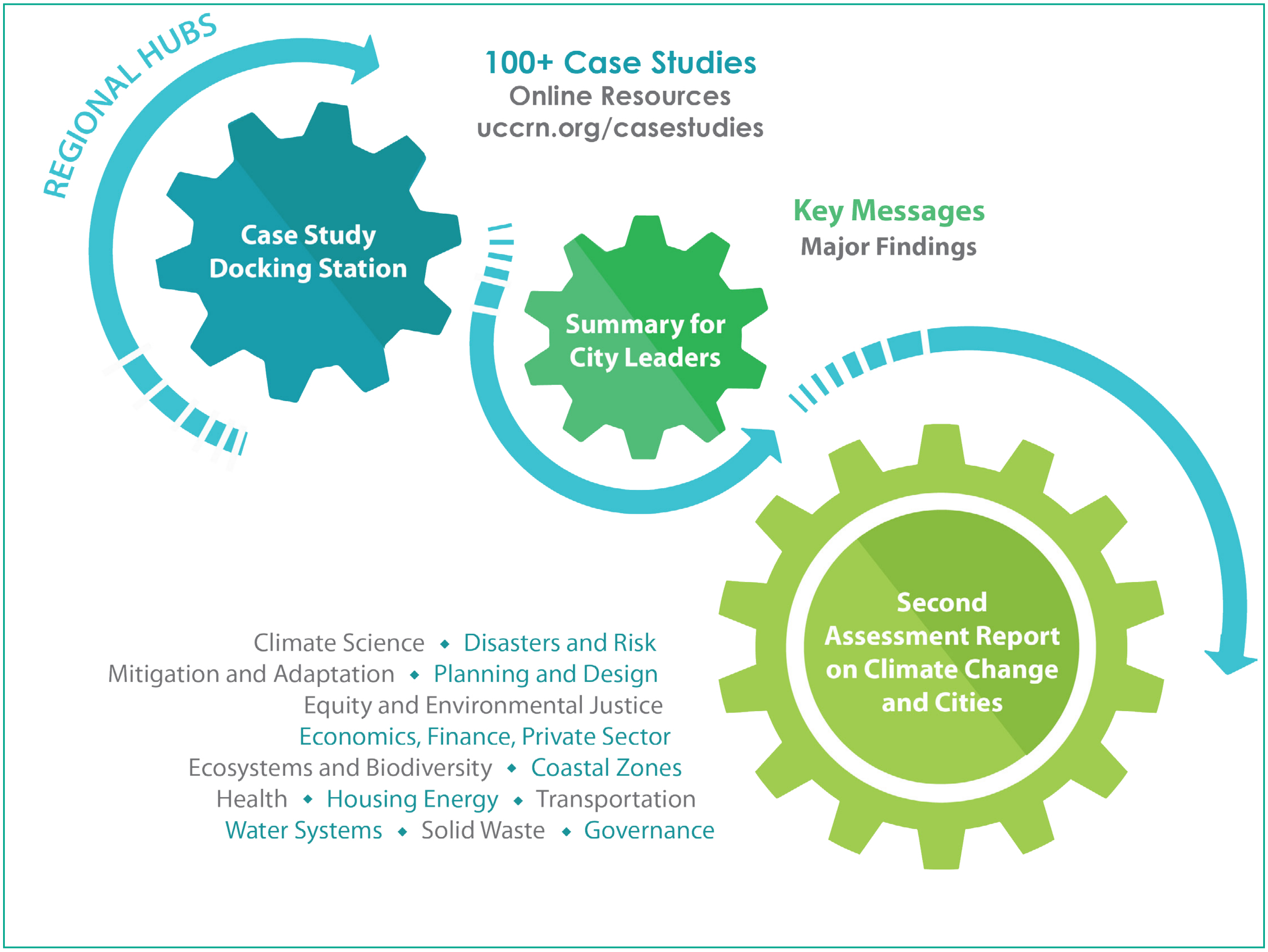


Figure 1: *Components of the Second Assessment Report on Climate Change and Cities (ARC3.2) and their interactions.*

ARC3.2 Summary for City Leaders
Urban Climate Change Research Network
Second UCCRN Assessment Report on Climate Change and Cities

Prepared for release at COP21 Climate Summit for Local Leaders in Paris, France (December 2015)

Recommended citation: Rosenzweig C., W. Solecki, P. Romero-Lankao, S. Mehrotra, S. Dhakal, T. Bowman, and S. Ali Ibrahim. 2015. *ARC3.2 Summary for City Leaders*. Urban Climate Change Research Network. Columbia University. New York.

Cover photo: Rio de Janeiro by Somayya Ali Ibrahim

ARC3.2
SUMMARY FOR CITY LEADERS

This is the *Summary for City Leaders* of the Urban Climate Change Research Network (UCCRN) *Second Assessment Report on Climate Change and Cities* (ARC3.2) (Figure 1). UCCRN is dedicated to providing the information that city leaders—from government, the private sector, non-governmental organizations, and the community—need in order to assess current and future risks, make choices that enhance resilience to climate change and climate extremes, and take actions to reduce greenhouse gas emissions.

ARC3.2 presents a broad synthesis of the latest scientific research on climate change and cities[1]. Mitigation and adaptation climate actions of 100 cities are documented throughout the 16 chapters, as well as online through the ARC3.2 Case Study Docking Station (www.uccrn.org/casestudies). Pathways to Urban Transformation, Major Findings, and Key Messages are highlighted here in the *ARC3.2 Summary for City Leaders*. These sections lay out what cities need to do achieve their potential as leaders of climate change solutions. UCCRN Regional Hubs in Europe, Latin America, Africa, Australia and Asia will share ARC3.2 findings with local city leaders and researchers.

The *ARC3.2 Summary for City Leaders* synthesizes Major Findings and Key Messages on urban climate science, disasters and risks, urban planning and design, mitigation and adaptation, equity and environmental justice, economics and finance, the private sector, urban ecosystems, urban coastal zones, public health, housing and informal settlements, energy, water, transportation, solid waste, and governance. These were based on climate trends and future projections for 100 cities around the world.

Climate Change and Cities

The international climate science research community has concluded that human activities are changing the Earth's climate in ways that increase risk to cities. This conclusion is based on many different types of evidence, including the Earth's climate history, observations of changes in the recent historical climate record, emerging new patterns of climate extremes, and global climate models. Cities and their citizens already have begun to experience the effects of climate change. Understanding and anticipating these changes will help cities prepare for a more sustainable future. This means making cities more resilient to climate-related disasters and managing long-term climate risks in ways that protect people and encourage prosperity. It also means improving cities' abilities to reduce greenhouse gas emissions.

While projections for future climate change are most often defined globally, it is becoming increasingly important to assess how the changing climate will impact cities. The risks are not the same everywhere. For example, sea level rise will affect the massive zones of urbanization clustered along the world's tidal coastlines and most significantly those cities in places where the land is already subsiding. In response to the wide range of risks facing cities and the role that cities play as home to more than half of the world's population, urban leaders are joining forces with multiple groups including city networks and climate scientists. They are assessing conditions within their cities in order to take science-based actions that increase resilience and reduce greenhouse gas emissions, thus limiting the rate of climate change and the magnitude of its impacts.

In September 2015, the United Nations endorsed the new Sustainable Development Goal 11, which is to "Make cities and human settlements inclusive, safe, resilient and sustainable." This new sustainability goal cannot be met without explicitly recognizing climate change as a key component. Likewise, effective responses to climate change cannot proceed without understanding the larger context of sustainability. As ARC3.2 demonstrates, actions take to reduce greenhouse gas emissions and increase resilience can also enhance the quality of life and social equity.

1. Cities are defined here in the broad sense to be urban areas, including metropolitan and suburban regions.

Pathways to Urban Transformation

Hyderabad, India | Cairo, Egypt | Paris, France | Phnom Penh, Cambodia | New York, USA | Rio de Janeiro, Brazil

As is now widely recognized, cities can be the main implementers of climate resiliency, adaptation, and mitigation. However, the critical question that ARC3.2 addresses is under what circumstances this advantage can be realized. Cities may not be able to address the challenges and fulfill their climate change leadership potential without transformation.

ARC3.2 synthesizes a large body of studies and city experiences and finds that transformation is essential in order for cities to excel in their role as climate-change leaders. As cities mitigate the causes of climate change and adapt to new climate conditions, profound changes will be required in urban energy, transportation, water use, land use, ecosystems, growth patterns, consumption, and lifestyles. New systems for urban sustainability will need to emerge that encompass more cooperative and integrated urban-rural, peri-urban, and metropolitan regional linkages.

Five pathways to urban transformation emerge throughout ARC3.2. These pathways provide a foundational framework for the successful development and implementation of climate action. Cities that are making progress in transformative climate change actions are following many or all of these pathways. The pathways can guide the way for the hundreds of cities–large and small/low, middle, and high income–throughout the world to play a significant role in climate change action. Cities that do not follow these pathways may have greater difficulty realizing their potential as centers for climate change solutions. The pathways are:

Pathway 1: Actions that reduce greenhouse gas emissions while increasing resilience are a win-win. Integrating mitigation and adaptation deserves high priority in urban planning, urban design, and urban architecture. A portfolio of approaches is available, including engineering solutions, ecosystem-based adaptation, policies, and social programs. Taking the local context of each city into account is necessary in order to choose actions that result in the greatest benefits.

Pathway 2: Disaster risk reduction and climate change adaptation are the cornerstones of resilient cities. Integrating these activities into urban development policies requires a new, systems-oriented, multi-timescale approach to risk assessments and planning that accounts for emerging conditions within specific, more vulnerable communities and sectors, as well as across entire metropolitan areas.

Pathway 3: Risk assessments and climate action plans co-generated with the full range of stakeholders and scientists are most effective. Processes that are inclusive, transparent, participatory, multi-sectoral, multi-jurisdictional, and interdisciplinary are the most robust because they enhance relevance, flexibility, and legitimacy.

Pathway 4: Needs of the most disadvantaged and vulnerable citizens should be addressed in climate change planning and action. The urban poor, the elderly, women, minority, recent immigrants and otherwise marginal populations most often face the greatest risks due to climate change. Fostering greater equity and justice within climate action increases a city's capacity to respond to climate change and improves human wellbeing, social capital, and related opportunities for sustainable social and economic development.

Pathway 5: Advancing city creditworthiness, developing robust city institutions, and participating in city networks enable climate action. Access to both municipal and outside financial resources is necessary in order to fund climate change solutions. Sound urban climate governance requires longer planning horizons, effective implementation mechanisms and coordination. Connecting with national and international capacity-building networks helps to advance the strength and success of city-level climate planning and implementation.

A final word on timing: Cities need to start immediately to develop and implement climate action. The world is entering into the greatest period of urbanization in human history, as well as a period of rapidly changing climate. Getting started now will help avoid locking-in counterproductive long-lived investments and infrastructure systems, and ensure cities' potential for the transformation necessary to lead on climate change.

Climate Observations and Projections for 100 ARC3.2 Cities

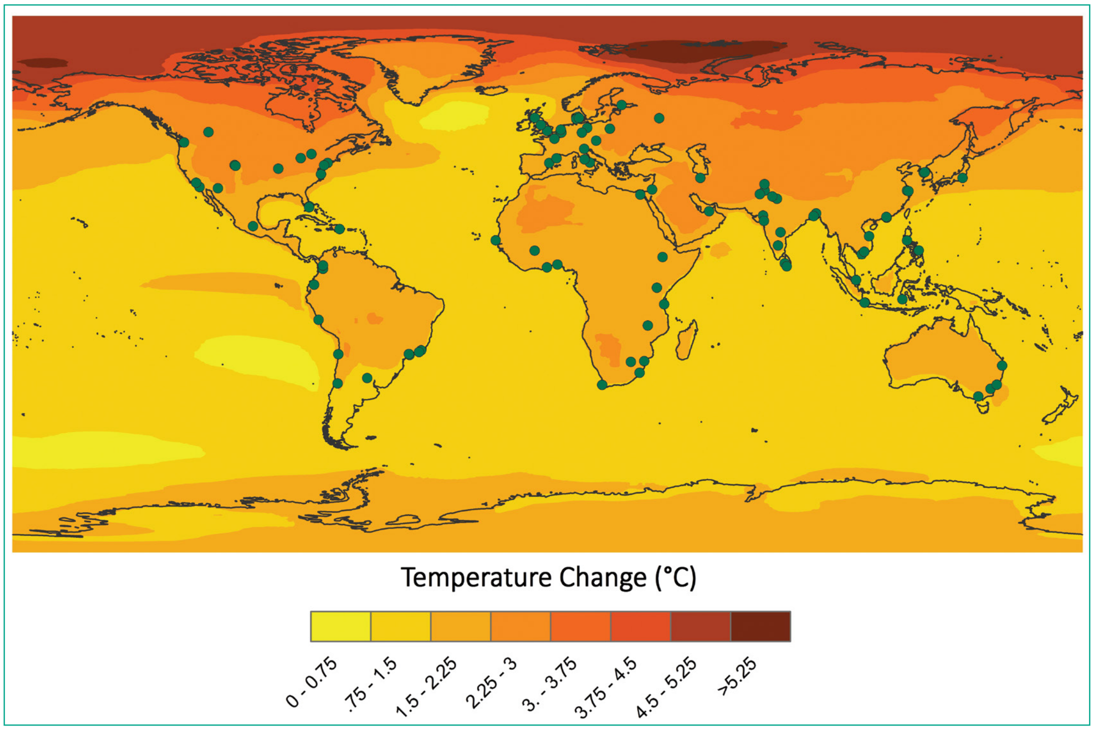


Figure 2: *Projected temperature change in the 2050s and ARC3.2 Cities. Temperature change projection is mean of 35 global climate models (GCMs) and one representative concentration pathway (RCP4.5). Colors represent mean annual temperature change for a mid-range scenario (RCP 4.5), from CMIP5 models (2040-2069 average minus 1971-2000 average).*

- Temperatures are already rising in cities around the world due to both climate change and the urban heat island effect. Mean annual temperatures in 39 ARC3.2 cities have increased at a rate of 0.12 to 0.45°C per decade over the 1961 to 2010 time period. [1]
- Mean annual temperatures in the 100 ARC3.2 cities around the world are projected to increase by 0.7 to 1.5°C by the 2020s, 1.3 to 3.0°C by the 2050s, and 1.7 to 4.9°C by the 2080s (Figure 2). [2]
- Mean annual precipitation in the 100 ARC3.2 cities around the world is projected to change by -7 to +10% by the 2020s, -9 to +15% by the 2050s, and -11 to +21% by the 2080s.
- Sea level in the 52 ARC3.2 coastal cities is projected to rise 4 to 19 cm by the 2020s; 15 to 60 cm by the 2050s, and 22 to 124 cm by the 2080s. [3]

1. Of the 100 ARC3.2 cities, 45 had temperature data available for the 1961 to 2010 time period. For each of these 45 cities, the trend was computed over the given time period. For the trends, 39 cities saw significant (at the 99% significance level) warming. Data are from the NASA GISS GISTEMP dataset.

2. Temperature and precipitation projections are based on 35 global climate models and 2 representative concentration pathways (RCP4.5 and RCP 8.5). Timeslices are 30-year periods centered around the given decade (e.g., the 2050s is the period from 2040 to 2069). Projections are relative to the 1971 to 2000 base period. For each of the 100 cities, the low estimate (10th percentile) and high estimate (90th percentile) was calculated. The range of values presented is the average across all 100 cities.

3. Sea level rise projections are based on a 4-component approach that includes both global and local factors. The model-based components are from 24 global climate models and 2 representative concentration pathways (RCP 4.5 and RCP 8.5). Timeslices are 10-year periods centered around the given decade (e.g., the 2080s is the period from 2080 to 2089). Projections are relative to the 2000 to 2004 base period. For each of the 52 cities, the low estimate (10th percentile) and high estimate (90th percentile) was calculated. The range of values presented is the average across all 52 cities.

What Cities Can Expect

Smog over Jakarta, Indonesia. Photo by Somayya Ali Ibrahim.

People and communities everywhere are reporting weather events and patterns that seem unfamiliar. Such changes will continue to unfold over the coming decades and, depending on which choices people make, possibly for centuries. But the various changes will not occur at the same rates in all cities of the world, nor will they all occur gradually or at consistent rates of change.

Climate scientists have concluded that, while some of these changes will take place over many decades, even centuries, there is also a risk of crossing thresholds in the climate system that cause some rapid, irreversible changes to occur. One example would be melting of the Greenland and West Antarctic ice sheet, which would lead to very high and potentially rapid rates of sea level rise.

MAJOR FINDINGS

- Urbanization tends to be associated with elevated surface and air temperature, a condition referred to as the *urban heat island*. Urban centers and cities are often several degrees warmer than surrounding areas due to presence of heat absorbing materials, reduced evaporative cooling caused by lack of vegetation, and production of waste heat.
- Some climate extremes will be exacerbated under changing climate conditions. Extreme events in many cities include heat waves, droughts, heavy downpours, and coastal flooding, are projected to increase in frequency and intensity.
- The warming climate combined with the urban heat island effect will exacerbate air pollution in cities.
- Cities around the world have always been affected by major, naturally occurring variations in climate conditions including the El Niño Southern Oscillation, North Atlantic Oscillation, and the Pacific Decadal Oscillation. These oscillations occur over years or decades. How climate change will influence these recurring patterns in the future is not fully understood.

KEY MESSAGES

Human-caused climate change presents significant risks to cities beyond the familiar risks caused by natural variations in climate and seasonal weather patterns. Both types of risk require sustained attention from city governments in order to improve urban resilience. One of the foundations for effective adaptation planning is to co-develop plans with stakeholders and scientists who can provide urban-scale information about climate risks—both current risks and projections of future changes in extreme events.

Weather and climate forecasts of daily, weekly, and seasonal patterns and extreme events are already widely used at international, national, and regional scales. These forecasts demonstrate the value of climate science information that is communicated clearly and in a timely way. Climate change projections perform the same functions on longer timescales. These efforts now need to be carried out on the city scale.

Within cities, various neighborhoods experience different microclimates. Therefore, urban monitoring networks are needed to address the unique challenges facing various microclimates and the range impacts of extreme climate effects at neighborhood scales. The observations collected through such urban monitoring networks can be used as a key component of a citywide climate indicators and monitoring system that enables decision-makers to understand the variety of climate risks across the city landscape.

Managing Disasters in a Changing Climate

Figure 3: *Damaged homes in New York City as a result of Hurricane Sandy, November 2012. Photo by Somayya Ali Ibrahim.*

Globally, the impacts of climate-related disasters are increasing. The impacts of climate-related disasters may be exacerbated in cities due to interactions of climate change with urban infrastructure systems, growing urban populations, and economic activities (Figure 3). As the majority of the world's population is currently living in cities–and this share is projected to increase in the coming decades, cities–need to focus more on climate-related disasters such as heat waves, floods, and droughts.

In a changing climate, a new decision-making framework is needed in order to fully manage emerging and increasing risks. This involves a paradigm shift away from impact assessments that focus on single climate hazards based on past events. The new paradigm requires integrated, system-based risk assessments that incorporate current and future hazards throughout entire metropolitan regions.

MAJOR FINDINGS

- The number of and severity of weather and climate-related disasters is projected to increase in the next decades; as most of the world's population live in urban areas, cities require specific attention on risk reduction and resilience building.

- The vulnerability of cities to climate-related disasters is shaped by cultural, demographic and economic characteristics of residents, local governments' institutional capacity, the built environment, the provision of ecosystem services, and human-induced stresses such as resource exploitation and environmental degradation such as removal of natural storm buffers, pollution, over-use of water, and the urban heat island effect.

- Integrating climate change adaptation with disaster risk reduction involves overcoming a number of barriers: such as adding climate resilience to a city's development vision; understanding of the hazards, vulnerabilities, and attendant risks; closing gaps in coordination between various administrative and sectoral levels of management; and development of implementation and compliance strategies and financial capacity.

- Strategies for improving resilience and managing risks in cities include the integration of disaster risk reduction with climate change adaptation; urban and land-use planning and innovative urban design; financial instruments and public-private partnerships; management and enhancement of ecosystem services; building strong institutions and developing community capabilities; and resilient post-disaster recovery and rebuilding.

KEY MESSAGES

Disaster risk reduction and climate change adaptation are the cornerstones of making cities resilient to a changing climate. Integrating these activities with a city's development vision requires a new, systems-oriented approach to risk assessments and planning. Moreover, since past events cannot inform decision-makers about emerging and increasing climate risks, systems-based risk assessments must incorporate knowledge about current conditions and future projections across entire metropolitan regions.

A paradigm shift of this magnitude will require decision-makers and stakeholders to increase the capacity of communities and institutions to coordinate, strategize, and implement risk-reduction plans and disaster responses. This is why promoting multi-level, multi-sectoral, and multi-stakeholder integration is so important.

Integrating Mitigation and Adaptation as Win-Win Actions

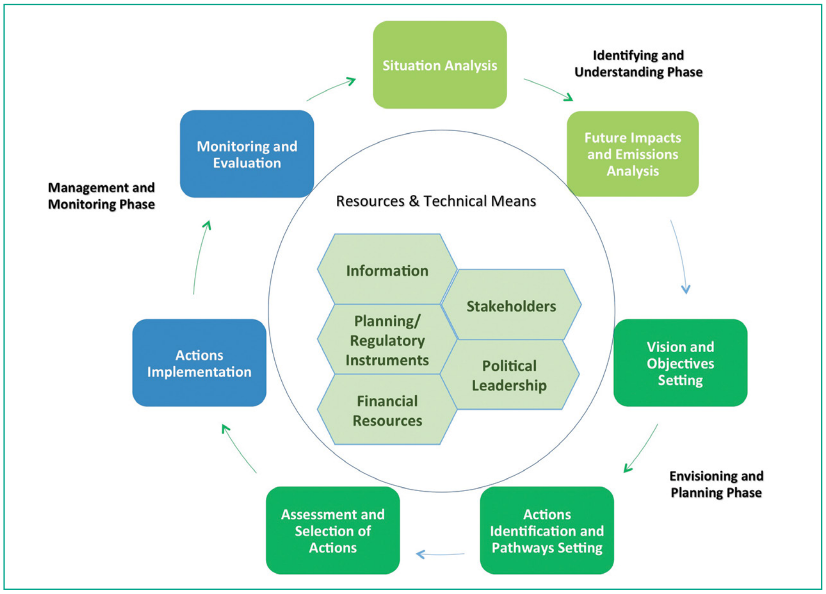


Figure 4: *Main resources and technical means that can be used by cities in their planning cycle for integrating mitigation and adaptation.*

Urban planners and decision-makers need to integrate efforts to mitigate the causes of climate change (mitigation) and adapt to changing climatic conditions (adaptation). Actions that promote both goals provide win-win solutions. In some cases, however, decision-makers have to negotiate trade-offs and minimize conflicts between competing objectives.

A better understanding of mitigation and adaptation synergies can reveal greater opportunities for urban areas. For example, strategies that reduce the urban heat island effect, improve air quality, increase resource efficiency in the built environment and energy systems, and enhance carbon storage related to land use and urban forestry are likely to contribute to greenhouse gas emissions reduction while improving a city's resilience. The selection of specific adaptation and mitigation measures should be made in the context of other sustainable development goals by taking current resources and technical means of the city, plus needs of citizens, into account.

MAJOR FINDINGS

- Mitigation and adaptation policies have different goals and opportunities for implementation. However, many drivers of mitigation and adaptation are common, and solutions can be interrelated. Evidence shows that broad-scale, holistic analysis and proactive planning can strengthen synergies, improve cost-effectiveness, avoid conflicts and help manage trade-offs.
- Accurate diagnosis of climate risks and the vulnerabilities of urban populations and territory are essential. Likewise, cities need transparent and meaningful greenhouse gas emissions inventories and emission reduction pathways in order to prepare mitigation actions.
- Contextual conditions determine a city's challenges, as well as its capacity to integrate and implement adaptation and mitigation strategies. These include the environmental and physical setting, the capacities and organization of institutions and governance, economic and financial conditions, and socio-cultural characteristics.
- Integrated planning requires holistic, systems-based analysis that takes into account the quantitative and qualitative costs and benefits of integration compared to stand-alone adaptation and mitigation policies (Figure 4). Analysis should be explicitly framed within local priorities and provide the foundation for evidence-based decision support tools.

KEY MESSAGES

Integrating mitigation and adaptation can help avoid locking a city into counterproductive infrastructure and policies. Therefore, city governments should develop and implement climate action plans early in their administrative terms. These plans should be based on scientific evidence and should integrate mitigation and adaptation across multiple sectors and levels of governance. Plans should clarify short, medium and long-term goals, implementation opportunities, budgets, and concrete measures for assessing progress.

Integrated city climate action plans should include a variety of mitigation actions—those involving energy, transport, waste management, and water policies, and more—with adaptation actions—those involving infrastructure, natural resources, health, and consumption policies, among others—in synergistic ways. Because of the comprehensive scope, it is important to clarify the roles and responsibilities of key actors in planning and implementation. Interactions among the actors must be coordinated during each phase of the process.

Once priorities and goals have been identified, municipal governments should connect with federal legislation, national programs, and, in the case of low-income cities, with international donors in order to match actions and foster helpful alliances and financial support.

Embedding Climate Change in Urban Planning and Design

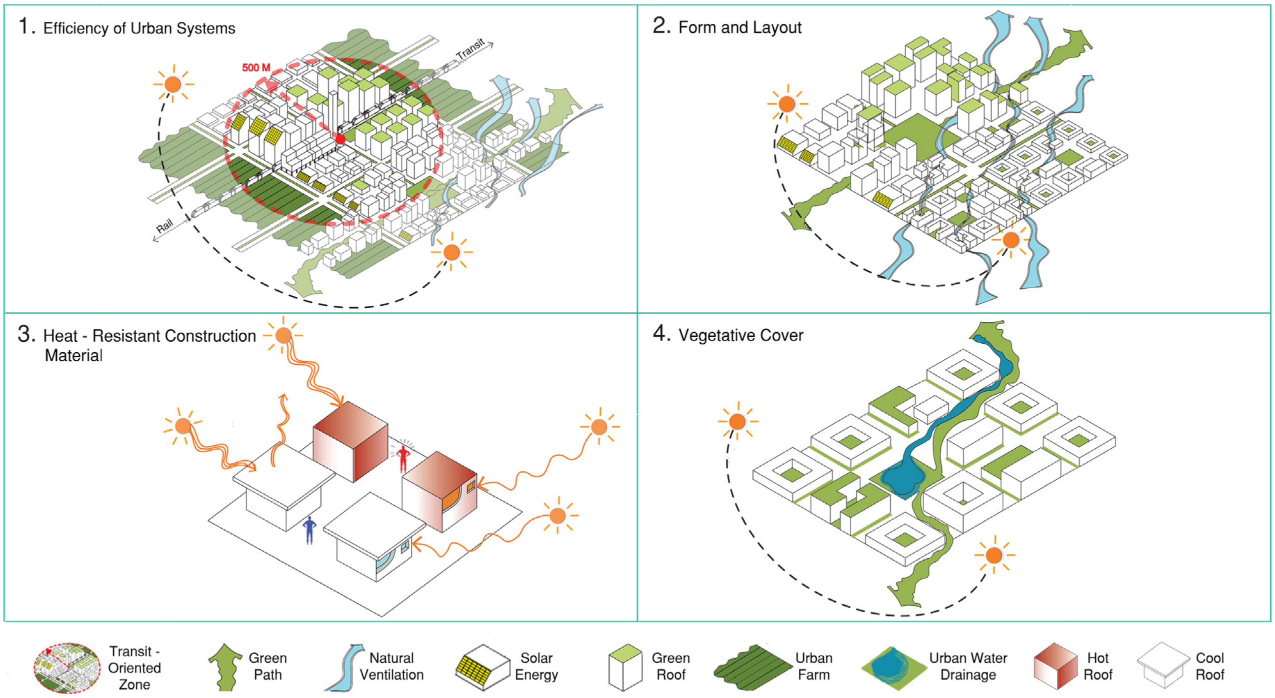


Figure 5: *Main strategies used by urban planners and designers to facilitate integrated mitigation and adaptation in cities: (a) reducing waste heat and greenhouse gas emissions through energy efficiency, transit access, and walkability; (b) modifying form and layout of buildings and urban districts; (c) use of heat-resistant construction materials and reflective surface coatings; and (d) increasing vegetative cover. Source: Urban Climate Lab, Graduate Program in Urban & Regional Design, New York Institute of Technology, 2015.*

Urban planning and urban design have a critical role to play in the global response to climate change. Actions that simultaneously reduce greenhouse gas emissions and build resilience to climate risks should be prioritized at all urban scales—metropolitan region, city, district/neighborhood, block, and building. This needs to be done in ways that are responsive to and appropriate for local conditions.

MAJOR FINDINGS

Urban planners and designers have a portfolio of climate change strategies that guide decisions on urban form and function (Figure 5).

- Urban waste heat and greenhouse gas emissions from infrastructure—including buildings, transportation, and industry – can be reduced through improvements in the efficiency of urban systems.
- Modifying the form and layout of buildings and urban districts can provide cooling and ventilation that reduce energy use and allow citizens to cope with higher temperatures and more intense runoff.
- Selecting construction materials and reflective coatings can improve building performance by managing heat exchange at the surface.
- Increasing the vegetative cover in a city can simultaneously lower outdoor temperatures, building cooling demand, runoff, and pollution, while sequestering carbon.

KEY MESSAGES

Climate change mitigation and adaptation strategies should form a core element in urban planning and design taking into account local conditions. Decisions on urban form have long-term (>50 years) consequences and affect the city's capacity to reduce greenhouse gas emissions and to respond to climate hazards. Investing in mitigation strategies that yield concurrent adaptive benefits should be prioritized.

Urban planning and design should incorporate long-range strategies for climate change that reach across physical scales, jurisdictions, and electoral timeframes. These activities need to deliver a higher quality of life for urban citizens as the key performance outcome.

Equity and Climate Resilience

Cities are characterized by the large diversity of socio-economic groups living in close proximity. Diversity is often accompanied by stratification based on class, caste, gender, profession, race, ethnicity, age, and ability. This gives rise to social categories that, in turn, affect the ability of individuals and various groups to endure climate stresses and minimize climate risks.

Differences between strata often lead to discrimination based on group membership. Poorer people and ethnic and racial minorities tend to live in more hazard-prone, vulnerable and crowded parts of cities. These circumstances increase their susceptibility to the impacts of climate change and reduce their capacity to adapt and withstand extreme events.

MAJOR FINDINGS

- Differential vulnerability of urban residents to climate change is driven by four factors: (1) differing levels of physical exposure; (2) urban development processes that have created a range of built-in risks, such access to critical infrastructure and urban services; (3) social characteristics that influence the allocation of resources for adaptation; and (4) access to power, institutions, and governance (Figure 6).
- Climate change amplifies vulnerability and hampers adaptive capacity, especially for the poor, women, the elderly, children, and ethnic minorities. These people often lack power and access to resources, adequate urban services, and functioning infrastructure. Gender inequality is particularly pervasive in cities, contributing to differential consequences of climate changes.
- While some extreme climate events, such as droughts, can undermine everyone's resource base and adaptive capacity, including better-off groups in cities; as climate extremes become more frequent and intense, this can increase the scale and depth of urban poverty overall.
- Mobilizing resources to improve equity and environmental justice under changing climatic conditions requires (1) participation by impacted communities and the involvement of civil society; (2) non-traditional sources of finance, including partnerships with the private sector; and (3) adherence to the principle of transparency in spending, monitoring, and evaluation.

KEY MESSAGES

Urban climate policies should include equity and environmental justice as primary long-term goals. They foster human wellbeing, social capital, and sustainable social and economic development, all of which increase a city's capacity to respond to climate change. Access to land situated in non-vulnerable locations, security of tenure, and access to basic services and risk-reducing infrastructure are particularly important.

Cities need to promote and share a science-informed policymaking process that integrates multiple stakeholder interests and avoids inflexible, top-down solutions. This can be accomplished by participatory processes that incorporate community members' views about resilience objectives and feasibility.

Over time, climate change policies and programs need to be evaluated and adjusted in order to ensure that sustainably, resilience, and equity goals are achieved. Budgetary transparency, equitable resource allocation schemes, monitoring, and periodic evaluation are essential to ensure that funds reach target groups and result in equitable resilience outcomes.

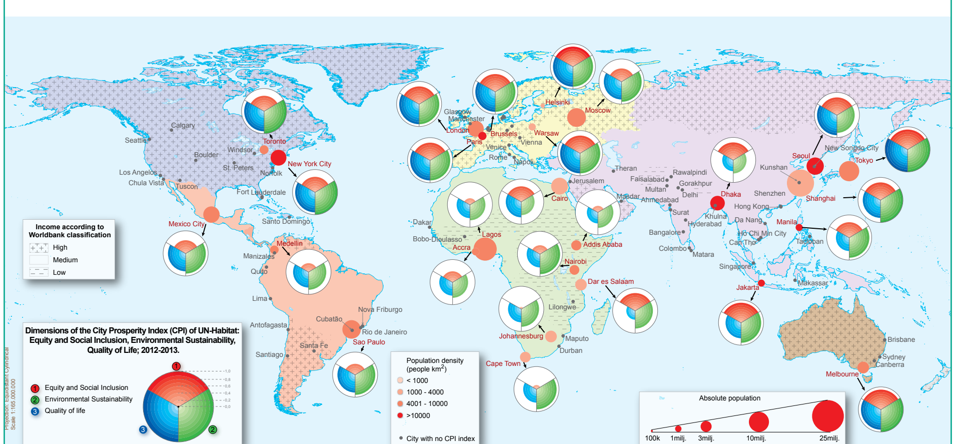


Figure 6: *Equity dimensions relevant to climate change impacts, adaptation, and mitigation in cities: outcome-based, distributive or consequential equity; and process-oriented or procedural equity. Source: Metz, 2000.*

Financing Climate Change Solutions in Cities

Since cities are the locus of large and rapid socioeconomic development around the world, economic factors will continue to shape urban responses to climate change. To exploit response opportunities, promote synergies between actions, and reduce conflicts, socio-economic development must be integrated with climate change planning and policies.

Public sector finance can facilitate action, and public resources can be used to generate investment by the private sector (Figure 7). But private sector contributions to mitigation and adaptation should extend beyond financial investment. The private sector should also provide process and product innovation, capacity building, and institutional leadership.

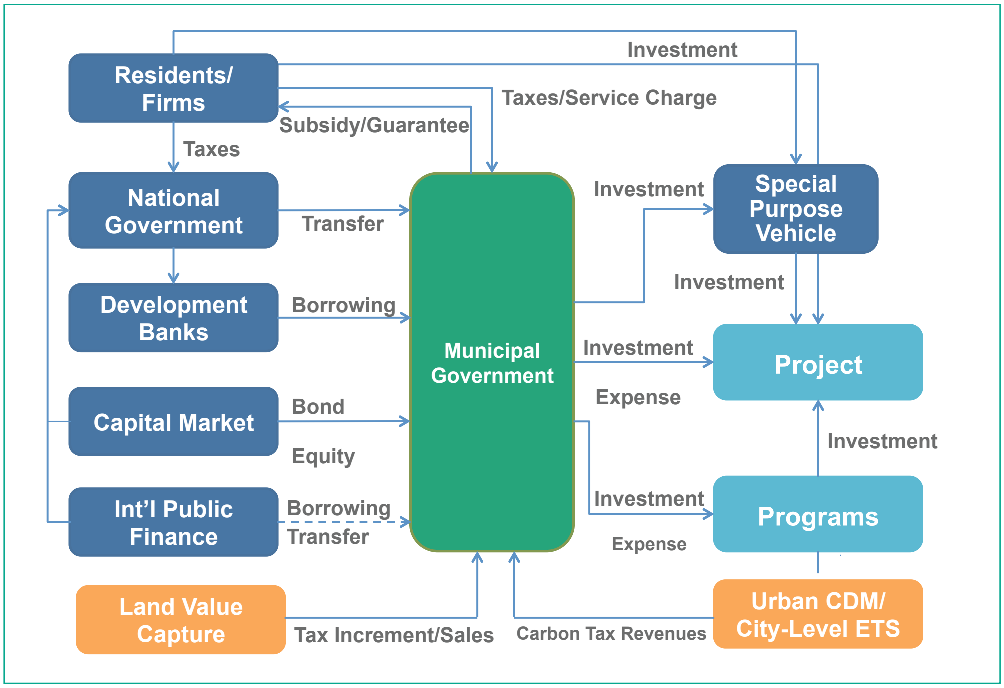


Figure 7: *Opportunities of climate finance for municipalities.*

MAJOR FINDINGS

- Implementing climate change mitigation and adaptation actions in cities can help solve other city-level development challenges, such as major infrastructure deficits. Assessments show that meeting increasing demand will require more than a doubling of annual capital investment in physical infrastructure to over $20 trillion by 2025, mostly in emerging economies. Estimates of global economic costs from urban flooding due to climate change are approximately $1 trillion a year.

- Cities cannot fund climate change responses on their own. Multiple funding sources are needed to deliver the large infrastructure financing that is essential to low-carbon development and climate risk management in cities. Estimates of annual cost of climate change adaptation range between $80-100 billion, of which about 80% will be borne in urbanized areas.

- Public-private partnerships are necessary for effective action. Partnerships should be tailored to the local conditions in order to create institutional and market catalysts for participation.

- Regulatory frameworks should be integrated across city, regional, and national levels in order to provide incentives for the private sector to participate in making cities less carbon-intensive and more climate-resilient. The framework needs to incorporate mandates for local public action along with incentives for private participation and investment in reducing business contributions to emissions.

- Enhancing credit worthiness and building the financial capacity of cities are essential to tapping the full spectrum of resources and raising funds for climate action.

KEY MESSAGES

Financial policies must enable local governments to initiate actions that will minimize the costs of climate impacts. For example, the cost of inaction will be very high for cities located along coastlines and inland waterways due to rising sea levels and increasing risks of flooding.

Climate-related policies should also provide cities with local economic development benefits as cities shift to new infrastructure systems associated with low-carbon development.

Networks of cities play a crucial role in accelerating the diffusion of good ideas and best practices to other cities, both domestically and internationally. Therefore, cities that initiate actions that lead to domestic and international implementation of nationwide climate change programs should be rewarded.

Urban Ecology in a Changing Climate

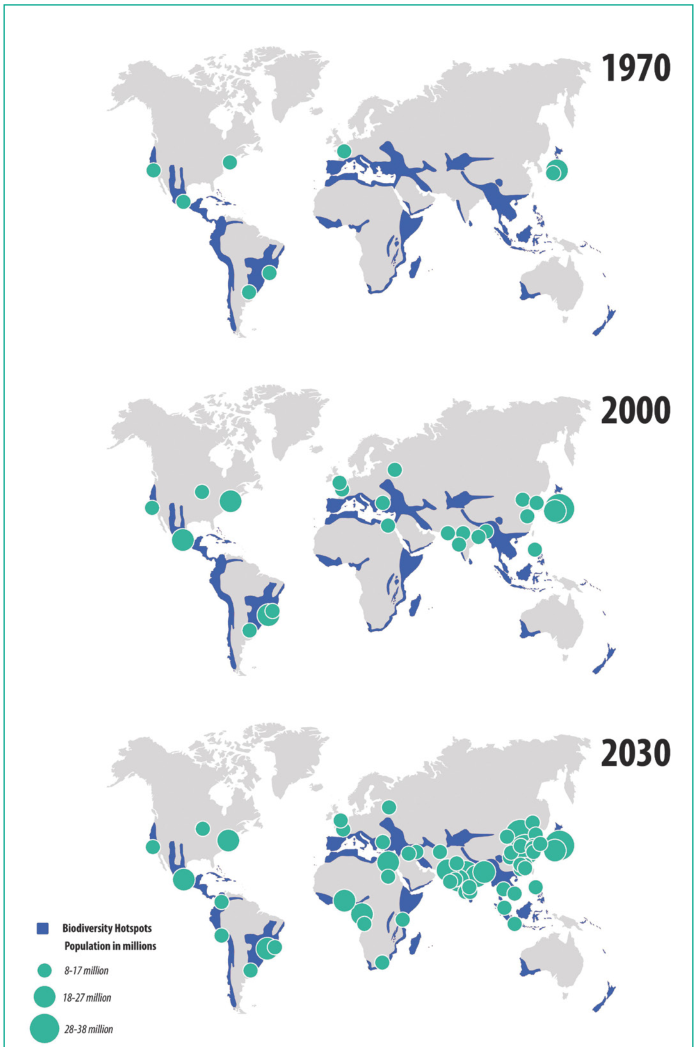


Figure 8: Urban areas (green) with large populations in 1970, 2000 and 2030 (projected), as examples of urban expansion in global biodiversity hotspots (blue).

Almost all of the impacts of climate change have direct or indirect consequences for urban ecosystems, biodiversity, and the critical ecosystem services they provide for human health and wellbeing in cities. These impacts are already occurring in urban ecosystems and their constituent living organisms.

Urban ecosystems and biodiversity have an important and expanding role in helping cities adapt to the changing climate. Harnessing urban biodiversity and ecosystems as adaptation and mitigation solutions will help achieve more resilient, sustainable, and livable outcomes.

Conserving, restoring, and expanding urban ecosystems under mounting climatic and non-climatic urban development pressures will require improved urban and regional planning, policy, governance, and multi-sectoral cooperation.

MAJOR FINDINGS

- Urban species and ecosystems are already being affected by climate change.
- Urban ecosystems are rich in biodiversity and provide critical natural capital for climate adaptation and mitigation.
- Climate change and urbanization are likely to increase the vulnerability of biodiversity hotspots, urban species, and critical ecosystem services (Figure 8).
- Investing in urban ecosystems and green infrastructure can provide cost-effective, nature-based solutions for adapting to climate change while also creating opportunities to increase social equity, green economies, and sustainable urban development.
- Enhancing urban ecosystems and green infrastructure investment has multiple co-benefits, including improving quality of life, human health, and social wellbeing.

KEY MESSAGES

Cities should follow a long-term systems approach to ecosystem-based climate adaptation. Such an approach explicitly recognizes the role of critical urban and peri-urban ecosystem services and manages them in order to provide a sustained supply of over time horizons of twenty, fifty, and one hundred years. Ecosystem-based planning strengthens the linkages between urban, peri-urban, and rural ecosystems through planning and management at both urban and regional scales.

The economic benefits of urban biodiversity and ecosystem services should be quantified so that they can be integrated into climate-related urban planning and decision-making. These benefits should incorporate both monetary and non-monetary values of biodiversity and ecosystem services, such as improvements to public health and social equity.

Cities on the Coast: Sea Level Rise, Storms, and Flooding

Coastal cities have lived with extreme climate events since the onset of urbanization, but climatic change and rapid urban development are amplifying the challenge of managing risks. Some coastal cities are already experiencing losses during extreme events related to sea level rise. Meanwhile, urban expansion and changes and intensification in land use put growing pressure on sensitive coastal environments through pollution and habitat loss.

The concentration of people, infrastructure, economic activity, and ecology within the coastal zone merits specific consideration of hazards exacerbated by a changing climate. Major coastal cities often locate valuable assets along the waterfront or within the 100-year flood zone, including port facilities, transport and utilities infrastructure, schools, hospitals, and other long-lived structures. These assets are potentially at risk for both short-term flooding and permanent inundation.

MAJOR FINDINGS

- Coastal cities are already exposed to storm surges, erosion, and saltwater intrusion (Figure 9). Climate change and sea level rise will likely exacerbate these hazards. Assessments show that the value of assets at risk in large port cities is estimated to exceed $3.0 trillion USD (5% of Gross World Product) in 2005.
- Expansion of coastal cities is expected to continue over the 21st century, with over half the global population living in cities in the coastal zone by mid-21st century. Annual coastal flood losses could reach $71 billion by 2100.
- Climate-induced changes will affect marine ecosystems, aquifers used for urban water supplies, the built environment, transportation, and economic activities, particularly following extreme storm events. Critical infrastructure and precariously built housing in flood zones are vulnerable.
- Increasing shoreline protection can be accomplished by either building defensive structures or by adopting more natural solutions, such as preserving and restoring wetlands or building dunes. Modifying structures and lifestyles to "live with water" and maintain higher resiliency are key adaptive measures.

KEY MESSAGES

Coastal cities must be keenly aware of the rates of local and global sea level rise and future sea level rise projections, as well as emerging science that might indicate more rapid rates of (or potentially slower rates) of sea level rise.

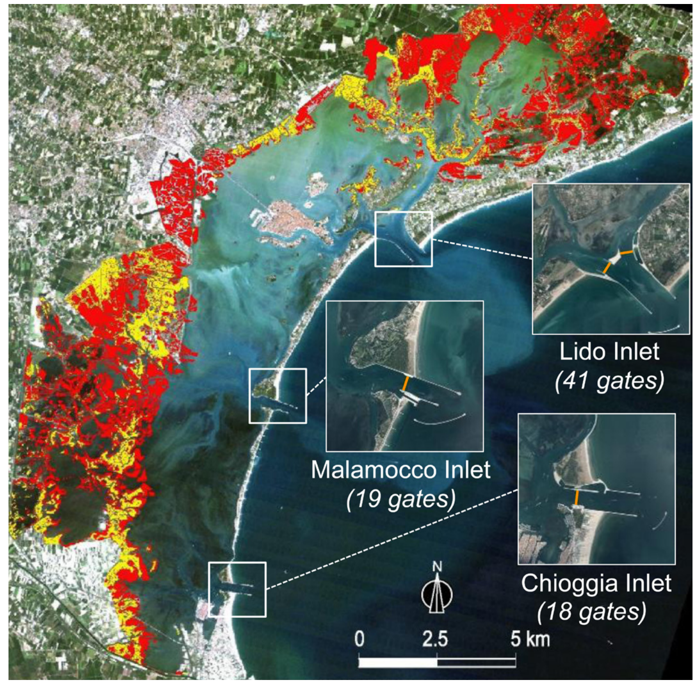


Figure 9: *The MOSE project for the defense of the City of Venice from high tides. Yellow, marsh areas surviving at the beginning of the 21st century; red, marshes that have disappeared over the course of the 20th century. Source: Modified from Consorzio Venezia Nuova - Servizio Informativo.*

An adaptive approach to coastal management will maintain flexibility to accommodate changing conditions over time. This involves implementing adaptation measures with co-benefits for the built environment, ecosystems, and human systems. An adaptive strategy requires monitoring changing conditions and refining measures as more up-to-date information becomes available.

Simple, less costly measures can be implemented in the short term, while assessing future projects. Land-use planning for sustainable infrastructure development in low-lying coastal areas should be an important priority. Further, cities need to consider transformative adaptation, such as large-scale relocation of people and infrastructure with accompanying restoration of coastal ecosystems.

Delivering integrated and adaptive responses will require robust coordination and cooperation on coastal management issues. This must be fostered among all levels of local, regional, and national governing agencies, and include engagement with other stakeholders.

Managing Threats to Human Health

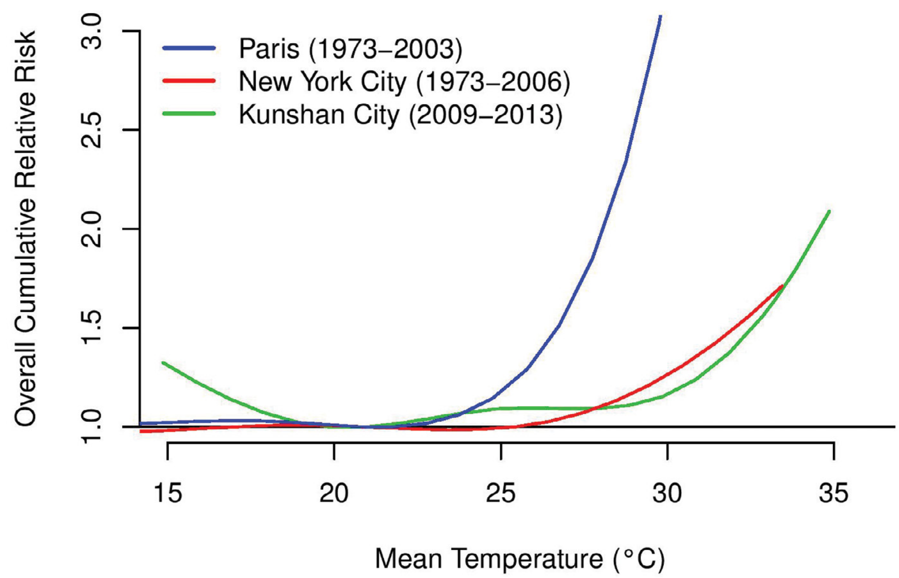


Figure 10: *Overall cumulative heat-mortality relationships in Paris (France), New York City (USA), and Kunshan City (China).*

Climate change and extreme events are increasing risks of disease and injury in many cities. Urban health systems have an important role to play in preparing for these exacerbated risks. Climate risk information and early warning systems for adverse health outcomes are needed to enable interventions. An increasing number of cities are engaging with health adaptation planning, but health departments of all cities need to be prepared.

MAJOR FINDINGS

- Storms, floods, heat extremes, and landslides are among the most important weather-related health hazards in cities (Figure 10). Climate change will increase the risks of morbidity and mortality in urban areas due to greater frequency of weather extremes. Children, the elderly, the sick, and the poor in urban areas are particularly vulnerable to extreme climate events.

- Some chronic health conditions (e.g., respiratory and heat-related illnesses) and infectious diseases will be exacerbated by climate change. These conditions and diseases are often prevalent in urban areas.

- The public's health in cities is highly sensitive to the ways in which climate extremes disrupt buildings, transportation, waste management, water supply and drainage systems, electricity, and fuel supplies. Making urban infrastructure more resilient will lead to better health outcomes, both during and following climate events.

- Health impacts in cities can be reduced by adopting "low-regret" adaptation strategies in the health system, and throughout other sectors, such as water resources, wastewater and sanitation, environmental protection, and urban planning.

- Actions aimed primarily at reducing greenhouse gas emissions in cities can also bring immediate local health benefits and reduced costs to the health system through a range of pathways, including reduced air pollution, improved access to green space, and opportunities for active transportation on foot or bicycle.

KEY MESSAGES

In the near term, improving basic public health and health care services; developing and implementing early warning systems; and training citizens' groups in disaster preparedness, recovery, and resilience are effective adaptation measures.

The public health sector, municipal governments, and the climate change community should work together to integrate health as a key goal in the policies, plans and programs of all city sectors.

Connections between climate change and health should be made clear to public health practitioners, city planners, policy-makers, and to the general public.

Housing and Informal Settlements

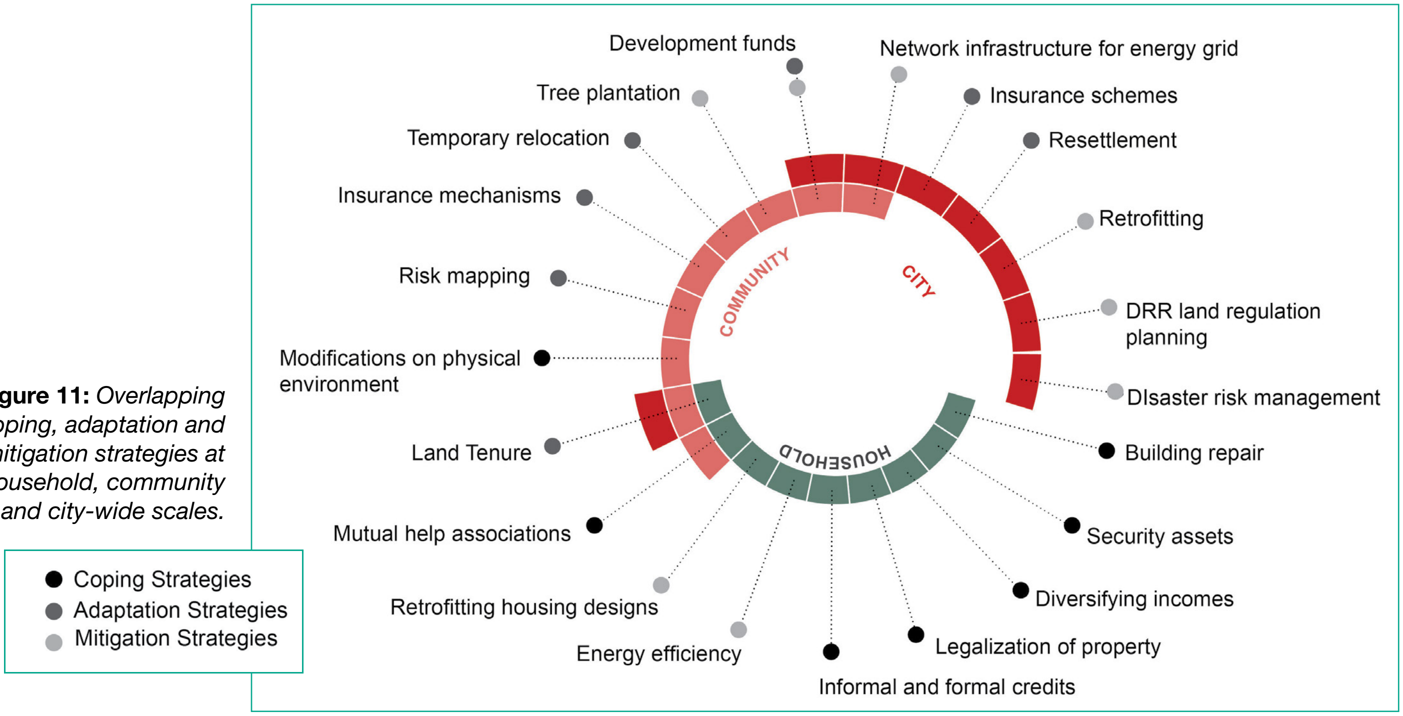


Figure 11: *Overlapping coping, adaptation and mitigation strategies at household, community and city-wide scales.*

Addressing vulnerability and exposure in the urban housing sector can contribute to the wellbeing of residents. This is especially true in informal settlements, where extreme climate events present the greatest risks. Understanding the impacts of mitigation and adaptation strategies on the housing sector will help decision-makers make choices that improve quality of life and close development and equity gaps in cities (Figure 11).

MAJOR FINDINGS

- The effects of hazards, people's exposure, and their vulnerability collectively determine levels of risk. Risks are associated with specific social and physical factors within each city. Mapping risks and developing early warning systems—especially for informal settlements—can provide information that decision-makers and stakeholders need to reduce vulnerability.
- Developed countries account for the majority of the world's energy demand related to buildings. Incentives and other measures are enabling large-scale investments in mass-retrofitting programs in higher-income cities.
- Housing construction in low- and middle-income countries is focused on meeting demand for over 500 million more people by 2050. Cost-effective, and adaptive building technologies can avoid locking in carbon-intensive and non-resilient options.
- Access to safe and secure land is a key measure for reducing risk in cities. Groups that are already disadvantaged in regard to housing and land tenure are especially vulnerable to climate.
- Among informal settlements, successful adaptation depends upon addressing needs for climate-related expertise, resources, and risk-reducing infrastructure.

KEY MESSAGES

City managers should work with the informal sector to improve safety in relation to climate extremes. Informal economic activities are often highly vulnerable to climate impacts, yet they are crucial to economies in low- and middle-income cities. Therefore, costs to the urban poor and their communities—both direct and indirect—should be included in loss and damage assessments in order to accurately reflect the full range of impacts on the most vulnerable urban residents and the city as a whole.

Widespread implementation of flood and property insurance in informal settlements can help reduce their high reliance on third-party subsidies and, hence, enhance their climate change resilience. This requires efforts to overcome the lack of insurance organization, and limited demand for insurance within these communities.

Retrofits to housing that improve resilience create co-benefits, such as more dignified housing, improvements to health, and enhanced quality of public spaces. Meanwhile, mitigating greenhouse gas emissions in the housing sector can create local jobs in production, operations, and maintenance, especially in low-income countries and informal settlements.

Energy Transformations in Cities

Demands on urban energy supply are projected to grow exponentially due to the growth trends in urbanization and the size of cities, industrialization, technological advancement, and wealth. Increasing energy requirements are associated with rising demands for vital services including electricity, water supply, transportation, buildings, communication, food, health, and parks and recreation.

With climate change, the urban energy sector is facing three major challenges. The first is to meet the rising demand for energy in rapidly urbanizing countries without locking into high carbon-intensive fuel such as coal. The second is to build resilient urban energy systems that can withstand and recover from the impacts of increasing extreme climate events. The third is to provide cities in low-income countries with modern energy systems while replacing traditional fuel sources such as biomass.

MAJOR FINDINGS

- Urbanization has clear links to energy consumption in low-income countries. Urban areas in high-income countries generally use less energy per capita than non-urban areas due to the economies of scale associated with higher density.
- Current trends in global urbanization and energy consumption show increasing use of fossil fuels, including coal, particularly in rapidly urbanizing parts of the world.
- Key challenges facing the urban energy supply sector include reducing environmental impacts, such as air pollution, the urban heat island effect, and greenhouse gas emissions; providing equal access to energy; and ensuring energy security and resilience in a changing climate.
- While numerous examples of energy-related mitigation policies exist across the globe, less attention has been given to adaptation policies. Research suggests that radical changes in the energy supply sector, customer behavior, and the built environment are needed to meet the key challenges.
- Scenario research that analyzes energy options requires more integrated assessment of the synergies and tradeoffs in meeting multiple goals: reducing greenhouse gases, increasing equity in energy access, and improving energy security.

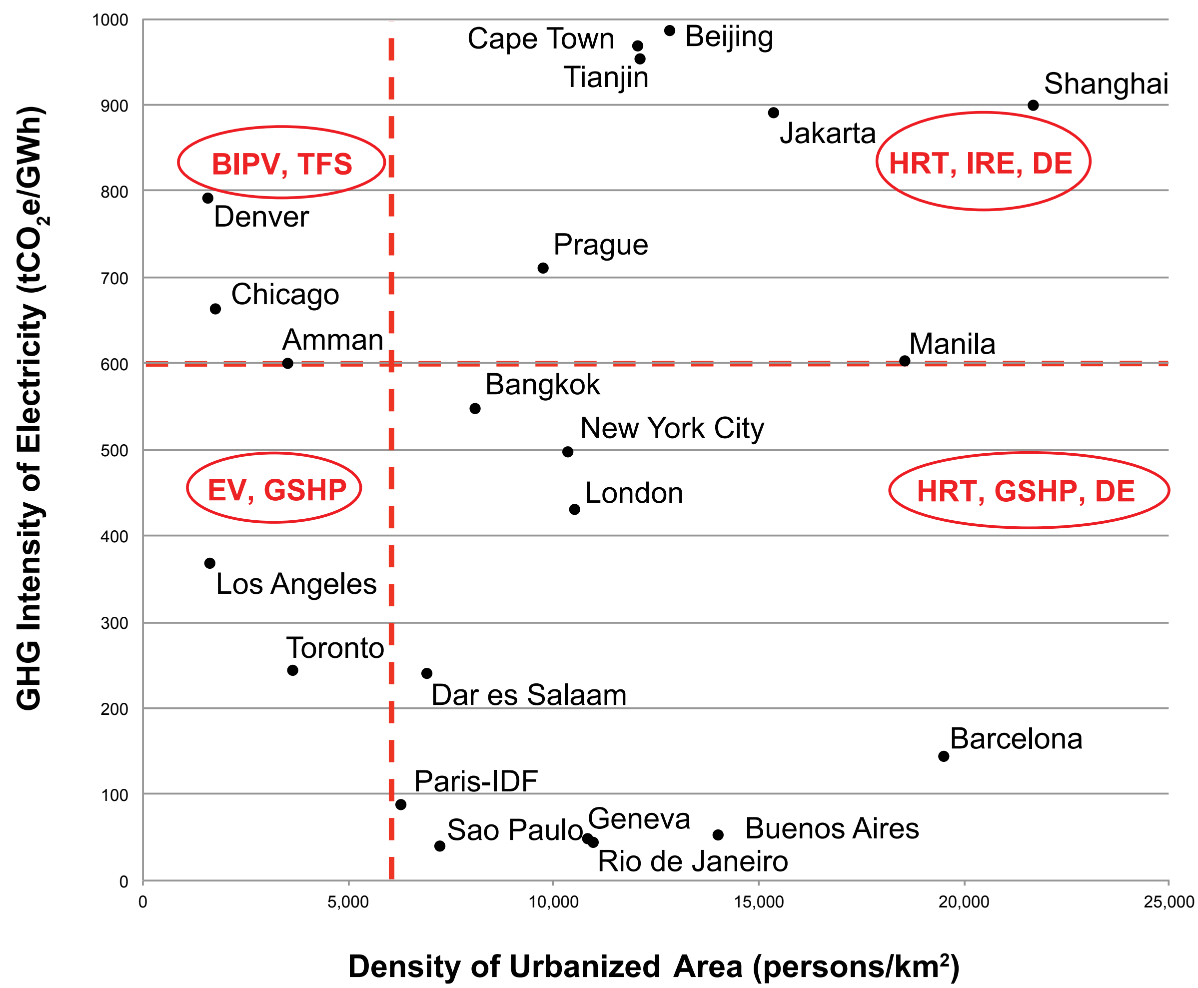
KEY MESSAGES

In the coming decades, rapid population growth, urbanization, and climate change will impose intensifying stresses on existing and not-yet-built energy infrastructure. The rising demand for energy services—e.g., mobility, water and space heating, refrigeration, air conditioning, communications, lighting, and construction—in an era of enhanced climate variation poses significant challenges for all cities.

Depending on the type, intensity, duration, and predictability of climate impacts on natural, social, and built and technological systems, threats to the urban energy supply sector will vary from city to city. Local jurisdictions need to evaluate vulnerability and improve resilience to multiple climate impacts and extreme weather events.

Yet future low-carbon transitions may also differ from previous energy transitions because future transitions may be motivated more by changes in governance and environmental concerns than by the socio-economic and behavioral demands of the past. Unfortunately, the governance of urban energy supply varies dramatically across nations and sometimes within nations, making universal recommendations for institutions and policies difficult, if not impossible. Given that energy sector institutions and activities have varying boundaries and jurisdictions, there is a need for stakeholder engagement across the matrix of institutions to cope with future challenges in both the short and long term.

In order to achieve global greenhouse gas emission reductions through the modification of energy use at the urban scale, it is critical to develop an urban registry that has a typology of cities and indicators for both energy use and greenhouse gas emissions (Figure 12). This will help cities benchmark and compare their accomplishments and better understand the mitigation potential of cities worldwide.



BIPV	Building Integrated Photovoltaics
DE	District Energy
EV	Electric Vehicles
GSHP	Ground Source Heat Pumps
HRT	Heavy Rapid Transit
IRE	Import Renewable Electricity
TFS	Transportation Fuel Substitution

Figure 12: *Low-carbon infrastructure strategies tailored to different cities based on urban population density and average GHG intensity of existing electricity supply. Source: Adapted from Kennedy et al., 2014.*

Transport as Climate Challenge and Solution

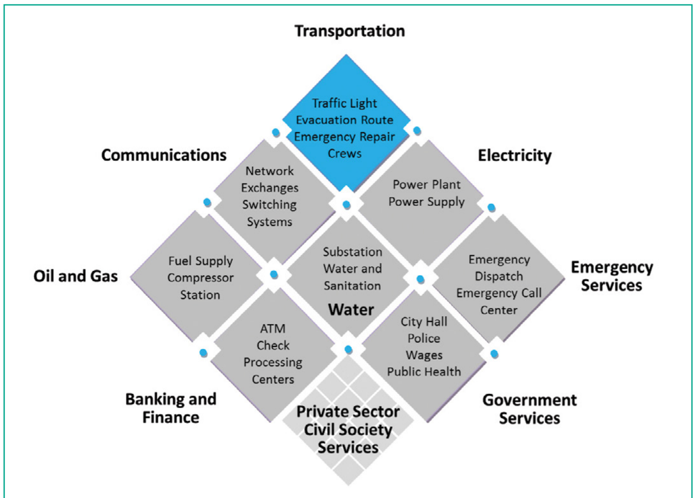


Figure 13: *Urban transport's interconnectivity with other urban systems Source: Adapted from Melillo et al., 2014.*

Urban transport systems are major emitters of greenhouse gases and are essential to developing resilience to climate impacts. At the same time cities need to move forward quickly to adopt a new paradigm that ensures access to clean, safe, and affordable mobility for all.

In middle-income countries, rising incomes are spurring demand for low-cost vehicles and, together with rapid and sprawling urbanization and segregated land use, are posing unprecedented challenges to sustainable development while contributing to climate change.

Expanded climate-related financing mechanisms are being developed at national and international levels such as the Green Climate Fund. Local policymakers should prepare the institutional capacity and policy frameworks needed to access financing for low-carbon and resilient transport.

MAJOR FINDINGS

- Cities account for over 70 percent of greenhouse gas emissions with a significant proportion due to urban transport choices. The transport sector directly accounted for nearly 30% of total end-use energy-related CO_2 emissions. Of these, direct emissions from urban transport account for 40%.
- Urban transport emissions are growing at two to three percent annually. The majority of emissions from urban transport is from higher-income countries. In contrast, 90% of the growth in emissions is from transport systems in lower-income countries.
- Climate-related shocks to urban transportation have economy-wide impacts, beyond disruptions to the movement of people and goods. The interdependencies between transportation and other economic, social, and environmental sectors can lead to citywide impacts (Figure 13).
- Integrating climate risk reduction into transport planning and management is necessary in spatial planning and land use regulations. Accounting for these vulnerabilities in transport decisions can ensure that residential and economic activities are concentrated in low-risk zones.
- Low-carbon transport systems yield co-benefits that can reduce implementation costs, yet policymakers often need more than a good economic case to capture potential savings.
- Integrated low-carbon transport strategies—Avoid-Shift-Improve—involve avoiding travel through improved mixed land use planning and other measures; shifting passengers to more efficient modes through provision of high-quality, high-capacity mass transit systems; and improving vehicle design and propulsion technologies to reduce fuel use.
- Designing and implementing risk-reduction solutions and mitigation strategies require supportive policy and public-private investments. Key ingredients include employing market-based mechanisms; promoting information and communication technologies; building synergies across land use and transport planning; and refining regulations to encourage mass transit and non-motorized modes.

KEY MESSAGES

Co-benefits such as improved public health, better air quality, reduced congestion, mass transit development, and sustainable infrastructure can make low-carbon transport more affordable and sustainable, and can yield significant urban development advantages. For many transport policymakers, co-benefits are primary entry points for reducing greenhouse gas emissions. At the same time, policymakers should find innovative ways to price the externalities—the unattributed costs—of carbon-based fuels.

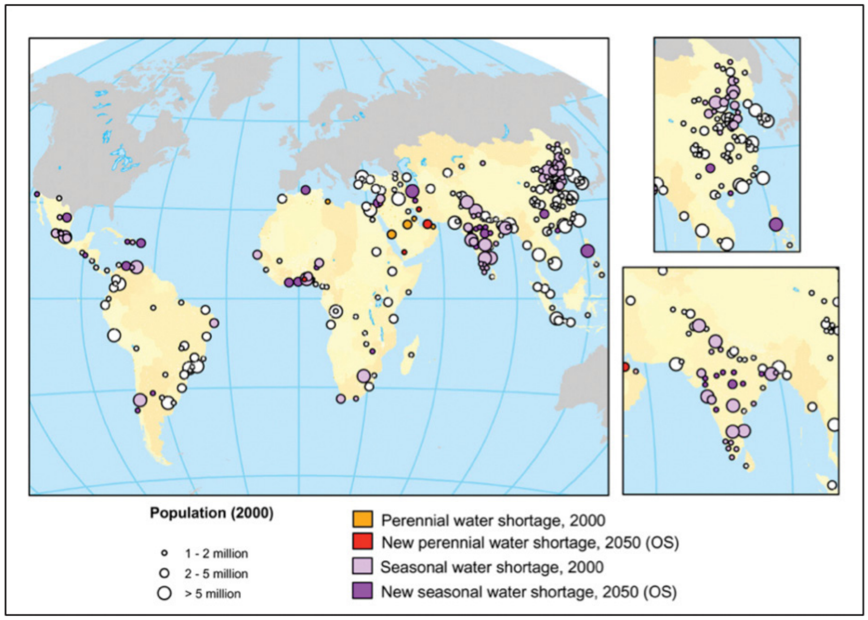
The interdependencies between transport and other urban sectors mean that disruptions to transport can have citywide impacts. To minimize disruptions due to these interdependencies, policymakers should take a systems approach to risk management that explicitly addresses the interconnectedness between climate, transport, and other relevant urban sectors.

Low-carbon transport should also be socially inclusive, as social equity can improve a city's resilience to climate change impacts. Automobile-focused urban transport systems fail to provide mobility for significant segments of urban populations. Women, the elderly, the poor, non-drivers, and disadvantaged people need urban transport systems that go beyond enabling mobility to fostering social mobility as well.

Sustaining Water Security

In regard to climate change, water is both a resource and a hazard. As a resource, good quality water is basic to the wellbeing of the ever-increasing number of people living in cities. Water is also critical for many economic activities, including peri-urban agriculture, food and beverage production, and industry. However, excess precipitation or drought can lead to hazards ranging from increased concentrations of pollutants—with negative health consequences, a lack of adequate water flow for sewerage, and flood-related damage to physical assets.

Projected deficits in the future of urban water supplies will likely have a major impact on both water availability and costs. Decisions taken now will have an important influence on future water supply for industry, domestic use, and agriculture.



Robert I. McDonald et al. PNAS 2011;108:6312-6317

Figure 14: *Distribution of large cities (>1 million population in 2000) and their water shortage status in 2000 and 2050. Gray areas are outside the study area.*

MAJOR FINDINGS

- The impacts of climate change put additional pressure on existing urban water systems and can lead to negative impacts for human health and wellbeing, economies, and the environment (Figure 14). Such impacts include increased frequency of extreme weather events leading to large volumes of storm water runoff, rising sea levels, and changes in surface water and groundwater.
- A lack of urban water security, particularly in lower-income countries, is an ongoing challenge. Many cities struggle to deliver even basic services to their residents, especially those living in informal settlements. As cities grow, demand and competition for limited water resources will increase, and climate changes are very likely to make these pressures worse in many urban areas.
- Water security challenges extend to peri-urban areas as well, where pressure on resources is acute, and where there are often overlapping governance and administrative regimes.
- Governance systems have largely failed to adequately address the challenges that climate change poses to urban water security. Failure is often driven by a lack of coherent and responsive policy, limited technical capacity to plan for adaptation, limited resources to invest in projects, lack of coordination, and low levels of political will and public interest.

KEY MESSAGES

Adaptation strategies for urban water resources will be unique to each city, since they depend heavily on local conditions. Understanding the local context is essential to adapting water systems in ways that address both current and future climate risks.

Acting now can minimize negative impacts in the long term. Master planning should anticipate projected changes over a timeframe of more than fifty years. Yet, in the context of an uncertain future, finance and investment should focus on low-regret options that promote both water security and economic development, and policies should be flexible and responsive to changes and new information that come to light over time.

Many different public and private stakeholders influence the management of water, wastewater, storm water, and sanitation. For example, land use decisions have long lasting consequences for drainage, infrastructure planning, and energy costs related to water supply and treatment. Therefore, adapting to the changing climate requires effective governance, and coordination and collaboration among a variety of stakeholders and communities.

Cities should capture co-benefits in water management whenever possible. Cities might benefit from low-carbon energy production and improved health with wastewater treatment. Investment strategies should include the application of life-cycle analysis to water supply, treatment, and drainage; use of anaerobic reactors to improve the balance between energy conservation and wastewater treatment; elimination of high-energy options, such as inter-basin transfers of water wherever alternative sources are available; and recovering biogas produced by wastewater.

Managing and Utilizing Solid Waste

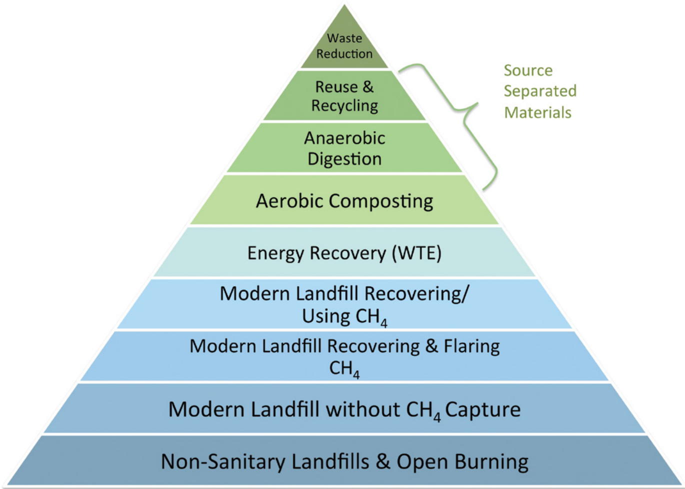


Figure 15: *The hierarchy of sustainable solid waste management. Source: Kaufman and Themelis, 2010.*

Municipal solid waste management is inextricably linked to increasing urbanization, development, and climate change. The municipal authority's ability to improve solid waste management also provides large opportunities to mitigate climate change and generate co-benefits, such as improved public health and local environmental conservation.

Driven by urban population growth, rising rates of waste generation will severely strain existing municipal solid waste infrastructure in low and middle-income countries. In most of these countries, the challenge is focused on effective waste collection and improving waste treatment systems to reduce greenhouse gas emissions. In contrast, high-income countries can improve waste recovery through reuse and recycling, and promote upstream interventions to prevent waste at the source.

Because stakeholder involvement, economic interventions, and institutional capacity are all important for enhancing the solid waste management, integrated approaches involving multiple technical, environmental, social, and economic efforts will be necessary.

MAJOR FINDINGS

- Globally, solid waste generation was about 1.3 billion tons in 2010. Due to population growth and rising standards of living worldwide, waste generation is likely to increase significantly by 2100. A large majority of this increase will come from cities in low- and middle-income countries, where per capita waste generation is expected to grow.

- Up to three to five percent of global greenhouse gas emissions come from improper waste management. The majority of these emissions are methane—a gas with high greenhouse potential—that is produced in landfills. Landfills, therefore, present significant opportunities to reduce greenhouse gas emissions in high- and middle-income countries.

- Even though waste generation increases with affluence and urbanization, greenhouse gas emissions from municipal waste systems are lower in more affluent cities. In European and North American cities, greenhouse gas emissions from waste sector account for 2–4 percent of the total urban emissions. These shares are smaller than in African and South American cities, where emissions from waste sector are 4–9 percent of the total urban emissions. This is because more affluent cities tend to have the necessary infrastructure to reduce methane emissions from municipal solid waste

- In low- and middle-income countries, solid waste management represents 3–15 percent of city budgets, with 80–90 percent of the funds spent on waste collection. Even so, collection coverage ranges from only 25–75 percent. The primary means of waste disposal is open dumping, which severely compromises public health.

- Landfill gas-to-energy is an economical technique for reducing greenhouse gas emissions from the solid sector. This approach provides high potential to reduce emissions at a cost of less than US$10/tCO2-eq. However, gas-to-energy technology can be employed only at properly maintained landfills and managed dumpsites, and social aspects of deployment need to be considered.

KEY MESSAGES

Reducing greenhouse gas emissions in the waste sector can improve public health; improve quality of life; and reduce local pollution in the air, water, and land while providing livelihood opportunities to the urban poor. Cities should exploit the low-hanging fruit for achieving emissions reduction goals by using existing technologies to reduce methane emissions from landfills. In low-and middle-income countries, the best opportunities involve increasing the rates of waste collection, building and maintaining sanitary landfills, recovering materials and energy by increasing recycling rates, and adopting waste-to-energy technologies. Resource managers in all cities should consider options such as reduce, re-use, recycle, and energy recovery in the waste management hierarchy.

Urban Governance for a Changing Climate

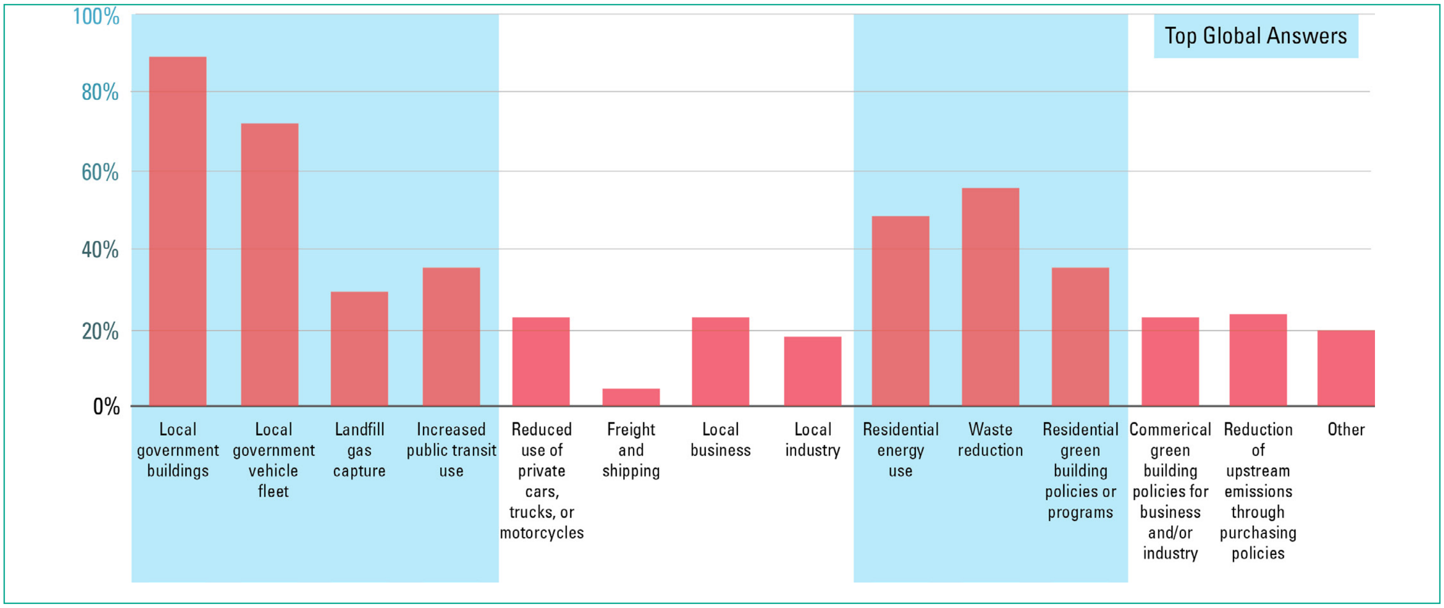


Figure 16: *Mitigation interventions and uptake by cities resulting in measurable emission reductions. Source: Aylett, 2014.*

Greenhouse gas emissions and climate risks in cities are not only local government concerns. They challenge a range of actors across jurisdictions to create coalitions for climate governance. Urban climate change governance occurs within a broader socio-economic and political context, with actors and institutions at a multitude of scales shaping the effectiveness of urban-scale interventions. These interventions may be particularly powerful if they are integrated with co-benefits related to other development priorities, creating urban systems (both built and institutional) that are able to withstand, adapt to, and recover from climate-related hazards.

Collaborative, equitable, and informed decision-making is needed in order to enable transformative responses to climate change, as well as fundamental changes in energy and land-use regimes, growth ethos, production and consumption, lifestyles, and worldviews. Leadership, legal frameworks, public participation mechanisms, information sharing, and financial resources all work to shape the form and effectiveness of urban climate change governance.

MAJOR FINDINGS

- While jurisdiction over many dimensions of climate change adaptation and mitigation resides at the national level, along with the relevant technical and financial capacities, comprehensive national climate change policy is still lacking in most countries. Despite this deficiency, municipal, state, and provincial governmental and non-governmental actors are taking action to address climate change (Figure 16).
- Urban climate change governance consists not only of decisions made by government actors, but also by non-governmental and civil society actors in the city. Participatory processes that engage these interests around a common aim hold the greatest potential to create legitimate, effective response strategies.
- Governance challenges often contribute to gaps between the climate commitments that cities make and the effectiveness of their actions.
- Governance capacity to respond to climate change varies widely within and between low- and high-income cities, creating a profile of different needs and opportunities on a city-by-city basis.
- The challenge of coordinating across the governmental and non-governmental sectors, jurisdictions, and actors that is necessary for transformative urban climate change policies is often not met. Smaller scale, incremental actions controlled by local jurisdictions, single institutions, or private and community actors tend to dominate city-level actions
- Scientific information is necessary for creating a strong foundation for effective urban climate change governance, but governance is needed to apply it. Scientific information needs to be co-generated in order for it to be applied effectively and meet the needs and address the concerns of the range of urban stakeholders.

Urban Governance for a Changing Climate (continued)

KEY MESSAGES

While climate change mitigation and adaptation have become a pressing issue for cities, governance challenges have led to policy responses that are mostly incremental and fragmented. Many cities are integrating mitigation and adaptation, but fewer are embarking on the more transformative strategies required to trigger a fundamental change towards sustainable and climate-resilient urban development pathways.

The drivers, dynamics, and consequences of climate change cut across jurisdictional boundaries and require collaborative governance across governmental and non-governmental sectors, actors, administrative boundaries, and jurisdictions. Although there is no single governance solution to climate change, longer planning timescales, coordination and participation among multiple actors, and flexible, adaptive governance arrangements may lead to more effective urban climate governance.

Urban climate change governance should incorporate principles of justice in order that inequities in cities are not reproduced. Therefore, justice in urban climate change governance requires that vulnerable groups are represented in adaptation and mitigation planning processes; priority framing and setting recognize the particular needs of vulnerable groups; and actions taken to respond to climate change enhance the rights and assets of vulnerable groups.

Rio de Janeiro. Photo by Somayya Ali Ibrahim.

8

Urban Ecosystems and Biodiversity

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This chapter should be cited as

McPhearson, T., Karki, M., Herzog, C., Santiago Fink, H., Abbadie, L., Kremer, P., Clark, C. M., Palmer, M. I., and Pernini, K. (2016). Urban ecosystems and biodiversity. In C. Rosenzweig, W. Solecki, P. Romero-Lankao, S. Mehrotra, S. Dhakal, and S. Ali Ibrahim (eds.), Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network. Cambridge University Press.

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Urban Ecology in a Changing Climate

Almost all of the impacts of climate change have direct or indirect consequences for urban ecosystems, biodiversity, and the critical ecosystem services they provide for human health and well-being in cities. These impacts are already occurring in urban ecosystems and their constituent living organisms.

Urban ecosystems and biodiversity have an important and expanding role in helping cities adapt to and mitigate the impacts of changing climate. Harnessing urban biodiversity and ecosystems as adaptation and mitigation solutions will help achieve more resilient, sustainable, and livable outcomes for cities and urban regions.

Conserving, restoring, and expanding urban ecosystems under mounting climatic and non-climatic urban development pressures will require improved urban and regional planning, policy, governance, and multisectoral cooperation.

Major Findings

- Urban biodiversity and ecosystems are already being affected by climate change.
- Urban ecosystems are rich in biodiversity and provide critical natural capital for climate change adaptation and mitigation.
- Climate change and urbanization are likely to increase the vulnerability of biodiversity hotspots, urban species, and critical ecosystem services.
- Investing in urban ecosystems and green infrastructure can provide cost-effective, nature-based solutions for adapting to climate change while also creating opportunities to increase social equity, green economies, and sustainable urban development.
- Investing in the quality and quantity of urban ecosystems and green infrastructure has multiple co-benefits, including improving quality of life, human health, and social well-being.

Key Messages

Cities should take a long-term, system-based approach to climate adaptation and mitigation. Nature-based approaches to address climate change in cities explicitly recognize the critical role of urban and peri-urban ecosystem services (UES) that require thoughtful management in order to ensure sustainable supply of environmental goods and services to residents who need them over the next 20, 50, and 100 years. Ecosystem-based planning can strengthen the linkages between urban, peri-urban, and rural ecosystems through participatory planning and management for nature-based solutions at both city and regional scales.

The economic benefits of urban biodiversity and ecosystem services should be quantified so that they can be integrated into climate-related urban resilience and sustainability planning and decision-making. These benefits should incorporate both monetary and non-monetary values of biodiversity and ecosystem services, including how they relate to physical and mental health and social equity in access to services.

8.1 Introduction

Climate change is already affecting cities and urbanized regions around the world impacting human populations and the built environment, as well as urban ecosystems and their associated biota (While and Whitehead 2013). Almost all of the impacts of climate change have direct or indirect consequences for urban ecosystems,[1] biodiversity,[2] and the critical ecosystem services[3] they provide for human health and well-being in cities (e.g., urban heat island [UHI] reduction) (The Economics of Environmentalism and Biodiversity [TEEB], 2011; Elmqvist et al., 2013). Increasing knowledge of the benefits of urban ecosystems for the livelihoods of urban residents suggests an important and expanding role for urban ecosystems and biodiversity in adaptation to local effects of climate change. However, conserving, restoring, and expanding urban ecosystems to enhance climate resilience and other co-benefits under mounting climatic and non-climatic stresses of growing urbanization and development processes will require improved urban and regional planning, policy, and governance and multisectorial cooperation to protect and manage urban ecosystems and biodiversity (Elmqvist et al., 2013; Solecki and Marcotullio, 2013; McPhearson et al., 2014).

In this chapter, we review key concepts, challenges, and ecosystem-based pathways for adaptation and mitigation of climate change in cities. This leads to and supports concepts, strategies, and tools of ecosystem-based adaptation, disaster risk reduction, and green infrastructure planning. Section 8.1 reviews the relationship among urban ecosystems, biodiversity, and ecosystems services as critical resources for climate adaptation and, to some extent, mitigation. Sections 8.2 and 8.3 discuss current and future climate-related challenges including hazards, risks, and vulnerabilities for urban biodiversity and ecosystem services. Section 8.4 discusses examples of how ecosystems can provide adaptive capacity and be used innovatively to reduce effects of climate change in urban systems, whereas Section 8.5 presents ecosystem-based adaptation as an effective entry point for nature-based solutions to building climate resilience in cities. Section 8.6 discusses the economic cost-effectiveness of ecosystem-based adaptation, with particular emphasis on investing in green infrastructure. Section 8.7 discusses how urban ecosystems intersect with urban planning and design (see also Chapter 5), the importance of engaging with diverse stakeholders, and how ecosystem-based planning and management can help address issues of social equity and environmental justice while yielding multiple socioeconomic benefits. Section 8.8 discusses important planning, governance, and management tools (see also Chapter 16). Sections 8.9 and 8.10 present the need for better linking science with policy, in particular for building urban climate resilience. Section 8.11 identifies remaining knowledge gaps and suggests avenues for future research. Section 8.12 provides a summary of recommendations for cities to harness urban biodiversity and ecosystems as nature-based solutions to adapt to the effects of and mitigate climate change that will help achieve more sustainable, resilient, and livable cities. Case Studies are provided throughout the chapter to illustrate effective, on-the-ground implementation of many of the ecosystem-based adaptation and mitigation strategies and approaches reviewed.

8.1.1 A Systems Approach to Ecology in, of, and for Cities

Cities and urban areas are complex systems with social, ecological, economic, and technical/built components interacting dynamically in space and time (Grimm et al., 2000, 2008; Pickett et al., 2001; McPhearson et al., 2016a). The complex nature of urban systems[4] can make it challenging to predict how ecosystems will respond to climate change (Batty 2008; Bettencourt and West, 2010; McPhearson et al., (2016b). This complexity is driven by many intersecting feedbacks affecting ecosystems, including climate, biogeochemistry, nutrient cycling, hydrology, population growth, urbanization and development, human perceptions and behavior, and more (Bardsley and Hugo, 2010; Pandey and Bardsley, 2013; Alberti, 2015).

[1] Urban ecosystems include all vegetation, soil, and water-covered areas that may be found in urban and peri-urban areas at multiple spatial scales (parcel, neighborhood, municipal city, metropolitan region), including parks, cemeteries, lawns and gardens, green roofs, urban allotments, urban forests, single trees, bare soil, abandoned or vacant land, agricultural land, wetlands, streams, rivers, lakes, and ponds (Gómez-Baggethun et al., 2013).

[2] "Biological diversity" means the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems.

[3] Ecosystem services are the benefits that people obtain directly or indirectly from ecosystem functions, such as protection from storm surges and heat waves, air quality regulation, and food, fiber, and fresh water (MA, 2005; TEEB, 2010; Gomez-Baggethun et al., 2013).

[4] Urban systems are defined here as those areas where the built infrastructure covers a large proportion of the land surface or those in which people live at high densities (Pickett et al., 2001).

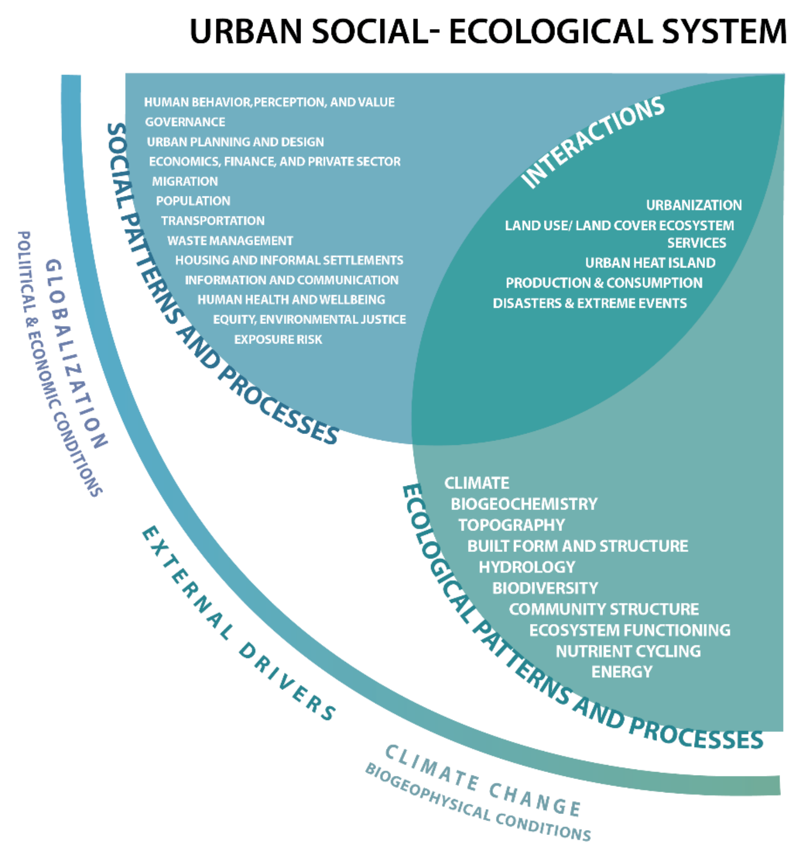

Figure 8.1 *Urban systems are complex and dynamically interactive and can be conceptualized and studied as social-ecological systems (SES) at multiple spatial or temporal scales. Urban SES consists of social and ecological components (broadly defined) that have their own internal patterns and processes, but these patterns and processes interact across the system in a number of ways to produce overall urban system dynamics, behavior, and emergent phenomena. Drivers external to the urban system are fundamentally important, but can affect social and ecological components and processes within the urban system with different strengths or intensity. This conceptual approach to studying urban SES is scale-independent and can therefore be applied at multiple spatial or temporal scales in urban areas.*

In urban ecology, cities and urbanized areas are understood to be complex human-dominated ecosystems (Pickett et al., 1997, 2001; Niemelä et al., 2011). These systems interrelate dynamically with the social, ecological, economic, and technological/built infrastructure of the city (Grimm et al., 2000; McDonnell and Hahs, 2013; McPhearson et al., 2016a) (see Figure 8.1). Patterns and processes of urban systems in this view emerge from the interactions and feedbacks between components and systems in cities, emphasizing the need to consider multiple sources of social-ecological patterns and processes to understand reciprocal interactions between climate change and urban ecosystems (see Figure 8.1). The urban ecosystem approach has developed rapidly in the past two decades incorporating methods and approaches from the social sciences, biophysical sciences, urban planning, and design to provide insight for developing and managing urban ecosystems to meet the needs of expanding urban populations in a changing climate (McDonnell, 2011; McPhearson et al., 2016a). We focus here on biodiversity and ecosystem functions and services provided by natural systems within urban and peri-urban areas.

Studies of the ecology *in* the city as well as ecology *of* the city (Grimm et al., 2000; Pickett et al., 2001) are both domains of urban ecology, a science increasingly focused on applying sustainability and resilience science *for* cities (Childers et al., 2014, 2015; McPhearson et al., 2016a). Defining clear boundaries for ecosystems *in* the city is challenging due to the fact that species and many of the relevant fluxes and interactions necessary to understand the functioning of urban ecosystems extend beyond the city boundaries defined by political borders (Solecki and Marcotullio, 2013; Andersson et al., 2015b). For example, nutrients, water, species, and humans all move across political boundaries, emphasizing the importance of regional planning and management. Thus, the relevant scope of urban ecosystem analysis reaches far beyond the municipal boundary. It comprises not only the ecological areas within cities, but also the peri-urban areas and linkages to nearby rural areas that are directly affected by the energy and material flows from the urban core, including city water catchments, peri-urban forests, and nearby cultivated fields (Grimm et al., 2000; Pickett et al., 2001; La Rosa and Privitera, 2013). Urban ecosystems therefore include all vegetation, soil, and water-covered areas that may be found in urban and peri-urban areas at multiple spatial scales (parcel, neighborhood, municipal city, metropolitan region), including parks, cemeteries, lawns and gardens, green roofs, urban allotments, urban forests, single trees, bare soil, abandoned or vacant land, agricultural land, wetlands, streams, rivers, lakes, and ponds (Gómez-Baggethun et al., 2013).

The social and biophysical context of urban areas influences resilience to climate change and other social-ecological challenges (Marcotullio and Solecki, 2013; Solecki and Marcotullio, 2013). For example, the bio-geophysical context of the city or urban area may determine how ecosystems in cities respond to climate change, extreme events, and urbanization (Schewenius et al., 2014). Urbanization and suburbanization in urban areas often reduce both species richness (i.e., the number of species) and evenness (i.e., the distribution of species) for most biotic communities (Paul et al., 2001; McKinney 2002). Changes in species richness and evenness have been found to affect the stability of ecosystems and their ability to deliver needed services for mitigating and adapting to climate change (Grimm, 2008; Cardinale et al., 2012). Additionally, many of the changes taking place in urban areas have analogues to those driven by climate change (e.g., elevated CO_2, higher temperatures, changes in precipitation), thus making urban systems useful models for examining the interaction of social and biophysical patterns and processes in changing climates (Grimm et al., 2008, Collins et al., 2000). Therefore, urban ecological approaches to improving climate adaptation and mitigation should employ a systems approach characterized by interdisciplinary, multiscalar studies and a focus on interactions and feedbacks to further develop an ecology *of* and *for* cities (see Figure 8.1) (Grimm et al., 2000; Pickett et al., 2001; McDonald et al., 2013; Childers et al., 2014, 2015; McPhearson et al., 2016). Green infrastructure and ecosystem-based adaptation are important components of nature-based solutions for climate adaptation and mitigation.

8.1.2 Urban Green Infrastructure

Many cities have already made significant progress employing urban ecological resources for climate change adaptation and mitigation as part of urban infrastructure design, planning, and development (Frischenbruder and Pellegrino, 2006). Green infrastructure is becoming a widely utilized nature-based solution for climate change adaptation and mitigation in cities (Florgard, 2007). We consider green infrastructure as a network of natural and semi-natural areas, features, and green spaces in rural and urban, terrestrial, coastal, and marine areas, which together enhance ecosystem health and climate change resilience, contribute to biodiversity, and benefit human populations through the maintenance and enhancement of ecosystem services (Pauleit et al., 2011; Kopperoinen et al., 2014). Green infrastructure is often also examined as a specific management tool for combining engineered and ecological systems (e.g., bioswales) in place of engineered non-ecological systems (e.g., concrete sewer drains) to provide ecosystem services such as cooling, stormwater management, UHI reduction, carbon storage, flood protection, and recreation (Novotny et al., 2010).

Case Study 8.1 Spanish Coastal Natural Protected Areas: Ebro Delta and Empordà Wetlands

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Keywords	**Sea level rise, vulnerability, ecosystems-based adaptation, coastal natural protected area**
Population (Study Region)	Ebro Delta: 48,031 Empordà wetlands: 43,354 (IDESCAT, 2015)
Area (Study Region)	Ebro Delta: 299.4 km2 Empordà wetlands: 123 km2 (IDESCAT, 2015)
Income per capita	$US28,520 (World Bank, 2015)
Climate zone	Temperate, dry summer, hot summer (Csa) (Peel et al., 2007)

Climate change is an increasingly significant global problem with potentially far-reaching consequences for coastal human communities, livelihoods, and ecosystems in the Mediterranean region. Seven economically, socially, and environmentally dynamic urban towns across coastal natural protected areas in Mediterranean Spain, the Ebro Delta (see Case Study 8.1 Figure 1), and Empordà wetlands have been particularly vulnerable to three aspects of climate change: (1) air and sea temperatures rise (2) sea level rise, and (3) decreased river flows (see Case Study 8.1 Table 1). In addition, intensification of coastal erosion, flooding, saltwater intrusion, and deficits in river sediment supply have been affecting natural habitats and livelihoods in these areas (Barnolas and Llasat, 2007; Candela et al., 2007; CIIRC, 2010; Day et al., 2006; Guillén and Palanques 1992; Jiménez et al., 1997; Martín-Vide et al., 2012; Sánchez-Arcilla et al., 2008).

Case Study 8.1 Figure 1 *Locations of the three municipalities in the Ebro Delta and coastal natural protected area. Source: Author*

Case Study 8.1 Table 1
Comparison of socioeconomic, environmental, and climate characteristics of the Ebro Delta and Empordà wetlands

	Ebro Delta	**Emporda wetlands**
Municipality(s)	Amposta, Deltebre, Sant Carles de la Rapita	Castello d'Empuries, Escala, Roses, Sant Pere Pescador
Physical territory	Coastal lagoons, marshlands, beaches, dunes, saltpans	Coastal lagoons, inland freshwater ponds, marshlands, beaches, dunes
Protection	Ramsar Convention on Wetlands (1986), Natura 2000, Special Protection Area for Birds	Ramsar Convention on Wetlands (1992), Natura 2000, Special Protection Area for Birds
Protected area	11,530 ha	10,830 ha
River(s)	Ebro	Muga, Fluvia
River regulation	Mequinega, Flix, Riba-roja dams	Boadella dam
Vegetation	*Arthrocnemetum fruticosi, Crucianelletum maritimae, Scirpetum maritimi-littoralis, Agropyretum mediterraneum*	*Salix alba, Fraxinus angustifolia, Rosa sempervivens, Arum iotalicum, Aristo lochia rotunda, Typha latifolia*
Fauna	*Anas strepera, Phoenicopterus roseus, Botaurus stellaris, Ardea purpurea, Larus audouinii*	*Coracias garrulus, Lanius minor, Buteo buteo, Falco subbuteo, Bos taurus domestica*
Climate	Mediterranean	Mediterranean
Air temperature (1990–2014)	Increase by 0.37°C/decade (Ebre Observatory)	Increase by 0.19°C/decade (Sant Pere Pescador)
Precipitation (1990–2014)	Slight increase (Ebre Observatory)	Decrease (Sant Pere Pescador)
River flow(s) (1990–2012)	Decrease by 14 m^3/s/decade (Ebro)	Decrease by 3.5 m^3/s/decade (Fluvia)
Sea level (1990–2014)	Increase by 3.9 cm/decade (Estartit)	Increase by 3.9 cm/decade (Estartit)
Sea temperatures (1990–2014)	Increase by 0.18°C (sea surface), 0.17°C (20 m), 0.28°C (50 m), 0.13°C/decade (80 m) (Estartit)	Increase by 0.18°C (sea surface), 0.17°C (20 m), 0.28°C (50 m), 0.13 °C/decade (80m) (Estartit)
Tourism	Ecotourism, birdwatching	Campsites, second homes, hotels, ecotourism, birdwatching, marina

Agriculture	Rice, citrus fruits	Fruits trees, vines, olives
Fishery	14% of Catalonia's fish production	11% of Catalonia's fish production
N° population (2014)	48,031	43,354

Source: ACA (2014); BirdLife International (2014a, 2014b); CREAF (2013); Ebre Observatory (2015); IDESCAT (2015); Meteo Estartit (2015); Ninyerola et al. (2004); SMC (2015); Wetlands International (1992, 1995)

This paper is based on studies that identified a local dimension of climate change adaptation relevant for maintaining a wide range of livelihoods while facing current and future climate change (Fatorić, 2010, 2014). These studies are in tune with Smit and Wandel (2006) who highlighted that adaptation is an outcome of the interaction of environmental, social, cultural, political, and economic forces. Analytically, adaptation is conceptualized in this paper as a set of technical options to respond to specific risks (Nelson et al., 2007) where the need for local stakeholder involvement has been increasingly acknowledged (Bormann et al., 2012; Cote et al., 2014; Eriksen et al., 2011; Mozumder et al., 2011). Different stakeholders may hold different knowledge, opinions, and understandings of the local context of adaptation. Thus, which specific sources of knowledge are recognized and used in decision-making process is crucial for determining which interests, development paths, and solutions are prioritized (Eriksen et al., 2011).

Local, regional, and national stakeholders belonging to various economic sectors (e.g., employees of local tourist information centers, farmers, peasants, engineers); public administrations (e.g., governmental officers), environmental organizations and research centers (e.g., members of environmental groups, scientists), and social organizations (e.g., members of social and ethnic organizations) linked to Ebro Delta and Empordà wetlands were selected to participate in the studies.

The results showed that adaptation appears to be taking place in the Ebro Delta and Empordà wetlands during the past few decades, but mainly through unsustainable measures (e.g., artificial or hard structures).

More than half of interviewed stakeholders reported that they favor "natural" adaptation measures such as (1) building and/or restoring coastal sand dunes and (2) raising ground level. Approximately one-quarter were in favor of "artificial" adaptation measures such as (1) seawalls, groins, and breakwaters; (2) flood and underwater gates; (3) beach nourishment; and (4) rainwater harvesting. The remaining stakeholders considered combining both types of measures. Stakeholders were also asked to consider coastal relocation as an adaptation option.

With respect to natural adaptation measures, building sand dunes parallel to the shoreline where none exists and/or restoring and stabilizing the existing ones was perceived as the optimal adaptation measure in both protected coastal areas. This option was often considered as the cheapest one for both study areas, and it is compatible with environmental sustainability actions. Moreover, building and restoring dunes can increase socioecological resilience in both areas and produce benefits in the absence of climate change effects.

Regarding raising ground level, the other natural adaptation measure, interviewees expressed little support for elevating ground level by a few centimeters. This might be due to weak technical and urban design skills among most stakeholders.

Artificial measures, on the other hand, did not have such unified support among stakeholders. For instance, dykes, seawalls, and breakwaters generated different opinions. About one-third of stakeholders were against "artificialization" mainly due to the current ecological value of both areas. Stakeholders perceived these measures as too costly to build and maintain. A small number of stakeholders were willing to maintain an already attractive landscape for economic activities (especially tourism) by implementing artificial measures.

Flood and saltwater intrusion gates were suggested and discussed, but gates may be not suitable measures because they entail significant investments. Beach nourishment was perceived by a minority of stakeholders as a suitable measure that is aesthetically pleasing and that sometimes can be implemented with a reasonable budget.

The studies also revealed that support for rainfall capture and storage in those parts of Mediterranean Spain where precipitation is likely to decrease and become more variable has not yet been prioritized.

Regarding coastal relocation, it was interesting to note a difference between the two study areas: according to population data (IDESCAT, 2015), the rate of registered foreign immigrants is higher in Empordà wetlands than in the Ebro Delta, and, interestingly, among the interviewed stakeholders in Empordà wetlands there was more willingness for relocation elsewhere as an "adaptation" measure than in the Ebro Delta. In this sense, it emerged that place attachment (and previous migration experience) among local residents is relevant when considering relocation as adaptation measure.

One of the lessons that can be drawn from this paper is the need to gather and integrate local understanding, perception, and knowledge with scientific knowledge in order to develop successful response to climate change, empower local decision-making, and preserve current ecosystems, livelihoods, and communities. Encouraging local communities and policy-makers to undertake short- and medium-term thinking and to develop adaptation planning with more desirable sustainable outcomes should be a priority in the Ebro Delta and Empordà wetlands. Stakeholders can help to raise awareness in order to implement adaptation measures based on technical solutions that would reduce the vulnerability of natural and socioeconomic systems and take advantage of any potential opportunities and benefits (Fatorić and Chelleri, 2012; Fatorić and Morén-Alegret, 2013; Fatorić et al., 2014). Another lesson that emerged from the research is that the optimal adaptation measure according to the stakeholders in both coastal protected areas is building and/or restoring coastal dunes, which is likely to be the most efficient and least expensive protection against various climate change effects (see Case Study 8.1 Figure 2). This highlights the need for dune conservation and maintenance as climate change reinforces the value of its protection capacity.

Case Study 8.1 Figure 2 *Dunes as "natural" adaptation measure in Empordà wetlands. Source: author*

Urban green infrastructure is a key strategy for mitigating and adapting to the effects of climate change. For example, the UHI effect can be reduced by several degrees through enhanced transpiration and the shading provided by street trees, green roofs, and parks (Onishi et al., 2010; Petralli et al., 2006; Rosenzweig et al., 2006; Susca et al., 2011; Taha, 1997). Vegetation also decreases energy use for heating and air conditioning (McPherson et al., 1997; Akbari et al., 2001, UNEP, 2011). Akbari et al. (2001) estimated that about 20% of the national cooling demand in the United States can be avoided through a large-scale implementation of heat-island mitigation measures through urban green infrastructure, particularly through urban forestry. Vegetation also adds to a city's mitigation efforts by capturing CO_2 through photosynthesis and absorbing atmospheric pollutants through dry deposition on leaves and branches uptake by stomata (Fowler, 2002; Ottelé et al., 2010; Sternberg et al., 2010). Green roofs and vegetated areas, including trees, increase rainwater infiltration and reduce peak flood discharge and associated water pollution while also providing mental and physical health benefits such as providing spaces for recreation and relaxation and decreasing the level of citizen stress (Dunnett and Kingsbury, 2008; Scholz-Barth, 2001; Czemiel Berndtsson, 2010; Carson et al., 2013) (see Figure 8.2).

Figure 8.2 *Urban trees and other types of green infrastructure can provide important climate adaptation and mitigation in cities. The quantity and quality of benefits (e.g., carbon storage, urban heat island mitigation, stormwater absorption) may depend on the urban context and configuration of trees in an urban landscape. A. Individual scattered street trees at 125th Street and Madison Avenue, Harlem. B Dense street trees at Eastern Parkway and Classon Avenue, Brooklyn. C. Street trees as a corridor connecting small- and medium-sized urban green spaces, Elmhurst, Juniper Valley Parks, and Lutheran All Faiths Cemetery, Queens. D. Dense urban street trees connecting large urban parks: Bronx Park and VanCortlandt Park. E. Disconnected urban green space with scattered trees, Green-Wood Cemetery, Brooklyn. F. Large urban forest, Forest Park, Queens.*

New York City, for example, launched the Green Infrastructure Plan in 2010 designed to invest in new and restored green infrastructure for stormwater management instead of traditional gray infrastructure. This included committing US$1.5 billion for green infrastructure development over the next 20 years (NYC Environmental Protection, 2010; see also Staten Island Blue Belt Case Study 8.2). Similarly, the city of Taizhou, China, located on the southeast coast of Zhejiang Province with 5.5 million inhabitants, developed a zoning plan (Yu and Li, 2006) that utilized green infrastructure to adapt urban growth to deal with potential impacts of climate change including preventing stormwater related floods and maintaining food production areas. The Taizhou plan incorporated ecological areas at multiple scales (local to regional) to maintain critical natural processes and flows including hydrology and biodiversity while simultaneously protecting cultural heritage sites and recreation areas (Gotelli et al., 2013; Yu and Li, 2006; Ahern, 2007). These and other relevant Case Studies described in this chapter demonstrate the importance and cost-effective benefits of incorporating urban ecosystems explicitly into urban design, management, planning, and policy for mitigating and adapting to the effects of climate change.

Case Study 8.2 New York City's Staten Island Bluebelt

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Keywords	**Urban stormwater management, urban biodiversity, blue-green network, ecosystem based adaptation**

Population (Metropolitan Region)	18,897,109 (US Census Bureau, 2010)
Area (Metropolitan Region)	17,319 (US Census Bureau, 2010)
Income per capita	$US54,960 (World Bank, 2015)
Climate zone	Dfa – Continental, fully humid, hot summer (Peel et al., 2007)

Summary

New York City faces growing impacts from climate change, an with increasing frequency of extreme weather events such as the 2012 Hurricane Sandy. The city's Staten Island Bluebelt stormwater management practice is one of the best cases of an integrated ecosystem based adaptation (EbA) and disaster risk reduction (DRR) response wherein traditional water bodies and depressions are managed to accommodate and slow flood water. Native vegetation sites are developed by expanding, buffering, and linking with existing parks and conservation areas to form an ecological network to deliver multiple ecosystem services.

Case Description

The Staten Island Bluebelt is a system of created wetlands developed since the 1990s to provide alternative, ecosystem-based stormwater management services in a rapidly developing borough of New York City (NYC). The Bluebelt has become a model for providing multiple ecosystem services including stormwater management, water quality improvement, wildlife habitat provisioning, environmental education, and increased property values.

Climate Change Issues

NYC has been facing growing hazards and risks of climate change such as sea-level rise, storm surge, rising temperatures, and other related issues. Hurricane Sandy was an example of an extreme climate event. Mean annual temperature and precipitation in NYC increased 4.4°F (15.33 °C) and 7.7 inches (18 cm), respectively, from 1900 to 2011, and sea level (at the Battery) has risen 1.1 feet (33.5 cm) since 1900. The model projections predict that, by 2050, the temperature will rise by 6°F (14.4 °C) and precipitation by 15% (New York Panel on Climate Change [NPCC2], 2013). NYC is now working with academia, civil society, and others to make the city's infrastructure and population more resilient and its infrastructure development sustainable. The high water table, poor drainage, and extensive wetlands of Staten Island challenge the development of a conventional stormwater drainage system. Cities across the world can learn from this good practice of stormwater management.

Case Study 8.2 Figure 1 *Extended detention Weir, Conference House Park, Staten Island Bluebelt. Photo credit: Jack Ahern*

Adaptation Strategy

In 1990, the NYC Department of Environmental Protection conceptualized the Bluebelt program and began constructing stormwater best management practices (BMP) along stream and wetland corridors to attenuate routine storm flow and improve water quality and flood flow (Ryan, 2006). The Bluebelt concept had two principal goals: (1) to provide basic stormwater infrastructure and (2) to preserve the last remaining wetlands in Staten Island. Since 1995, more than fifty sites have been developed under the Bluebelt program, all of which were justified by a cost-benefit analysis comparing Bluebelt development costs with those of a conventional piped stormwater storage system. The cost-benefit analysis indicated a direct saving of $US30 million (http://cooper.edu/isd/news/waterwatch/statenisland).

The Bluebelt's principal function is to slow, store, treat, and attenuate stormwater in created wetlands and stormwater BMP in a self-regulating native ecosystem. Bluebelt facilities are designed as a "treatment train" of BMP's starting with a constructed "micropool" or fore-bay that receives stormwater from a trunk outlet. The stormwater flow then passes to an extended detention wetland where water is attenuated through contact with native wetland plants and soils. Native wetland plants sequester nutrients and add oxygen to wetland soils, facilitating the bacterial breakdown of nitrogen and phosphorous. Field stones are installed in culvert bottoms to reduce stream velocity and provide fish habitat.

Bluebelt design practices emphasize native plant species and communities including rare and near extinct plants. Wetland plants are sourced from local nurseries or rescued from local development sites using custom excavating buckets to enable transplanting the full soil profile along with the wetland trees and shrubs. Bioengineering techniques including fascines, mats, and rolls are used to restore and stabilize slopes and stream banks with native wetland tree and shrub species. Bluebelts are constructed to intentionally include habitat "niches" with brush piles, downed trees, and boulder piles. Removed trees with roots attached are placed in the bottoms of Bluebelt ponds to create diverse microhabitats for fish and amphibians. Dead trees are left standing to provide habitat for cavity-nesting birds (Brauman et al., 2009).

Case Study 8.2 Figure 2 *An aesthetic bridge connecting different ecosystems.*

Bluebelts are carefully designed to fit and complement their community context. For example, dams and bridges are built from fieldstone to evoke the character of the region's many historical bridges and dams. Bluebelt sites are selected to expand, buffer, and link up with existing parks and conservation areas, forming an ecological network to deliver multiple ecosystem services. Bluebelt trails are designed to link adjacent parks and provide direct community access for recreation. The adopt-a-bluebelt program has been successful in engaging community residents and environmental groups with basic maintenance tasks.

Water quality and flow monitoring by the US Environmental Protection Agency found nutrient removal rates exceeded the national standards for pollutant removal. Wildlife monitoring by the Audubon Society has found a large number of breeding birds in the Bluebelt, including green herons, wood thrushes, and great-crested flycatchers. Fish passage provided by fish ladders support migratory breeds, such as the American eel, that go upstream to spawn. Mosquitoes are controlled through the Bluebelt's constant through-flow of water that minimizes their breeding grounds as well as the support that BMP provides to populations of beneficial insects that feed on mosquitoes.

Lessons Learned

The Bluebelt is a good example of a "green infrastructure" – a hybrid engineered and natural system designed to provide a suite of specific urban infrastructure and ecosystem services. It represents an example of an efficient system because of its innovations and collateral ecosystem services, including as a wildlife habitat provision, as a community recreation and education facility, and in increased property values.

Motivated by the success of this case, the Bluebelt concept is being exported to other NYC boroughs under the City's multiple plans, including the High Performance Infrastructure and new stormwater management plans and the NYC sustainability plan or "PlaNYC 2030." Bluebelts are also being considered to address ongoing combined sewer overflow (CSO) problems in other boroughs under the Jamaica Bay Watershed Plan. However, in other NYC boroughs, land use is more intensive and there are few existing wetlands and large areas of undeveloped land. In these boroughs, blue belts will be built on public lands, including highway verges and parks because these have higher environmental values than other land uses.

Conclusion

The Bluebelt is an effective adaptation response to effects of climate change on an urban environment. Staten Island was directly in the path of the 2012 super storm Hurricane Sandy, and the Bluebelt demonstrated its resilience and adaptability. Although the storm surge and intense precipitation from Sandy exceeded the treatment capacity of the Bluebelt, it returned to a functional condition soon after the storm passed. The Bluebelt has saved the city more than US$80 million (Mayor's Office, 2012) in comparison with a conventional stormwater drainage system.

8.1.3 Urban Biodiversity and Ecosystem Services

Nature in cities plays a crucial role as the ecological basis for human–nature interactions and the production of UES (see Box 8.1; Figure 8.3)(Kowarik 2005; Bolund and Hunhammar, 1999; Gómez-Baggethun et al., 2013; TEEB, 2011; Kremer et al., 2016a). Biodiversity and ecosystems in cities are increasingly linked to human health and well-being, livability, and the quality of urban life (McGranahan et al., 2005; Gómez-Baggethun et al., 2013; McPhearson et al., 2013). For example, urban trees can remove harmful air pollution, provide shade during heat waves, absorb and store carbon, and create spaces for contemplation, aesthetic and spiritual enjoyment, and social cohesion (see Table 8.1; Figure 8.2) (TEEB, 2011; McPhearson 2011; Gómez-Baggethun et al., 2013; Andersson et al., 2014a; Nowak et al., 2013).

Box 8.1 Urban Ecosystem Services

Urban ecosystem services (UES) refer to those ecosystem functions that are used, enjoyed, or consumed by humans in urban areas and can range from material goods (such as water, raw materials, and medicinal plants) to various non-market services (such as climate regulation, water purification, carbon sequestration, and flood control) (Gómez-Baggethun et al., 2013). The Millennium Ecosystem Assessment (MA) classified ecosystem services into four different categories: (1) provisioning services, (2) supporting services (3) regulating services, and (4) cultural services (Convention on Biological Diversity [CBD], 2009), which have been modified and updated by the Economics of Ecosystems and Biodiversity (TEEB, 2010) project and applied to the urban context (TEEB, 2011) (see Figure 8.2). Provisioning services include the material products obtained from ecosystems, including food, fiber, fresh water, and genetic resources. Regulating services include water purification, climate regulation, flood control and mitigation, soil retention and landslide prevention, pollination, and pest and disease control. Cultural services are the nonmaterial benefits from ecosystems including recreation, aesthetic experience, spiritual enrichment, and cognitive development, as well as their role in supporting knowledge systems, social relations, and aesthetic values (Andersson et al., 2014b; Chan et al., 2011). Finally, supporting or habitat services are those that are necessary for the production of all other ecosystem services including provisioning of habitat for species, primary production, nutrient cycling, and maintenance of genetic pools and evolutionary processes (Gómez-Baggethun et al., 2013).

Table 8.1
Key abiotic, biotic, and cultural functions of green urban infrastructure

Abiotic	Biotic	Cultural
Surface-groundwater interactions	Habitat for generalist species	Direct experience of natural ecosystems
Soil development process	Habitat for specialist species	Physical recreation
Maintenance of hydrological regime(s)	Species movement routes and corridors	Experience and interpretation of cultural history
Accommodation of disturbance regime(s)	Maintenance of disturbance and successional regimes	Provide a sense of solitude and inspiration
Buffering of nutrient cycling	Biomass production	Opportunities for healthy social interactions
Sequestration of carbon and (greenhouse gases)	Provision of genetic reserves	Stimulus of artistic/abstract expression(s)
Modification and buffering of climatic extremes	Support of flora-fauna interactions	Environmental education

Adapted from Ahern (2007: 269).

Biodiversity is the fundamental basis for the generation of ecosystem services (see Figure 8.3)(Elmqvist et al., 2013; Gomez-Baggethun et al., 2013). There are many ecosystem services that cannot be imported and must be supplied locally within urban ecosystems (McPhearson et al., 2013b, 2014; Andersson et al., 2014a). For example, utilizing urban parks, green walls and roofs, and street trees to adapt to and mitigate impacts of climate change such as urban heat must occur locally (Gill et al., 2007; Pataki et al., 2011). Urban ecosystems are therefore especially important in delivering climate-related ecosystem services with direct impact on human health, well-being, and security (Novotny et al., 2010; Elmqvist et al., 2013; McPhearson et al., 2015). Additionally, investing in urban ecosystems for climate adaptation and mitigation can create multiple co-benefits by simultaneously generating other ecosystem services important to human health and well-being in cities (see Figure 8.4).

ECOSYSTEM SERVICES: DEFINITIONS AND EXAMPLES

PROVISIONING SERVICES: SERVICES THAT DESCRIBE THE MATERIAL OR ENERGY OUTPUTS FROM ECOSYSTEMS

Ecosystem Service	Service Description	Example
Food	Ecosystems provide the conditions for growing food. Food comes principally form managed agro-ecosystems, but marine and freshwater systems, forests and urban horticulture also provide food for human consumption	In Havana, Cuba (1996), a significant proportion of the urban population's food was produced within urban gardens, including 8,500 tons of agricultural produce, 7.5 million eggs and 3,650 tons of meat (according to a review by Altieri, 1999)
Raw Materials	Ecosystems provide a great diversity of materials for construction and fuel including wood, biofuels and plant oils that are directly derived from wild and cultivated plant species.	Non-timber forest products such as rubber, latex, rattan and plant oils are very important in trade and subsistence- the annual global trade in such products is estimated to amount to US$101 Billion (Roe et al. 2002)
Fresh Water	Ecosystems play a vital role in providing cities with drinking water, as they ensure the flow, storage and purification of water. Vegetation and forests influence the quantity of water available locally	Estimates of the value fo the services of a South African mountain fynbos ecosystem with an area of only 4 km^2 indicated that water production was the biggest contributor to the total value of the system. The value was estimated to range from approximately US$4.2M to 66.6M in 1997, according to how well the system is managed.
Medicinal Resources	Biodiverse ecosystems provide many plants used as traditional medicines as well as providing raw materials for the pharmaceutical industry. All ecosystems are a potential source of medicinal resources.	80% of the world's people are still dependent on traditional herbal medicine (WHO 2002), while the sale of medicines derived from natural material amounts to US$57B per year (Kaimowitz 2005)

REGULATING SERVICES: SERVICES THAT ECOSYSTEMS PROVIDE BY REGULATING THE QUALITY OF AIR AND SOIL OR PROVIDING FLOOD AND DISEASE CONTROL, ETC

Ecosystem Service	Service Description	Example
Local climate and air quality regulation	Trees and green space lower the temperature in cities whilst forests influence rainfall and water availability both locally and regionally. Trees or other plants also play an important role in regulating air quality by removing pollutants from the atmosphere.	In Cascine Park in Florence, Italy, the urban park forest was shown to have retained its pollutant removal capability of about 72.4 kg per hectare per year (reducing by only 3.4 kg/ha to 69.0 kg/ha) over 19 years, despite some losses due to cutting and extreme climate events (Paoletti et al. 2011). Harmful pollutants removed included O_3, CO, SO_2, NO_2, and particulate pollutants as well as CO_2.
Carbon sequestration and storage	Ecosystems regulate the global climate by storing greenhouse gases. As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues thus acting as carbon stores.	Urban trees too, are important in carbon sequestration: in the United States, their annual gross carbon sequestration amounts to 22.8 million tons of carbon per year (as calculated in 2002) (Nowak and Crane 2002). This is equivalent to the entire USA population's emissions in five days. This sequestration service is valued at US$460 million per year, and US$14,300 million in total.
Moderation of extreme events	Ecosystems and living organisms create buffers against natural disasters, thereby preventing or reducing damage from extreme weather events or natural hazards including floods, storms, tsunamis, avalanches and landslides. For example, plants stabilize slopes, while coral reefs and mangroves help protect coastlines from storm damage.	In the case of the Californian Napa City, USA, the Napa river basin was restored to its natural capacity by means of creating mudflats, marshes and wetlands around the city (TEEBcase by Almack 2010). This has effectively controlled flooding to such an extent that a significant amount of money, property, and human lives could be saved.
Waste-water treatment	Ecosystems such as wetlands filter effluents. Through the biological activity of microorganisms in the soil, most waste is broken down. Thereby pathogens (disease-causing microbes) are eliminated, and the level of nutrients and pollution is reduced.	In Louisiana, USA, it was found that wetlands could function as alternatives to conventional wastewater treatment, at an estimated cost saving of between US$785 to $34,700 per hectare of wetland (in 1995) (Breaux et al. 1995).
Erosion prevention and maintenance of soil fertility	Soil erosion is a key factor in the process of land degradation, desertification and hydroelectric capacity. Vegetation cover provides a vital regulating service by preventing soil erosion. Soil fertility is essential for plant growth and agriculture and well functioning ecosystems supply soil with nutrients required to support plant growth.	A study estimated that the total required investment to slow erosion to acceptable rates in the USA would amount to US$8.4 billion, yet the damage caused by erosion amounted to US$44 billion per year. This translates into a US$5.24 saving for every US$1 invested (Pimentel et al. 1995).
Pollination	Insects and wind pollinate plants which is essential for the development of fruits, vegetables and seeds. Animal pollination is an ecosystem service mainly provided by insects but also by some birds and bats.	Some 87 out of the 115 leading global food crops depend upon animal pollination including important cash crops such as cocoa and coffee (Klein et al. 2007).
Biological control	Ecosystems are important for regulating pests and vector borne diseases that attack plants, animals and people. Ecosystems regulate pests and diseases through the activities of predators and parasites. Birds, bats, flies, wasps, frogs and fungi all act as natural controls.	Water hyacinth was brought under control in southern Benin using three natural enemies of that plant (De Groote et al. 2003). Whereas the biological control project cost only US$2.09 million in present value, its accumulated value is estimated to amount to US$260 million in present value (assuming the benefits stay constant over the following 20 years), representing a very favourable 124:1 benefit cost ratio.

HABITAT OR REGULATING SERVICES: THESE SERVICES UNDERPIN ALMOST ALL OTHER SERVICES. ECOSYSTEMS PROVIDE LIVING SPACES FOR PLANTS OR ANIMALS; THEY ALSO MAINTAIN A DIVERSITY OF PLANTS AND ANIMALS.

Ecosystem Service	Service Description	Example
Habitats for species	Habitats provide everything that an individual plant or animal needs to survive: food, water, and shelter. Each ecosystem provides different habitats that can be essential for a species' lifecycle. Migratory species including birds, fish, mammals and insects all depend upon different ecosystems during their movements.	In a March 2010 article (IUCN 2010), IUCN reports that habitat loss is the single biggest threat to European butterflies, and may lead to the extinction of several species. Habitat loss was said to occur most often as a result of changes in agricultural practice, climate change, forest fires, and expansion of tourism.
Maintenance of genetic diversity	Genetic diversity (the variety of genes between, and within, species populations) distinguishes different breeds or races from each other, providing the basis for locally well-adapted cultivars and a gene pool for developing commercial crops and livestock. Some habitats have an exceptionally high number of species which makes them more genetically diverse than others and are known as 'biodiversity hotspots'.	In the Philippines, an initiative to conserve local varieties of rice aided in the development of rice strains that are better adapted to local conditions - giving greater yield, a quality seed supply, and decreasing dependence on plant breeders - at a much lower cost than that of formal plant breeding (SEARICE 2007).

CULTURAL SERVICES: THESE INCLUDE THE NON-MATERIAL BENEFITS PEOPLE OBTAIN FROM CONTACT WITH ECOSYSTEMS. THEY INCLUDE AESTHETIC, SPIRITUAL AND PSYCHOLOGICAL BENEFITS.

Ecosystem Service	Service Description	Example
Recreation and mental and physical health	Walking and playing sports in green space is a good form of physical exercise and helps people to relax. The role that green space plays in maintaining mental and physical health is increasingly becoming recognized, despite difficulties of measurement.	A review article examined the monetary value of ecosystem services related to urban green space, based on 10 studies, including 9 cities from China and 1 from the USA (Elmqvist 2011). It reported that on average, 'Recreation and Amenity' and 'Health effects' contributed a value of US$5,882 and US$17,548 per hectare per year respectively to the total average of US$29,475 per hectare per year provided by the seven identified ecosystem services in the various studies.
Tourism	Ecosystems and biodiversity play an important role for many kinds of tourism which in turn provides considerable economic benefits and is a vital source of income for many countries. In 2008 global earnings from tourism summed up to US$944 billion. Cultural and eco-tourism can also educate people about the importance of biological diversity.	Based on the amounts of money people spent on travel and local expenditure in order to visit Coral reefs in Hawaii, it was estimated that the value associated with these reefs amounted to US$97 million per year (TEEBcase by van Beukering and Cesar 2010). This implies that reef tourism resulted in significant income generation for individuals, companies, and countries.
Aesthetic appreciation and inspiration for culture, art and design	Language, knowledge and the natural environment have been intimately related throughout human history. Biodiversity, ecosystems and natural landscapes have been the source of inspiration for much of our art, culture and increasingly for science.	Prehistoric rock art of southern Africa, Australia, and Europe, and other examples like them throughout the world, present evidence of how nature has inspired art and culture since very early in human history. Contemporary culture, art and design are similarly inspired by nature.
Spiritual experience and sense of place	In many parts of the world natural features such as specific forests, caves or mountains are considered sacred or have a religious meaning. Nature is a common element of all major religions and traditional knowledge, and associated customs are important for creating a sense of belonging.	In the example of the Maronite church of Lebanon, the church committed to protecting a hill in their possession, comprising rare remainders of intact Mediterranean forest. Independent of scientific and legal arguments, because this was in line with Maronite culture, theology and religion (Palmer and Finlay 2003).

Figure 8.3 *Investing in urban ecosystems for climate adaptation and mitigation can create multiple co-benefits by simultaneously generating other ecosystem services important to human health and well-being in cities. Here we describe ecosystem services relevant to cities. Ecosystem services can be divided into four categories: provisioning services, regulating services, habitat or supporting services, and cultural services with examples of each. Modified and adapted from TEEB Manual for Cities (2011)*

8.2 Challenges for Maintaining Urban Biodiversity and Ecosystem Services

Biodiversity protection and adaptive urban ecosystem management, planning, and restoration are critical to maintain a resilient supply of climate-relevant UES in the face of global environmental change (McPhearson et al., 2014a). Globally, urban land cover is projected to increase by 1.2 million square kilometers by 2030, nearly tripling the urban area in 2000; this could result in considerable loss of habitats in key biodiversity hotspots, including the Guinean forests of West Africa, the tropical Andes, the Western Ghats of India, and Sri Lanka (Seto et al., 2012). Mediterranean habitat types are particularly affected by urban growth because they support a large concentration of cities as well as many habitat-restricted endemic species—species that occur nowhere else in the world (Elmqvist 2013). Although urban land area globally comprises a small fraction of total land area, the impacts of urbanized land on biodiversity, ecosystem services, and other environmental impacts are wide-reaching (Schewenius et al., 2014; McPhearson et al., 2013c).

Figure 8.4 *Investing in urban ecosystems and green infrastructure can provide multiple co-benefits. This shows a cultural co-benefit of urban and peri-urban trees through tapping sugar maple (Acer saccharum) trees in Pound Ridge, New York. Maple sugar tapping represents a seasonally occurring peri-urban and urban food production ecosystem service that has long-standing cultural traditions in many northern countries. Photo credit: Timon McPhearson. Adapted from Andersson et al.* (2015*b)*

For example, expansion of urban development into the world's remaining hotspots (see Figure 8.5) for species and genetic diversity has implications for both urban and global biodiversity. These changes have downstream impacts on local ecosystem service provisioning that can feed back to influence urban climate and regional climate change. The direct and indirect effects of land-use changes outside of cities, which can include damming of rivers, water diversions, and agricultural practices, can also have effects on the capacities of ecosystems inside cities to function and produce services (Schewenius et al., 2014; Seto, 2013; Ignatieva et al., 2010). Moreover, the ability of species to move within and among urban landscapes is considered a key issue of biodiversity adaptation to climate change, one that suggests the need for cities to improve habitat connectivity and use green corridors for healthy, functioning urban ecosystems.

Case Study 8.3 The Serra do Mar Project

Oswaldo Lucon

São Paulo State Environment Secretariat

Keywords	**Resettlement, biodiversity protection, climate resilience, urban ecology, floods, landslides, ecosystems**
Population (Metropolitan Region)	1,664,136 (IBGE, 2015)
Area (Metropolitan Region)	2,405 km² (IBGE, 2015)
Income per capita	$US9,850 (World Bank, 2015)
Climate zone	Af – Tropical rainforest (Peel et al., 2007)

A partnership of the Inter-American Development Bank (IDB) and the São Paulo State Government, the Serra do Mar and Mosaics System Recovery Program has been recognized as an international standard for resettling communities in disaster-prone, ecologically sensitive areas. *Mosaics* are sets of protected areas located nearby or juxtaposed to each other. Their main purpose is to promote integrated and participatory management of their components, respecting the different categories of management and conservation objectives. Mitigation strategies comprise halting deforestation, reforestation, and wastewater treatment. Adaptation strategies are based on the resettlement of populations living in landslide- and flood-prone areas. The Program started in the city of Cubatão and part of the Baixada Santista Metropolitan Region (BSMR) of 2,405 square kilometers

(IBGE, 2015). Topography varies from cliffs (700 m) to plains (average 3 m above sea level). The Atlantic Forest is a UNESCO Biosphere Reserve, one of the planet's biologically richest regions and also one of the most endangered. Overexploitation and biome devastation have resulted in only 7% of the Brazilian Atlantic Forest being preserved in fragments of more than 100 acres.

Case Study 8.3 Figure 1

In the Southeastern State of São Paulo, the Atlantic Forest is concentrated in the *Serra do Mar*, squeezed between the coastal BSMR (nine cities, 1.6 million people) and the São Paulo Metropolitan Region (19 cities and 20 million people). The 133,000 square kilometers of the Serra do Mar State Park cover twenty-four municipalities in the state. Additionally, three mosaics (Paranapiacaba, Jureia-Itatins, and Jacupiranga) allow for buffer zones between urban and native preserved areas. Despite having been reduced and highly fragmented, the Atlantic Forest is habitat to more than 20,000 plant species – a wealth of diversity greater than that found in North America (17,000 species) and Europe (12,500 species). Out of the native plant species, 8,000 are endemic; that is, native species that only exist in Brazil (IAD and São Paulo State Government, 2009). Degradation of the forest had its origins in the construction of roads. In the highly industrialized city of Cubatão, settlements on hillsides (*bairros-cota*) invaded areas belonging to the Serra do Mar State Park. Illegal occupations harmed not only the Park, but also created several hazards to its inhabitants: landslides, floods, road accidents, and freshwater contamination.

Case Study 8.3 Figure 2 *Settlements on hillsides (bairros-cota) invaded areas belonging to the Serra do Mar State Park, creating several hazards to its inhabitants, including landslides, floods, road accidents, and freshwater contamination.*

In the first stage, the São Paulo Government contributed 65% of the US$470 million budget, and the IDB allocated the remaining 35%. In the Project, geotechnical studies mapped and classified risk areas. A second criterion estimated the potential damage to dwellings and their residents, considering their positions and distances to critical slopes plus the degree of building vulnerability (construction pattern and level of urban consolidation). A joint analysis of these criteria established a mapping of risk sectors, with hotspots defined (IDB and São Paulo State Government, 2013). In 2007, new settlements were halted ("frozen") through supervision of the Military Police, with protective measures for the Park that included preventing deforestation, fires, and the capture of wild animals and extraction of plant species, and monitoring of the various sectors of the *bairros-cota* to prevent their expansion (IDB and São Paulo State Government, 2013).

Case Study 8.3 Figure 3

A total of 7,388 irregular households were identified, with around 7,760 families and 7,843 buildings. The resettlement program was followed by an environmental education program, an enrollment process, sealing buildings, commissioning basic housing and urbanization projects, obtaining environmental licenses, conducting public hearings, and negotiating with the IADB for co-financing. Benefits include improved living conditions for around 3.2 million people in the surrounding area, an increase to 60 thousand visitors per year in the Park, improved biodiversity, improved water quality, strengthened management and protection of conservation units (an additional 20,000 hectares of Atlantic Forest; recovery of 1,240 hectares of State Park), and lowered disaster risk, plus more sustainable sources of income.

More than 5,000 families living in at-risk or protected areas have been resettled and assisted with housing and upgraded infrastructure. Living in new structured communities, they have also benefited from professional training programs for construction professionals, gardeners, and nurserymen to work on the reforestation of the reclaimed areas. The second phase of the program aims at assisting approximately 25,000 families with resettlement or infrastructural upgrading. Building improvements included two or three types of houses with diversified typologies, accessibility for the disabled, preservation of significant green areas, and improved urban infrastructure. Family assistance combines social, cultural, economic, and environmental aspects. Resettlement has brought innovations that enabled families to feel sufficiently engaged before and after moving from their homes, including the choice of one of fifteen housing options. Housing units were not donated, and leaving a house where one had lived for a long time is not an easy decision, even if it means moving to better conditions. Therefore, for families who live in rural or peri-urban areas, other methods have been developed.

To anchor all actions, synergy among institutions has proved decisive. In 2009, the state joined the United Nations Environment Program (UNEP)'s Sustainable Social Housing (Sushi) initiative for building sustainable social housing for low-income populations. A pilot neighborhood (Residencial Rubens Lara) in Cubatão City has been developed and today is recognized by the UNEP as a replicable model for other countries. In 2012, the Serra do Mar Social and Environmental Recovery Program earned the Greenvana GreenBest award, the highest distinction conferred in Brazil for environmental initiatives. The Serra do Mar Program went beyond the limits of the City of Cubatão. It now covers the whole of the Atlantic Forest of São Paulo, extending throughout the Park (north and south of the state) to the Jureia-Itatins territory and the Units for Marine Conservation. The extended program is called Serra do Mar and the Atlantic Forest Mosaics System Social and Environmental Recovery Program (CDHU, 2012; São Paulo, 2013).

Cities and urban regions often have a perhaps surprisingly high level of biodiversity, including both native species and non-native species from around the world (Müller et al., 2013; Aronson et al., 2014). Urban species can therefore be an important component of regional and global biodiversity. Cities are often concentrated along coastlines, major rivers, and islands, which are also areas of high species richness and endemism, with many cities existing in close proximity to protected areas (see Figure 8.6) (Güneralp et al., 2013; McDonald et al., 2013). However, because expanding urban areas encompass an increasingly larger percentage of global biodiversity hotspots, it is all the more critical to safeguard urbanized biodiversity hotspots and promote ecological conservation in urban, peri-urban, and nearby rural areas.

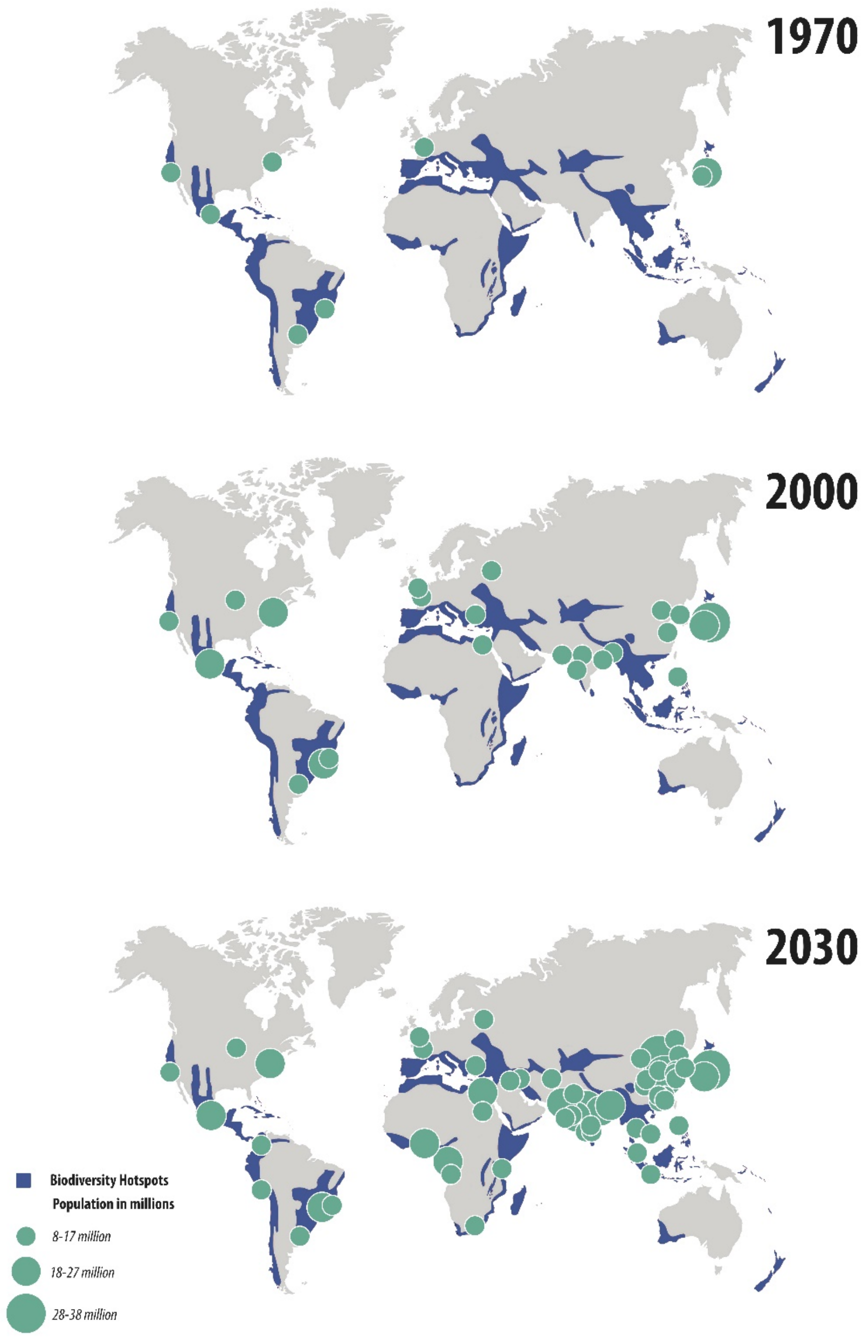

Figure 8.5 *As urban areas expand into some of the most sensitive biodiversity areas globally, urban biodiversity conservation and ecological planning will have an increasing impact on global biodiversity and ecosystems and the services they provide to both urban and rural residents. Urban areas with large populations in 1970, 2000, and 2030 (projected) are shown in green as examples of urban expansion in global biodiversity hotspots (in blue). The cities shown have a projected population of more than 8 million in 2030, according to UN World Urbanization Prospects 2014.*

Ecosystems are highly fragmented in urban areas, which can alter the genetic diversity and long-term survival of sensitive species. To ensure viable urban populations, urban planners and designers need to understand species' needs for habitat quality and connectivity among suitable habitat patches. For example, the connectivity of the habitat network within the urban area can play a major role for ground-dwelling animal movement, as for the European hedgehog in Zurich (Braaker et al., 2014). Understanding and planning for greater habitat connectivity through the use of green corridors is a key tool for city planners to design appropriate management and conservation strategies of urban biodiversity and to improve the resilience of species to climate change. Furthermore, it is important to understand how the impacts of climate change in cities will create risks and affect the vulnerability of urban ecosystems. The ability of ecosystems to sustain levels of biodiversity at or above the thresholds necessary for maintaining ecosystem integrity is critical to sustainable delivery of ecosystem services important for meeting urban sustainability and resilience goals (Andersson et al., 2014a).

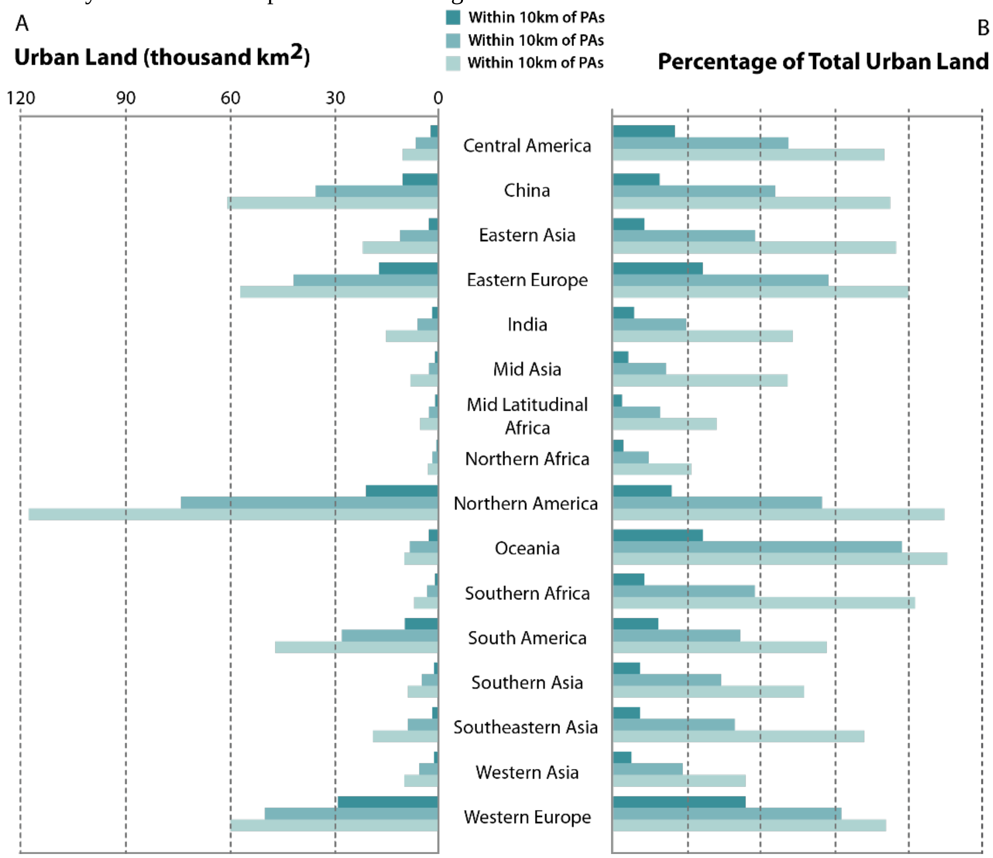

Figure 8.6 *Urban areas are expanding into protected areas in all parts of the world. Figure shows (a) urban extent and (b) percentage of total urban extent within a distance of, from top to bottom, 10, 25, and 50 kilometers of protected areas (PAs, e.g., national parks) by geographic region circa 2000. Adapted from McDonald et al. (2013) and Güneralp and Seto (2013)*

8.2.1 Current Effects of Climate Change on Urban Biodiversity and Ecosystems

All urban ecosystems will experience the effects of climate change. Additionally, many cities are located in geographic areas that are especially vulnerable to both existing and projected climate hazards, such as coastal flooding, landslides, and extreme events. Climate change is impacting a broad spectrum of urban ecosystem functions, biodiversity, and ecosystem services (Rosenzweig et al., 2011; Solecki and Marcotullio, 2013; UN Habitat, 2011). Urban ecosystems are already under general stress from development, pollution, and direct human use (Elmqvist et al., 2013), and climate change variability poses additional challenges for urban species and ecosystems. For example, in a comprehensive review of the potential impacts of climate change on urban biodiversity in London, Wilby and Perry (2006) highlight the importance of four threats to biodiversity in the city: competition from non-native species, pressure on salt marsh habitats from rising sea levels, drought effects on wetlands, and changing phenology of multiple species as earlier springs occur more frequently (Hunt and Watkiss, 2011).

The UHI effect in cities can change the reproductive and population dynamics of animals. Insect life cycles and migration patterns have been well-documented, with changes in the life cycle of certain insects having already occurred in response to urban warming (Parmesan, 2006; Parmesan and Yohe 2003). Butterfly species in Ohio, for example, appear to have shifted when they fly in response to urban warming. Some native butterfly species appear to be at risk due to the shortening of their flight periods (Diamond et al., 2013). In Raleigh, North Carolina, the abundance of the gloomy scale butterfly (*Melanaspis tenebricosa*) increases with increases in impervious surfaces that create warmer forest temperatures and therefore drive increased reproduction rates, thus contributing to greater population growth for this urban forest pest (Dale and Franck 2014). This suggests that urban trees could face greater herbivory in the future as a consequence of the increased fitness of some herbivorous arthropods under warming scenarios. However, more research is needed to generalize these results to other urban areas.

Although other ecological and socioeconomic factors are affecting vegetation in urban areas, many of the non-native invasive species colonizing cities originate in warmer areas and are benefiting from changing climate conditions (Sukopp and Wurzel, 2003). In mountain regions, climate is already causing changes in vegetation structure and diversity (Theurillat and Guisan 2001; ICIMOD, 2009). The response of trees to extreme climatic events may be species-specific. For example, in Dresden, a study of oak trees showed that *Quercus petrea* and *Q. rubra* are better adapted to warm and dry conditions than are *Acer platanoides* and *A. pseudoplatanus* (Gillner et al., 2014).

Case Study 8.4 Ecosystem-Based Climate Change Adaptation in the City of Cape Town

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Keywords	**Ecosystem based adaptation, disaster risk reduction. flood water, wetlands, stormwater management**
Population (Metropolitan Region)	3,740,025 (City of Cape Town, 2015)
Area (Metropolitan Region)	2,461 km² (City of Cape Town, 2015)
Income per capita	$US6,050 (World Bank, 2015)
Climate zone	Csb – Temperate, dry summer, warm summer (Peel et al., 2007)

Summary

Cape Town is adapting to growing urban climate change vulnerability and impacts. The city, with its rich biodiversity and unique ecosystems, historically used hard engineering measures to reduce growing flood and storm surge risks. However, in recent years, the role of ecosystem services is being recognized and included in urban climate change adaptation plans. Recent initiatives by the city administration to identify and spatially map UES, in particular in relation to the bionet map, to establish critical connectivity corridors suggest a good start in mainstreaming climate change in urban development planning and environment conservation.

Case Description

Cape Town, with an area of 2,460 square kilometers and a population of approximately 3.7 million has close to 38% low-income households, indicating high poverty incidence. The city's population also has a high disease burden due to the high prevalence of HIV and tuberculosis. More than 58% of the adult population has a below high school level education, and 16.9% of the population is unemployed. The city is characterized by urban sprawl and rapidly expanding informal poor settlements on the lowland areas that are known as the Cape Flats. The increasing demand for housing continues to place a burden on city authorities and on remnant urban biodiversity.

Cape Town is located in the Cape Floristic Region, the smallest and most diverse floral kingdom on earth: the region hosts almost 9,000 plant species on 90,000 square kilometers – some 44% of the flora of the subcontinent on a mere 4% of its land area. Of approximately 3,350 indigenous plant species within the metropolitan boundary, 190 are endemic to the city that also hosts 19 of 440 National Vegetation Types (Cilliers and Siebert, 2012). The process of urbanization has significantly contributed to the erosion of local biodiversity, putting further stress on eleven nationally recognized critically endangered vegetation types in the city. The City is host to 83 mammal, 364 bird, 60 reptile, 27 amphibian, and 8 freshwater fish species. The lowlands historically hosted the greatest vegetation type and floral diversity, and the majority of this has been lost to urban settlements. Some 450 of these indigenous plant species are listed as threatened or near-threatened, and 13 species are known to be extinct.

Case Study 8.4 Figure 1 *Iconic Table Mountain of Cape Town viewed from the Durbanville Conservation Area. Credit: Pippin Anderson*

Remnant natural ecosystems are highly fragmented, with little connectivity. Fire is used as a management tool in a burning rotation of 10–15 years, which poses a management challenge in an urban setting, threatening both property and life. Introduced invasive plant species suppress indigenous biodiversity and yield high fuel loads that, under a rising temperature regime, lead to hotter and more dangerous fires.

Cape Town is a water-scarce area. Current climate change predictions suggest increased rainfall variability with associated future increases in periods of drought and water shortages. Climate change predictions suggest hotter, more frequent, and runaway fires. Cape Town, with its 307 kilometers of coastline, is at threat from climatic hazards such as sea level rise and increased storm surge.

Climate Change Vulnerability and Impacts

Climate change is occurring faster in South Africa than in other parts of the world. Mean annual temperatures have increased faster than the global average during the past 50 years. Extreme rainfall and drought events have also increased in frequency. Urban areas are particularly vulnerable due to stormwater surge, flooding, uncontrolled fire, and coastal erosion. The Cape Town region is likely to face significant climate change risks with predicted increases in temperature in all seasons, reductions in rainfall, greater evaporation, more intense and frequent winds, and greater coastal erosion and storm surge with changes in the frequency and intensity of extreme weather events. Increased rainfall intensity predicted will exacerbate flooding, especially in high water table areas on the Cape Flats. Flooding is exacerbated due to the canalized nature of rivers where natural vegetation buffers have been removed.

Adaptation Strategy

The City has adopted an integrated water resource management (IWRM) approach that includes demand-side water management. Acknowledging the role of invasive plant species in reducing water availability, the government public works program seeks to train and employ unskilled and unemployed labor to clear invasive vegetation, producing positive outcomes in biodiversity, social benefits, and water yield.

Adaptation measures to increased flood risk include both engineering and ecological solutions that includes the creation of retention ponds and resilient infrastructure, regular drain cleaning, better disaster warning systems, the decanalizing of rivers, and the restoration of riparian vegetation to vulnerable areas. However, engineering solutions get less attention mostly due to the high costs and flood disaster relief funding structures.

Case Study 8.4 Figure 2 *Controlled burning of urban vegetation.*

Fire, an ecologically necessary measure to promote indigenous flora, is being used more judiciously. The intensity and season of firing are being regulated to have positive implications for biological processes of recruitment and regeneration. Use of a fire regime during periods of drought, higher wind speeds, and generally greater climate variability is being used strictly for assured biodiversity and employment generation. Government public works – "working for water" and "working on fire" programs – are used to reduce large fuel loads and minimize runaway fires. These programs train firefighters in ecological fire management using higher public safety protocols in urban fire management. In general, these programs, set up to address various environmental and social issues, have proved to be an important vehicle for generating adaptive capacity and change in the face of threats posed by climate change.

Drivers

The City administration has taken a number of measures to adapt to climatic changes and mitigate threats. Historical measures, such as sea embankments to protect infrastructure, are now recognized as extremely expensive to maintain and sometimes ineffective. Acknowledging the high costs of these engineering measures, the City is employing more ecosystem-based approaches including the protection and restoration of extensive wetlands sites that can absorb large volumes of water and dissipate wave energy (ICLEI, 2012). Efforts are on to restore dune vegetation and to open paths of sand to improve sand supply to these mobile systems that have frequently become cut off due to hard engineering solutions employed in the past. These ecosystem-based adaptation (EbA) measures are providing green employment and thus contributing to the City's poverty reduction goal.

Impact and Lessons Learned

These multipronged adaptation approaches have drawn involvement from multiple stakeholders and worked to create better impacts and synergy. The City is trying to secure the establishment of a "bionet" – a network of green open spaces – that would serve to improve biodiversity areas by allowing for greater flexibility and opportunity for species conservation, provide vegetated areas for water infiltration, and reduce flooding and storm surge impacts. The role of ecosystem services will become critical in the face of climate change. The initiatives by City government to identify and maintain ecosystem services and a biodiversity corridor suggest a good start in mainstreaming climate change in urban development planning and environment conservation.

Trees have been perhaps better studied than other taxonomic groups in urban areas. Urban trees experience multiple forms of stress including heat stress, low air humidity, and soil drought. Rapid climate change can have a significant impact on the distribution and biology of trees. In Philadelphia, climate change is influencing the biology of urban tree pathogens and pests. Results from a recent study indicate that the future climate in Philadelphia will become less optimal for multiple tree species since major pests and diseases are likely to become more problematic (Yang, 2009).

Comparing urban and rural species has yielded a useful understanding of urban biodiversity responses to changing climate. Woodall et al. (2010) compared tree species compositions in northern urban areas to tree compositions in forestland areas. They found that some tree species native to eastern US forests of southern latitudes have been planted or are present in northern urban forests, indicating the tolerance of southern species in northern urban ecosystems. Although urbanization and climate change can both profoundly alter biological systems, scientists often analyze their effects separately. Recent studies are beginning to look at these impacts on organisms simultaneously to better understand how multiple simultaneous stressors might affect species, but more research is needed (Diamond et al., 2013).

Table 8.2
Effects of urban climate and environment on urban agriculture

Drivers of plant production	Compared to rural areas	Observed positive effects	Observed negative effects	Resulting impact on urban crop yield	Expected future dynamics of drivers
Length of the growing season	7 to 8 days longer	Potential of double cropping systems		Higher	Increase
Time to flowering	Earlier		Risk of asynchrony between timing of flowers and pollinator presence	Lower	Increase
CO_2 concentration	Higher	Increased photosynthesis rate in many vegetable crops (C_3 plants)		Higher	Increase
Temperature	Higher	Increased photosynthesis rate	Decreased photosynthesis rate (in case of extreme temperature), increased irrigation water demand	Higher, lower	Increase
Wind speed	Lower	Reduced plant mechanical damages	Increased leaf gas exchanges	Higher	?
Vapour pressure deficit	Higher (less air humidity)		Greater plant transpiration, moisture stress, reduced photosynthesis rate, reduced rainwater infiltration in soil, lower soil moisture	Lower	?
Ground level ozone concentration	Higher (sometimes lower)		Decreased photosynthesis rate, lower root-to-shoot ratio, premature leaf senescence	Lower-higher	Increase
NO_2 concentrations	Higher	Easier nitrogen nutrition	Delayed flowering, accelerated plant senescence	Higher-lower	Increase
Soil water infiltration	Lower		Higher moisture stress	Lower	Increase-decrease

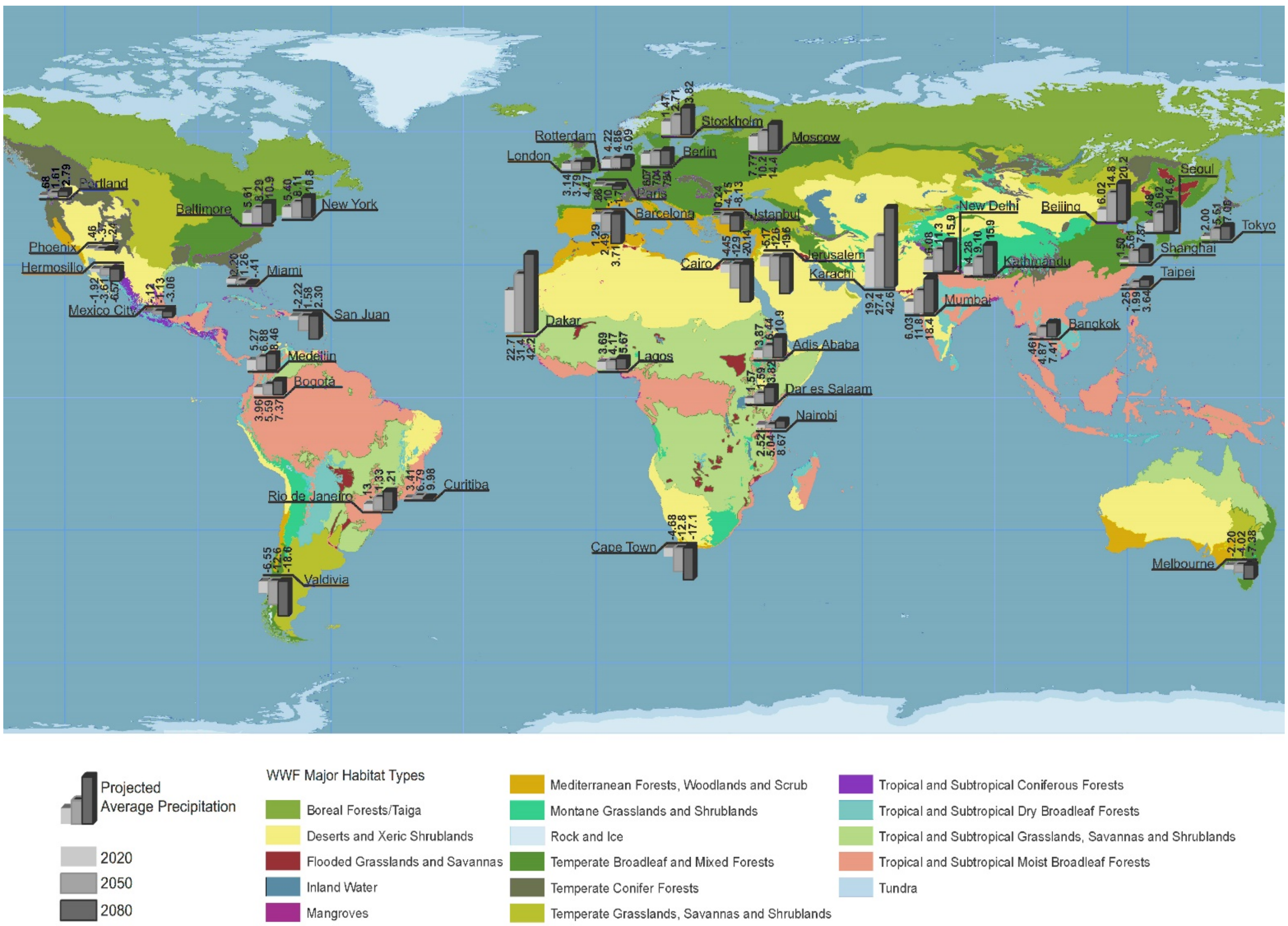
Adapted from Wortman and Lovell (2013)

8.2.2 Projecting Impacts of Climate Change on Urban Biodiversity and Ecosystems

Projecting impacts of climate change on the distribution of species is complex, with many factors to consider including dispersal ability, species interactions, and evolutionary changes (Pearson and Dawson 2003; Gilman et al., 2010; Urban et al., 2012). Still, future climate change in cities, when combined with additional urban stressors such as short-lived climate pollutants, land use change, and direct human impacts is expected to pose difficult challenges for urban species and ecosystems. Maintaining adequate levels of biodiversity and managing urban ecosystems to ensure a resilient supply of critical ecosystem services that are necessary for expanding urban populations may become increasingly challenging in the future as climate change intensifies its effects on cities. Which ecosystems will be most affected in the near and longer term future may be signaled by current species' responses to climate change (Parmesan, 2006; Gillner et al., 2014). The risks and vulnerabilities associated with climate change in urban ecosystems are likely to vary with temporal and spatial scale and nature of change (e.g., chronic vs.

acute), although in general they are expected to increase over the next several decades (Solecki and Marcotullio, 2013).

We present here new regionally downscaled climate projections using the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) scenarios for forty global cities spanning small, large, and megacities in multiple contexts including coastal and inland cities in the Global North and Global South in the 2020s, 2050s, and 2080s (see Figure 8.7a, 8b). Projections for both temperature and precipitation show wide variation in cities around the world, with temperature generally increasing and precipitation both increasing and decreasing depending on location. Effects on ecosystems will vary considerably from city to city, and therefore it is not possible to suggest general management or planning approaches. Instead, decision-makers in cities and urban areas will need to take into account locally relevant climate projections combined with data on sensitive species or ecosystems to develop plans and adaptive management strategies to safeguard urban ecosystems and the benefits they provide for climate adaptation and mitigation (as well critical co-benefits for human well-being). These downscaled climate projections suggest that urban planning, policy, and management must pay close attention to decisions and actions involving urban ecosystems that may be directly impacted by uncertain climate futures.



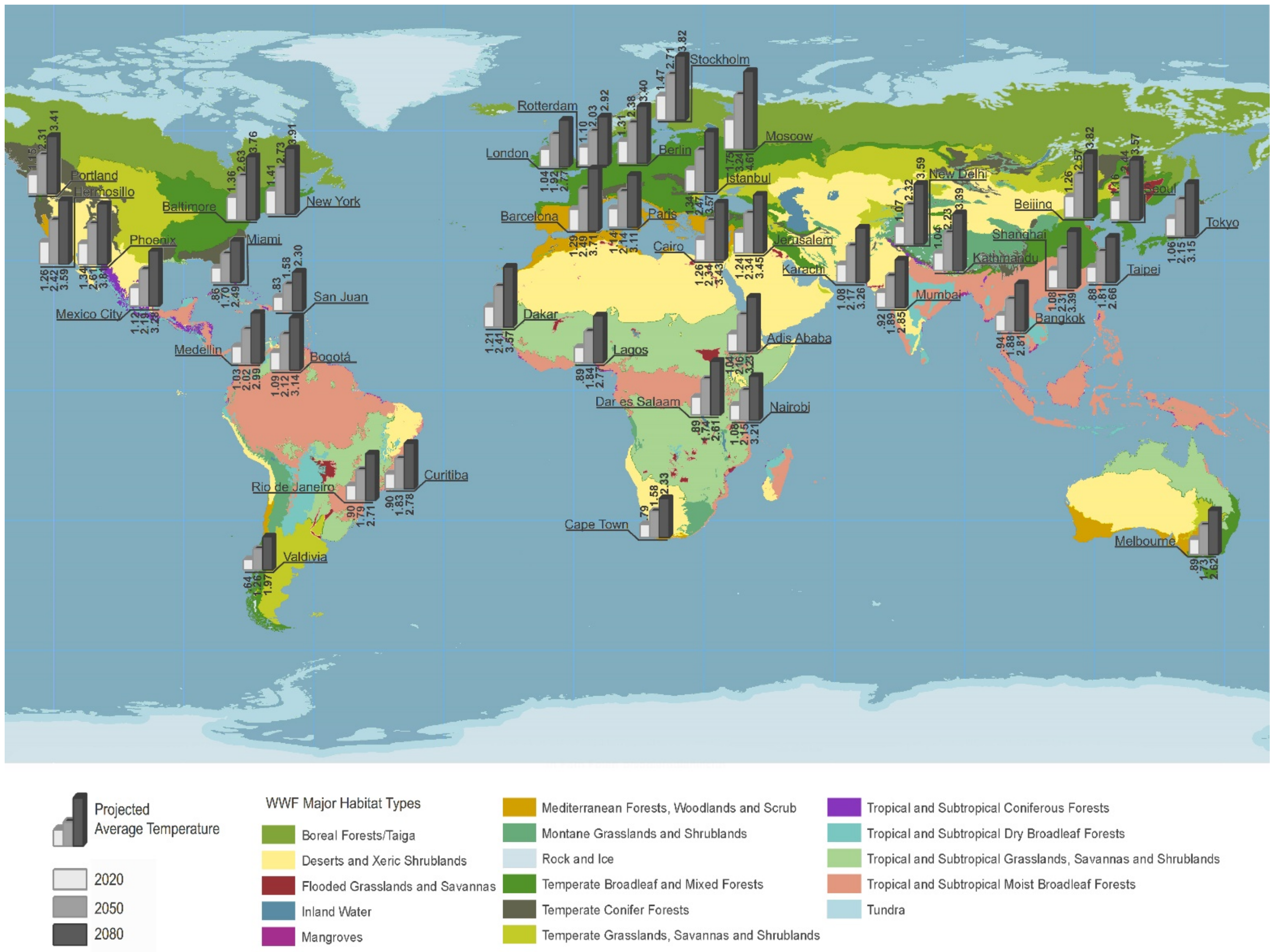


Figure 8.7 *Climate change in cities is already having significant impacts on urban biodiversity and ecosystems. Further impacts of rising temperatures and increasing or decreasing precipitation suggest increasing ecological impacts over time, with concurrent affects on the ability of urban ecosystems to provide nature-based solutions for building climate resilience in cities. Here we show projected average temperature and precipitation for forty global cities in 2020, 2050, and 2080. Cities represent a range of small, large, and megacities in the Global North and Global South, including inland and coastal cities. Temperature (8.7a) (in °C) and precipitation (8.7b) (% change) projections are based on thirty-three Global Climate Models and two Representative Concentration Pathways (RCP 4.5 and RCP 8.5) downscaled from regional to city spatial extent. Changes are relative to the 1971–2000 base period. The time slices are the 30-year periods on which the projections are centered (e.g., the 2020s is the period from 2010 to 2039).*

8.3 Climate Change Hazards, Risks, and Vulnerabilities for Urban Ecosystems

When combined with socioeconomic changes, there are multidimensional vulnerabilities affecting biodiversity and urban ecosystems. Heat stress, inland and coastal flooding, droughts, cyclones, fire, and extreme rainfall pose risks to urban ecosystems, populations, and economies (Intergovernmental Panel on Climate Change [IPCC] AR5, 2014). Massive land conversion from natural ecosystems to a built environment exposes urban landscapes to loss of biodiversity, flash floods, droughts, and pollution while urban sprawl and poor urban design further threaten urban biodiversity (Munaung et al., 2013; IPCC, 2014). Recent studies demonstrate how climate change is reinforcing urban ecosystem vulnerability through unsustainable development, agricultural land conversion, and degradation of ecosystem services that affect the ability of ecosystems to meet urban climate adaptation and mitigation goals (UN Habitat, 2009, 2011; ; Satterthwaite et al., 2007).

8.3.1 Climate Hazards and Risks

Urban climate hazards are defined as the climate-induced stressors or drivers that affect urban ecosystems. Examples include elevated temperature, changes in precipitation patterns, sea level rise, and the build-up of short-lived climate pollutants such as black carbon (see Figure 8.7), as well as changes in the frequency and intensity of extreme events such as storm surge, flash floods, heat and cold waves, and wild fires (UNEP, 2011). The cascading effects of climate change can have both direct and indirect effects on biodiversity and ecosystems. Climate change also has significant economic and human impacts and can extend from infrastructure and built environment sectors to natural ecosystems (Hallegatte et al., 2010; Ranger et al., 2010; Frumkin et al., 2008; Keim, 2008; Solecki and Marcotullio, 2013). For example, in cities with diminishing precipitation, the vegetated cover of green roofs may face drought risks. Increased exposure due to rising populations and growth of human settlements in flood- and landslide-prone areas exacerbate climatic hazards as well as socioeconomic risks, thus emphasizing the sensitive interactions among climate (urban) ecosystems, and communities.

8.3.1.1 Thermal Hazards

Changing temperature regimes (see Figure 8.7a) can have both direct and indirect effects on the organisms that live in cities and the ecosystem services that they provide. At the individual and species population level, many physiological processes such as photosynthesis, respiration, growth, and flowering of plants are affected by changing temperature. Elevated temperature can affect growth and reproductive rates either positively or negatively for plants (Hatfield, 2011) while also inducing a range of landscape-level impacts including on bio-geochemical cycles and watershed hydrology (Suddick et al., 2012). Warming conditions in New York City, for example, have led to changes in tissue chemistry in tree seedlings relative to cooler, non-urban settings, resulting in more rapid shoot growth but reduced root mass (Searle et al., 2012). Higher temperatures can also lead to increased physiological stress on wildlife, affecting their behavior and reproduction (Marzluf, 2001) (see also Section 8.2.1).

8.3.1.2 Drought Hazards

More intensive increases or decreases in precipitation can lead to significant water-related urban hazards including drought and severe water shortages (IPCC, 2013). Reductions in precipitation can be exacerbated by warming temperatures, which increase water losses to evapotraspiration driven by hydrological alterations from surface water diversion and groundwater extraction (Pataki et al., 2011). Increased frequency and duration of droughts exacerbated by warming can also increase evapotraspiration (Leipprand and Gerten, 2006). Increased evapotranspiration reduces water availability and groundwater resources, often leading to increased salinization and water stress affecting both the quality and quantity of water to plants, with negative consequences on floral and faunal biodiversity and productivity (Alberti and Marzluf, 2004). For example, projected drought conditions in Manchester, England, are likely to reduce the cooling services provided by grasslands, which may increase the local UHI and wild fires (Gill et al., 2013). Current drought in California is affecting drinking water supplies and is also having dramatic effects on peri-urban agriculture; this has led to historic water conservation measures to deal with drought stress. Drought affects both street trees and urban parklands and will likely have cascading effects on herbivores, soil fauna, and other components of urban biodiversity, as well as effects on urban residents through decreased water availability affecting livability (Gillner et al., 2014; Wilby and Perry 2006).

8.3.1.3 Flood Hazards

More frequent and increased precipitation (see Figure 8.7b) can lead to significant urban flood hazards. Flash floods, in addition to damaging critical infrastructure and directly impacting the lives of urban dwellers, also are harmful to urban water supplies and drainage systems and can have lasting negative impacts on ecosystems (IPCC, 2013). Increasing extreme precipitation events in combination with land cover changes and increased frequency of tropical cyclones and subsequent altered water flow in urban watersheds is likely to result in an increased incidence of flooding in many cities (Depietri et al., 2012; IPCC, 2013). Flood hazards include the short-term impacts of the force of moving water (e.g., flash floods), inundation, and drowning, which cause longer-term impacts resulting from sediment movement (erosion and deposition), soil processes, and the distribution of pathogens that precipitate negative public health impacts (ICIMOD, 2012; Teegavaerapu and UNESCO, 2012; Wisner et al., 2003; Walker et al., 2008). For cities along rivers and coastlines, rising sea levels and increasing storm surges will increase urban flooding as well (Mosely 2014). Coastal flooding due to sea level rise can lead to increased salinization and reduced groundwater recharge (Chan et al., 2011; IPCC, 2013), which can decrease habitat quality for biodiversity.

Climate change in cities will lead to increased precipitation in some places and decreased precipitation in others (see Figure 8.7a). In cities projected to receive increased precipitation, increased discharge into surface waters will have ecosystem consequences. For example, urban development affected the ability of watersheds in Baltimore, Maryland, to retain nitrogen, and urban watersheds showed increased sensitivity to climate variation (Kaushal et al., 2008). Loss of this urban ecosystem function in Baltimore (nitrogen retention) led to increased nitrogen downstream, with negative consequences for the ecology and economy of the Chesapeake Bay. On the other hand, freshwater wetlands with reduced hydrologic inputs could become even further water-limited, with negative effects on both ecosystem services and biological diversity (World Bank, 2015). The modification of climate within and around cities combined with increasing drought stress from decreased precipitation illustrates how climate change will affect many urban ecosystems worldwide (UN Habitat, 2011).

Case Study 8.5 Gazelle Valley Park Conservation Program

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Keywords	**Biodiversity, urban planning, development, Jerusalem mountain gazelle, ecosystems**
Population (Metropolitan Region)	981,735 (CBS, 2012)
Area (Metropolitan Region)	649,296 km² (CBS, 2012)
Income per capita	US$35,440 (World Bank, 2015)
Climate zone	Csa- Temperate, dry summer, hot summer (Peel et al., 2007)

Case Description

The historic city of Jerusalem is also a well-known place for its rich natural heritage of Biblical flora and fauna that has developed as an integral part of the city landscape. The city is a significant habitat for half a billion birds since it lies on one of the most important global bird migration routes following the course of the Great Rift Valley. The credit for creating this rich ecosystem and wealth of biodiversity within a city lying in water-scarce area goes to the Gazelle Valley Park Conservation Program (Marianne, 2015).

The major issue of climate change faced by the city is shortage of water and the threat of desertification. Temperatures in the Middle East region are not rising as fast as in other parts of the world, but the region is already experiencing weather extremes and the process of desertification is on the rise. Although rainfall has increased, so has evaporation. The impact of climate change on the region's natural flora and fauna is still mild mainly because of their historical adaptation capacity to moisture stress and high temperatures. However, future predictions are that, due to extreme heat and water stress, plants and animals will have difficulty surviving (Schuster, 2015).

Climate Change Adaptation Strategy

The City of Jerusalem has assumed the responsibility for improving and maintaining its unique desert and hilly ecosystems to preserve its floral and faunal biodiversity in the face of increasing climate change stresses. In 2009, Jerusalem joined the International Council for Local Environmental Initiatives/Local Action for Biodiversity (ICLEI/LAB) Network to further pursue sustainable development measures. In the context of Jerusalem's LAB Legacy project for the International Decade of Biodiversity, Jerusalem has established the Gazelle Valley Conservation Program to protect and restore one of the city's unique biodiversity areas and to plan the development of a park for both wildlife preservation and local recreation at the site. The area has recently been designated as an urban nature park – a local model of sustainable development (www.Jerusalem.muni.il).

The Gazelle Valley is situated on a sixty-acre undeveloped tract of land in southwest Jerusalem, between two residential neighborhoods and closed in by major roadways. After being used for agricultural purposes during the 1960s and 1970s, the land, a rich wildlife habitat, was left as open space while the surrounding urban area continued to develop. The mountain gazelle (*Gazella gazella*), an indigenous species particularly prevalent in this part of the Jerusalem hills, has been roaming the valley and sustaining on its natural resources since ancient times. It is also the site of ancient terraces with orchards that still bear fruit.

In the late 1990s, a residential plan was established for the Gazelle Valley, threatening to destroy the gazelle habitat and remove a vital open space in the city. The Jerusalem branch of the Society for the Protection of Nature (SPNI) opposed the development plan, citing that it was a reversal of established urban planning principles. Local residents and activists joined SPNI to launch a campaign to save the Valley.

The Gazelle Valley Citizen Action Committee was thus formed. Understanding the need for a comprehensive plan, the Committee, together with SPNI, commissioned an alternative plan focusing on conservation and restoration of the site's unique biodiversity. After 10 years of rigorous grassroots opposition, the city decided to withdraw the residential plan and designate the Gazelle Valley a natural heritage site. In addition, the conservation plan was approved by the Local Planning Committee in 2009, marking the first time that local authorities approved a development plan initiated by residents. This civil society initiative for environmental protection in Jerusalem was also a significant victory for the environmental movement in the region.

Case Study 8.5 Figure 1 *Revived urban biodiversity.*

Climate Change Adaptation

The development of the Gazelle Valley Park in Jerusalem plays an important role in the city's promotion of climate change adaptation. Water conservation is a significant aspect of the park design. Apart from the need to regulate the drainage basin, water features prominently in the plan as a vital natural resource for sustaining the local biodiversity. In addition, regulation of existing water systems is being planned to enhance the beauty of the site and serve to attract visitors. The plan includes a series of runoff collection pools that will have the capacity to store 20,000 cubic meters of rainwater and seepage. In addition, a runoff filtration system is also planned for sedimentation of solids in water entering the park. To control seasonal flood zones, the valley's natural irrigation system will be rehabilitated, facilitating the restoration of the site's ancient agricultural terraces. In order to prevent erosion and control channel flow, two gravel-lined streams will be dug in alignment with the local topography to control channel flow and prevent erosion. Proper rainwater management will not only create a buffer zone between the conservation area and the adjacent recreational area, it will also help mitigate climate change effects and the effects of increased urbanization around the Valley.

Case Study 8.5 Figure 2 *Gazelle Valley Park, Jerusalem City.*

Impact and Lesson Learned

The park is expected to serve local residents and visitors with a public activity core (differentiated from the animal habitat), including pedestrian and bike paths, gazelle observation points, a bird watching route, agricultural gardens, and an educational visitor center. The Gazelle Valley Conservation Program in Jerusalem demonstrates that through proper planning practices, conservation efforts in an urban setting can facilitate both climate change adaptation and promote efficient ecosystem management. In the case of Jerusalem, it is anticipated that this effort will also produce an effective interface between biodiversity and human activity. The city government is taking the lead in mobilizing stakeholders in steering this green adaptation project.

8.3.1.4 Hazards Related to Shifting Species Distributions

Species movement in response to climatic regime shifts has already been well-documented (Parmesan 2006; Parmesan and Yohe, 2003; Porter et al., 2013; ICIMOD, 2009). Organisms at the edge of their distributions may decline as temperature or other climate conditions shift outside their physiological tolerances. For example, plant and animal species may shift northward seeking cooler temperatures following climate shifts, meaning that cities in the tropical and subtropical belts may lose species faster (Gonzales et al., 2010; Grimm et al., 2013). Changing climate may also affect the introduction of new species in urban ecosystems by reducing noninvasive and native species while favoring weedy and urban-adapted species (Kendle and Forbes 1997; Booth et al., 2003; Heutte and Bella 2003). Warming cities (see Figure 8.7a) may find new problems with invasive species and pests that had formerly been limited by cold conditions. The most adaptive species in an era of changing urban climate are likely to include more weeds, pests, and invasive species, such as the introduced Burmese python in Florida (IPCC, 2014). Species that are highly specialized and heat sensitive may be threatened with local extinction driven also by an inability to move to new areas as urban development expands.

The distribution of pathogens is also likely to shift with changing climate, with consequences for both resident organisms and the ecosystem functions they provide. For example, climate change is likely to influence the distribution of the mosquito *Aedes aegypti*, the primary urban vector of dengue and yellow fever viruses (Eisen et al., 2014). Ultimately, changes in species distributions are expected to modify the ecological interaction networks in cities and have the potential to promote invasive species, which could accelerate the loss of urban biodiversity (Kendal et al., 2012; Nobis et al., 2009).

It is important to recognize that none of these hazards and risks operates in isolation. For example, changes in CO_2 concentrations may or may not amplify the impacts of changes in precipitation, temperature, or other climate hazards on urban vegetation (Zavaleta et al., 2003) suggesting the need for further research to better understand critical feedbacks in the urban system. Thus, integrating all of the ecosystem processes and recognizing that there are critical feedbacks among ecological, built, and social components of urban systems will yield a more thorough understanding of climate risks to urban biodiversity and ecosystems.

8.3.2 Urban Ecosystem Vulnerability

Vulnerability may be considered a lack of resilience or a reduction in adaptive capacity (Tyler and Moench, 2012). However, the complexity of urban ecosystems is characterized by vulnerability along multiple dimensions. Urban ecosystems share many of the same types of climatic vulnerabilities as non-urban ecosystems. However, urban ecosystems are also exposed to a number of unique stressors and therefore they experience greater exposure to hazards such as a high concentration of population, the inherent role of non-climate stressors, and the UHI phenomena (Farrell et al., 2015). The extent of human conversion of the landscape and anthropogenic inputs of materials, energy, and organisms are all greater in cities, which can affect climate vulnerability in a variety of ways (Fitzpatrick et al., 2008, Loarie et al., 2008). Rapid urban growth and local landscape dynamics[5] contribute to national, regional, and global-scale climate change driven by elevated rate of greenhouse gas (GHG) emissions, radiative forcing[6] of non-greenhouse gases, and alteration of rainfall patterns by short-lived climate pollutants (black carbon, tropospheric ozone, and methane) (Parmesan, 2006; Pielke et al., 2002; Cerveny and Balling, 1998; UNEP, 2011).

In the urban ecosystem context, exposure to multiple stressors is a real concern, particularly in developing countries where socioeconomic and political drivers along with climate variability play important roles (Leichenko and O'Brien, 2008). However, there are very few studies that have assessed the multidimensional nature of urban ecosystem vulnerability important for planning appropriate adaptation measures (IPCC 2007, Williams et al., 2008). Assessing the vulnerability of urban ecosystems to climate change is critical to include as part of urban planning, policy, and design processes that intend to ensure sustainable delivery of ecosystem services into the future (McPhearson et al., 2015a).

Vulnerability of urban ecosystems can be assessed at multiple levels within the urban system, including for the individual organism (e.g., physiological health and reproductive success of humans, plants, and other biota), populations, and for larger landscapes (e.g., land use and land cover, biogeochemical cycling) (Kalusmeyer et al., 2011; Vignola et al., 2009; UNEP-WCMC, 2009; Violin et al., 2011). Most studies to date examine vulnerability at the species level or, in some cases, landscape level. Williams et al. (2008) and Glick et al. (2011) have developed species-level vulnerability assessments in which they define "species vulnerability as a function of climate change–related impacts and the adaptive capacity of the species." However, given the strong connections among urban, peri-urban, and rural landscapes, it is important to assess combined and connected cumulative effects of exposure and sensitivity to climate change. Kalusmeyer et al. (2011) argue that assessing vulnerability at landscape level is cost effective and a more useful tool for decision-makers than, for instance, single-species focused vulnerability assessment (see Box 8.2).

Box 8.2 Ecosystem Vulnerability

Klausmeyer et al. (2011) used a vulnerability assessment tool for climate change impacts on biodiversity using landscape-scale indicators in California. This method allows biodiversity managers to focus analysis on the species likely to be most

[5] Landscape dynamics is a concept of landscape equilibrium highlighting the spatial and temporal scaling of disturbance regimes and their influence on equilibrium/non-equilibrium dynamics in a particular landscape (Pielke et al., 2002).

[6] "Radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system, and is an index of the importance of the factor as a potential climate change mechanism" (IPCC, 2001).

vulnerable and to decide on the best adaptive strategies to reduce vulnerability to climate change. Based on results, the authors recommended that state biodiversity managers focus on minimizing current threats to biodiversity (9% area), reducing constraints to adaptation (28%), reducing exposure to climatic changes (24%), and implementing all three (9%). In 12% of the high-vulnerability areas, current conservation goals have to change; in remaining areas, no additional actions are required. This tool can also help to identify adaptation measures focused on endangered species only**.**

8.4 Adaptive Capacity and Urban Ecosystem Resilience

The adaptive capacity of species in urban landscapes is a function of ecology, physiology, and genetic diversity (Kalusmeyer et al., 2011; Williams et al., 2008). The adaptive capacity of an urban ecosystem is also the degree to which system dynamics can be modified to reduce risk. Traditionally, adaptive capacity focused on human actors and institutions, but, in the context of urban biodiversity and ecosystems, nonhuman actors, behavior, species interactions, and human–ecological interventions are also important. For example, human-induced adaptive capacity could include planting species that are more tolerant of higher temperatures and droughts. Nonhuman-derived adaptive capacity could include natural processes that change ecosystem components rapidly for organisms like insects populations persisting despite changing climate. Adaptation measures such as introducing green infrastructure (e.g., urban green spaces, constructed wetlands, agricultural land in outlying flood-prone areas) can reduce thermal loads and flood hazards and improve water and air quality for vulnerable biota (Depietri et al., 2012)(see also Case Study 8.2, Staten Island Bluebelt, and Case Study 8.5, Jerusalem Gazelle Park). In addition, cities are dependent on urban and peri-urban ecosystems for food production, water provision, and air quality regulation, meaning that the adaptive capacity of a specific urban area depends at least partially on local to regional considerations (Tyler and Moench, 2012).

Resilience to climate change is a growing priority among urban decision-makers. Improving resilience will require transformations in social, ecological, and built infrastructure components of urban systems (Tyler and Moench, 2012; Ernstson et al., 2010). Urban ecosystem are important components when building urban resilience through their ability to absorb climate-induced shocks and ameliorate the worst effects of extreme climate events (McPhearson et al., 2015a). However, disturbances of sufficient magnitude or duration, such as prolonged drought, can push biodiversity and ecological relationships beyond safe thresholds for reliable production of ecosystem services and may require new approaches to land-use planning and adaptation that focus on building ecological resilience (Folke et al., 2004).

Cities are increasingly seeking to enhance adaptive capacity of urban ecosystems through, for example, green infrastructure, including urban agriculture, landscape conservation, green roofs, green walls, and other green and open spaces that conserve ecosystem values and functions (Kremer et al., 2016a). Building urban parks and other green spaces and adding vegetation strips to densely built neighborhoods can help reduce thermal hazards, manage stormwater, and enhance health benefits, thus enhancing climate change resilience (e.g., in Rio de Janeiro City). From a climate and resource efficiency perspective, the spatial configuration of green spaces is particularly important to mitigate the UHI effect and to conserve water and energy use. Cities with a combination of a high percentage of green areas, high edge density (distribution of the green space), and high patch density (number of patches per unit area) can more effectively respond to climate extremes such as heat waves and heavy precipitation (European Environment Agency [EEA], 2015; Maimaitiyiming et al., 2014). This suggests that policy and urban planning should ideally prioritize connected green corridors of critical mass rather than a multitude of fragmented green spaces; nevertheless, the total percentage of green space independently is likely most impactful for climate resiliency and, in practice, is often more feasible to create.

Many cities are vulnerable to the hazards associated with climate change as a function of their location (UN Habitat, 2011). For example, cities are disproportionately distributed along coasts and major rivers, which increases their vulnerability to floods and storm surges. Urban ecosystem managers planning species- and landscape-level adaptation often have multiple goals such as protecting land, restoring habitat, encouraging compatible lands uses, and reducing fragmentation (Heller and Zavaleta, 2009). Building resilient urban ecosystems therefore needs flexible, modulating, and safe-to-fail approaches that can adapt to uncertainty and extreme climate events such as typhoons, hurricanes, and superstorms (e.g., super storm Hurricane Sandy in New York City, 2012) (Tyler and Moench, 2012). Also, greater coordination and networks among governance structures that manage local ecosystems and urban biodiversity, including cemeteries, golf courses, urban parks, and neighborhood gardens, would strengthen ecosystem functioning as well as the associated and essential social-ecological engagement (Ernstson et al., 2010).

8.4.1 Interactions between Social and Ecological Infrastructure

The vulnerability of urban ecosystems and biodiversity is intrinsically linked to human activities that drive urban system dynamics. The urban population, with its resource consumption and waste generation activities, the built infrastructure system (buildings, transportation infrastructure, utilities), and the direct and indirect modifications to the landscape (e.g., changes in vegetation, water courses and storage, microclimate, etc.) all create a distinct set of vulnerabilities for the systems and biota embedded in cities (Alberti, 2015). These vulnerabilities are manifested at multiple spatial scales. At the very local level, the altered microclimate and hydrology of a city street will affect the ecosystem services generated by local trees, wildlife, and microbes. Within larger ecosystems embedded in cities, such as remnant forests and urban agriculture and wetlands, the direct effects of human activities and infrastructure need to consider both local and landscape-level management to reduce hazards exposure and risks simultaneously at multiple levels.

8.4.2 Adaptive Management of Vulnerable Urban Biota

The multidimensional nature of urban vulnerability impacts urban biodiversity components including diversity of plants, animals, and microbes within city boundaries. These groups are all influenced by environmental changes associated with both urbanization and human management. City managers should support both biological communities that have persisted since before urban development (e.g., remnant forest patches, indigenous wildlife that have adapted to urban conditions) and novel communities that depend on human inputs (e.g., managing pests, deliberately or accidentally introduced species) (Aronson et al., 2014). For example, cities create novel ecosystems and habitats outside their natural biome, such as hot metro tunnels in cold regions, lakes and ponds in arid areas, and dry soils in humid areas that contribute to increased biodiversity levels often observed in urban areas compared to surrounding ecosystems (McKinney, 2002). Urban biodiversity vulnerability can be mediated by direct and indirect human management of habitats. For example, the response of indigenous species in remnant ecosystems is affected by regional climate shifts, local ecological dynamics, and the local impact of the city itself (e.g., augmented warming, altered water resources, direct human impact, etc.). These urban influences can be moderated by direct human management that reduces their exposure and sensitivity, for example by eradicating pest organisms or creating conservation programs for rare or endangered and endemic species. The Gazelle Valley Park Conservation Program is an example of how climate change adaptation can be combined with biodiversity conservation through ecosystem management.

Case Study 8.6 Medellín City: Transforming for Life

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Keywords	**Urban development; transportation; adaptive urban planning; resilient infrastructure, ecosystems**
Population (Metropolitan Region)	3,731,000 (Alcaldia de Medellín, 2015)
Area (Metropolitan Region)	1.152 km² (Alcaldia de Medellín, 2015)
Income per capita	US$7,130 (World Bank, 2015)
Climate zone	Am- Monsoon-influenced humid subtropical (Peel et al., 2007)

Medellín is an inspiring example of sustainable and innovative urban development with good governance, community participation, and business partnerships. City leaders can take some credit for transforming the city into a vibrant, socially cohesive, and more environmentally resilient city through initiating adaptive and flexible urban planning strategies with effective implementation. The positive impact of mass transportation, green spaces, and equitable benefit sharing resulted in citizen participation, stakeholder involvement, and government support for urban development. The effective use of social networks and good communication by city leaders sustained community support.

Case Description

Medellín, located in mountainous Aburrá Valley, is a Colombian city with a history of sustainable urban development processes. Many of the poor communities living on the mountainous slopes were challenged for safety and access to essential city services. City leadership has since provided public safety, security, easy mobility, access, amenities, and opportunities. Medellín also developed affordable mass transport systems – the world's first cable car system – the Metrocable – and also a Metro to address both access and pollution problems. Today, Medellín is famous for its social cohesion, business-friendly environment, and people- and environment-centric city government and a high quality of life. How Medellín transformed itself from a city with high socioeconomic challenges to one described as "a great inspiration to other cities facing similar issues" can be attributed to Medellín's bold, visionary leadership, which encompassed diverse stakeholders to deliver a series of small-scale but high-impact, innovative green urban projects (Eveland, 2012).

Socioeconomic and Environmental Issues

By the 1970s, Medellín demographically had grown by almost twenty-fold – from around 60,000 in 1905 to more than 1 million – to become the second largest city of Colombia. A large number of poor were living in precarious socioeconomic and ecological conditions, suffered exclusion, and were struggling with a high cost of living. Medellín entered a cycle of decline in its economic base, which led to a consolidation of a segregated, unequal, and conflict-ridden society and degrading ecosystem. By the early 1980s, Medellín faced a host of social and economic upheavals that led to government failure. In response, the city unleashed social mobilization processes that constituted the genesis for a collective construction of a new vision of urban development, one that led to political and strategic processes that began major change and development pathways in the city. The community responded with significant efforts toward collective dialogue in which a broad cultural and pedagogical process laid the groundwork for civic and citizen-led projects. This included environmentally sensitive urban development planning and program implementation.

Adaptive Change Process

Affordable mobility played an important role in achieving equitable connectivity between urban and rural sections in Medellín (Moreno et al., 2013) As well as setting a process of forming neighborhoods in response to functional interests and a population demanding specific interventions, expanding the city's services to include green spaces throughout the city improved its greening index, making the city more climate resilient (Green City Index [GCI], 2010).

Milestones were conceived during the 1980s and 1990s as the Strategic Plan of Medellín and the Metropolitan Area 2015. This generated a broad and pluralistic project of continuity and consistency in a society that was in crisis. A participatory process was developed for sustainable development that became a foundation for environmentally friendly policies and practices.

In 1995, the Metro became operational – a point of origin for the Integrated Mass Transit System that linked physical, institutional, virtual, sustainable, and environmental modes of mass transit with efficiency and effectiveness. The Metro system serves the current as well as future transportation needs of all inhabitants. This has helped Medellín to minimize its ecological footprint and protect biodiversity and ecosystem services in the spaces freed-up by the Metro.

A joint exercise between government and development agencies has been proposed to assess the vulnerability dynamics of the territory, along with implementing sustainable alternatives to mitigate climate impacts in both urban and rural areas of the Valle de Aburrá. With a holistic adaptation approach, criteria are enforced to ensure the security of the both the people and the ecosystem within the city's territory. The Integrated Transport System of the Aburrá Valley (SITVA), the Inventory of Greenhouse Gases, the Environmental Classrooms Program of Integrated Solid Waste Management, Linear Parks and Ecological Corridors, Best Practices of Sustainable Consumption and Production, the More Forests to Medellín project, and Integral Water Management among others have positively contributed to the improvement of indicators of an adaptive urban system. Linear parks in particular help the city protect itself from storms and increased pollution.

Impacts and Lessons Learned

The city's Green Belt encourages conditions and opportunities for integral human resources development in the transition zone between urban and rural regions. The Green Belt is important as a way to regulate city expansion into sensitive ecosystems and has helped to conserve and protect natural habitat.

The River Park is another intervention and urban renewal project of the Medellín River environment, connecting the city with efficient mobility, public space, and environmental interventions. Engineering and urbanism work hand in hand so that the city's rivers can form the structural axis of citizenship.

This ongoing process of transformation has shown that it is possible to build a community-driven, environmentally friendly project in a city. The city's development plan is based on a territorial focus on its urban–rural areas and contains a systemic view of development to overcome inequities expressed in the territory. This has inspired bottom-up planning processes and public–private partnerships to find innovative alternatives.

Medellín's Home for Life initiative recognizes that a participative society and good governance are combined in an institution that seeks equity as a result of political and social rationality. Here, the urban development goes beyond different forms of land use and integrates a combined human–environmental urban ecosystem framework. The lessons learned in these efforts will prove useful in confronting the daunting challenges of adapting to climate change.

Case Study 8.6 Figure 1 *Medellín's green belt. Note: pictures are property of the Municipality of Medellín. Source: Documents owned by the Municipality of Medellín and Development Plan 2012–2015: Medellín, a home for life.*

Conclusion

The main driver of Medellín's transformation has been city government's efforts to be inclusive, fair, participatory, and environmentally sound in urban development governance. These approaches transformed Medellín into a model of sustainable urban livability and earned it the 2014 Lee Kuan Yew World City Prize Special Mention. Medellín aspires to continue advancing as an innovative and intelligent city, and hopes to facilitate the exchange of experiences and the advancement of collective knowledge among cities and their inhabitants. To promote sound green design and appropriate policies embracing multidimensional development, building resilient rules, regulations, and capacity and citizen's participations have been the key factors.

Another example is how integrated urban water management can reduce the vulnerability of urban ecosystems and biodiversity (see Case Studies 9.5 and 14.B, Rotterdam). Management of water resources for drinking and sanitation, as well as the hazards associated with water (flooding, landslides, etc.), can alter water flow and storage for the benefit of urban plants. Management of urban hydrological systems through improved greening can decrease the vulnerability of urban ecosystems. For example, during drought periods, a small share of water resources may be reserved as environmental flow for use by plants and animals, thus allowing ecological systems such as forests, wetlands, and streams to survive and maintain adaptive capacity. While drought may affect an entire region, urban ecosystems where water resources are well managed can reduce the impact of such climate-driven water stress, but only provided that urban ecosystem management activities are part of a larger system-level urban resilience plan.

8.5 Ecosystem-Based Adaptation and Nature-Based Solutions

In the urban context, healthy ecosystems can replace or complement often expensive "hard" or engineered infrastructure (e.g., sea-walls, dykes or embankments for river control, and shelters). EbA[7] and similar nature-based solutions have been widely recognized as "soft," safe-to-fail, and often less expensive approaches to climate resilience that values and uses ecological services for adaptation (Huq et al., 2013; CBD, 2009). EbA approaches can generate numerous co-benefits and indirect ecological and social benefits to both non-urban and urban communities in ways that support urban transitions to sustainable,

[7] Ecosystem-based adaptation is an approach to planning and implementing climate change adaptation by considering ecosystem services and their uses for human well-being (MEA, 2005).

livable communities (UNFCCC Secretariat, 2011, 2013; UNEP, 2012; Huq et al., 2013; Zandersen et al., 2014). The contribution of green infrastructure to EbA in the form of urban parks, avenue plantation, and urban forestry can also provide small levels of GHG mitigation by storing carbon in soils and vegetation. Multiple co-benefits are also expected from the integration of climate change adaptation and biodiversity conservation measures (ICLEI-Africa, 2013; UNEP, 2009). For example, although not a direct goal of climate adaptation, city green spaces have been shown to have important societal co-benefits including but not limited to lower crime rates, reduced level of stress, enhanced cognitive capacities, and improved public health (Troy et al., 2012; Demuzere et al., 2014). The Singapore Case Study (Case Study 8.7) illustrates how EbA can be integrated with disaster risk reduction strategies.

UES may play an increasingly vital role as cities grow in population size and contain larger senior age cohorts than any other settled topography. The 2003 heat wave in Europe resulting in more than 70,000 deaths can be seen as an early warning of more severe climatic conditions to come, with climate change being viewed as a new public health threat (Petkova et al., 2014). In the United States, heat is the greatest weather-related cause of human death because increasing temperatures above 90°F (32°C) aggravate air pollution and ozone levels and result in greater health risks, including respiratory illness (e.g., asthma) and heart attacks, particularly among urban dwellers. High GHG emissions compound temperature levels, leading to forecasts of even higher US summer temperatures and health concerns in coming years (Kenward et al., 2014). As climate change becomes increasingly viewed in the context of public health, cities that incorporate green infrastructure in urban planning and the built environment, and that safeguard local biodiversity, will optimize their urban ecosystems services for temperature mitigation, thus strengthening climate resiliency as well as improving quality of life (Santiago Fink, 2016).

Box 8.3 Urban and Peri-Urban Agriculture and (Agro) Forestry for Climate Change Adaptation and Mitigation

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The IPCC's AR5 (IPCC, 2013) projects that, due to climate change, there is likely to be a loss of food production and productive arable lands in many regions. Cities with a heavy reliance on food imports and the urban poor will be significantly affected. Adaptation options and local responses mentioned in the report include support for urban and peri-urban agriculture, green roofs, local markets, enhanced social (food) safety nets, and the development of alternative food sources, including inland aquaculture (University of Cambridge and ICLEI, 2014).

Urban and peri-urban agriculture have long been recognized as a potential food security and income strategy (Zezza and Tasciotti, 2010; De Zeeuw et al., 2011; FAO, 2014). However, its potential contribution as a climate change adaptation and, to a lesser extent, mitigation strategy has only been more recently studied and acknowledged (Lwasa, 2013; Dubbeling, 2014: Lwasa and Dubbeling, 2015). Because a clear framework and tools for monitoring the contributions of urban and peri-urban agriculture and forestry (UPAF) to climate change mitigation and adaptation was not available until recently, the potential to integrate UPAF into city climate change plans was limited.

A recent (2012–2014) collaboration between UN Habitat and the Resource Centers on Urban Agriculture and Food Security (RUAF) Foundation-International aimed to respond to these gaps by (1) enhancing the awareness of local authorities and other stakeholders involved in urban climate change programs, land use, agriculture, and green spaces regarding the potentials (and limitations) of UPAF for climate change adaptation and mitigation and (2) assisting interested cities and other local actors to integrate urban agriculture into local climate change and land-use policies and strategies and to initiate pilot actions that "showcase" replicable urban agriculture models. At the same time, RUAF Foundation and the Climate Development Knowledge Network (CDKN) developed and tested a monitoring framework in an attempt to quantify the impacts of UPAF on climate change adaptation and mitigation in participating cities.

Box 8.3 Figure 1 *Multifunctional design of urban greenways in Bobo Dioulasso (Burkina Faso). Source: F. Skarp*

One of the partner cities, Bobo-Dioulasso, in Burkina Faso, is characterized by increasing urbanization resulting from industry and economic growth, as well as from the return of migrants following an internal crisis in Ivory Coast. The city is built up in housing blocks with square open urban lots between them. The municipality is trying to preserve these lots (called greenways) for greening (agroforestry) and multifunctional (recreation and urban agriculture production) activities as part of their parks and gardens program and climate change adaptation strategy. Satellite images and remote sensing data were used to quantify the effect of land uses on land surface temperatures (LSTs). A comparison of 1991–2013 data showed that LST differences between urban and peri-urban areas increased approximately 6% a year. The study also showed that mean LSTs over a 10-year period were consistently cooler (0.3°C) in the three specific green infrastructure areas analyzed than in adjacent urbanized areas (Di Leo et al., 2015). This may have important effects on human well-being. In addition, the greenways will contribute to increased infiltration and retention of stormwater, with a reduced runoff coefficient of 4%, thus possibly reducing flood risks in periods of intensive rainfall. Monitoring has also shown that production from a first production cycle (August–October 2013) from open fields can contribute to at least 6% of the monthly food expenditures of the producing households involved in the project (RUAF Foundation, 2014).

In the same way, these productions contribute to a more permanent availability of home-produced food for these households. Such increased diversification of food and income sources helps to increase the resilience of poor households, which are generally vulnerable to increases in food prices (Dubbeling, 2014). Furthermore, preservation of green infrastructure is highly relevant because municipalities in Africa, as elsewhere, regularly encourage infill developments and higher housing densities that lead to the reduction or loss of green spaces and gardens. In the period 2013–2014, the municipality of Bobo-Dioulasso decided to (1) install and institutionalize a municipal committee for the future management of the greenways (2) draft and adopt a technical statute for the greenways promoting their productive and multifunctional use, and (3) adopt a set of specifications applicable to the exploitation of the greenways. The draft legal texts were submitted to and adopted by the Environment and Local Development Commission of the Municipality in January 2014. On March 26, 2014, the proposal to install the municipal committee was unanimously adopted by the municipal council. A provision of €20,000 was made in the 2013–2014 municipal budget to cover the functioning and activities of the greenway management committee and to support maintenance of the existing productive greenways as well as their replication on other greenways (RUAF Foundation, 2014).

In comparison to Bobo-Dioulasso, where increasing urban temperatures and urban heat islands are one of the main (predicted) climate change impacts, the city of Kesbewa, Sri Lanka, has to deal not only with increasing temperatures but also with more intense rainfall and regular flooding. Kesbewa is a medium-sized, rapidly expanding city located at 25 kilometers from the capital Colombo. Kesbewa city used to be characterized by a large presence of agricultural and rice-producing fields, the latter taking place in lower lying areas and flood zones. Much of the agricultural activity has been abandoned due to rice production from the north of the country being more economically viable and due to sale of land for urbanization. The rapid filling and conversion of the paddy lands to residential and commercial areas has significantly altered natural water flows and drainage. Coupled with an increase in average rainfall and heavy rainfall events, this has resulted in recurrent flooding and related damage to infrastructure, utility supply, and the urban economy in some parts of Kesbewa (University of Morotuwa, 2012).

Box 8.3 Figure 2 *Rehabilitated paddy areas with vegetables growing on raised bunds in Kesbewa, Sri Lanka. Source: Janathakshan*

It was for this reason that the Ministry of Agriculture, Western Province, with support of UN Habitat, RUAF, and the local nongovernmental organization Janathakshan, decided to implement a pilot project on rehabilitating abandoned paddy lands by promoting the production of traditional varieties of salt-resistant paddy rice that fetch good market prices combined with the growing of vegetables on raised beds. By re-establishing the flood regulation and ecosystem services of these areas, this strategy will not only contribute to reducing flood risk but also to increasing urban food production and income generation for the involved farming households. Support for urban agriculture as a flood risk mitigation or stormwater management strategy was also taken up in cities like Bangkok after the 2012 flooding (Boossabong, 2014) and in New York (Cohen and Wijsman, 2014).

Support for this program and its expansion is being institutionalized in policy uptake at different levels. At the local level, the preservation of agricultural areas and flood zones is included in the Kesbewa Urban Development Plan. At the provincial level, urban agriculture is now considered a climate change adaptation strategy for the province. The current Climate Change Adaptation Plan 2015–2018 of the Western Province of Sri Lanka (Ministry of Agriculture, 2014) now specifically includes action lines regarding the expansion of urban and peri-urban agriculture and agroforestry, the management of paddy lands as a flood risk reduction strategy, and the reduction of food miles by promoting localized production. And, at the national level, prescribed land use for low-lying urban and peri-urban rice fields now allows for the new production model as part of the revised "Paddy Act" (RUAF Foundation, 2014).

More localized food production may also have positive impacts on reducing energy use and emissions related to food transport (cold) storage, and packaging. In both Kesbewa and Rosario, Argentina, actual urban consumption patterns and food flows were analyzed and scenarios developed to calculate the potential impacts of increased local food production. Assuming similar production systems would be applied in both distant rural (current production locations) and peri-urban areas for production of the main consumed vegetables in Rosario (potato, squash, beans, and lettuce), CO_2 emissions related to such food consumption would be reduced by about 95%. Analysis of production capacity in Rosario's peri-urban areas shows that such local production is feasible.

In response, the Municipality of Rosario has already zoned—in its urban development plan—an additional 4,000 hectares of its remaining greenbelt for vegetable production and has, in collaboration with the Province of Sante Fe, started a pilot program to support horticulture producers using ecological production techniques and opportunities for direct marketing. A first agreement was signed with the Association of Hotels and Restaurants for this purpose (Dubbeling, forthcoming).

Box 8.3 Figure 3 *Horticulture production in Rosario's greenbelt.*

The amount of food that can actually be produced in urban and peri-urban areas was more recently the subject of study in Almere, the Netherlands, and in Toronto, Canada. A 2012 scenario study done in Almere found that 20% of total food demand (in terms of potatoes, vegetables, fruits, milk, and eggs) projected for a future population of 350,000 inhabitants can be produced locally, within a radius of 20 kilometers of the city. More than 50% of the needed area is devoted to animal production (grass and fodder). By replacing 20% of the food basket with local production in Almere while at the same time promoting fossil fuel reduction in production, processing, and cooling through the use of renewable energy sources, energy savings (363 TJ) would add up to the equivalent of the energy use of 11,000 Dutch households. Savings in GHG emissions (27.1 Kt CO_2 equivalent) would equal carbon sequestration in about 1,360 hectares of forest or the emission of 2,000 Dutch households. The largest savings are due to reduction in transport, replacing fossil fuel use with renewable energy sources (solar, wind energy; use of excess heat from greenhouses, and replacing conventional with organic—or ecological—production (Jansma et al., 2012).

8.6 Urban Agriculture and Forestry

With increasing urbanization, climate change, and growing urban demand for food, cities need to address the triple challenge of climate change mitigation and adaptation, as well as the provision of basic services, including food, to vulnerable residents. Barthel et al. (2013, 2015) suggest that urban agriculture production in its many forms has been supporting urban resilience throughout the history of urban development. The examples here show that urban and peri-urban agriculture and forestry may provide helpful strategies to address this triple challenge (see Box 8.3). The future upscaling of these interventions will need new urban design concepts and the development of local and provincial climate change action and city development plans that recognize urban agriculture as an accepted, permitted, and encouraged land use. The involvement of the subnational (e.g., provincial) government is key to addressing agriculture and land-use planning at larger scales (outside municipal boundaries), facilitating access to financing, and developing the regional policies that must accompany city-level strategies (Dubbeling, 2014).

8.7 Ecosystem-Based Mitigation Strategies

Urban areas are likely to face the most adverse impacts of climate change due to high concentration of people, resources, and infrastructure (Revi et al., 2014). Climate change mitigation is therefore required to reduce the source and enhance the sink of GHGs, especially carbon. Since the potential for GHG mitigation in urban areas remains limited, combining green infrastructure and EbA may increase urban CO_2 sinks (Rogner et al., 2007), although estimates for different kinds of green infrastructure remain contested (Pataki et al., 2011). Urban land-use changes have significant impact on GHG emissions and carbon sequestration, as well as on albedo, which plays an important role in radiative forcing and the carbon cycle. New and updated urban plans warrant the inclusion of both climate change resilience measures as well as long-term mitigation strategies that will need to be supported by metrics and decision-support tools that demonstrate GHG reductions; clearly, land use and transportation as well as green infrastructure indicators will need to be among them (Condon et al., 2009).

Integrated urban planning that incorporates a multidisciplinary perspective to target schemes that also support increased use of green infrastructure, forest restoration, and other EbA approaches can help advance sustainable urban development while reinforcing climate mitigation and enhancing the quality and quantity of UES (RUAF, 2014; Ecologic Institute, 2011; Georgescu et al., 2014). For example, incorporating green infrastructure in urban design, especially in warmer climates, can potentially reduce the use of air conditioning, cause significant energy savings, and therefore indirectly reduce GHG emission (Alexandri and Jones, 2008; Georgescu et al., 2014).

8.8 Cross-Cutting Themes

8.8.1 Urban Planning and Design

Designing, planning, and managing complex urban systems for climate resilience and human health and well-being require ecosystems to be resilient to effects of climate change and be able to sustainably and reliably provide critical ecosystem services over time (McPhearson et al., 2014b). Urban planning and design are key processes that determine the quantity, quality, and accessibility of urban residents to UES. Urban development often replaces natural elements with built and impervious surfaces, which can degrade and eliminate ecosystems, natural processes and flows (e.g., water and nutrients cycles), and biodiversity (Alberti, 2008; Colding, 2011; Novotny et al., 2010). Impervious surfaces also exacerbate climate-related problems such as the UHI effect, flooding, and other stormwater management concerns. To counter these trends, ecosystem-based approaches in urban planning and design practices are emerging. Ecosystem-based approaches can include urban green infrastructure in ways that enhance regulating and cultural ecosystem services and restore native biodiversity. In a growing number of cities, local communities and city planners are collaborating to create new green spaces and improve existing ones using GIS and other holistic spatial planning tools and technologies (Pickett and Cadenasso 2008).

Box 8.4 Cities Biodiversity Outlook: Key Messages

1. Rich biodiversity can exist in cities.
2. Biodiversity and ecosystem services are critical natural capital.
3. Maintaining functioning urban ecosystems can significantly enhance human health and well-being.
4. Urban ecosystem services and biodiversity can help contribute to climate change mitigation and adaptation.
5. Ecosystem services must be integrated into urban policy and planning.

Source: Adapted from Secretariat of the Convention on Biological Diversity (2012)

Over the past few decades, "ecocities" and "green cities" theories began to emphasize the importance of ecosystems within cities and in linked rural areas as a way to provide important ecosystem services to city residents (Yang, 2013). Innovative urban planning theories such as Ecological Design (Rottle and Yocom, 2011), New Urbanism, Sustainable Urbanism (Farr, 2008), Ecological Urbanism (Mostafavi and Doherty, 2010), Agricultural Urbanism (De La Salle and Holland, 2010), Landscape Urbanism (Waldheim, 2007), Green Urbanism (Beatley, 2000), Biophilic Urbanism (Beatley, 2009), Ecocities (Register, 2006), and Ecopolises (Ignatieva et al., 2010) emphasize ecological restoration and connected multifunctional green infrastructure in dense, compact cities. These new approaches in urban planning are beginning to prioritize walkable and mixed land uses, emphasizing designs that cater to the needs of people and other living things (Register, 2006). In this way, urbanizing areas can start to facilitate climate mitigation and adaptation as co-benefits with efforts to reduce waste, consumption, and GHG emissions (Register, 2006).

Sustainable urban design seeks to maximize the quality of the built environment and minimize impacts on the natural environment, transforming impervious areas into high-performance landscapes (McLennan, 2004). Inter- and transdisciplinary, collaborative and strategic urban planning and design, based on restoration and reconnection of green areas at different scales, can offer numerous benefits (Breuste et al., 2008; Colding, 2011; Novotny et al., 2010; McDonald and Marcotullio, 2011; Pauleit et al., 2011; Ignatieva et al., 2010; Ahren, 2013). For example, urban planning and design that promotes habitat connectivity through linkages or clustering of landscapes, parks, and green infrastructure can increase the provision of multiple ecosystem services such as recreation, stormwater management, and biodiversity preservation (Colding, 2011). More recent approaches to urban green infrastructure design also acknowledge ecosystem disservices (see Box 8.5), the need to account for disservices as well as tradeoffs and synergies in biodiversity, and different ecosystem services (Von Döhren and Haase, 2015; Gomez-baggethun et al., 2013; Kronenberg, 2015).

Box 8.5 Ecosystem Disservices

Although urban planning and design is increasingly embracing urban ecosystems as cost-effective design solutions, it has yet to deal with the emerging knowledge of how ecosystems can also create negative impacts on human well-being, known as "ecosystem disservices." Although green infrastructure provides a wide range of services, they also generate disservices (Gomez-Baggethun et al., 2013; McPhearson, 2014; Döhren and Haase, 2015) that are important to take into account in urban planning and management. For example, green roofs have value in improving the quality of runoff by reducing pollutants release (Dunnett and Kingsbury, 2008), but some studies have noted the negative effect of the roofing materials used on the quality of runoff water due to chemicals or metal compounds (Bianchini and Hewage, 2012) and also on air quality by the emission of volatile organic compounds and nitrogen oxides (Kaye, 2004). Similarly, urban trees can produce pollen that negatively affects allergies sufferers and may affect asthma rates in cities. Working closely with local ecological experts when developing green infrastructure will be important to understand the inherent tradeoffs to maximize ecosystem services and minimize disservices associated with particular species or species assemblages (McPhearson et al., 2014; Döhren and Haase, 2015).

In both urban and non-urban contexts, climate change is associated with the increased frequency and intensity of extreme events and accelerated loss of urban biodiversity (Thomas et al., 2004). Adapting to urban climate change in the face of an uncertain magnitude of risk, vulnerability, and impacts means that urban planners should have both short- and long-term adaptation options for which a constant flow of information and knowledge is critical. Ongoing assessment of the state of urban ecosystems and ecosystem services across multiples scales and functions can support the planning and design of interconnected urban social-ecological systems (Kremer et al., 2016a).

8.8.2 Equity, Environmental Justice, and Urban Ecosystem Services

Human and nonhuman vulnerabilities are intimately intertwined at the urban scale, and the most vulnerable (including both human and nonhuman) species lack the power and capacity to respond to climate change impacts (Steele et al., 2015). From an environmental justice[8] perspective, the quantity, quality, and accessibility of urban ecosystems and their services is unevenly distributed across urban populations, with the poor and minorities often disproportionally affected by environmental hazards and ecosystem disservices and lack of access to essential ecosystem services (Pham et al., 2012; McPhearson et al., 2013a).

For example, the location, structure, and quality of urban parks present a long-term environmental justice challenge. Access to parks provides ecosystem services benefits such as recreation, physical activity, public health, aesthetic value, education, and sense of place. Historically, it has been demonstrated that the urban poor were often forced to leave their homes to create space for the creation of urban parks (Taylor, 2011). More recent research shows that the health and well-being of minorities and low-income populations are affected by the lack of access to high-quality, large, urban parks (Boone et al., 2009; Loukaitou-sideris and Stieglitz, 2002; Miyake et al., 2010) and

[8] Environmental justice is a normative concept and social movement concerned with the spatial distribution of environmental goods and ills (Ernstson, 2013), as well as with the social structure and institutional context in which environmental decisions are made (Cole and Foster, 2001).

other kinds of green spaces – such as urban vacant lots – that produce social and ecological benefits (McPhearson et al., 2013). A recent study in Bogota, Colombia (Escobedo et al., 2015) identified marked inequalities in ecosystem services provision by urban trees. The poorest socioeconomic stratum had the lowest tree and crown size, whereas the wealthiest stratum had the largest tree attributes.

Minorities and the poor are also more likely to use urban biodiversity directly as a source of livelihood and thus are more impacted by the effect of climate change and pollution on natural resources such as fisheries and urban agriculture, especially in low- and middle-income countries (Corburn, 2005; National Environmental Justice Advisory Council, 2002). It will be important to consider the spatial distribution of environmental justice in planning and decision-making on policies related to ecosystem services. For example, the location of new green infrastructure can improve environmental justice by locating natural spaces and elements in proximity to otherwise underserved populations. The opposite may be true if new green infrastructure is located at the expense of such populations, where, for example, gentrification processes together with new green space development increase the cost of housing and force low-income residents to relocate (Wolch et al., 2014). Addressing environmental justice issues requires participatory planning and community-based strategies to address the structural changes that may be required (e.g., by improving the access of marginalized groups to green spaces and providing them with opportunities for recreation, urban agriculture, flood protection, urban heat reduction, and other ecosystem services without forcing the displacement of affected groups).

Case Study 8.7 Singapore's Ecosystem-Based Adaptation

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Keywords	**Flood risks, ecosystem-based adaption, resilience, greeneries**
Population (Metropolitan Region)	5,469,700; (Department of Statistics Singapore, 2015
Area (Metropolitan Region)	718.37540/ km² (Department of Statistics Singapore, 2015)
Income per capita	US$52,090 (World Bank, 2015)
Climate zone	Af – Tropical rainforest (Peel et al., 2007)

Summary

Singapore has taken an integrated and interdisciplinary approach to urban biodiversity conservation and restoration of ecosystems by adopting both biological and engineering approaches to climate change adaptation and mitigation. Multidimensional strategies are planned and implemented to address multiple climate stressors such as temperature and sea level rise and increased water-induced hazards. Restoring terrestrial and marine biodiversity through both in-situ and ex-situ conservation work and building green infrastructures such as urban parks, wetlands, and roadside avenues have increased urban greeneries and carbon sequestration and reduced flood disaster risks. These integrated ecosystem-based adaptation and disaster risk reduction measures have made a resilient Singapore.

Case Description

Singapore has taken a holistic approach to addressing climate change vulnerability and impact to its urban ecosystems. It carried out two national climate change studies incorporating vulnerability assessments that investigated physical and meteorological parameters by using statistical and/or dynamical downscaling to better understand the implications of latest Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) climate change projections at regional and local levels[9] (National Climate Change Secretariat [NCCS], 2012). It was followed by studying a range of downstream impacts that fed into adaptation plans based on a risk assessment exercise done across all government agency levels (NCCS, 2012).

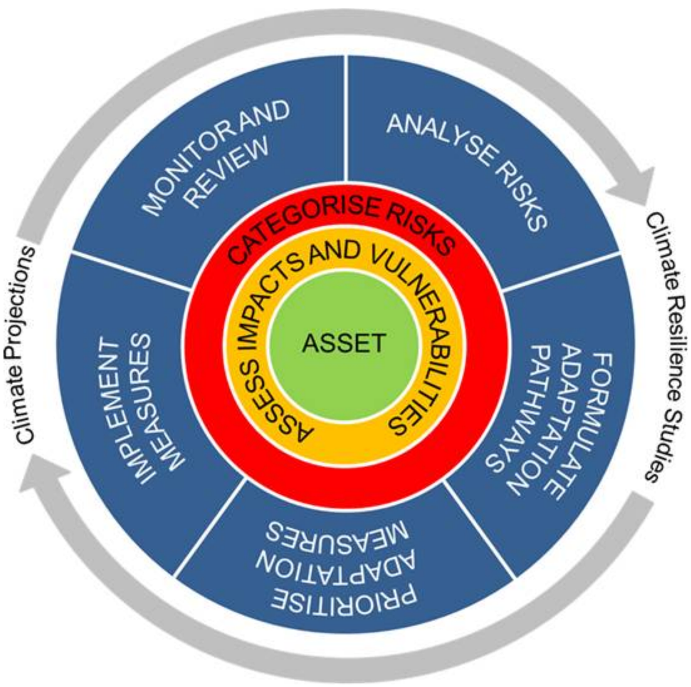
The aim of adaptation and mitigation plans includes reducing emissions across sectors (NEA, 2013), building capabilities to adapt to the impact of climate change, and harnessing green growth opportunities, as well as forging partnerships on climate change actions. The approach assesses Singapore's physical vulnerabilities to climate change based on a resilience framework (RF) to guide measures against potential climate change impacts. The RF ensures that appropriate adaptation measures are identified and implemented by adopting a cyclical approach to risk appraisal and adaptation planning. The cycle is shown in Figure 1.

Climate Change Impacts on Biodiversity

While assessing risks and planning adaptation measures, it was ensured that an understanding of biological and environmental assets was gained through risk identification and quantification. Biodiversity assets are understood through continuing surveys, such as site- or habitat-specific studies including the Terrestrial Sites Survey (2002–2003), Natural Areas Survey (2005–2007), and Comprehensive Marine Biodiversity Survey (2011–2015) to

[9] The Strategy, developed with public and private sector consultation, is available at https://www.nccs.gov.sg/sites/nccs/files/NCCS-2012.pdf

update information on the flora and fauna of Singapore. Regular and ad-hoc assessments of biodiversity and environmental assets are undertaken as part of long-term adaptation planning using a cyclical approach shown in Case Study 8.7 Figure 1.



Case Study 8.7 Figure 1. *Cyclical approach of adaptation planning.*

Vulnerability and Impacts Assessment and Adaptation Planning

The first vulnerability assessment looked at plant groups particularly vulnerable to climate change, such as figs (as keystone species for vertebrates), *dipterocarp* trees (whose bi-annual mass flowering events are keyed to the intensity and frequency of El Nino events), bryophytes (group susceptible to drought), and the effects on planted roadside trees.

Challenges have been encountered in the administrative definition and categorization of natural assets (e.g., whether each tree, each species, or each population in different areas is to be considered a separate asset) and in suggesting biological thresholds or tipping points that might be related to the various climate change parameters (rainfall, sea level, sea surface temperature, wind) in a way that facilitates risk assessment.

Past fragmentation of Singapore's forests makes them vulnerable to future long-term changes such as increased likelihood or duration of drought and higher average temperatures. Wetlands are exposed to rainfall changes, sea level rise, or water quality changes related to warming and changes in precipitation. Sea level rise will be a challenge for mangroves, which cannot retreat inland because of competing land use. Corals, which require sunlight, might not be able to grow upward quickly enough to keep pace with rising sea levels. In addition, a 1–2°C rise in sea water temperatures will lead to coral bleaching. The strategies adopted to build up the resilience of these taxonomic groups are to conserve as broad a spectrum of species as possible and to safeguard known sources of propagules.

Ecosystem-Based Adaptation

To help Singapore's biodiversity withstand the potential impacts of climate change, National Parks is working with other agencies and the community to safeguard existing species, increase connectivity of various green areas across the island, and enhance the resilience of ecosystems. This includes measures to restore forest and mangrove areas through planting and through minimization of other pressures (e.g., by removing alien invasive competitors and controlling ship wakes on mangrove coasts). Singapore has a very high proportion of planted roadside trees; efforts are made to diversify plant species used, intensify planting, create more complex 3D layering, and increase connectivity between green areas.

To keep the city green, tree management and maintenance is being intensified and enhanced. National Parks manages approximately 350–3,500 kilometers of roadside greenery islandwide as part of the effort to lower ambient temperatures. Parks and greenery are not viewed as merely the passive victims of climate change, but as tools for adaptation and mitigation. In addition, National Parks continues to support research that investigates the responses of coral reef communities to climate change triggers and promotes strategies that increase biodiversity resilience.

Case Study 8.7 Figure 2 *A well-planned urban ecosystem.*

Building Resilient Water System

Water resource management is a key priority for Singapore. An increase in weather variability may bring more frequent or more severe cycles of floods and droughts threatening the reliability of the city's water supply. To ensure a sustainable water supply for Singapore's population and industry, Singapore has built a robust and diversified water supply through four "national taps": namely, local catchment water, imported water, treated recycled water (NEWater), and desalinated water. In particular, NEWater and desalinated water are not dependent on rainfall and are thus more resilient sources in times of dry weather. Regarding flood water management, efforts are made to enhance resilience against coastal erosion and inundation associated with rising sea levels coupled with short-lived, extreme meteorological events (MEWR, 2014). A risk map study was done to better identify the specific coastal areas at risk of inundation and the potential associated damage. The results will help develop long-term coastal protection strategies.

Case Study 8.7 Figure 3 *Innovations in urban greenery development.*

Recognizing the impact of the greater weather uncertainties as well as the constraints to drainage planning posed by increasing urbanization, Singapore has revamped its drainage management approach to strengthen its flood resilience. The strategy is to optimize the management of stormwater using a holistic source-pathway-receptor approach that looks at catchmentwide ecosystem-based solutions to achieve higher drainage and flood protection standards. It covers the entire drainage system, addressing not just the pathway over which the rainwater travels. A new provision has been added to its new surface water drainage regulation, which requires developers/owners of land size 0.2 hectares or more to implement measures to slow surface runoff and reduce the peak flow of stormwater into the public drainage system by implementing on-site detention measures such as green roofs, rain gardens, and detention tanks.

Conclusion

Comprehensive and ecosystem-based adaptation strategies used by Singapore to enhance urban resilience are broad and interdisciplinary. These are approached from a multiagency and multidisciplinary perspective. Additional efforts are constantly added in coordination with agencies and development partners under a common framework on risk, adaptation, and mitigation.

Pascual et al. (2010) argue that the institution of payment for ecosystem services (PES) is another policy area where distributive justice has critical importance. Although PES theory commonly disregards distributed justice questions, actual programs are often required to take such issues into consideration for legitimacy and stakeholder buy-in. Depending on the fairness criterion used (e.g., equal distribution, need, compensation), the outcome of PES programs are determined by an equity–efficiency interdependency analysis (Pascual et al., 2010). By including a fairness criterion of some kind, programs can offer a mechanism to more systematically include equity and justice issues in management and planning for UES (Salzman et al., 2015).

Climate change effects in coastal cities expose the complexities and challenges of developing policy to address issues of distributive justice. For example, in New York City, Hurricane Sandy in 2012 devastated many coastal communities. Federal, state, and city programs determined the redevelopment path of such communities with some areas purchased for the sole purpose of creating new protective natural coastal buffer zones (NYS, 2013). While this effort aimed at improving the adaptive capacity of the entire city to future extreme weather events, it also affected low-income urban residents who were unable to rebuild their houses and thus were forced to relocate (Sandy Redevelopment Oversight Group, 2014). In other cases, newly required building elevations and other building reinforcement policies mean that the individual's or community's ability to pay determines whether a family is able to rebuild its residence or is instead forced to relocate (Consolo et al., 2013). Planning decisions can, of course, be complex, such as determining how best to serve residents in low-income countries where informal urban settlements are located in flood-prone areas, thus emphasizing the need to consider the broader complexity of the social, ecological, and economic linkages of the urban system.

8.8.3. Economics of Ecosystem-Based Adaptation and Green Infrastructure

Green infrastructure and other types of urban ecosystems in urban areas generate monetary and nonmonetary value through the provision of ecosystem services (Gomez-Baggethun et al., 2013; Kremer et al., 2016b). A major advantage of green infrastructure and EbA strategies is that they offer some of the most cost-effective adaptation options available to cities (TEEB, 2011). Around the world, evidence is mounting that effective planning, design, and management of nature in urban areas can provide multiple benefits and cost-effective solutions where traditional "gray" infrastructure solutions alone have been prohibitively costly. Linking green and gray infrastructure can provide cities both cost-effectiveness and improved function.

For example, management of stormwater runoff through green infrastructure is becoming increasingly popular among cities due to the cost savings it provides by reducing the need for new gray infrastructure to reduce local flooding and sewage overflows in combined sewage systems (see Case Studies 9.4 or 14.B, Rotterdam). Green infrastructure methods such as green streets, tree plantings, and rain barrel installations are estimated to be three to six times more effective for stormwater management than further expanding gray infrastructure (Foster et al., 2011). A US Environmental Protection Agency report analyzing thirteen case studies from cities such as New York, Philadelphia, Portland (Oregon), and Seattle found that although each municipality or entity used different cost and benefit matrices, in most cases green infrastructure was found to cost less than gray alternatives and to provide multiple benefits (NYC, 2010). Portland's Cornerstone project to disconnect downspouts resulted in the removal of approximately 1.5 billion gallons of runoff from the city's combined sewer system (Foster et al., 2011), and, in Philadelphia, more than 100 green acres were constructed and 3,000 rain barrels distributed to support increase stormwater absorption. A life cycle analysis of Low Impact Development (LID) in a New York City neighborhood found a strategy that included permeable pavement and street trees to be cost effective even though it only considered energy saving in downstream treatment plants; this has mirrored similar studies conducted in other cities.

Other important examples of ecosystem services include flood risk reduction by extending time lag between floods and storm runoff and temperature regulation, ground water recharge, and air purification. Rezoning areas for green infrastructure or restricted development are cost-effective ways to address flood risks (Foster et al., 2011). Kousky et al. (2013) evaluate avoided flood damages against the cost of preventing development on flood-sensitive lots in Wisconsin and New York. Their findings highlight the importance of the spatially specific characteristics of the lot as a way to create a cost-effective flood protection plan.

UHI research shows that the loss of urban vegetation increases the energy costs of cooling (McPherson et al., 1997). Significant savings can accrue due to the reduction of power generation through the implementation of green infrastructure (ACCCRN, 2015; Rosenzweig et al., 2009). For example, one study in Los Angeles showed that increasing pavement reflectivity by 10–35% could produce a 0.8°C decrease in UHI temperature and an estimated savings of US$90 million per year from lower energy use and reduced ozone levels (Foster et al., 2011).

Case Study 8.8 The Thorton Creek Water Quality Channel

Nate Cormier

SvR Design Company

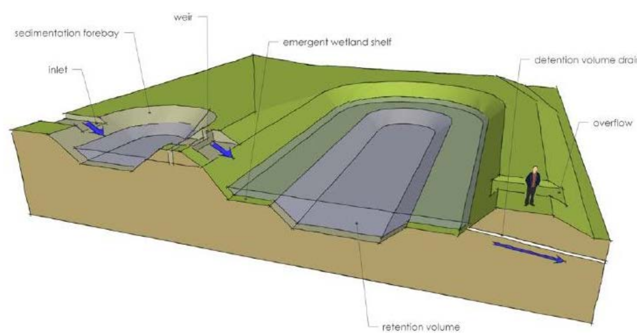
Keywords	**Stormwater treatment, green infrastructure, public space, ecosystem based adaptation**
Population (Metropolitan Region)	3,613,621 (US Census Bureau, 2010)
Area (Metropolitan Region)	15,209 km² (US Census, Bureau, 2010)
Income per capita	US$54,960 (World Bank, 2015)
Climate zone	Csb – Temperate, dry summer, warm summer (Peel et al., 2007)

The Thornton Creek Water Quality Channel, located at the headwaters of the South Branch of Thornton Creek, Washington, is a multipurpose water management project providing multiple environmental and social benefits to the urban population of Seattle. This facility addresses the problem of both heavy sedimentation and polluted water flow into the natural creek in the hilly catchments of Seattle. The integrated water treatment and management plant captures runoff from the human populated upstream watershed areas and treats it before it flows into the Thornton Creek and Lake Washington. The environmentally sound water cleaning facility occupies minimal space but provides multiple spatial and environmental benefits to the local community. It has also led to the development of a new neighborhood that is emerging as a growing urban center of the city. The facility can be termed as classic example of urban green infrastructure.

Innovative and Resilient Design

The project uses natural drainage system revival technology simulating the natural process of water flow to clean polluted and silted water and allow the cleaned water to flow through natural percolation and seepage systems year-round. The environmentally friendly design (Case Study 8.8 Figure 1) has developed natural landscaping and public pathways giving easy access to citizens to different public facilities and private buildings located throughout the area.

This model project offers the last available opportunity to improve the quality of stormwater runoff before it reaches the creek. The channel design diverts stormwater from the drainage pipe under the site to a series of surface swales landscaped with special soils and native plants. These ponds interrupt runoff speed, allowing water to seep into the soil and removing pollutants in the process. The channel regulates the water flow both during wet and dry weather, allowing for continuous cleaning of stormwater.



Case Study 8.8 Figure 1 *An innovative natural drainage outline.*

The community-driven project turned into a collective action effort that met the broad objectives of major stakeholders and fulfilled their common goals. The design has allowed development of diverse types of residential buildings, job-creating private sector enterprises, retail shops, and rest and recreation places while preserving a natural environment. This is in contrast to what existed before – a gray and brown parking lot that was eye sore to environmentalists. The provision of public open space has been used to raise environmental awareness thus providing long-term benefits, albeit of intangible nature. The facility has attracted significant private-sector investment in terms of the residential and commercial complex. The modest US$14.7 million that cost to build the Thornton Creek facility is believed to have generated more than US$200 million in the form private-sector–led investment in the city, thus catalyzing the Northgate neighborhood as a vibrant urban center of Seattle (Benfield, 2011).

Adaptation Strategy

Carved out of a former mall parking lot, the Thornton Creek Water Quality Channel provides public open space for Seattle's Northgate neighborhood while treating urban stormwater runoff from 680 acres of North Seattle. This project grew out of grassroots efforts to transform the piped Thornton Creek that ran under the parking lot to a natural water catchment system. Political leaders overcame a number of barriers that stood between developers and environmentalists by establishing a broad-based Northgate Stakeholder Group to find a way to integrate private development, public open space, and a major stormwater facility. What resulted through these collective efforts is an adaptive and resilient urban ecosystem management project providing multiple climate change adaptation and social benefits.

Opened in 2009, this catalytic natural space provides pedestrian connectivity among a major transit hub, community services, housing, and retail outlets. There is a continuous expression of water flowing, pooling, and cascading in the channel. During and after storms, the full capability of the broad channel bottom is engaged for water quality treatment. Overlooks and bridges allow users to enjoy the channel habitats and wildlife. Seat walls, benches, and interpretive artwork contribute to an inviting environment where visitors can linger and learn in a high-performance landscape (Case Study 8.8 Figure 2).

Case Study 8.8 Figure 2 *An example of human-developed biodiversity and ecosystem.*

The project has resulted in:

- A successful community process that balances public and private goals in support of environmentally compatible development and socioeconomic sustainability developed in a highly contested urban space
- The ability to catalyze more than US$200 million in investment in adjacent private residential and commercial development, generating jobs and economic opportunities
- An illustration of how to transform a former mall parking lot, a common "grayfield" in many American communities, into an aesthetically and environmentally productive urban landscape.
- Water quality treatment for runoff from 680 acres within a beautiful setting where visitors can learn about natural systems and the restoration of a historic creek.
- Increases in open space in the Northgate Urban Center by 50% to provide an oasis of native vegetation for neighbors and wildlife thus promoting urban biodiversity.

The key lessons learned are that (1) multistakeholder processes and community-driven initiatives lead to change in developing urban resilience and (2) both bottom-up and top-down processes are necessary, provided the city government recognizes and internalizes both in urban ecosystem-based adaptation planning and implementation.

8.8.4 Payment for and Valuation of Ecosystem Services

PES and the valuation of ecosystem services schemes are increasingly used by many cities as a more efficient approach to supplying essential ecosystem services. However, PES schemes are not often decided based on proper valuation and often fail to address the issue of social equity; in some cases, they exacerbate poverty and equity by raising prices or introducing a fee on previously low-priced or free services (Pascual et al., 2009).

Common valuation methods include preference-based approaches and biophysical approaches (Sukhdev et al., 2010). *Preference-based approaches* include all monetary and nonmonetary societal value settings, and *biophysical approaches* include assessments that are grounded in the processes, flows, and structures of the ecosystem (Sukhdev et al., 2010; Gomez-Baggethun et al., 2013). An important characteristic of urban green infrastructure is that it generates multiple benefits and different types of values (Kremer et al., 2016b). One of the challenges in the evaluation of the cost effectiveness of green infrastructure is accounting for societal and cultural benefits and values that are not easily quantifiable in monetary terms. For example, a study of flood protection strategies in the Netherlands found engineering methods to be most cost-effective when not considering nonmonetary benefits, but when those were included (e.g., social and cultural values), green infrastructure became more competitive. Such integration is at the forefront of current UES research (Haase et al., 2014).

8.8.5 Economic Valuation Tools

Because of a growing effort to support the integration of green infrastructure into the urban landscape, software tools are becoming increasingly available to urban planners and decision-makers for the evaluation of certain ecosystem services and benefits. For example, i-Tree[10] is a suite of software tools built by the US Department of Agriculture Forest Service that allows the quantification of ecosystem services benefits from urban trees; the Green Values Calculator[11] is a tool for comparing performance, costs, and benefits of green infrastructure practices; and InVEST[12] is a suite of software models for the assessment of ecosystem services values and tradeoffs (Nowak et al., 2013). Such tools enable the valuation of UES and support the integration of green infrastructure into urban planning. However, major gaps remain in the capacity to value urban green infrastructure and the ecosystem services it provides, including public participation in the valuation process, the integration of monetary and nonmonetary values through multicriteria analysis and other methods, scale- and thresholds-dependent values, and bridging supply and demand for the purpose of valuation (Gómez-Baggethun et al., 2013; Haase et al., 2014). Additionally, costs of EbA and nature-based solutions for climate mitigation and adaptation often have to be estimated, especially with respect to future costs, since adaptation is a long-term process. In most cases, obtaining reliable cost data will continue to be a challenge requiring several sources of evidence ranging from project case studies to national-level assessments.

8.8.6 Combining Adaptation and Mitigation in Climate Resilience Strategies

Although adaptation is necessary to minimize the unavoidable impacts of climate-induced risks and hazards, mitigation is needed to reduce urban GHG emissions and their impacts in the short- and long-term. An integrated strategy that combines all types of adaptation and resilience building measures together with mitigation strategies will have the highest level of co-benefits for human well-being (Satterthwaite et al., 2008; Karki et al., 2011). Risks and vulnerabilities are highly shaped by local environmental conditions, site characteristics, natural resource availabilities, and environmental hazards (IPCC, 2007; and Satterthwaite et al., 2008). Urban adaptation aims at reducing vulnerabilities and enhancing the resiliency of systems, agents, and institutions, and it needs to be planned by taking a holistic view of the broader urban landscape since urban areas depend on surrounding peri-urban and rural areas for ecosystem services (Tyler and Moench, 2012).

Strategies for urban ecosystem adaptation need to recognize that climate change may undermine the ability of contiguous urban and peri-urban social ecological systems to provide critical ecosystem services (Satterthwaite et al., 2008). Therefore, urban adaptation planning should ensure the sustained flow of provisioning (e.g., food, water) and regulating (e.g., clean air) ecosystem services to urban communities (Locatelli et al., 2010; McPhearson et al., 2015). In many parts of the world, the relationships among urban ecosystems, adaptation, and livelihoods is changing in fundamental ways as urban economic systems diversify across the urban–peri-urban spectrum, thus creating mixed or interlinked economic and environmental systems. Understanding these changes and their implications on the vulnerability of urban populations and ecosystems is essential to developing integrated adaptation and resilience building strategies for cities.

For example, Singapore has taken steps to restore its biodiversity and enhance UES (see Case Study 8.7, Singapore). The city has increased green cover from 35.7% to 46.5% in 20 years and also has set aside approximately 10% of its total land for green infrastructure (Lye, 2010) to provide increased climate change mitigation in the city in addition to improving ecosystem services that support adaptation. Similarly Seattle, Edmonton, Stockholm, Copenhagen, and many other cities have restored or created new urban ecosystems that ensure a more sustainable flow of ecosystem goods and services to the city dwellers now and in the future (Zandersen et al., 2014).

[10] https://www.itreetools.org
[11] http://greenvalues.cnt.org/national/calculator.php
[12] http://www.naturalcapitalproject.org/InVEST.html

8.8.7 Governance for Biodiversity for Human Well-Being

In many parts of the world, the relationship between urban ecosystems and overall urban development is changing in fundamental ways (Tzoulas et al., 2007). Understanding these changes and their implications is necessary for holistic sustainable urban development. Specifically, over the coming decades, two interacting forces will influence urban economic and ecological systems especially in developing countries: (1) intensifying processes of technological and economic globalization that are already increasing pressures on urban/peri-urban ecosystems through shifting patterns of dependency and (2) multiple environmental stress at all levels—from local to regional—mainly due to the impacts of climate change. These changes will likely undermine the ability of complex urban ecosystems to provide critical services—water, energy, food, clean air, and healthy and livable habitats—to their population, thus underlining the critical importance of urban planning, policy, and governance to safeguard urban and peri-urban biodiversity and ecosystem services.

The decisions and deliberations of the UN Convention on Biological Diversity (CBD, 2009) as well as many others (ICLEI-Africa, 2013; UNEP, 2009; IUCN, 2009; have created an emerging global effort to enhance urban ecosystem governance structures by capturing the nexus between urban biodiversity and climate change. These efforts have urged for biodiversity vulnerability assessments and research on links between biodiversity loss and urbanization (Wilkinson et al., 2010; 2013; Schewenius et al., 2014). Figure 8.8 illustrates the current international governance landscape for urban biodiversity and ecosystem services, although it is constantly evolving. Still, progress remains at a formative stage as stakeholders and urban actors struggle to fully understand their respective roles and establish coordination mechanisms to exploit the latent potential of biodiversity and ecosystem services in cities for climate change adaptation.

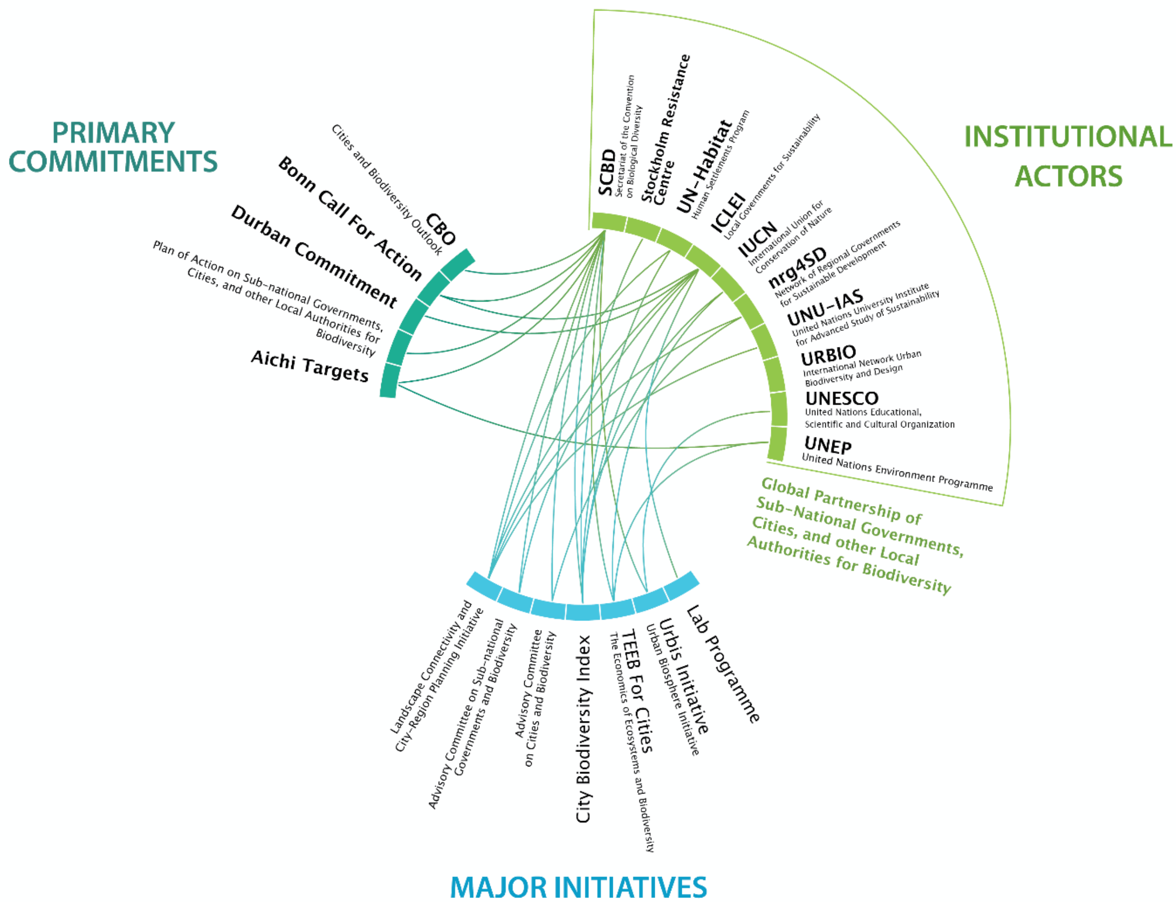


Figure 8.8: *Overview of global governance arrangements for urban biodiversity and ecosystem services. Source: UN Habitat (2012)*

Increasing a city's capacity to meet growing challenges can depend on the development of a holistic governance approach in which the city is understood as a dynamically interacting social-ecological system (Frantzeskaki and Tilie, 2014) (see Chapter 16, Governance and Policy). Increased linkages among strategies, projects, and actors (Meyer et al., 2012), including the active involvement of local citizens, is important for identifying needs, challenges, and design policies and efficiently implement them (Ward et al., 2013; Wardekker et al., 2010). Creating strong links between formal governance and informal, on-the-ground participants and managers is crucial to forming holistic governance with greater potential for successful urban ecosystem management outcomes. However, informal participation and management is seldom translated into formal governance in urban settings (Colding, 2013). The Thornton Creek Water Quality initiative of Seattle city is an example that shows how a local community-driven project supported by city government is generating multiple benefits and synergies.

Governing ecosystem processes requires coordination across different levels of policy, legislation, and jurisdictional authorities. Urban ecosystems and biodiversity benefits often transcend administrative boundaries, thus necessitating collaboration among national, regional, and local-level agencies (Ernstson et al., 2010; McPhearson et al., 2014). The multiscalar and multisectoral relationships that impact urban biodiversity and ecosystem services create urban governance and policy challenges because decisions by one branch and one level of fragmented urban and national government structures can create long-term implications for the entire urban ecosystem landscape (Asikainen and Jokinen, 2009; Ernstson et al., 2010; Borgström et al., 2006). Apart from this scale mismatch issue, there is also a functional mismatch between ecosystems and the institutions managing them (Cumming et al., 2006) because different decision-makers are operating within and beyond the city and urban landscape boundaries. However, if different units of city and peri-urban governments worked in tandem, a number of synergies in the governance of urban biodiversity and ecosystem services is possible (Raudsepp-Hearne et al., 2010). This requires functioning and dynamic science–policy linkages at regional scales, challenging the current structure of governance frameworks, practices, and institutions.

Despite new research initiatives and science–policy platforms, significant challenges remain in equitably managing biodiversity and ecosystem services in urban and peri-urban areas for the mutual benefit of humans and other species (Schewenius et al., 2014). Rapid urbanization is occurring in places that face some of the most severe challenges to public health and urban biodiversity conservation. Additionally, these same urban systems are where systems of formal government and planning tend to be weak and the capacity to influence policy is inadequate (Wilkinson et al., 2013).

Effective city governance will play a key role in determining the future of biodiversity across the world, not least because cities are rapidly expanding into the world's biodiversity hotspots. Significant urban ecosystem policy changes will need to accompany or even precede effective governance practices in order to direct future urban growth so that biodiversity and the ecosystems services it provides are safeguarded (Seto et al., 2012; Wilkinson et al., 2013). Ecosystem protection in cities will rely on increasing efforts by parks and natural area managers to focus on those management outcomes that seek to maximize ecosystem functioning for services – in many places an abrupt shift from existing or past management goals. Supporting a diversity of governance systems, from official regulations to informal governance systems (e.g., local governance of urban allotment gardens) can provide a multilayered protection system and strengthen support through multiple stakeholders (Schewenius et al., 2014). Additionally, flexible policies and regulations will be needed to accommodate unanticipated climate changes and ecological responses.

8.9 Science–Policy Linkages

Adaptive and resilient urban ecosystem conservation requires policies that are based on synthesized and relevant knowledge systems, local evidence, and multilevel, multidisciplinary, and multistakeholder consultations and inputs (IUCN, 2009; Van Kerkhoff and Lebel, 2006). Three important challenges inhibit the use of climate and conservation science in managing and planning urban ecosystems: (1) research capacity and activities are often scattered so that policy-influencing efforts are uneven in distribution and quality across sectors and regions (Haase et al., 2014); (2) data and information availability and usability are limited due to knowledge gaps and scale-appropriate specificity (e.g., in Sweden, local planners and decision-makers found it difficult to implement national biodiversity strategies because they were too general and abstract); and (3) policy-makers and other decision-makers often have limited capacity to access, interpret, and act on research information on technical subjects such as biodiversity and climate change, particularly where results are complex and reflect inherent uncertainties at multiple scales (Amin, 2007). Urban policy-makers therefore face significant challenges when seeking to increase the resilience of communities and the built environment to the effects of climate change (Frantzeskaki et al., 2016).

An integrated and coordinated urban planning, design, and implementation policy that considers biodiversity and ecosystem services should address multiple co-benefits from human health improvement, climate change adaptation, biodiversity conservation, and disaster management. For example, increasing green space, tree cover, and water bodies in urban areas, in addition to moderating UHI effects, will also sequestrate carbon, control pollution such as aerosol dusts, regulate hydrological processes, and influence regional climate (Hamstead et al., 2015; Larondelle et al., 2014). Policy actions that take advantage of the complex concepts of multifunctionality, synergies, and tradeoffs require science- and evidence-based policy processes that integrate ecosystem-based approaches in governance areas such as disaster management, community actions, and linking adaptation with sustainable development goals and practices (Elmqvist, 2013). Such processes involve key urban actors (including politicians) and civil societies in urban conservation activities that can translate research-based information and knowledge into use by policy-makers and other decision-makers (Elmqvist et al., 2013; Mincy et al., 2103; OECD/CDRF, 2009).

Co-production of knowledge, where the users of the knowledge are involved from the beginning in the research and review process, is another key component of successful science-based policy-making. Lessons from the Asian Cities Climate Change Research Network (ACCCRN) has concluded that urban process needs to be based on multiple stakeholder engagement and iterative shared learning dialogue that can bring a broad range of perspectives to city managers. Recognizing that urban policies are neither objective nor neutral and that politics remain paramount in policy-making processes (ODI, 2005) emphasizes that shared-learning processes (Institute for Social and Environmental Transition [ISET], 2010) and co-production can help raise awareness and empower stakeholders with new and consolidated knowledge.

Strategies to effectively link science with policy and action need to (1) involve key actors (local residents, planners, designers, managers, policy-makers, NGOs) in the process of identifying problems and the actions they can take (i.e., shared learning and knowledge coproduction), (2) produce grounded evidence where action can be used to respond to ecosystem changes that are relevant to members of communities and key sectoral decision-makers, (3) effectively communicate evidence to an array of end users so that they understand and can act on it (translation of research results into use depends critically on how we communicate via direct experience, accessible products, and, for academic and policy global audiences, peer-reviewed articles), and (4) design research outputs to respond to the types of information different types of actors need and can relate to (e.g., cost-benefit analyses and regulatory regimes for government and multilateral investors, new business opportunities for the private sector, equity concerns for the community groups, and examples of tangible solutions to common climate vulnerabilities that individuals and households face). These approaches can help to build incremental science–policy linkages that support efforts to transition cities toward sustainability and resilience.

Box 8.6 WWF's Earth Hour City Challenge

The World Wildlife Fund (WWF) supports a vision of the world where people and nature thrive. In an increasingly urbanizing world, achieving this vision means working together with cities to make them livable and sustainable. WWF is the world's largest conservation organization, working not only on wildlife protection but also on food, oceans, forests, water, and climate change. WWF is bringing together its network of experts on renewable energy, public engagement, nature-based adaptation, and many other disciplines to address the issues cities are facing in the 21st century, in particular the threat of climate change and its associated hazards.

WWF's signature program for cities is the Earth Hour City Challenge (EHCC). EHCC was created in 2011 to mobilize action and support from cities in the global transition toward a sustainable future. It has since grown to encompass cities in twenty countries around the globe. Last year, 166 participating cities reported their climate data, commitments, and a total of 2,287 mitigation actions on the carbon*n* Climate Registry (cCR) for review by an esteemed jury of experts. The jury, comprising high-level representatives from key city networks, development banks, institutions, universities, and enterprises, evaluate the participating cities' goals and strategies. Every year, one city from each participating country is awarded the title National Earth Hour Capital. From among these inspiring finalists, the jury then selects one Global Earth Hour Capital. WWF offices in twenty countries support cities on EHCC communications and low-carbon project implementation.

One key objective with the EHCC has been to gather a critical mass of city reporting on their climate commitments and climate action in order to raise the awareness of decision-makers involved in global climate negotiations and increase aspirations and actions at the national level.

The We Love Cities campaign profiles finalists and spurs interaction between cities and their citizens through social media. Public engagement and raising awareness around the positive stories on local climate action are key components of the program. We Love Cities invites citizens from around the world to express their love through votes, tweets, and Instagram pictures and by submitting suggestions on how their cities can be more sustainable. These suggested improvements are shared among all the participating cities. More than 300,000 people who truly love their cities and want to see them become more sustainable have engaged in this campaign.

WWF works closely with International Council for Local Environmental Initiatives (ICLEI)-Local Governments for Sustainability to run the EHCC as well as many country-level programs that extend technical and communications support to cities around the world. In addition to ICLEI, WWF is partnered with other leaders in addressing climate change including C40 Cities Climate Leadership Group, Compact of Mayors, Rockefeller 100 Resilient Cities, US Agency for International Development, and more.

Technical guidance and original research from WWF are also available to support cities including the Green Recovery and Reconstruction Training Toolkit; Green Flood Risk Management Guidelines; Urban Solutions for a Living Planet; Measuring Up 2015, Financing the Transition: Sustainable Infrastructure in Cities; and Reinventing the City.

8.10 Knowledge Gaps and Areas for Further Research

Sustainable generation and management of urban biodiversity and ecosystem services in the face of the challenges posed by climate change, population growth, poverty, and environmental degradation requires adaptive human and institutional capacity that can enhance resilience, human well-being, and conservation(TEEB, 2010; Elmqvist et al., 2013; RUAF, 2014). However, a common problem that urban policy-makers and city managers face when dealing with climate change is bridging significant knowledge gaps. This is especially challenging in the context of climate change effects on cities and urban areas (Elmqvist et al., 2013). The recent release of the IPCC AR5 report makes headway in bridging the knowledge gap at the global level (IPCC, 2014), but for many urban areas, especially in developing countries, data and knowledge gaps remain a problem at both local and regional levels. Enhancing urban biodiversity and ecosystem services while tackling climate change and a host of social issues in cities requires a continuous flow of knowledge-based solutions. Missing empirical evidence and practical ecological knowledge on urban biodiversity and ecosystems management often prevents city managers from recognizing the value of ecosystems for the development of more climate resilient urban systems.

Additionally, significant knowledge gaps remain in understanding the current status of biodiversity in cities. Despite growing databases and new global analyses of urban biodiversity and ecosystem services (Elmqvist et al., 2013; Gomez-Baggethun et al., 2013; Aronson et al., 2014), most cities, especially in low- and middle-income countries do not have adequate data on the status and extent of biodiversity and urban ecosystem resources. Leveraging UES for climate resilience is hampered by this lack of data, with multiple global and local agencies and institutions calling for national, regional, and local biodiversity and ecosystem assessments.

Producing tools and guidelines on how to effectively manage and govern urban ecosystems so that critical services are available to local populations remains an area in need of additional research and practice-based expertise (Schewenius et al., 2014). Benefits of biodiversity and ecosystems are not equally distributed in urban areas. Often, poor communities or housing for them (e.g., Cape Flats) are blamed for biodiversity loss and habitat fragmentation in spite of their low per capita impact or having been pushed to the most marginal and fragile sites (Ernstson et al., 2010a). Improving equitable distribution and access to ecosystem services, whether it is for shade relief from urban heat waves or protection from climate-driven extreme events such as flooding in coastal cities, depends on increasing equality and reducing mismatches between ecosystem services supply and social demand for these services (McPhearson et al., 2014; Salzman et al., 2015).

Although cities and urbanized regions depend on biodiversity in ecosystems to sustain human health and well-being (TEEB, 2011), this relationship is not well understood for all ecosystem services, and the connection between biodiversity and human livelihoods has yet to be widely incorporated in urban policy and planning (Hansen et al., 2015; McPhearson et al., 2014; McPhearson et al., 2016). We also still know little about how biodiversity, ecosystem function, and ecosystem services are related in urban environments. Empirical and theoretical research on the relationships among biodiversity (including native and non-native species), ecosystem function, and ecosystem services is critical for developing design standards for climate resilient green infrastructure.

8.11 Recommendations for Policy-Makers

The growing impacts of climate change and climate variability on interconnected human–environmental urban systems are increasing the vulnerability of both human and ecosystems in cities. Cities are particularly at risk. Ecosystems in urban contexts underpin the security of public health, water, food, industrial activities, biodiversity conservation, energy, and transport, as well as recreation and tourism sectors. Effective management of urban ecosystems using multisector and multiscale approaches will be key in the pursuit of climate resilient, sustainable urban development.

Adaptive management of ecosystems at landscape or watershed scales involving all stakeholders across municipal boundaries is critical to safeguarding ecological resources for climate adaptation and mitigation. Investing in green infrastructure and EbA is particularly relevant for cities and urbanized regions because it can integrate climate change adaptation and disaster risk reduction, providing cost-effective nature-based solutions for addressing climate change in cities (UNEP, 2012; Munroe et al., 2010). Investment in green infrastructure and EbA can generate multiple co-benefits for human well-being by mainstreaming climate and environmental considerations across urban systems and encouraging the sustainable management of ecological resources to improve the resiliency of inhabitants, built environments, and urban infrastructure. These approaches have the potential to mainstream environmental and climate change information into urban planning, decision-making in urban design, and management and implementation processes. Research in urban systems is making clear the cost-effective, widely beneficial impacts of investing in biodiversity and urban ecosystems for climate adaptation. We suggest the following policy-relevant recommendations:

1. Invest in ecosystem-based adaptation and green infrastructure planning as a critical component of climate adaptation strategies and urban development but also for improved health, disaster risk reduction, and sustainable development.
2. Incorporate the monetary and nonmonetary values of biodiversity and ecosystem services into cost-benefit analyses for climate adaptation and urban development and develop innovative means of financing (e.g., public–private partnerships) for urban ecosystem and biodiversity protection, restoration, and enhancement.
3. Utilize a systems approach to ecosystem-based climate adaptation, explicitly recognizing the social-ecological relationships that co-produce ecosystem services and drive ecological dynamics in urban systems.
4. Plan and manage for a sustained supply of critical urban and peri-urban ecosystem services over longer-term time horizons (20, 50, 100 years).
5. Strengthen urban–peri-urban–rural linkages through integrated and multidisciplinary urban and regional ecosystem

planning and management and involve local communities and diverse stakeholders to reduce the vulnerability of urban poor and minorities.

6. Launch collaborative, cross-boundary, and co-designed urban biodiversity and ecosystem research and advocacy programs to inform policies and planning and further develop nature-based solutions toward more resilient, livable, and sustainable urban futures.

8.12 Conclusion

Urban areas all over the globe, especially in developing countries, are growing rapidly in both population and area and are putting pressure on urban biodiversity and ecosystems to support urban livability, sustainability, and climate resilience. Climate change and its impact on cities amplify the effects of more typical urban stressors for ecosystems. Urban biodiversity and ecosystems will need to be safeguarded and enhanced to support climate mitigation and adaption efforts and deliver critical, nature-based co-benefits for human well-being in cities. Urban ecosystems can help offset the worst impacts of climate change, including reducing the impact of extreme events by regulating hydrology, local climate, and providing critical ecosystem services. City leaders need to recognize the interdependence of the city with peri-urban and rural surroundings and continue to broaden their planning horizon to regional levels to account for the fact that species, ecosystems, and people cross municipal boundaries and so must planning, management, and governance.

Urban and peri-urban ecosystems provide critical natural capital for climate change adaptation in cities and urban regions. Ecological spaces in cities, including all forms of green infrastructure, provide important ecosystem services such as UHI mitigation, coastal flood protection, and stormwater mitigation. Urban ecosystems are already and will continue to be affected by climate change. Cities should utilize, protect, and restore these ecosystems when seeking to improve urban resilience to the effects of climate change. City planners, managers, and decision-makers can utilize nature-based solutions to design and implement climate adaptation and mitigation strategies in combination with more traditional built infrastructure solutions. Investing in natural capital is a cost-effective strategy that also generates multiple co-benefits that enhance human well-being. In this way, urban ecosystems simultaneously provide means for improving urban resilience, livability, equity, and sustainability.

Building climate resilient urban communities entails a socio-ecological framework as opposed to socio-technological approaches (Berkes and Folke, 1998) that can reconnect cities to the biosphere (Andersson et al., 2014). Investing in urban ecosystems for climate adaptation and mitigation makes good sense because it is cost-effective and provides numerous co-benefits that can improve equity and livability in cities. Mounting evidence of the benefits of urban ecosystems as nature-based solutions calls for strengthening climate resiliency by investing in good governance, flexible institutions, and collaborative programs. We find through this review that urban biodiversity and ecosystem services are critical to develop climate resilient cities.

ANNEX 8.1 Stakeholder Engagement

To better gauge a stakeholder understanding of urban ecosystems and biodiversity for climate change adaptation and mitigation, a two-pronged approach was used to reach a diverse array of stakeholders. Chapter authors met informally with various stakeholders at workshops and meetings in Berlin, New York, Rotterdam, Stockholm, and Paris, engaging with a multidisciplinary, global group of actors who contributed broader perspectives on urban climate change and development issues. Despite these engagements being held in the United States and Europe, the stakeholders engaged were geographically, gender, and ethnically diverse, capturing views of managers, designers, citizens, planners, and policy-makers and other decision-makers. Additionally, an electronic survey was conducted to gather the views of a wider community for more formalized engagement with stakeholders. The goal of the survey was to better understand how a broad range of stakeholders perceives urban ecosystems, their value, and their role in reducing climate change impacts and improving the resilience of cities.

Annex 8.2 Urban Ecosystem and Biodiversity Stakeholder Engagement Survey

Authored by Helen Santiago Fink, Quynn Nguyen, and Chapter Lead Authors

The stakeholder survey period was October 20–November 21, 2014, during which sixty-two responses were collected and then analyzed.

This basic survey instrument (Exhibit 8.A) was designed as part of the research for this chapter to solicit information from two key stakeholders groups (see Exhibit 8.B for Stakeholder list): (1) urban professionals/practitioners or those entities involved in shaping or influencing the physical urban space, including planners, architects, engineers, political/regulatory decision-makers, real estate and construction industry professionals, environmental NGOs, and others; and (2) urban end-users, which includes everyone who uses and benefits from the urban environment, from the general public to households; visitors; business enterprises; social, service, and learning facilities; and many others. The survey was developed by a subgroup of the chapter authors and reviewed by external reviewers. The twenty survey questions were structured in four parts: (1) profile of the anonymous responder, (2) role/value of urban ecosystem and biodiversity, (3) relationship of ecosystems services to climate change, and (4) socioeconomic and policy measures to support urban ecosystems services.

The survey received responses from various regions of the world, including Africa, South America, Asia, and the United

States and Europe (with the largest representation). In respect to responder profiles, statistics indicated that 90% were urban dwellers; 40% were government employees; and 60% held a master's degree. Awareness of the term "urban ecosystem services" (UES) was indicated by 59% of the responders, with 28% never having heard of the term before this survey and 13% somewhat aware. The role of UES was seen by 80% of responders as valuable for aesthetics, recreation, health, pollution control, and climate mitigation and adaptation; however, climate change recorded the lowest (9%) among them all. Rural areas and wealthy populations were seen to benefit more, despite 57% of all responders acknowledging the benefits of UES for all groups. When asked to rate the value of UES among sixteen potential attributes, air quality (80%) and a healthy life (78%) followed by water quality (66%) received the highest responses. Physical, psychological, and spiritual well-being, as well as recreation/leisure, were rated high by approximately 53% of responders. Climatic benefits such as carbon sequestration, temperature reduction, and extreme weather events (e.g., landslide prevention) received 50%. UES ratings were 21% for cultural and sport activities, and education received 48% with pollination of crops being an outlier with only one response.

Annex Box 8.1 Stakeholder Survey

Chapter authors pursued a two-pronged approach to engage a multidisciplinary group of stakeholders to contribute broader perspectives on the chapter's themes: (1) consultations at relevant international conferences and workshops and (2) a detailed online survey. Although the survey had limitations in sample size (n = 62), it offers insights into the views of an international audience and suggests key points for broader stakeholder engagement. Key findings included:

- Stakeholders are strongly in support of protecting and enhancing UES for climate action, human well-being, and general quality of life. Despite 27% of survey respondents reporting that they had not heard of the term "urban ecosystem services," survey results suggest wide public support for investing in urban ecosystems for climate adaptation and mitigation.
- The role of urban ecosystems services was seen by 80% of survey responders as valuable for a multitude of issues including aesthetics, recreation, health, and pollution control; however, climate change was among the lowest (9%) reported benefit.
- Stakeholders' "strong concern for climate change" and high agreement on "associated benefits of ecosystem services" calls attention to the value of increasing awareness to better communicate the multiple benefits of urban ecosystems to society.
- Survey results indicated a favorable "willingness to pay" for ecosystem services that provide climate mitigation and adaptation.
- Research is needed to fully understand how to positively encourage "human/personal attachment to the natural environment" (acknowledged by 89% of survey responders) to promote environmental stewardship and the development of stronger policy actions and fiscal instruments to advance climate decision-making and investment for natural capital and nature-based solutions.

Because of the small sample size of sixty-two responders, the chapter authors are cognizant of the limitations to generalizing the findings of the survey's results. It is unrealistic to correlate the results to the wider population. Nevertheless, the survey highlights some key points for further investigation on the developing role of UES in the climate change agenda. Engagement with practitioners and decision-makers (e.g., city managers, administrators, policy-makers) at multiple levels, including with active end-users of ecological infrastructure (e.g., urban naturalists, conservationists, researchers, non-profits, NGOs, governments, social institutions, museums, community groups, and citizenry), could benefit from increased social-learning models promoting environmental education as an opportunity for increased stakeholder engagement. Communicating the critically important role that the natural environment and biodiversity play in both climate adaptation and mitigation, as well as in their nexus, is a cornerstone to elevating the climate and sustainable cities dialogue and practical action in urban areas.

In a number of separate questions, the relationship between UES and climate change was highly correlated, with 82% acknowledging a connection (see Annex Figure 8.A); similarly, 72% of responders indicated being "very concerned" about climate change. UES were perceived as important to help or be "able to protect" health (93%), water and sewage (82%), and property values (80%), while both food supply and employment recorded a lower response (65%). There was general willingness to support UES for climate change action through economic and financial measures by around 65% of respondents. Combinations of fiscal instruments were favored by almost half of responders, yet when viewed individually, specific measures such as a carbon tax (46%), general government budget (51%), and penalty for polluters (43%) rated among the highest (see Annex Figure 8.B). The level of support was strongly recorded on a personal basis, with 68% of responders willing to volunteer and participate in a planning process for urban ecosystems for environmental protection. Regulatory encumbrances on land use were also overwhelmingly supported (62%) in order to provide more green space in cities, including restrictions on responders' private property.

Overall, the survey suggests strong support for protecting and enhancing UES for climate action, with strong co-benefits for human well-being. The result is encouraging, given the fact that 27% of responders had not heard of the term "urban ecosystem services" before and thus indicating potentially wider multistakeholder support. The high rating for "strong concern for climate change" and a majority agreeing on reaping "associated benefit of ecosystem services" calls attention to the need for increased awareness in building efforts to educate the public on the multiplicity of benefits provided by urban ecosystems to society. The survey result indicating a general "willingness to pay" for UES to contribute to both climate mitigation and adaptation, and this suggests increasing opportunities to incorporate EbA and green infrastructure development (among other measures) into local and national urban policies and practices. Research is needed to understand how to positively exploit the strong response of a "human/personal attachment to the natural environment" (acknowledged by 89% of survey responders) toward the development of stronger policy actions, integrated planning, and fiscal instruments to advance climate change decision-making and investment in building climate resilient cities.

Annex Figures 8.A and 8.B. *Results of stakeholder engagement survey. A. Demonstrates broad understanding of relationship between urban nature and climate change. B. Shows possible climate change risk reduction programs and how they are prioritized among stakeholder respondents.*

Exhibit 8.A Urban Ecosystem and Biodiversity Stakeholder Engagement Survey

1. Where do you live? (Choose one only)
- **(a)** Urban area (city) Name and Country: __________________________
- **(b)** Non-urban areas (suburban and rural areas) – Name and Country: _____________

2. What is your employment? (Choose one only)
- **(a)** Government employee
- **(b)** Private sector employee
- **(c)** Self-employed
- **(d)** Civil society/NGO/nonprofit
- **(e)** Development partner (donor) agencies
- **(f)** Others

3. Which best describes your household status?
- **(a)** Single
- **(b)** Married with no children
- **(c)** Married with children
- **(d)** Other

4. What is your highest level of education?
- **(a)** Post/doctoral degree
- **(b)** Master degree
- **(c)** Bachelor degree
- **(d)** High school degree (12 years of education)
- **(e)** Less than high school degree

5. What in your view is the role of Ecosystems (or Nature such as trees, parks, gardens, animals, lakes, rivers, wetlands, green spaces, etc.) in a city?
- **(a)** Aesthetic value
- **(b)** Recreation
- **(c)** Pollution control
- **(d)** Climate change adaptation and mitigation
- **(e)** Others
- **(f)** All

6. In your view which section or who in society benefits the most from Ecosystem(s) in your community/city?
- **(a)** Rich class
- **(b)** Middle class
- **(c)** Poor class
- **(d)** Other
- **(e)** Everyone

7. Which sector or community benefits most in the world from Ecosystems?
- **(a)** Urban populations
- **(b)** Rural populations
- **(c)** Global population
- **(d)** Governments
- **(e)** Businesses

8. Select the importance of each of the benefits of Ecosystems/Nature in a city (rating from 1 to 5 [highest]):

(a)	Recreation and leisure	1	2	3	4	5
(b)	Sports activities	1	2	3	4	5
(c)	Cultural activities	1	2	3	4	5
(d)	Healthy life	1	2	3	4	5
(e)	Water quality	1	2	3	4	5
(f)	Air quality	1	2	3	4	5
(g)	Physical well-being	1	2	3	4	5
(h)	Psychological well-being	1	2	3	4	5
(i)	Spiritual well-being	1	2	3	4	5
(j)	Urban temperature	1	2	3	4	5
(k)	Flood prevention	1	2	3	4	5
(l)	Landslide prevention	1	2	3	4	5
(m)	Food production	1	2	3	4	5
(n)	Carbon sequestration	1	2	3	4	5
(o)	Pollination of crops	1	2	3	4	5
(p)	Others ___________	1	2	3	4	5

9. Have you heard about *Urban Ecosystem Services* before this Survey?

(a) Yes
(b) Somewhat
(c) No

10. How concerned are you about Climate Change?

(a) Very concerned
(b) Somewhat concerned
(c) Not concerned

11. Is there a connection between Urban Ecosystems **(Nature in a city) and Climate Change?**

(a) Yes
(b) Maybe
(c) No

12. Can Urban Ecosystems HELP with or PROTECT the following?

12.1 PEOPLE

(a)	Health	Yes	Somewhat	No
(b)	Injuries/risks (on personal level)	Yes	Somewhat	No
(c)	Security (on community/city level)	Yes	Somewhat	No
(d)	Food supply	Yes	Somewhat	No
(e)	Water supply	Yes	Somewhat	No

12.2 ASSETS

(a)	Property values	Yes	Somewhat	No
(b)	Business losses	Yes	Somewhat	No
(c)	Foreign/domestic Investment	Yes	Somewhat	No

12.3 INFRASTRUCTURE

(a)	Roads	Yes	Somewhat	No
(b)	Electric power	Yes	Somewhat	No
(c)	Water and sewage	Yes	Somewhat	No
(d)	Public transportation	Yes	Somewhat	No
(e)	Employment/jobs	Yes	Somewhat	No

13. Can expanding urban green areas in the city help prevent global warming and/or reduce greenhouse gas emissions (GHGs)?

(a) Yes
(b) Maybe
(c) No

14. Can Urban Ecosystems in the city offer a better quality of life?

(a) Yes
(b) Maybe
(c) No

15. Would you be willing to pay for preserving and/or expanding Urban Ecosystems to help with Climate Change risks?

(a) Yes
(b) Somewhat
(c) No

16. How should a Climate Change risk reduction programme through urban ecosystem improvement be funded?

(a) Carbon tax
(b) Penalty fee for pollution/carbon emissions
(c) Donations
(d) Government budget
(e) Public–private partnerships

17. Would you be willing to participate in the process of Urban Ecosystem planning and environmental protection/conservation on a personal/volunteer level?

(a) Yes
(b) Maybe

(c) No

18. Would you be willing to have more regulations/laws that would require more green spaces in public and private areas?
    - (a) Yes
    - (b) Maybe
    - (c) No
19. Would be you be willing to have a restriction(s) on your property/land in order to have a greener city/community?
    - (a) Yes
    - (b) Maybe
    - (c) No
20. Do you feel a personal attachment to the natural environment?
    - (a) Yes
    - (b) No
    - (c) Somewhat

Exhibit 8.B Urban Ecosystems and Biodiversity Stakeholders List

Institutional (representatives of):

Public:

1. *City (Executive)*
    - **a.** Climate Change – adaptation/mitigation
    - **b.** Urban Planning
    - **c.** Environmental
    - **d.** Housing
    - **e.** Health
    - **f.** Education
    - **g.** Transportation
    - **h.** Urban conservation (infrastructure)
    - **i.** Parks and gardens (Green areas)
2. *Metropolitan/State (Executive)*
    - **a.** Climate Change – adaptation/mitigation
    - **b.** Environmental
    - **c.** Economy
    - **d.** Transportation
    - **e.** Health
    - **f.** Education
    - **g.** Housing
    - **h.** Infrastructure
3. *City and State Councils (Lawmakers)*

    Representatives of related areas (as above)

Private Economic Sectors' Associations

- **a.** Real Estate
- **b.** Infrastructure
- **c.** Industry
- **d.** Commerce
- **e.** Transportation
- **f.** Tourism

Private Civil Society's Associations

- **a.** Residents
- **b.** Arts and Culture, Education, Social, and Environmental NGOs
- **c.** Professionals (urban planners, architects, landscape architects, engineers, foresters, agronomy, etc.)
- **d.** Informal active organized groups

Individuals (users)

- **a.** Parks and trails
- **b.** Public transportation
- **c.** Pedestrians in busy streets
- **d.** Private transportation (car drivers)

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Chapter 8 Case Study References

Case Study 8.1 Coastal Natural Protected Areas in Mediterranean Spain: The Ebro Delta and Emporda Wetlands

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