Nature in the Urban Century

A global assessment of where and how to conserve nature for biodiversity and human wellbeing

The Nature Conservancy

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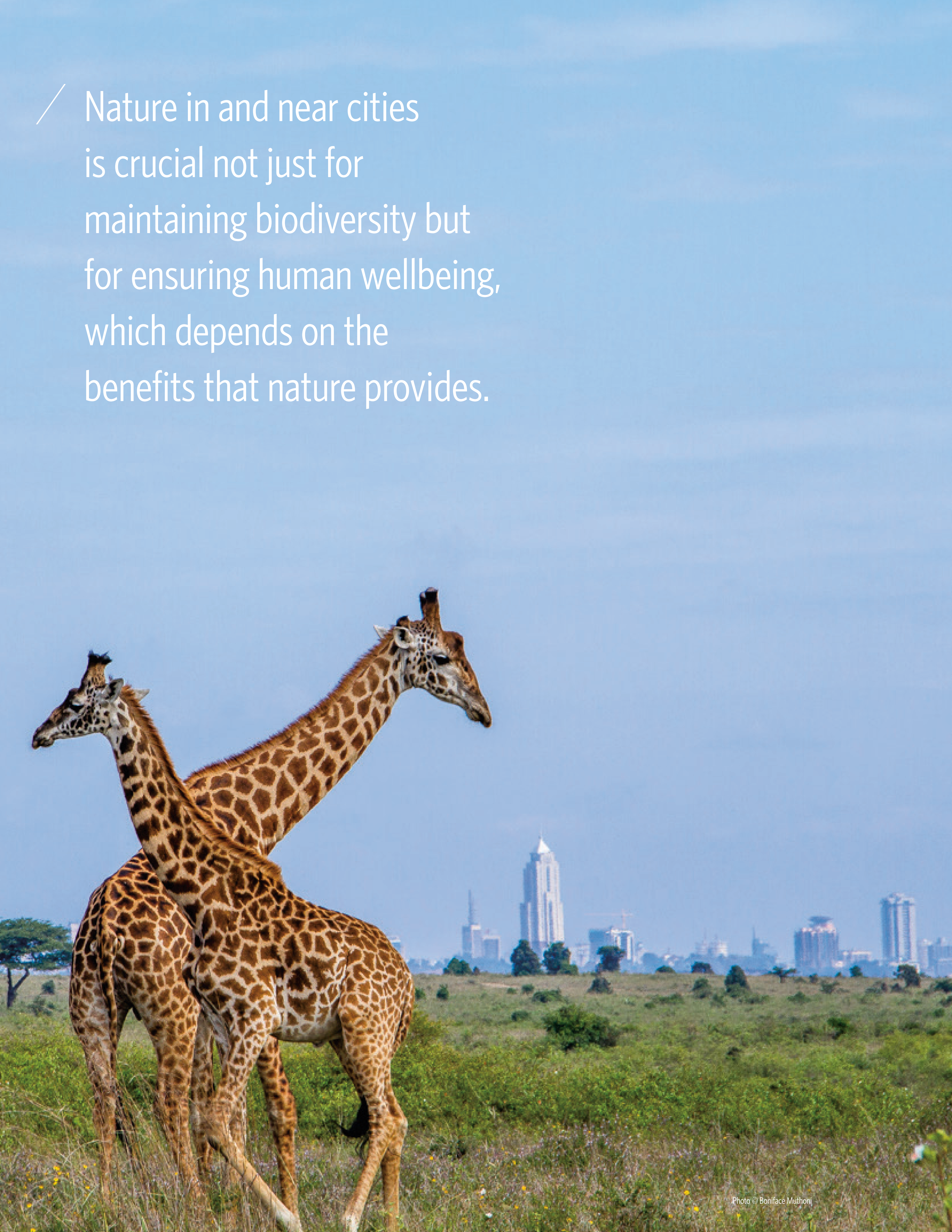
Nature in and near cities is crucial not just for maintaining biodiversity but for ensuring human wellbeing, which depends on the benefits that nature provides.



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Governments around the world need to plan for a positive natural future.

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Executive Summary

This century will be remembered as the urban century. Our generation will witness the most significant urban growth in human history. By 2050, there will be 2.4 billion more people in cities, a rate of urban growth that is equivalent to building a city with the population of London every seven weeks. Humanity will urbanize an area of 1.2 million km^2, larger than the country of Colombia (*Figure 1*). Cities have been called humanity's greatest invention, a way of living that can bring many benefits, including increased economic productivity and innovation, greater opportunities for education and individual enhancement, and more efficient use of natural resources and energy. The urban century thus holds enormous opportunity for humanity. However, the Urban Century also presents a challenge to the global environment, both directly through the expansion of urban area and indirectly through urban energy and resource use.

Urban growth is one of the main global issues that the Convention on Biological Diversity (CBD) must address to meet its ambitious goals. Governments must envision a positive natural future for our urban century, a future in which sustainable urban growth occurs in appropriate places while nearby nature is protected, restored, and enhanced. Nature in and near cities is crucial not just for maintaining biodiversity but also for ensuring human wellbeing, which depends on the benefits that nature provides.

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This report presents a business-as-usual scenario, which assumes that current urban growth trends continue, and quantifies the impact that urban growth could have on biodiversity and human wellbeing. This report also quantifies the significance of natural habitat for climate mitigation and adaptation. We end by highlighting solutions that can help avoid the negative impacts forecasted under our business-as-usual scenario—ways that governments at all levels can plan and implement a positive natural future for our urban century.

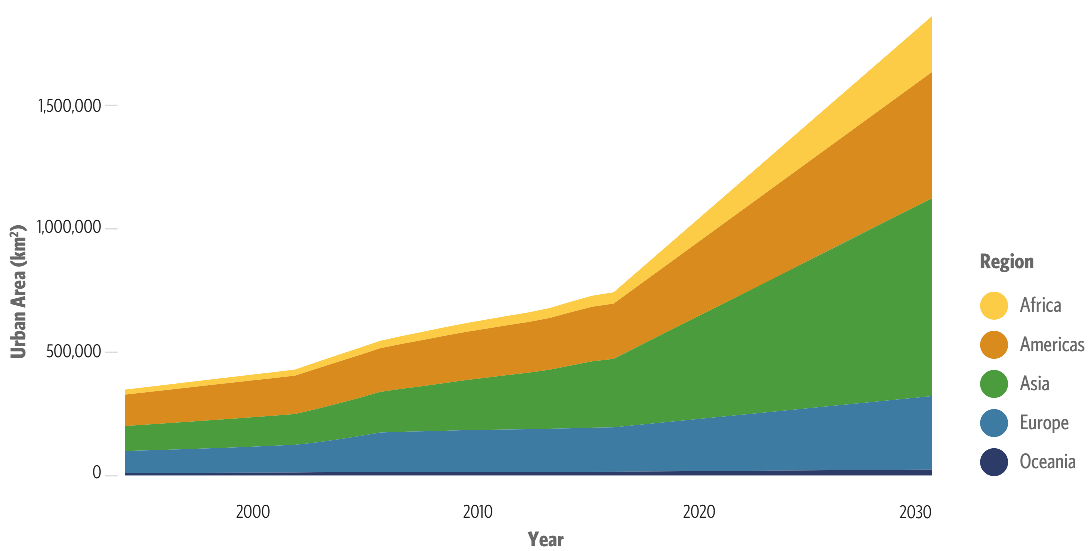

Figure 1: Urban land area by region (1992 – 2030).

The challenge of managing urban growth

This report depicts how the projected rapid rates of urban growth could, if poorly planned, destroy natural habitat and greatly impact biodiversity and human wellbeing. Urban growth, per se, has been considered relatively little under the CBD process to date. However, preventing habitat conversion and increasing land protection are both key goals of Aichi Targets 5 and 11, and both issues are, and will continue to be, affected by urban growth. Urban growth also affects numerous other issues that are related to CBD's Aichi Biodiversity Targets, such as ecosystem service provision (Aichi Target 14) and ecosystem resilience (Aichi Target 15).

Report Findings Dashboard

Infographic: Rhiannon Hare/TNC.

Urban Growth:

By 2050, there will be **2.4 billion** more people in cities

This rate of urban growth is the equivalent of building a city with the population of London **every 7 weeks**

Humanity will urbanize an area of **1.2 million km²,** larger than the country of Colombia

Coastal Resilience:

Coastal habitats reduce the risk of coastal hazards, such as coastal flooding and erosion during storms.

By 2030, urban area is forecast to more than double, **to 23,000 km²** in low-lying coastal zones where natural habitat plays a critical role in reducing coastal hazards

This increases the number of urban dwellers dependent on natural ecosystems in coastal areas.

Natural Habitat:

1992 - 2000

Urban growth was responsible for **190,000 km²** of natural habitat lost

29% of strictly protected areas[1] were less than 50 km from urban areas

2000 - 2030

Urban growth could threaten **290,000 km²** of natural habitat

40% of strictly protected areas[1] are projected to be within 50 km of an urban area

[1] *as defined by IUCN's Protected Area Categories*

Carbon Storage:

(as forecast in business-as-usual scenario)

Urban growth would destroy natural habitat that stores an estimated **4.35 billion** metric tons of CO_2

This is the equivalent of carbon dioxide emissions from **931 million** cars on the road for one year

Globally avoiding the release of carbon from habitat loss due to urban growth has a social value of **182.8 billion USD**

assuming the U.S. Environmental Protection Agency's social cost of carbon (USD 42/t CO2 eq)

Where and how much natural habitat could be lost?

Historically, urban growth has been a major cause of natural habitat loss, directly impeding progress toward Aichi Target 5, which aims to at least halve the rate of loss of all natural habitats. This report shows that urban growth was responsible for the loss of 190,000 km^2 of natural habitat between 1992-2000 (*Figure 2*), which equates to 16% of all the natural habitat lost over this period. Biomes with large amounts of natural habitat lost due to urban growth include temperate forests, deserts and xeric shrublands, and tropical moist forests. In the future, this trend will continue, especially in tropical moist forests. This report shows that urban growth could threaten 290,000 km^2 of natural habitat by 2030.

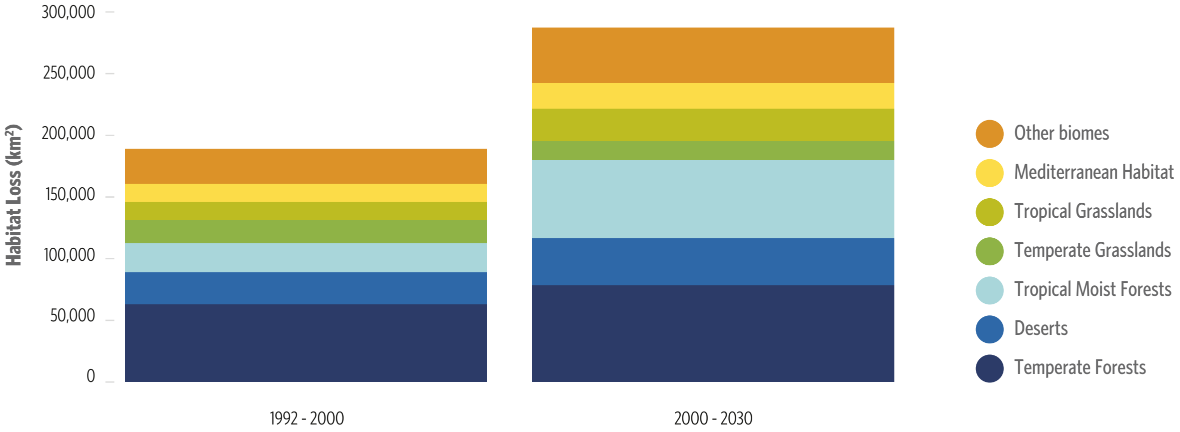

Figure 2: Habitat lost, by biome, due to urban growth, both historically (1992-2000) and projected (2000-2030).

Countries projected to lose the most natural habitat due to urban growth (> 10,000 km^2) include the United States, Brazil, Nigeria, and China (*Figure 3*). Though these are the countries with the largest projected natural habitat loss, there are many other countries projected to experience significant habitat loss. Mitigating these losses will be key if countries are to achieve their CBD commitments.

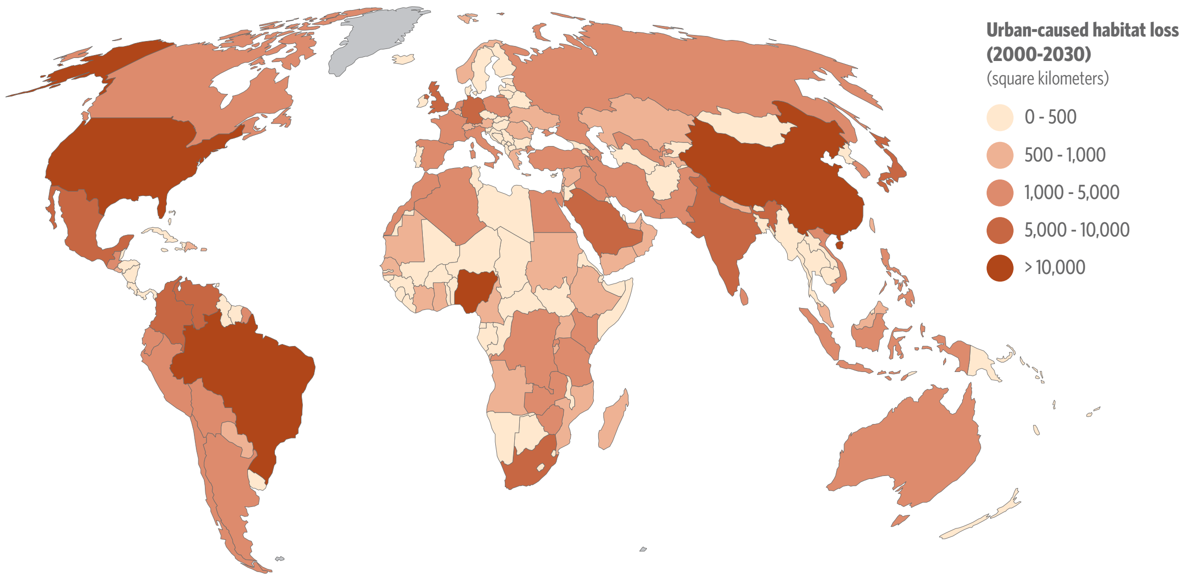

Figure 3: Projected habitat loss due to urban growth by country (2000-2030).

Potential urbanization impacts on areas of high biodiversity and endemism are spatially concentrated (*Figure 4*). This spatial concentration of urban impacts on biodiversity points to definite areas to focus urban conservation actions. For instance, conservation action on just 49,000 km^2 could help protect Key Biodiversity Areas (KBAs) at risk from urban growth.

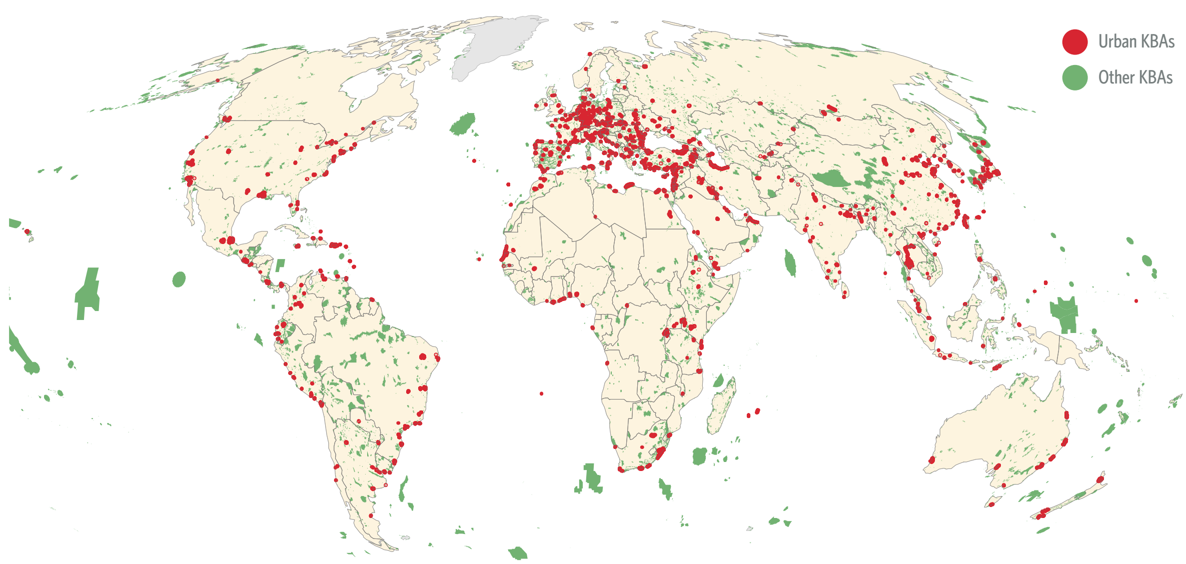

Figure 4. Key biodiversity areas (KBAs) that will be impacted by urban growth are highlighted in red. These KBAs have >5% of their area forecasted to be urbanized by 2030.

How will protected areas be affected?

If current trends continue, urban growth could degrade the global network of protected areas and the benefits they provide. Literature reviews have established that negative impacts from cities on protected areas become more frequent when there is less than 50 km between a protected area and a city. Negative impacts experienced in protected areas near cities include increased poaching, illegal logging and harvesting, trampling or other damage to vegetation, alterations in disturbance regimes like fire frequency, and alterations in abiotic conditions such as increased temperature and higher concentrations of air pollutants. Our analysis shows that in 1992, 29% of strictly protected areas (International Union for Conservation of Nature [IUCN] categories I-IV) were less than 50 km from urban areas. By 2030, we project the percentage to increase dramatically (*Figure 5*), with 40% of strictly protected areas and 1 in 2 loosely protected areas within 50 km of an urban area. This increased proximity will raise the likelihood of negative impacts on these urban-adjacent protected areas, as well as the management costs of trying to prevent negative impacts.

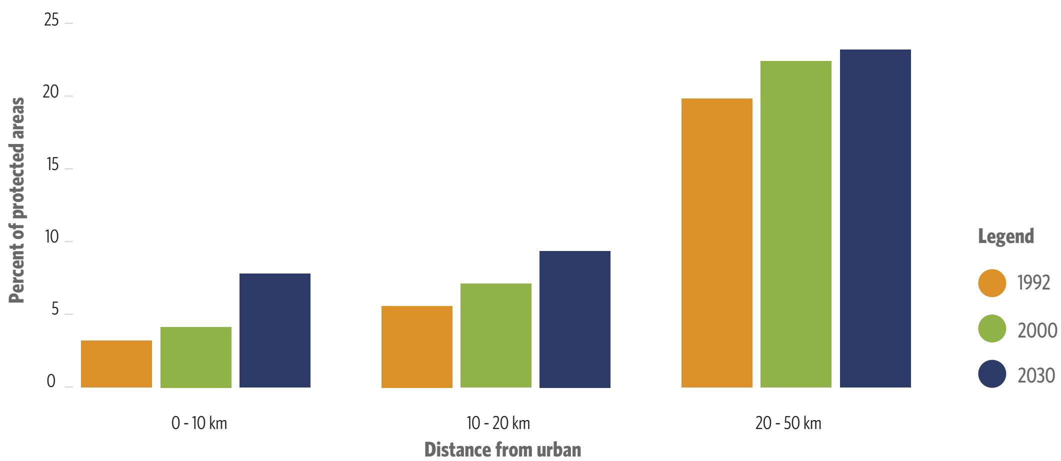

Figure 5: Distance from protected areas (PAs) to urban area for strictly protected areas (IUCN categories I-IV). Summing across all three distance categories, in 1992 29% of PAs were within 50 km of an urban area, while in 2030 40% of PAs will be.

Protected area management techniques exist that can mitigate many of the negative urban impacts on protected areas while fostering closer connections between people and nature. For instance, the IUCN Urban Conservation Strategies Specialist Group offers guidelines for managing protected areas near cities. Over a longer time frame, planned urban growth can prevent ecological degradation and maintain connectivity between patches of natural habitat. By planning proactively for how to manage protected areas in an urban world, countries can safeguard their investments in protected areas and continue to make progress toward their CBD commitments.

Implications for climate action

Natural habitats play an important role in climate mitigation by sequestering and storing of carbon in their biomass. We quantify how much carbon dioxide would be released as a result of natural habitat lost due to urban growth between now and 2030. We find that urban growth, if occurring as forecast in our business-as-usual scenario, would destroy natural habitat that stores an estimated 1.19 billion metric tons of carbon, or 4.35 billion metric tons of carbon dioxide (*Figure 6*). This is equivalent to the annual carbon dioxide emissions from 931 million cars on the road. The greatest potential overall release of carbon from habitat loss due to urban growth will occur in Brazil, the U.S., and Nigeria. We estimate that globally avoiding the release of carbon from habitat loss due to urban growth has a social value of 182.8 billion USD, assuming the U.S. Environmental Protection Agency's social cost of carbon (USD 42/t CO_2 eq).

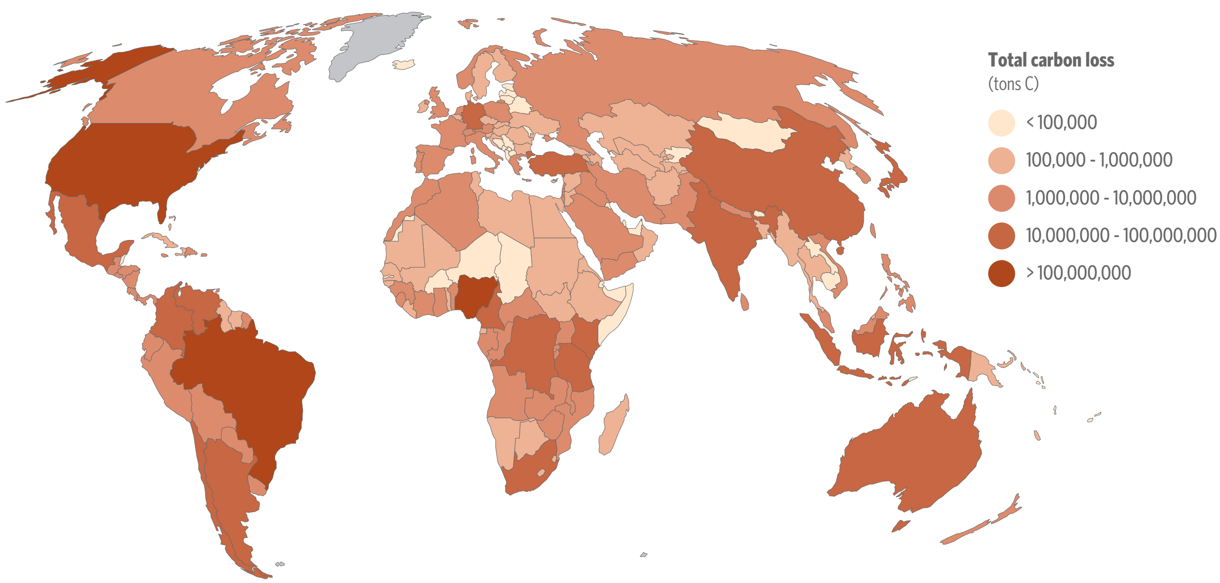

Figure 6. Total carbon (in metric tons) lost due to urban growth into natural habitat (2000-2030), by country.

Natural habitats, whether inside urban areas or in their surroundings, also provide several ecosystem services that are important for climate adaptation, such as reducing the risks of flooding and reducing temperatures in urban areas during heat waves. This report focused on one important service, the role that coastal habitats play in reducing the risk of coastal hazards, such as coastal flooding and erosion during storms. By 2030, urban area is forecast to more than double in low-lying coastal zones where natural ecosystems provide high levels of coastal risk-reduction services, to a total of 23,000 km^2 of urban area. More urban dwellers will be living in these zones, increasing the number of people dependent on these risk-reduction services. At the same time this urban growth, if poorly planned, could destroy coastal habitat and reduce the provision of these same risk-reduction services.

A call to action in the urban century

Governments around the world need to plan for a positive natural future, one where urban growth and development occurs while biodiversity and human wellbeing are protected. Some actions are crucial if we are to take advantage of this unique moment:

Integrate local governments in national planning from the start: Countries use National Biodiversity Strategies and Action Plans (NBSAPs) to delineate how they will achieve progress towards CBD goals. There is an urgent need to better consider urban growth in the next iteration of NBSAPs, as well as in sub-national and local Biodiversity Strategies and Action Plans. National governments should integrate local governments into the planning process and set aside appropriate resources, supporting local governments as they implement these plans. The financial and resource commitments that countries make to urban conservation should match the scale of the challenge that poorly planned urban growth poses to the goals of the CBD.

Empower cities to plan for a positive natural future: Urban growth plans need to incorporate information on biodiversity and ecosystem service value. The Exploring Solutions section of the full Nature in the Urban Century report presents tools and guidelines that cities can use to effectively create "greenprints" of urban growth. These greenprints plan for how to protect and restore existing habitat that is important for biodiversity and ecosystem services, as well as create new natural features (e.g., parks, street trees) that achieve the same goals. Participatory methods can be used to identify positive futures based on the local preferences of different city stakeholders. Governments at all levels should empower cities and metropolitan areas to plan effectively for protecting biodiversity.

Leverage international institutions: International institutions will play a key role in influencing the design and funding of cities of the future. We call for more extensive consideration of urban growth impacts on biodiversity and ecosystem services in the funding decisions of major institutions, both multilateral and bilateral. Major international funding sources, such as the Global Environmental Facility and the Green Climate Fund, should seek to directly appropriate funding to mitigate the impact of urban growth on biodiversity and ecosystem services, focusing especially on key priority areas where the impact is likely to be largest. Similarly, bilateral donors should aim to fund projects that minimize urban growth impacts on key priority areas.

Create a CBD for the urban century: We call upon Parties to the CBD to view the time between now and 2020 as a period to plan what urban conservation investments are needed to meet the challenge urban growth poses to the goals of the CBD. This would require working to ensure full integration of urban issues into the post-Aichi targets. This could be done through the creation of an urban target, or through the creation of explicit urban-related metrics that measure progress against the current Aichi Target 5 (halving habitat loss) and Aichi Target 11, which aims to protect at least 17% of terrestrial and inland water areas and 10% of coastal and marine areas. It is our hope that the next meeting of the CBD in 2020 will be a moment for Parties to the CBD to make significant commitments to protect biodiversity and human wellbeing in the urban century.

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The diversity of life on Earth is integral to human wellbeing.

Photo © Richard Newstead

Nature in the urban century

The diversity of life on Earth is integral to human wellbeing. Natural habitat is important not just for the biodiversity it support, but for the role it plays in supporting human livelihoods, health and wellbeing[1]. Nature provides resources: food, firewood, materials for shelter, forage for livestock. It helps maintain water quality and quantity, helps clean and cool the air, and reduces the risks from natural hazards. Natural areas are places to recreate, for physical and mental health, and places of aesthetic beauty. Human civilization has always depended on these benefits that nature provides. And now we are amid a dramatic change in how humans live and work.

// Urban planning only occasionally considers the ecosystems and biodiversity found in and around cities.

This century will be remembered as the urban century. The United Nations Department of Economic and Social Affairs estimates that by 2050, roughly 68% of the world's population will be urban (World Urbanization Prospects 2018)[2] – making the next 30 years the scene of the largest human settlement transformation in human history. In Asia alone, projections highlight an urban population jump from 44% in 2010 to 64% in 2050. Cities have been called humanity's greatest invention [3] , a way of living that can bring many benefits, including increased economic productivity and innovation, greater opportunities for education and individual enhancement, and more efficient use of natural resources and energy. The urban century thus holds enormous opportunity for humanity. However, the urban century also presents a challenge to the global environment, both directly through the expansion of urban area and indirectly through urban energy and resource use.

Urban growth is one of the main global issues that the Convention on Biological Diversity (CBD) must address to meet its ambitious goals. Governments must envision a positive natural future for the coming urban century, a future in which sustainable urban growth occurs in appropriate places while nearby nature is protected, restored, and enhanced. Nature in and near cities is crucial not just for maintaining biodiversity but also for ensuring human wellbeing, which depends on the benefits that nature provides.

Yet, urban planning only occasionally considers ecosystems and biodiversity found into and around cities, and where consideration is given, it is often not well integrated in holistic, sustainable urban design. Moreover, few countries have national and subnational policies on sustainable urban development or land use. Without these explicit policies, it is difficult to mitigate biodiversity loss due to urban expansion. There is considerable need for knowledge and tools to aid the planning and management of natural systems at multiples scales.

If we do not adequately plan for urban growth in areas with globally-significant biodiversity, the world may fail to meet its ambitious targets under the CBD. Without considering the important role ecosystems play for human wellbeing through ecosystem services, the international community could also miss its targets under the UN Framework Convention on Climate Change (UNFCCC), the Sustainable Development Goals (SDGs), and the New Urban Agenda.

The Nature in the Urban Century Assessment began as a direct response to policymakers' needs. At the last Conference of the Parties of the CBD in Cancun, Mexico, a gathering brought together many representatives of national governments, international agencies, and civil society to discuss how urban growth is affecting progress toward the goals of the CBD. The consensus at the event was that urban growth was a significant issue, which should be better addressed in the CBD process. Participants identified the urgent need to connect scientific information on urban growth with policymakers. This assessment serves as the first step toward connecting scientific knowledge to action for the CBD's Parties. We hope that by providing key information to the CBD, UNFCCC, Global Environment Facility (GEF), Intergovernmental Panel on Climate Change (IPCC), and Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), we can help these institutions accelerate responses to the challenge of global urban growth, catalyzing a turning point for these institutions in how they plan for and respond to global urban growth.

This report presents a business-as-usual scenario, which assumes that current urban growth trends continue, and quantifies the impact that urban growth could have on biodiversity and human wellbeing. This report also quantifies the significance of natural habitat for climate mitigation and adaptation. We end by highlighting solutions that can help avoid the negative impacts forecasted under our business-as-usual scenario, ways that governments at all levels can plan and implement a positive natural future for our urban century.

Why conduct this assessment now?

How cities grow and develop can have negative implications for protecting biodiversity and for climate change mitigation and adaptation. While rapid urban growth will occur over the next several decades, there is a unique urgency to act *now*. Decisions taken by governments in the next few years could significantly change and help shape how cities grow and develop. This section focuses on the unique moment of opportunity for the Convention on Biological Diversity and for the set of international treaties focused on climate change.

An urban opportunity

In 2018, the countries of the world will meet for the 14th Conference of the Parties (COP-14) to the CBD. COP-14 will be a key moment, as Parties to the CBD begin to evaluate progress toward the Aichi targets. These targets will expire in 2020, and discussions have already begun about the next set of targets for the CBD. National governments and international institutions are, in parallel, considering significant new commitments they would like to make to biodiversity conservation in 2020. There is talk of 2020 being the "Paris moment" for biodiversity, where the Parties to the CBD may agree to a major, significant global framework for biodiversity conservation, similar in ambition to the Paris Agreement of the UNFCCC.

Recently, the Global Environmental Facility (GEF) has adopted new programmatic priorities for the GEF-7 funding phase (2018-2022). These priorities shape investments of GEF resources by recipient countries in projects that address some of the world's most pressing environmental problems. GEF-7 expands its existing program on Sustainable Cities from the previous phase to include a wider array of investment opportunities for achieving a range of global environmental benefits. The new strategy has an additional focus on natural infrastructure and includes support for integrated land-use planning and infrastructure integration for cities and surrounding landscapes that will generate benefits for biodiversity.

Now is the time to push for urban issues to be further incorporated into CBD and GEF processes. This report quantifies how much urban growth has converted natural habitat, to give policymakers an understanding of how urban growth has affected achievement of Aichi Target 5, which calls for the rate of loss of all natural habitats to be at least halved by 2020. We also quantify how urban growth has fragmented and degraded protected areas, to increase policymakers understanding of how urban growth has affected achievement of Aichi Target 11, which calls for at least 17% of terrestrial and inland water areas and 10% of coastal and marine areas to be meaningfully protected by 2020. Moreover, the report also presents forecasts of where future urban growth could potentially impact areas of biodiversity and ecosystem service importance. We hope that this data will lead to significant future commitments to manage urban growth, and inform how national governments and institutions including the GEF prioritize their investments.

Climate change adaptation in the urban century

The world's fight against climate change, embodied in the commitment of Parties to the UNFCCC, is also at a significant moment. Through the Paris Agreement, the Parties committed to ambitious Nationally Determined Commitments (NDCs) to reduce greenhouse gas emissions. The Paris Agreement is expected to significantly increase the flow of finance for climate mitigation and adaptation, toward a stated goal of $100 billion per year. Much of this money will go to actions focused on reducing emissions, such as fostering energy efficiency, or grey infrastructure projects that increase climate adaptation capacity, such as new sea walls. However, a fraction of this climate finance will go toward Ecosystem-Based Adaptation (EBA) projects that use the conservation, sustainable management, and restoration of ecosystems to help people adapt to the changing climate.

Several key science institutions are reevaluating their research focus relating to EBA, recognizing the significance of urbanization. The IPCC has recognized the importance of cities in the global climate response and has planned for a Special Report on Climate Change and Cities for its seventh assessment cycle. Working with academia, urban practitioners and relevant agencies , the IPCC also cosponsored an International Conference on Cities and Climate Change Science in March 2018. Working with conference participants, the conference's Scientific Steering Committee has developed a Global Research and Action Agenda on Cities and Climate Change Science. This Research and Action Agenda identifies built and blue/green infrastructure as a key topical research gap to addressing climate change in cities. Similarly, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is taking an increasing interest in establishing an urban working group, in recognition that urban growth will both impact and depend on ecosystem services.

The CBD can help the UNFCCC identify opportunities for EBA to achieve their climate adaptation goals. This report forecasts where urban areas are most dependent on ecosystems for climate adaptation services, in the hope that knowledge of these priority places can influence major investments in EBA, making these investments more efficient and more successful.

Scope of this report

This assessment is meant to be a brief synthesis for policymakers of data on how urban growth is now affecting and will continue to affect biodiversity in the coming decades. There are a few limitations of the report that readers should bear in mind:

- We have aimed to be concise, summarizing important key trends for the CBD member countries and parties, rather than encyclopedic and comprehensive. Readers should be aware that there is a very large body of scientific literature on cities and nature, which we have tried to reference as appropriate. A good starting place for those looking for more detail is the book *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities*, a thorough assessment of the state of the related literature up to 2013 [4].

- This report focuses on terrestrial biodiversity, only occasionally discussing the impacts on freshwater and marine biodiversity from urban growth.

- Our analysis concentrates primarily on the direct impacts of urban-caused habitat loss on biodiversity. We do not discuss in detail the many indirect effects cities have on the natural environment, as (for example) they use natural resources, consume energy, and produce waste. These indirect effects and the "teleconnections" between cities and the broader landscape can be quite important [5].

- This report's discussion of human wellbeing concentrates on climate adaptation (especially coastal hazard reduction) and climate mitigation, and how urban growth affects these potential benefits. We acknowledge that nature provides many other important benefits for human wellbeing. One useful introduction to the broad set of benefits that urban nature provides is *Conservation in Cities: How to Plan & Build Natural Infrastructure* [6].

- We only briefly discuss the important role that nature can play within cities for improving human wellbeing [7]. This was a conscious choice on our part, since human-designed features within cities (like planted street trees) harbor relatively less biodiversity than remnant natural habitat patches at the fringes of urban area. However, we acknowledge that nature within cities, sometimes called "natural infrastructure", is often essential for human wellbeing [6] and may serve as habitat for important elements of biodiversity.

- We present in this report possible solutions, ways cities can protect biodiversity and ecosystem services as they grow. Our presentation of these solutions is necessarily concise, and we link to longer descriptions where available.

Photo © Kwong Shun Cheong

Urban growth trends

In 1950, just 30% of global population lived in urban areas (World Urbanization Prospects 2018) [2]. Since then, the draw of cities as economic and cultural hubs promising an improved standard of living has resulted in a significant increase in the proportion of the world's population residing in urban areas. In 2018 over half of the world's population (55%) live in urban areas. This increase in the proportion of people in urban areas, coupled with the rapid population increase since 1950, has resulted in significant urban population growth in the last seven decades. In 1950, 751 million people lived in urban areas, while in 2018, 4.2 billion people live in urban areas.

Humanity's increasing propensity for city life has broad implications for global patterns of land use. As the number of people living in cities swells, so too does the amount of land required to accommodate them. There are different definitions of urban area [2], which can influence both the measurement and forecasting of urban growth. As this assessment is conducted at the global scale, we adopted the definition of urban area used in remote sensing studies, where urban land cover is composed of more than 50% non-vegetative, human-constructed elements (e.g. roads, buildings) [8]. The European Space Agency's Climate Change Initiative (CCI) provides an annual global land cover dataset from 1992 to 2015, which demonstrates the increase in urban land cover over this period. This dataset is summarized in Figure 7 which shows the increase in total urban land area by region.

In 1992, 349,000 km^2 of the earth's surface were urbanized. By 2015, this area had more than doubled, to 744,000 km^2 (*Figure 7*). The bulk of this growth occurred in Asia, which saw a growth in urban area of 176,000 km^2 over this period, an increase of 174%. The Americas and Europe had the next greatest urban growth, adding 97,000 km^2 and 91,000 km^2 respectively. Urban land in Africa increased by a comparably modest 26,000 km^2, but this figure represents an increase of 124% since 1992, highlighting the rapid urban growth that African countries have experienced over this period.

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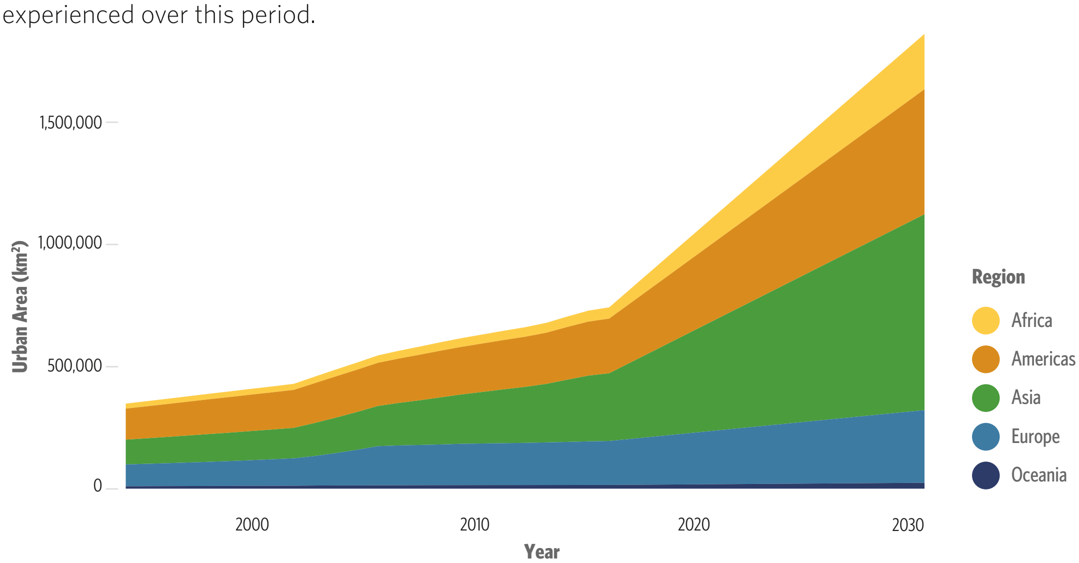


Figure 7: Regional urban land area over time. Historical data for the period 1992 – 2015 taken from the CCI landcover dataset. Future urban area forecasted out to 2030 is taken from Seto et al. (2012). See Methods section for details

This sizable urban growth is expected to continue. By 2050, the total urban population is forecasted to have increased by 2.5 billion people (World Urbanization Prospects 2018) [2] and urban area will need to expand to accommodate this increase in population.

Urban land projections, such as those developed by Seto et al. [9], attempt to predict the future global urban land footprint. By analyzing forecasted population trends, and existing land use, Seto *et al.* [9] have modeled predicted urban growth between 2000 and 2030. The amount of forecasted growth, by region, is shown in Figure 7.

By examining the projected growth in urban land area between 2000 and 2030 at the country level, we can understand where urban growth will primarily be taking place (*Figure 8*). The bulk of urban growth will occur in developing countries. China will see more urban growth than any other country, with a total of 208,000 km^2 of urban growth forecast, equivalent to 18.6% of the global total. India is predicted to have the second largest amount of urban growth at 78,000 km^2. The United States is the developed nation that will see the greatest amount of urban growth, with a predicted total of 76,000 km^2 of new urban land by 2030. Other countries with significant forecasted urban growth include Brazil, Nigeria, Pakistan, Egypt, Japan, and Mexico.

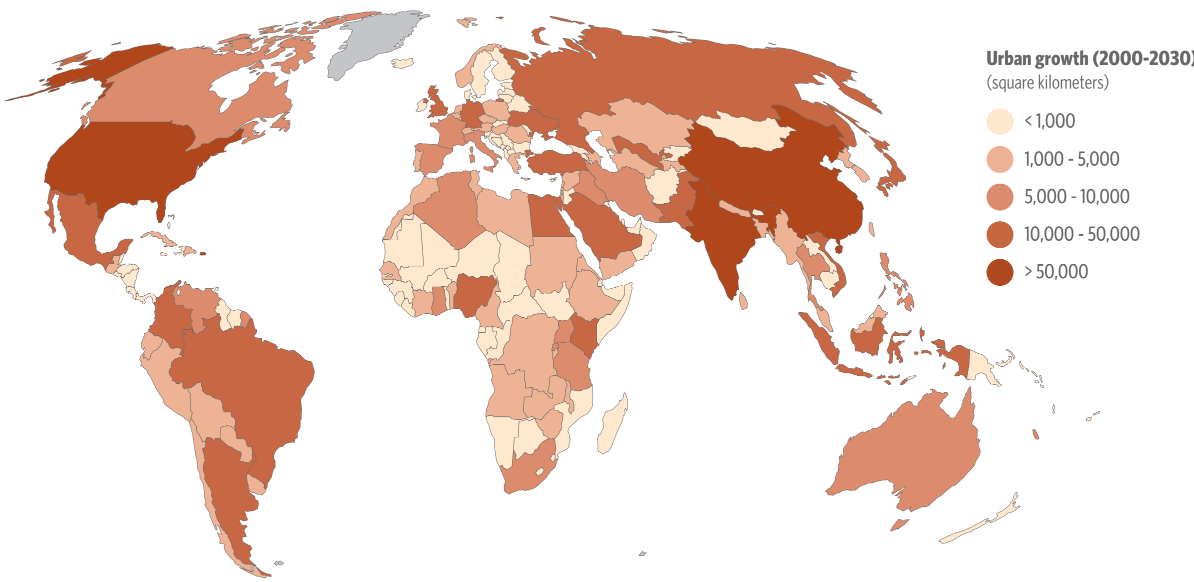


Figure 8: Projected urban land expansion for the period 2000 – 2030, by country

Drivers of urban land expansion

Why is this significant global urban growth occurring? Several key drivers of urban growth are discussed below. In this report, we use "urbanization" to refer to the process by which a greater fraction of the total population lives in cities, while we use the term "urban growth" to refer to the growth (in area or population) of cities. It is important to realize these are different concepts: The United States, for instance, is already a highly urbanized society, with a large portion of its population in cities, but the United States is still forecast to have significant urban growth in many metropolitan areas.

The magnitude of urban growth in area is largely determined by the rate of urban population growth, the urban population density, and the amount of urban land per capita. The relative influence of each of these drivers may differ from one region to another leading to varying rates, magnitudes, and patterns of urban growth across the world.

1. Economic Growth

Historically, economic growth and urbanization have largely been concurrent trends, with economic development over time correlated with an increase in the proportion of people living in cities [10]. This relationship between the two is bidirectional in that strong urban economies pull more people into the city in search of greater economic prospects, and once people are in cities they often have access to better employment and education opportunities, helping to drive further economic growth [10]. In general, therefore, as countries develop economically a greater proportion of people live in cities, thus increasing the urban land footprint. It is expected that some 35% of urban growth between 2018 and 2050 will be in three rapidly developing countries of the Global South: China, India and Nigeria [10].

Economic growth further influences patterns of urban land-use conversion through changes in per capita energy and food consumption, which, are associated with increasing levels of affluence. As economies develop urban households have the financial means to build large single-family homes that occupy a larger footprint than more compact multifamily dwellings. Households of means are also more likely to own a car, which allows them to live further from their place of employment, increasing urban sprawl [11].

2. Demographic Changes

A significant portion of future urban growth will come from large-scale migration of people from rural to urban areas. Studies of historical trends indicate that rural-to-urban migration typically makes up around 40% of total urban population growth [10]. In some cases the motivation for migration will originate in the hardships associated with life in rural areas, known as push factors, which may include rural poverty, lack of employment opportunities, drought, degradation of natural resources or conflict [12]. The decision to migrate may also be motivated by the allure of urban areas, or 'pull factors', such as more abundant and higher paid employment opportunities, better education or better access to essential services such as sanitation and healthcare [12].

Urban population can also grow because of intrinsic increase, if births exceed deaths. Urban population growth is affected by fertility rates but also strongly affects fertility rates. All else being equal, urban areas with higher net fertility rates have higher rates of urban population growth. However, fertility rates tend to decline after rural migrants move to urban areas. As the percentage of urban population of the world increased from 30% in the 1950s to over 50% in 2018, the average fertility rate decreased from 5 children per woman to 2.5 children per woman [13]. Despite some regional differences, the inverse relationship between urbanization and fertility rate holds across the world [14]. This decline in fertility can be attributed to factors like more economic opportunities, better education for women, and lower infant mortality rates.

3. Technology

Technological innovations shape economic growth and thus patterns of urban growth. For example, in the United States, steam engine and railway transport in the 1850s allowed food and other commodities to be shipped from the interior of the U.S. to markets on the East Coast. Profiting from this trade, new cities then arose in the interior U.S., perhaps most notably Chicago [15]. Similarly, the technological advancement of the automobile and its increasing availability during the 20th century increased mobility and allowed the development of new suburbs with lower population densities [16]. More recently, the internet has changed patterns of commuting, employment, and firm location, with unclear implications for overall urban form [17].

4. Cultural Influences

Significant cultural differences across the world have traditionally influenced the development and planning of cities. Cities in North America and Australia have lower population densities than those in most of the rest of the world. Though these differences still manifest in differential rates of urban expansion and differences in urban form across different regions, trends for development and planning of cities have been becoming more uniform over the past few decades. Urban population density has been decreasing in most parts of the world (at different rates) under the common influences of increased car ownership [18], decreased average household size [11], and desire to have larger living space [19]. Still, certain regional characteristics persist, such as those found in informal settlements, primarily located in South American, Asian and African cities [20, 21].

5. Governance

Government policies can affect the aforementioned factors, altering the magnitude and location of urban expansion [22]. Land ownership and investment affect the purchase and sale of properties and land in and around cities. Economic policies including taxation, subsidization, or deregulation can alter the scope of economic opportunities, and thus either encourage or discourage rural-urban migration. Specific demographic policies, such as the registration system in China, aim directly to control population growth in major cities, by capping the number of registered urban residents and denying services to unregistered rural migrants [23]; while the country's Western Development Program has accelerated the growth of cities in western China [24]. Policy can also influence population density and thus the size of an urban area. In the United States, for instance, policies including relatively lower taxes on fossil fuel and government subsidies for highway infrastructure encourage automobile over public transit use, leading to urban sprawl [25].

Challenges in Projecting Urban Land Expansion

While significant amounts of urban growth are certain, there is uncertainty in projections of that growth. Developing projections of urban growth first relies on having robust data from which historical trends and relationships can be observed. It is then necessary to make assumptions about how the drivers of urban growth will change in the future. The types of data used and the assumptions made about alternative futures can produce different results and introduce uncertainty. These are explored further in this section.

1. Historical observations

This report utilizes data from rigorous assessments of urban land use that have been widely cited in the global change literature. However, it is important to acknowledge that these data have their own uncertainty. This uncertainty may originate in the different methods to develop datasets that define urban land, such as differences in the spatial resolution of remote sensing products or regional differences in accuracy of urban population censuses. Urban land is also difficult to define, and thus difficult to measure accurately. Urban and rural land uses lie on a spectrum and classification of urban vs. rural land requires a clear demarcation of thresholds. Assessments typically use factors such as the proportion of land occupied by buildings and infrastructure, or the density of the human population to define such thresholds. Differences in the ways that these thresholds are defined will produce different estimates of urban area.

The variability in measurements of urban land can be observed through comparison of datasets. The European Commission's Global Human Settlement Layer (GHSL) [26], a 1-km gridded dataset of urban land cover from which the CCI Land Cover is partly derived, records a global total of 700,000 km^2 of urban land in 2015. The CCI Land Cover data used in this assessment records a relatively similar amount of urban area, 744,000 km^2 in 2015. However, there is greater variability in urban land extent in preceding years. For example, the GHSL recorded 122,000 km^2 more urban area than the CCI Land Cover dataset in 2000.

2. Alternative futures

Uncertainty is inherent in forecasting. A model may only account for a few select factors that are deemed relevant based on historical data and available theory. However, it may add too much complexity to the model to include all of the factors that may significantly influence regional and local urban land expansion such as climatic factors, agricultural productivity, poverty, land-use policies, international capital flows, and infrastructure investments [27]. Significant changes in national urbanization policies such as reforms on land management and fiscal arrangements across the government hierarchy may also alter the spatial pattern of urban land expansion within a country. Large-scale changes in transportation networks, in the spatial distribution of populations, social upheaval and economic crises are other examples of phenomena that are hard to predict. Additionally, large-scale behavioral changes may progress slowly over a long time period but may accelerate upon reaching a critical threshold [28]. However, such uncertainties can be addressed by developing alternative scenarios on which models are run or by incorporating a probabilistic approach in the modeling forecasts to capture as much of the uncertainty as possible [29].

Comparisons of urban land datasets demonstrate that the science of measuring and predicting urban land use is evolving and complex. However, there is a clear indication, across multiple studies, that urban land cover growth will be rapid during the 21st century and that this will have significantly influence biodiversity.

Biodiversity affects human wellbeing directly and through changes to ecosystem services.

Photo © James Folder

Impacts of urban growth on biodiversity

Biodiversity change

Following the Convention on Biological Diversity, biodiversity is defined as the variability among living organisms, from genes to biomes (CBD Article 2). This encompasses diversity within, and among, species and ecosystems. Human activity has affected biodiversity across the planet, resulting in a global extinction rate (an estimated 906 species since 1600) that is now one hundred to one thousand times the historical rate [30]. Estimates of elevated rates of global extinction also come from projections based on the impacts of current and projected habitat loss [30, 31]. Reports of global population declines give another measure of biodiversity change. Trends differ in different ecosystems, with terrestrial systems declining by 38%, marine systems declining by 36% and freshwater systems being reduced to less than 25% of its abundance in 1970 [32-34]. Together, these findings indicate major impacts on global biodiversity, which are projected to be sustained throughout the current century [30, 35, 36].

// Human activity has affected biodiversity across the planet, resulting in a global extinction rate that is now at least one hundred times the historical rate.

While global biodiversity is declining, the rate, magnitude, and even direction of biodiversity change can vary considerably depending on the spatial scale. At smaller spatial scales, such as the scale of tens of kilometers, data assessments reveal systematic declines in biodiversity due to land cover change, including urban growth and human population density [37-40]. However, this picture of biodiversity decline at smaller scales is complemented by data syntheses [41-44] that report evidence for no systematic decline in trends of species richness at very small scales (< 1 km), although strong geographic biases in sampling and the absence of baseline information suggest these findings may not be globally representative [45]. There is also evidence that in many regions and at some spatial scales species richness may be recovering or increasing due to rates of non-native species expansion exceeding rates of local extirpation [46, 47]. Overall, human activity is consistently understood to be the dominant driver of biodiversity change from local to global scales.

Scientists and decision-makers have typically broken down this human impact on biodiversity into five key drivers: habitat loss and degradation, climate change, excessive nutrient loads and pollution, over-exploitation and unsustainable use, and invasive species [48]. The role of urban growth is less often emphasized in relation to biodiversity change, even though urban expansion contributes substantially to these five drivers. Although cities make up a small proportion of worldwide land cover, urban growth has a considerable influence on biodiversity change at multiple scales, from neighborhoods to the globe (*Figure* 9).

Multiscale Biodiversity Outcomes are Mediated by Cross-Scale Interactions

The study of urban impacts on biodiversity change to date has largely occurred at the global scale. Here we emphasize four scales which must be considered to understand biodiversity change due to urban growth: global, regional, city and neighborhood. Both challenges to biodiversity and opportunities for protection and restoration can span these scales. The effects of interactions across scales must be considered to properly account for both urban-biodiversity tradeoffs and synergies arising from decisions to protect biodiversity.

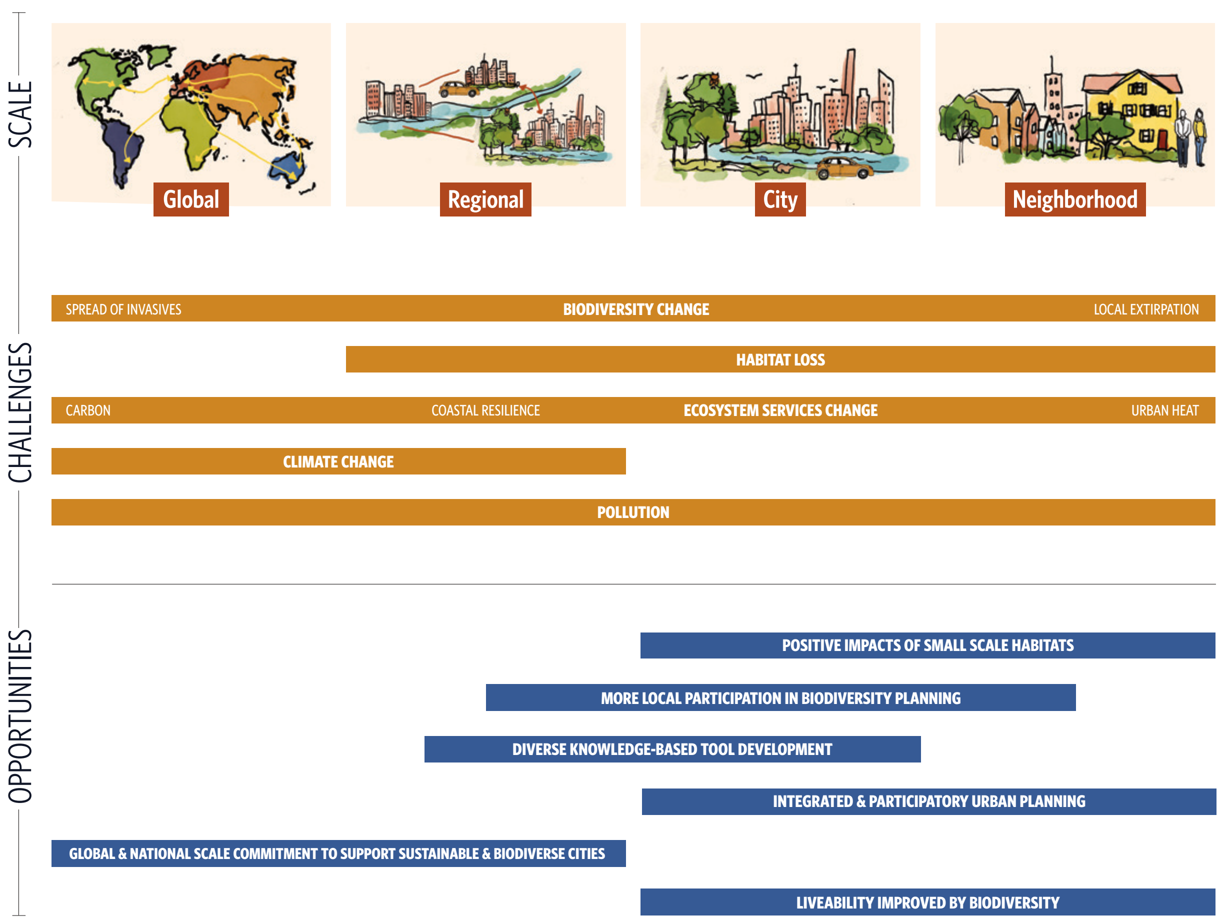


Figure 9: Multi-scale opportunities and challenges.

The effect of urban growth on biodiversity can in turn affect ecosystem services and human wellbeing [4, 49, 50] (*Figure 10*). Urbanization affects both biodiversity and ecosystem services via its influence on many drivers. For example urban sprawl drives habitat loss and fragmentation. Biodiversity change subsequently affects human wellbeing directly, and through changes to ecosystem services. Impacts on ecosystem services influence people's values, the structure of human institutions, and society's decision-making. These socio-economic changes in turn affects people's actions, feeding back to further influence urbanization and drivers of biodiversity change. This general framework can be adapted to understand the effect of urbanization on specific ecosystem services, for example those related to climate mitigation (*Figure 10, middle panel*) and adaptation (*Figure 10, bottom panel*).

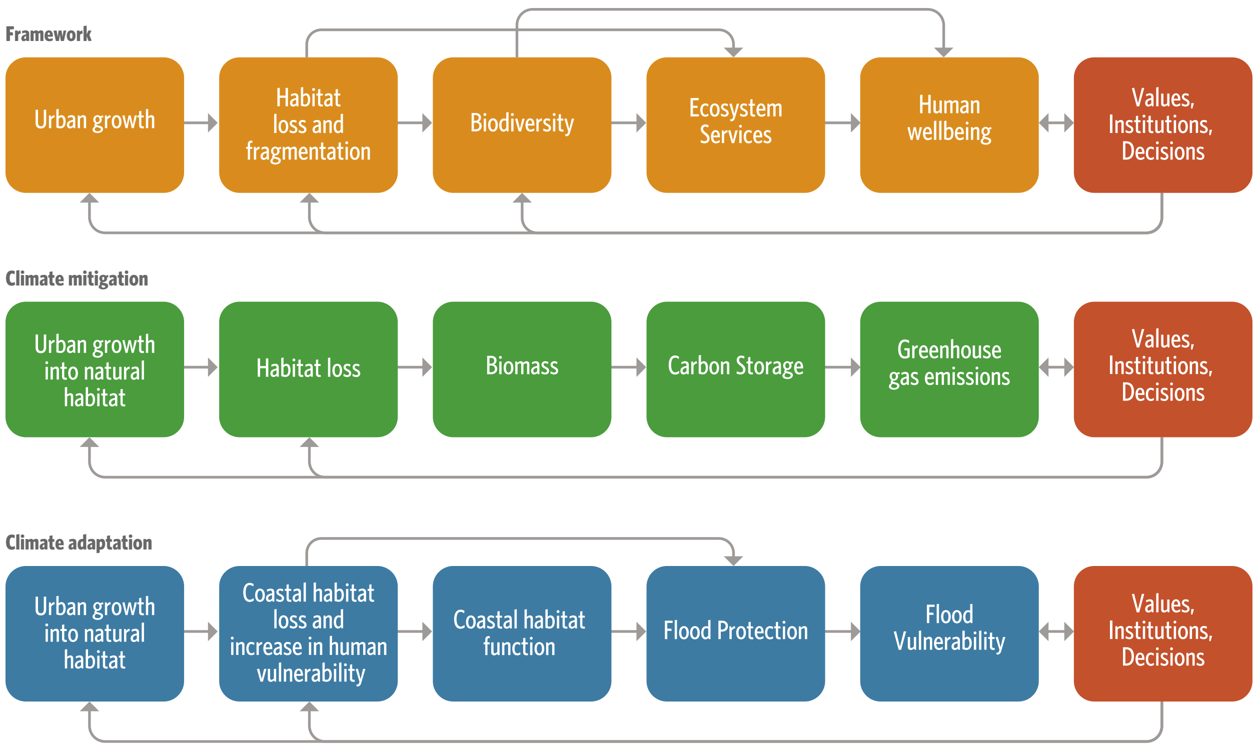


Figure 10: Conceptual linkages between urbanization, biodiversity, and human wellbeing.

For much of this assessment we focus on the direct impact of urban growth on natural habitat, and its consequences, because past assessments have suggested that this direct impact will have significant implications for biodiversity and human wellbeing [4]. We acknowledge that urban areas can also provide important opportunities for conservation. Natural infrastructure within urban areas, for example, may provide support for species of conservation concern [38, 51, 52]. The degree to which cities facilitate many aspects of biodiversity depends on the size, quantity, and quality of green spaces [53]. There is a growing body of knowledge about how to manage cities for increased biodiversity [6, 54, 55].

Urbanization is a major driver of habitat loss

As the section on Urban Growth Trends shows, urban growth has increased dramatically in recent decades. Not all urban growth directly affects natural habitat, because sometimes cities expand onto agricultural land, or other land already converted by humans [56]. However, a significant fraction of urban growth occurs on natural habitat, and historically urban growth has been a major driver of habitat loss. Between 1992 and 2000 urban growth caused the conversion of approximately 190,000 km^2 of natural habitat globally (*Figure 11*). This accounts for 16% of the total natural habitat loss during this period. This kind of large urban impact on natural habitat has directly affected the progress toward the ambitious goals of Aichi Target 5, to reduce the rate of natural habitat loss by at least half.

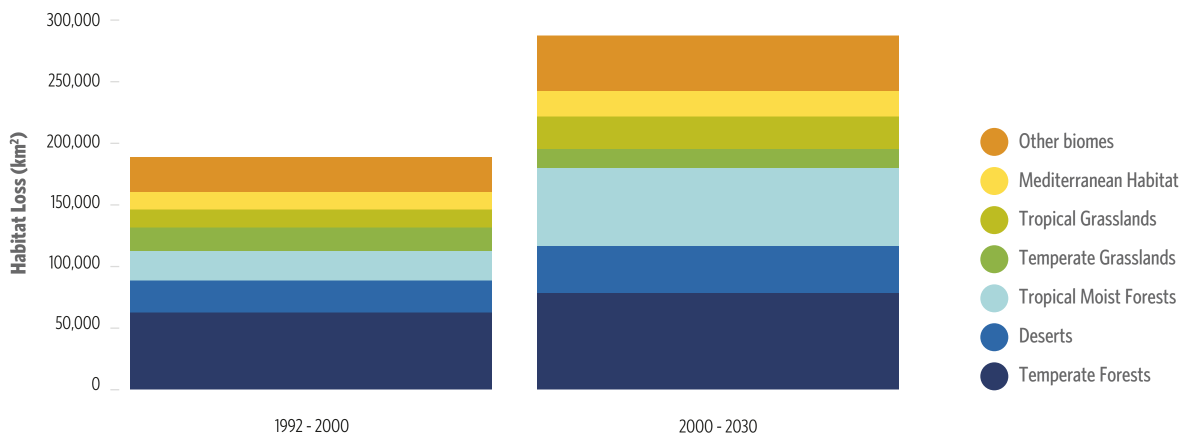


Figure 11: Habitat lost, by biome, due to urbanization, both historically (1992-2000) and projected (2000-2030). Note that a few biomes with comparatively few hectares of habitat lost to urban development are grouped together under the category "Other biomes".

In terms of area, the greatest impact of urban growth on natural habitat during the period from 1992 to 2000 was in temperate broadleaf forests (*Figure 11*), the dominant biome type in Europe, the eastern United States, and northern China. The next greatest impact was in the deserts biome (which includes xeric shrublands), found in the southwestern United States, North Africa, the Middle East, and parts of Pakistan and Central Asia. Tropical moist forests were the third most impacted biome, and are found in southern China, West Africa, and parts of Brazil. Other biomes that were significantly affected in this period include temperate and tropical grasslands, as well as Mediterranean habitat.

Forecasted patterns of urban-caused impacts on natural habitat from 2000 to 2030 are similar to historical patterns but they show an increase of urban growth affecting biomes more frequently found in developing countries (*Figure 11*). The area affected by urbanization will increase relative to the 1992 to 2000 period in almost all biomes, but the increase will be most notable in tropical moist forests. This biome is home to some of the most rapidly expanding urban areas such as those along the Brazilian coast, in West Africa, Southeast Asia, and Indonesia. As the tropical moist forest biome is also the most biodiverse, the rapid growth of cities poses a substantial threat to the goals of the CBD if not properly managed.

Urbanization is forecast to convert a total of 290,000 km^2 of habitat between 2000 and 2030, the equivalent to the size of Italy or the Philippines. Note that measuring urban growth's impact by the total area impacted can be misleading, since biomes with a small total area can easily be lost in the analysis (See Table 1), and therefore the percentage of the biome that will be lost due to urban growth is also important to quantify. In proportional terms urban growth during this period is forecasted to cover around 2.9% of the total area of the mangrove biome, much more than any other biome type. The Mediterranean biome is also forecast to be highly impacted in proportional terms, with 0.6% of this biome affected by urban growth between 2000 and 2030. By contrast, the tundra and boreal forest/taiga biomes are forecast to be minimally impacted by urban growth between 2000 and 2030, simply because there are so few cities at the high latitudes at which these biomes occur.

Country-level forecasts of urban growth's impact on natural habitat are shown in *Figure 12*. In terms of the total area of natural habitat forecast to be lost, four countries exceed 10,000 km^2: the United States, Brazil, Nigeria, and China. However, there are many countries on each continent (excluding Antarctica) that are forecasted to have high levels of urban-caused habitat loss. It is interesting to compare the patterns of habitat loss in Figure 12 with the patterns of total urban growth shown in Figure 8. Some countries, such as India, have a large amount of urban growth forecasted, but only a moderate amount of habitat conversion forecasted, because a large fraction of urban growth is happening on agricultural lands rather than natural habitat. China is an interesting case study, because growth in northern China is primarily occurring in agricultural lands, while growth in southern China is more heavily affecting natural habitat [56].

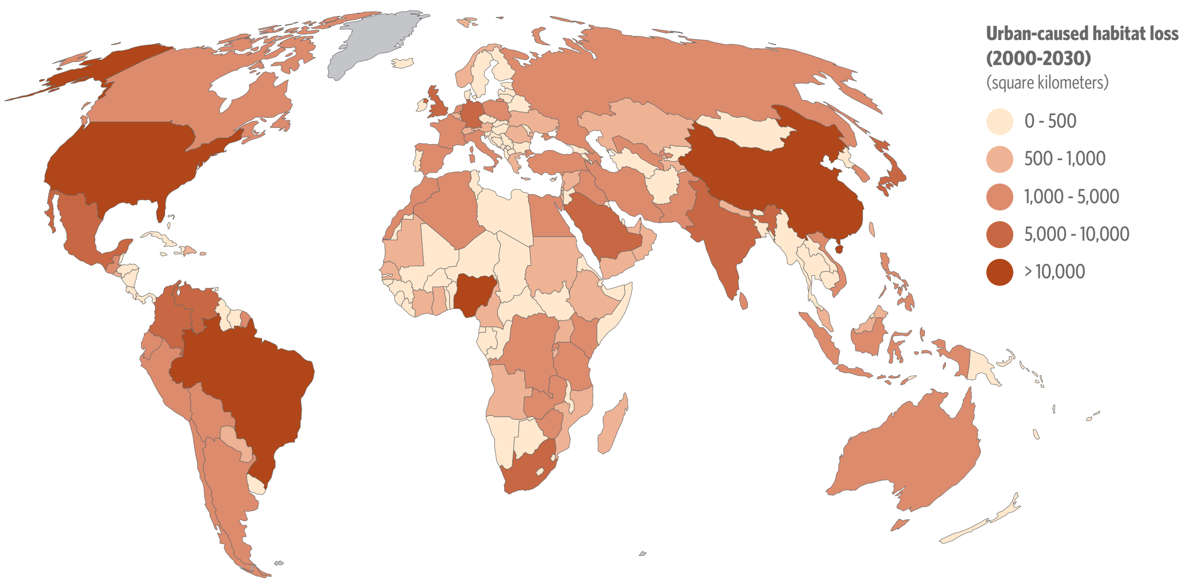


Figure 12: Habitat loss projected (2000-2030) by country.

Urban growth causes habitat fragmentation

Urban growth doesn't just reduce habitat area, it also fragments and affects the remaining habitat, often leading to a consequent decline of species richness and abundance [57, 58]. Habitat fragmentation may be defined as a discontinuity in the spatial distribution of environmental resources and ecosystem conditions. Fragmentation can affect the survival, reproduction, and mobility of multiple interacting species [59]. Habitat loss and fragmentation are rarely spatially uniform and may occur across a landscape over a period of decades [60, 61], leaving a discontinuous mosaic of remnant habitat fragments of many sizes, interspersed with other land cover types, including agriculture, disturbed vegetation and built human infrastructure.

Habitat fragmentation in urban environments results in lasting alterations to the physical environment (e.g. light and temperature), degrading ecosystem function [58, 62, 63] which leads to declines in ecosystem service provision [49]. Changes in habitat patterns resulting from urban sprawl cause important impacts on biodiversity in urban areas, namely the loss of diversity and a more homogenized species composition [64]. In fact, habitat area and fragmentation are known to have important impacts on biodiversity for a wide range of groups including plants, amphibians, birds and insects [65]. Populations occupying smaller and more isolated habitat areas experience harsher environmental conditions, and therefore face a higher risk of extinction [66, 67]. The types of species lost from fragmented landscapes depends upon species' traits, including their size and mobility [67, 68].

Patterns of habitat loss and fragmentation due to urban sprawl

Habitat loss and fragmentation result in a reduction of habitat patch size and an increase in their isolation. During urban area growth, the degree of habitat fragmentation generally increases with habitat loss [69]. Different fragmentation patterns exist across cities. Angel et al. [70] found, using a global sample of 120 cities, that fragmentation decreases with city size but increases with average income in a city. Cities with higher levels of car ownership, and those that constrain urban development through zoning or land-use regulation, are also less fragmented. Importantly, these outcomes occur within municipal boundaries, but also beyond the geographic limits of the city proper in the suburbs and exurbs of the metropolitan area. Figure 13 shows patterns of urban growth for a few example cities.

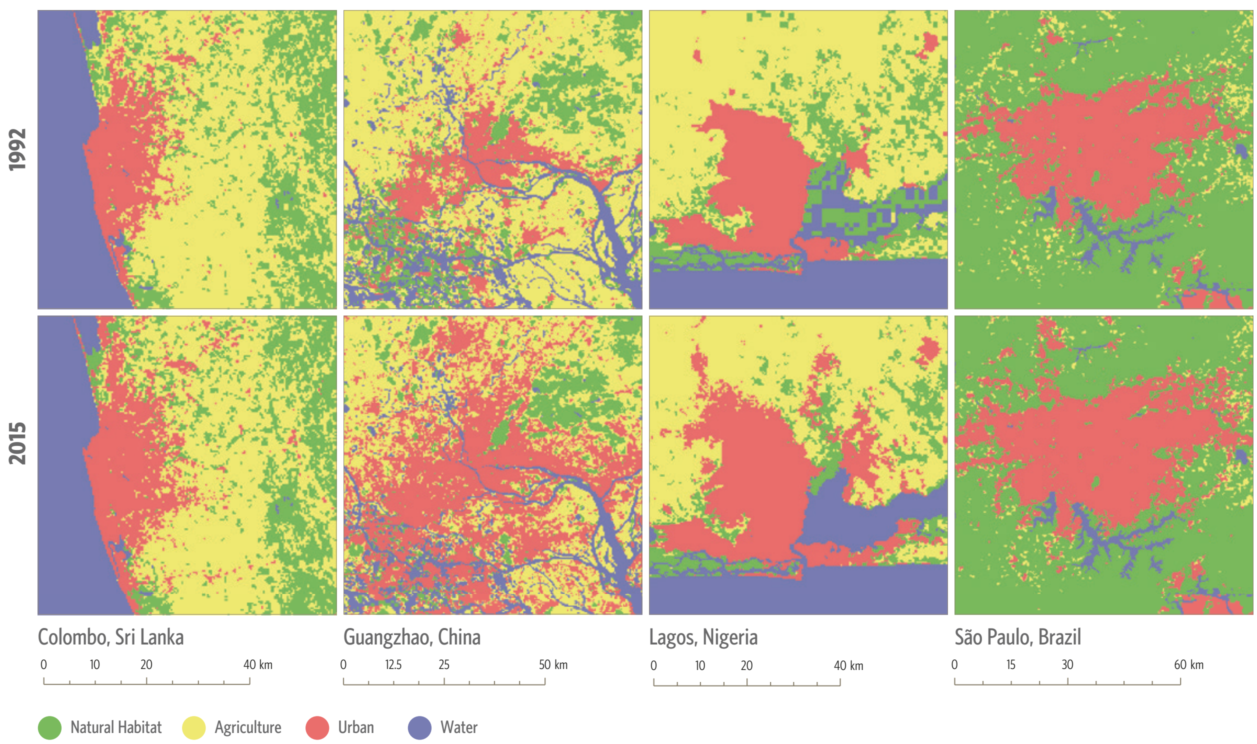


Figure 13: Changes in land-cover of Colombo, Guangzhao, Lagos, and São Paulo (1992-2015), based on the CCI Land Cover.

Moreover, as urban areas expand, linear infrastructures including roads, railways, fences and power lines also expand, further fragmenting the metropolitan area and surrounding natural habitats. For example, China has experienced extremely rapid urban growth since the 1990's with an average annual urban growth rate of ca. 8-9% [69, 71]. Fragmentation by major transportation systems within China varies widely, with almost all eastern provinces, especially areas near big cities, having high levels of fragmentation; and several eastern-Chinese provinces having among the most severe landscape fragmentation in the world [72, 73]. This massive linear infrastructure has resulted in significant natural habitat loss in some areas of China [71].

Linear infrastructure, beyond further reducing or degrading habitat quality, can have additional negative impacts for species inhabiting and passing through metropolitan areas. Above all, they can be responsible for direct mortality (roadkill, collisions and electrocution), which may significantly imperil animal population persistence in urban areas. For example, most animal species are susceptible to becoming roadkill, and high rates of mortality have been recorded throughout the world, including for insects [74], amphibians [75], reptiles [76], birds [77], and mammals [78].

Urban-caused habitat loss is associated with imperilment

Habitat loss— whether driven by urban growth or by the expansion of other anthropogenic land-use, like agriculture— is the preeminent cause of terrestrial vertebrate species imperilment. One systematic review, Evolution Lost: Status & Trends of the World's Vertebrates [79], stated that "overwhelmingly, habitat loss is the greatest threat to all vertebrate groups." Agriculture and logging are the two most common drivers of habitat loss, followed by residential and commercial development from urban growth, which is listed as a threat to approximately one in three threatened vertebrate species.

For this report, we wanted to examine how frequently species listed as threatened on the International Union for Conservation of Nature (IUCN) Red List had a fraction of their habitat urbanized (*Figure 14*). Threatened here was defined as listed as Vulnerable (VU), Endangered (EN), or Critically Endangered (CR). After analyzing the ranges of all IUCN Red List terrestrial mammals and amphibians, we found that 14.8% of these species had between 1% and 5% of their range converted to urban area in 2000. Another 4.7% of these species have lost between 5% and 20% of their range to urban growth. A further 1.1% of these species are highly impacted by urbanization, with more than 20% of their range lost to urban growth.

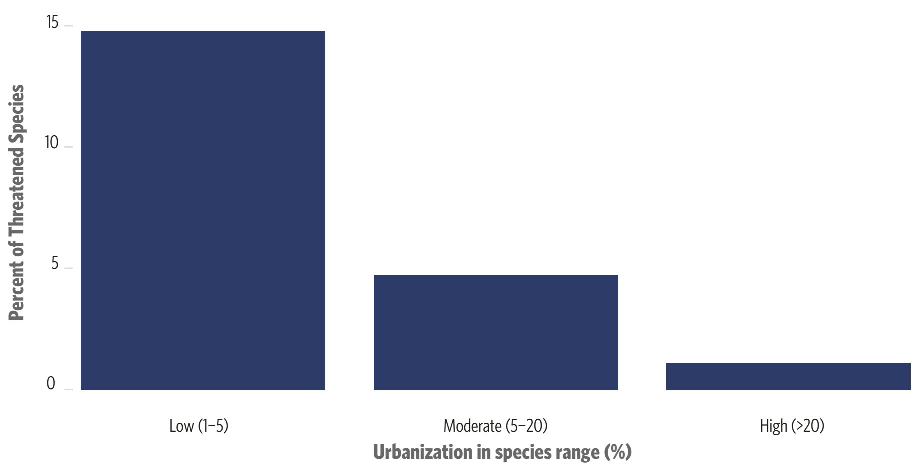


Figure 14: Percent of IUCN Red list species listed as threatened (defined as being listed as Critically Endangered, Endangered, or Vulnerable), that have a fraction of their range urbanized in 2000.

Habitat loss is, of course, far from the only factor that leads to species imperilment. Species with small ranges are more likely to be imperiled, and there are other characteristics of a species' life cycle that make them more or less likely to be imperiled [79]. Nevertheless, it is instructive to look at a list of some IUCN Red List species that are listed as threatened and have more than 20% of their range lost to urban growth (See Table 2).

Photo © milehightraveler

A larger proportion of amphibians have small ranges than mammals, and species with small ranges are more likely to have a large fraction of their range urbanized than those with large ranges. This explains the greater frequency of threatened amphibians than mammals in Table 2. Indeed, most of the species listed in Table 2 (both amphibians and mammals) have very small ranges, having been observed in only a few localities.

Table 2 only lists threatened species with more than 20% of their area urbanized. However, there are species with larger ranges that still have significant fractions of those ranges urbanized. For instance, several mammals along the Atlantic coast of southeastern Brazil have been affected by urban growth near Sao Paulo and Rio de Janeiro: the southern muriqui (*Brachyteles arachnoides*, Endangered), which has a range of 86,000 km^2, 7.8% of which is urban; and the buffy-tufted marmoset (*Callithrix aurita*, Vulnerable), which has a range of 160,000 km^2, 5.8% of which is urban. Another mammal species with a similar degree of urban conversion is the water deer (*Hydropotes inermis*, Vulnerable), which has a range of 182,000 km^2, 5.8% of which is urban, including urban areas such as Shanghai and Seoul. Among the amphibians, the Arroyo toad (*Anaxyrus californicus*, Endangered) has a range of 58,000 km^2, 6.5% of which is urban, including urban areas like Los Angeles, San Diego, and Tijuana.

Many of these species would likely be rare and listed as threatened by the IUCN regardless of the amount of urban area nearby, because of other threats to their persistance. However, the significant degree of urban area in their surroundings means that urban issues must be considered in these species' management plans. It is important to emphasize that habitat loss need not be a death sentence for a species. With proper land protection and management, species can survive even when a portion of their habitat is lost due to urban growth or other forms of land conversion, if the remaining habitat is large enough to support a viable population.

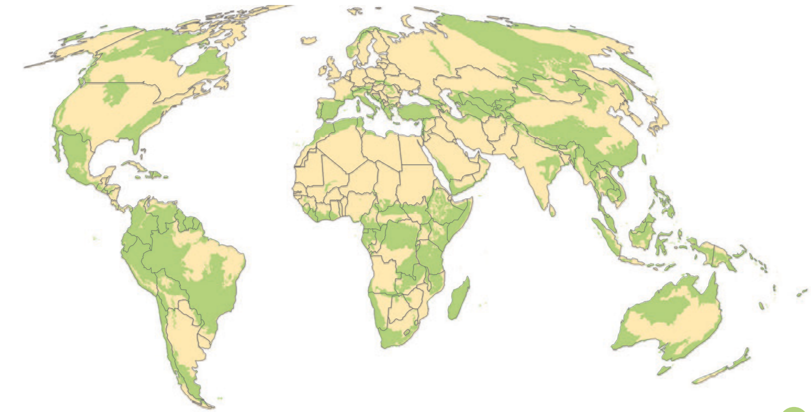
Photo © Marbá-Jonathan Díaz

Urban impacts on biodiversity are spatially concentrated

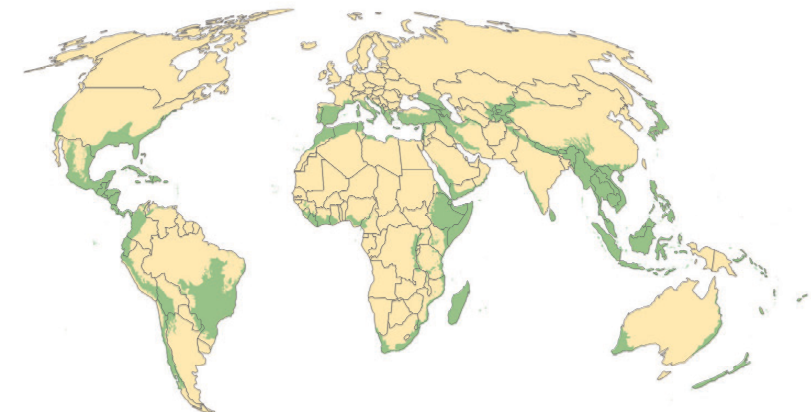
As shown above, urban growth will significantly imperil many different types of habitat, from tropical forests to deserts to temperate grasslands. Insight into conservation priorities can be gained by comparing our scenario of habitat loss with metrics of global biodiversity importance. One challenge, though, is that there are many different metrics of biodiversity importance currently in use. On the web site associated with this assessment (www.urbannature100.org), there is an interactive map to visualize the threat urban growth poses. In this report, where we can only present static images, we show the spatial patterns of multiple metrics of biodiversity. We then present in the next section a more focused analysis of the impact of urban growth on one commonly-used metric of biodiversity importance, Key Biodiversity Areas (KBAs).

Figure 15 presents some commonly used metrics of conservation importance. The Global 200 ecoregions (top left) are a selection of ecoregions identified as conservation priorities due to having high species richness or endemism, or due to having a high degree of threat [80, 81]. Within the Global 200 ecoregions, areas we have forecasted to have significant urban growth include central Mexico, the southern coast of Brazil, and southern China. The Biodiversity Hotspots (bottom left) are regions with more than 1,500 endemic vascular plants that have lost more than 30% of their original natural habitat [82]. Areas forecasted to have significant urban growth within the Biodiversity Hotspots are broadly similar to those in the Global 200 ecoregions, and include central Mexico and the southern coast of Brazil. The Alliance for Zero Extinction (AZE) sites (top right) are where the only known population of a particular species exists [83]. AZE sites forecasted to have significant urban growth are in the regions mentioned above, but are also disproportionately found on islands, such as in Madagascar, Indonesia and Papua New Guinea. Finally, Key Biodiversity Areas (bottom right) are identified following the IUCN's Global Standard for the Identification of Key Biodiversity Areas. Sites must meet one or more of 11 criteria, such as threatened biodiversity, geographically restricted biodiversity, ecological integrity, biological processes, or irreplaceability [84, 85]. For instance, AZE sites and surrounding natural habitat are often designated as KBAs.

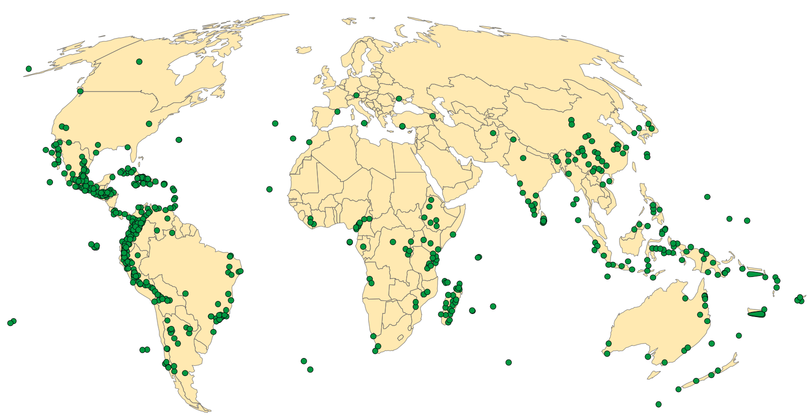
// Biodiversity loss is forecasted to be highly spatially concentrated.



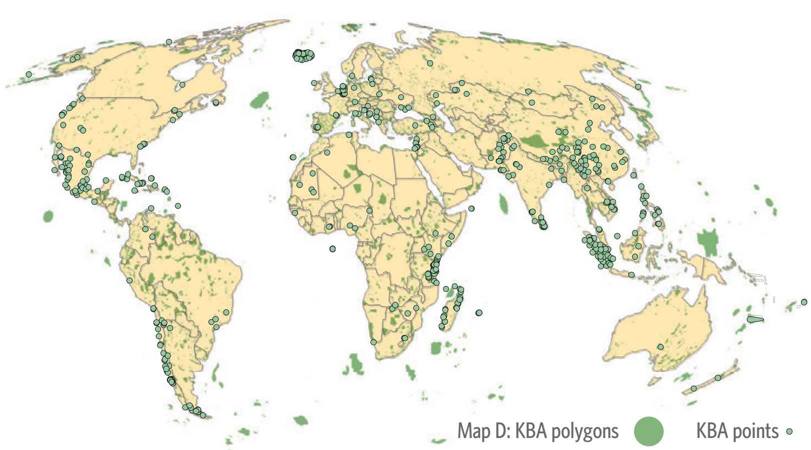
Map A: Global 200 Priority Ecoregions



Map B: Biodiversity hotspots



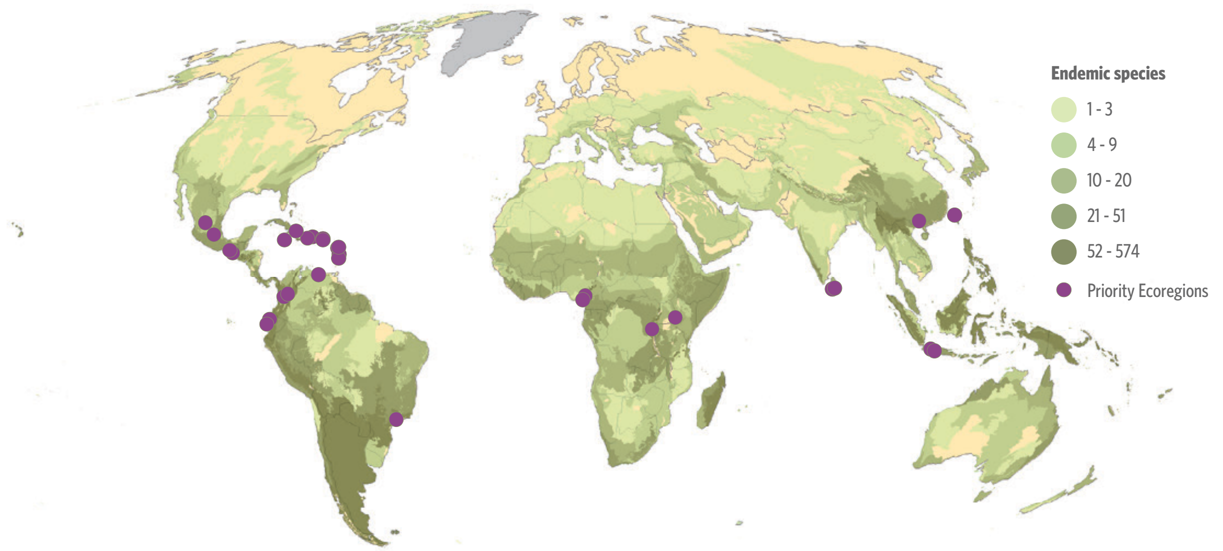
Map C: Alliance for Zero Extinction Sites



Map D: KBA polygons KBA points

Figure 15: Maps of conservation priorities. **A:** The Global 200 Priority Ecoregions are ecoregions identified as conservation priorities for their richness, endemism, threat, or other characteristics. **B:** The Biodiversity Hotspots, regions with more than 1,500 vascular endemic plants and that have lost more than 30% of their original natural vegetation. **C:** The Alliance for Zero Extinction sites are locations where the only known population of extremely rare species exist. **D:** Key Biodiversity Areas, that meet criteria in five broad categories of threatened biodiversity; geographically restricted biodiversity; ecological integrity; biological processes; and irreplaceability.

At least two studies have compared information on conservation importance with urban growth scenarios, to identify urban conservation priorities (*Figure 16*). First, vertebrate endemism for some well-studied taxonomic groups (amphibian, birds, mammals, and reptiles) is shown in Figure 16 (top). A recent paper by McDonald et al., "[Conservation Priorities to Protect Vertebrate Endemics from Global Urban Expansion](#)" [56] systematically compared urban growth scenarios with endemism data, and found that globally, 13% of endemics are in ecoregions under high threat from urban expansion. Biodiversity loss is forecasted to be highly spatially concentrated, with 78% of endemics threatened by urban growth occurring in just thirty priority ecoregions (4% of all ecoregions). Many of these priority ecoregions occur on islands, such as Sri Lanka, Puerto Rico, Hispaniola, and Jamaica. Natural habitat protection of 41,000–80,000 km^2 would be needed in these 30 priority ecoregions to safeguard endemic vertebrates. Table 2 from McDonald et al. [56] lists ecoregion priorities, along with the cities affecting them, and the forecasted range of potential natural habitat loss.



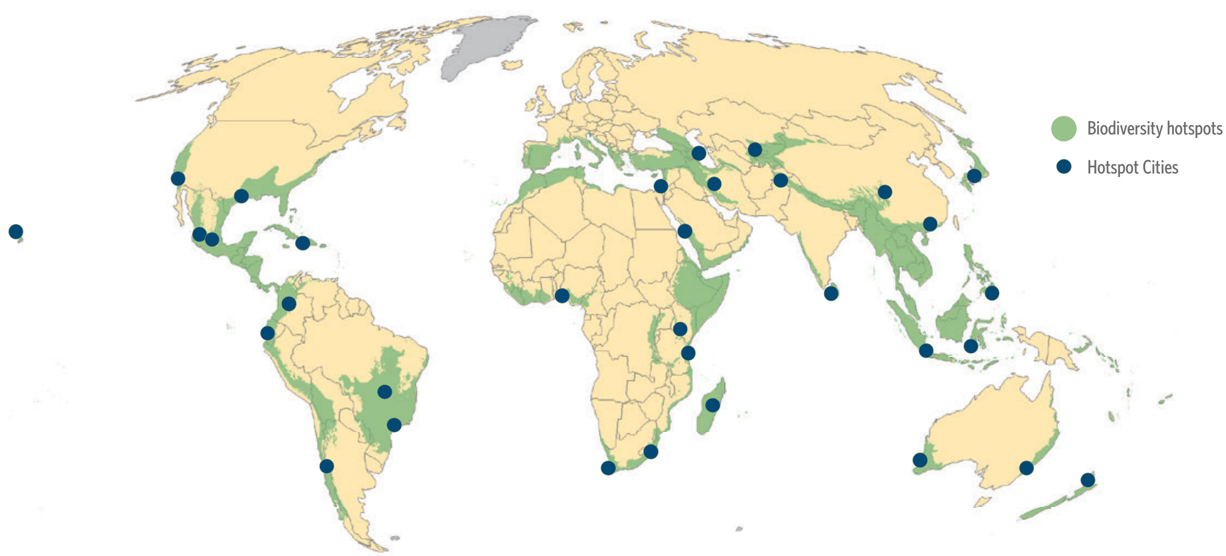


Figure 16: Conservation information can be used to set urban conservation priorities. Top: Endemic vertebrate species (amphibians, birds, mammals, and reptiles) in ecoregions. Marked with purple dots are the 30 priority ecoregions identified by McDonald et al. (2018), which selected ecoregions with high endemism and substantial natural habitat loss forecasted. Bottom: The Biodiversity Hotspots. Marked with blue dots are the 33 cities identified as urban conservation priorities in Weller et al. (2017), which selected the city in each hotspot with the largest forecasted population growth.

Photo © Atakorn

Second, a recent report by Weller et al., "Atlas for the End of the World" [86], identified cities in Biodiversity Hotspots. For each hotspot, they selected the city with the largest forecasted increase in population from 2016 to 2030. *Figure 16* (bottom) shows the thirty-three cities they identified. Note that most selected hotspot cities are along coastlines and on islands, such as Sri Lanka (Colombo) and Hispaniola (Port Au Prince). The Hotspot Cities section of the Atlas [86] lists all 33 cities, along with detailed city-level maps of potential urban growth impacts on natural habitat.

Urban impacts on Key Biodiversity Areas

We now focus on urban impacts on the world's Key Biodiversity Areas (KBAs), as they are one of the most accepted measures of conservation importance [84, 85]. A large fraction of the world's terrestrial KBAs are or will be impacted by urban growth (*Figure 17*). By 2030, 9.1% of KBAs will have between 1-5% of their area urbanized. 3.2% of KBAs will have between 5-10% of their area urbanized. Summing up, one in ten KBAs (9.9%) will have more than 5% of their area urbanized by 2030. Surprisingly, around 2.1% of the world's KBAs will have more than 50% of their area urbanized and will be extremely impacted by urban growth.

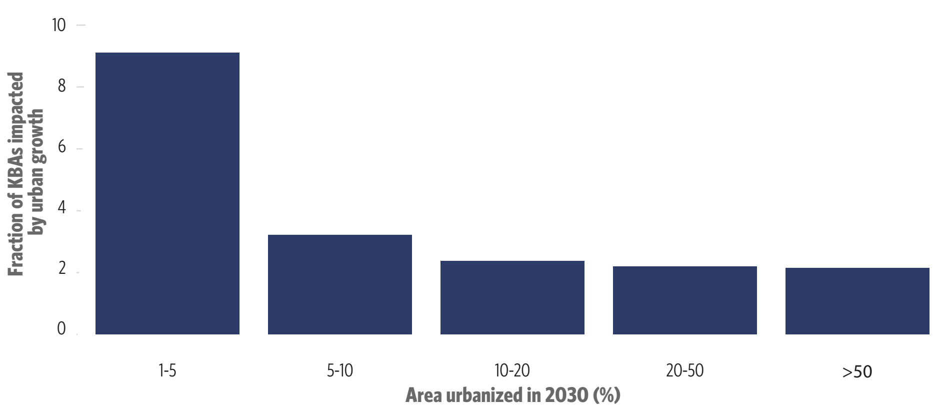


Figure 17: The fraction of the world's terrestrial Key Biodiversity Areas (KBAs) that are impacted by urban growth. KBAs are divided into categories, based upon the area urbanized within the KBA by 2030.

KBAs that will be impacted by urban growth are shown in Figure 18, where impact is defined as having more than 5% of their area urbanized by 2030. Many of these urban impacted KBAs are found in Europe. Another concentration of urban-impacted KBAs is in Latin America, especially in Central America, the Caribbean, and the western and southern coasts of South America. East Asia has a concentration of urban-impacted KBAs, especially in China, Taiwan, Korea, and Japan. In Africa, urban-impacted KBAs are most commonly found along coastal regions such as along the Mediterranean, the Gulf of Guinea, and the coast of South Africa. Uganda, Rwanda, Kenya, and Tanzania have another cluster of urban-impacted KBAs.

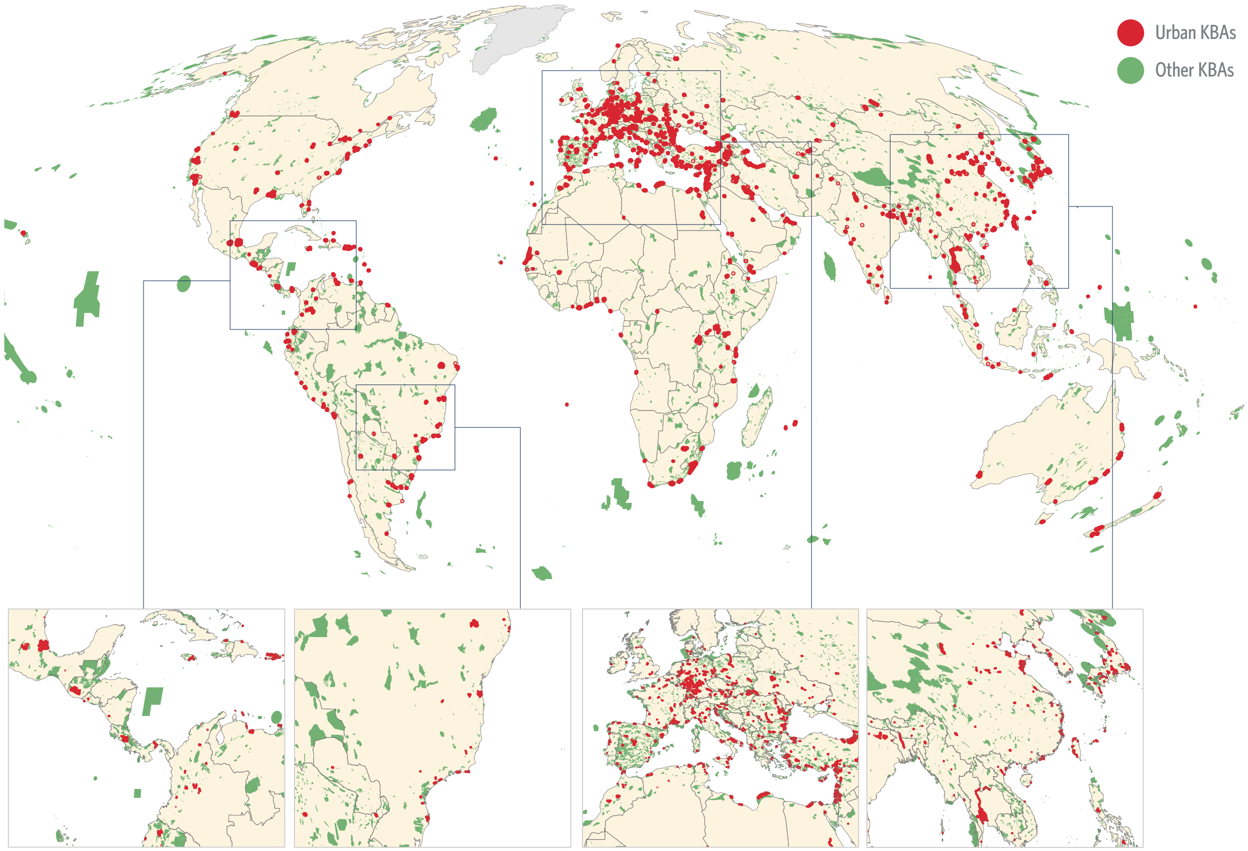


Figure 18: Key biodiversity areas (KBAs) that are impacted by urban growth (>5% of their area forecasted to be urbanized by 2030). Shown is a global map (top panel), as well as inset maps for Central America, Europe, Brazil, and China.

While the large fraction of KBAs that are or will be impacted by urban growth can be daunting, it is worthwhile to consider the positive side to this spatial concentration of biodiversity impact. The urban-impacted KBAs in Figure 18 have a total area of 320,000 km^2. On average, around 16% of the area of these KBAs will be urbanized by 2030. That implies that there will be 52,000 km^2 of area within these KBAs that could be lost to urban growth, unless growth is otherwise limited or managed. Compared to the 290,000 km^2 of habitat globally between 2000 and 2030 that is forecast to be urbanized, this is fairly small. Conservation action to protect these urban KBAs could serve as a focused first step toward mitigating the impact of global urban growth on biodiversity.

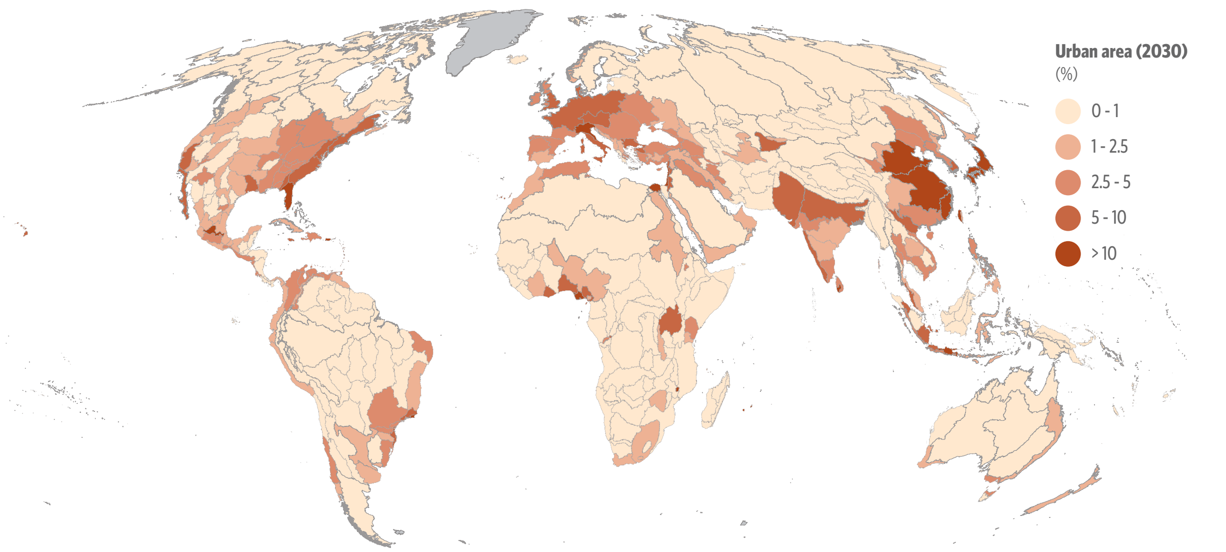
Urban impacts on freshwater and marine biodiversity

This report has focused on terrestrial biodiversity. This is primarily a reflection of the fact that there are more studies of the direct impact of urban growth on terrestrial habitats than on freshwater or marine habitats, and because it is more straightforward analytically to intersect maps of urban growth with terrestrial habitats than it is to model the complex effects urban growth has on the hydrologic cycle. Nevertheless, it is clear from existing scientific reviews that urban growth can have a significant impact on freshwater and marine biodiversity. In this subsection, we try to highlight major types of impact, citing works that discuss these issues in more detail.

Freshwater

It is clear that cumulatively, cities and associated development have a significant impact on freshwater biodiversity [79]. Freshwater ecosystems are only 0.8% of the Earth's surface, but harbor about 6% of all described species. The best studied freshwater taxonomic group is fish (*Pisces*). Across both freshwater and marine fish, around 15% are listed as threatened on the IUCN Red List. There is some evidence that freshwater fish are more threatened than marine fish, with an estimated 65% reduction in monitored freshwater fish populations since 1970. Urban growth is associated with an increase in water pollution and sedimentation, which is the most common threat to freshwater fish species. Similarly, urban growth often increases road construction and energy-sector development, which often leads to dams and other barriers to fish migration, the second most common threat to freshwater species. Residential and commercial development, often associated with urban growth, is listed as a threat to around one in five freshwater fish species.

By overlaying information on urban growth on maps of the freshwater ecoregions of the world [87], we can gain insight into which areas are likely to be most impacted by urban growth (*Figure 19, Top)*. Freshwater ecoregions that will be highly urbanized in 2030 include those in China such as the lower Huang He and lower Yangtze, as well as those freshwater ecoregions that comprise much of Japan and Taiwan. In the United States, the Florida peninsula is one freshwater ecoregion that will be highly urbanized in 2030. Also important in setting conservation priorities is the degree of freshwater species richness and imperilment in a freshwater ecoregion. For instance, previous scientific studies [88] have called out the Western Ghats freshwater ecoregion in India as one place with significant future forecasted urban growth and with high levels of fish richness and endemism.



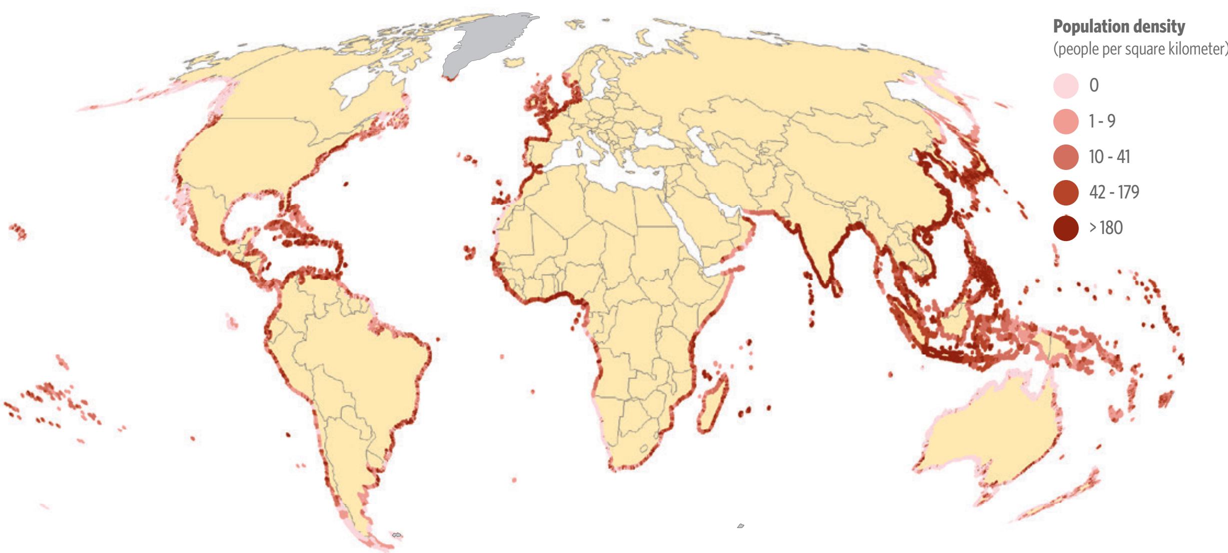


Figure 19: Urban growth impacts on freshwater and marine ecosystems. **Top:** The proportion of area urban in 2030 in the Freshwater Ecoregions of the World. **Bottom:** The population density along coastlines in 2020.

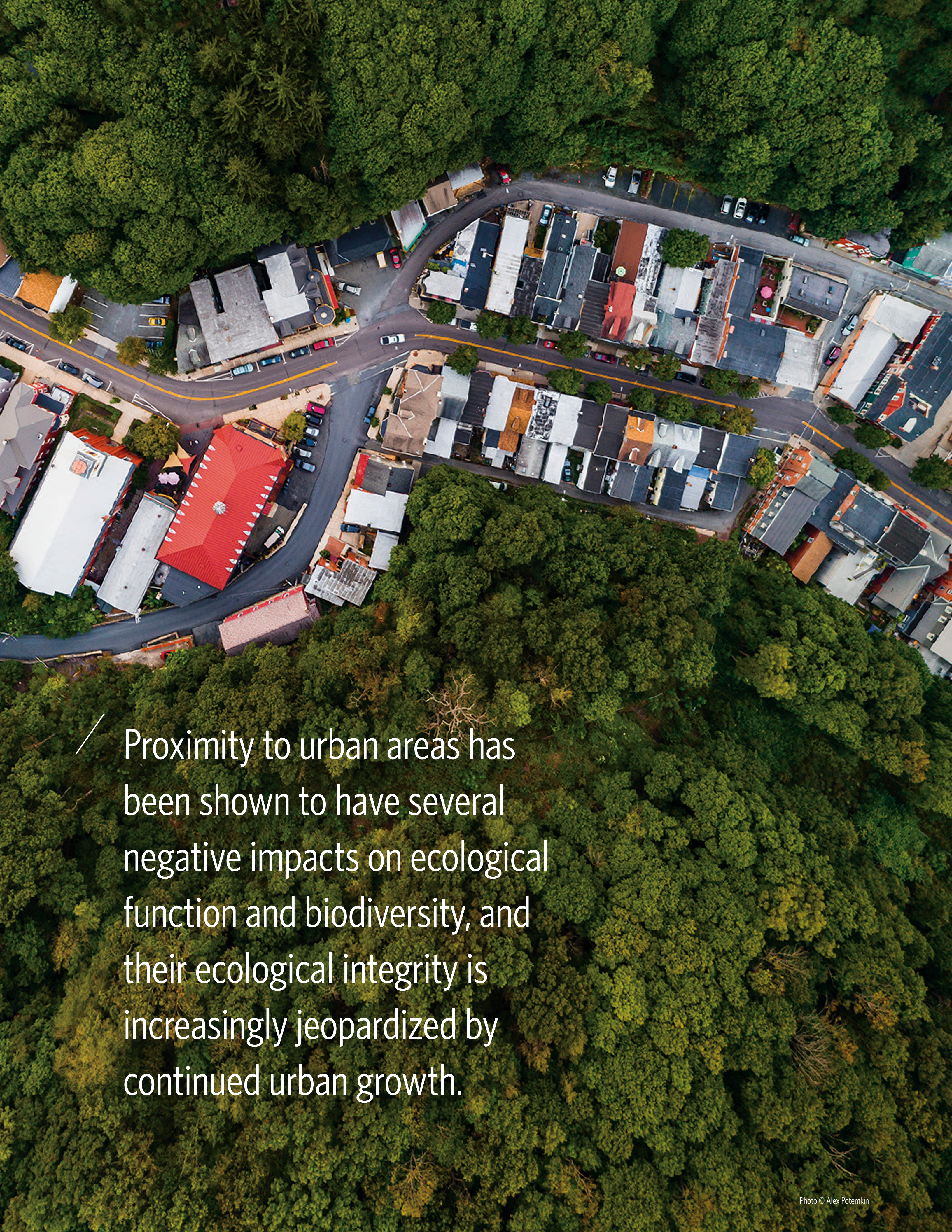
This section has focused on the impacts of urban growth on freshwater ecosystems, but of course cities also depend on ecosystem services from freshwater ecosystems for human wellbeing. Perhaps foremost among these is drinking water. Intact natural ecosystems, both freshwater and terrestrial, play a crucial role in maintaining water quality and, in some cases, quantity [89, 90]. Freshwater ecosystems, in conjunction with wetlands and floodplains, provide many other ecosystem services of importance to urban dwellers, such as stormwater management and flood risk mitigation [6]. See the section on “Integrating nature into cities” for more discussion of how these ecosystem services can be incorporated into cities, for the benefit of biodiversity and human wellbeing.

Marine

The evidence suggests that urban growth also has significant impacts on marine biodiversity, although perhaps of slightly lower magnitude than for freshwater biodiversity. For instance, for marine fish, there has been a 20% reduction in population observed since 1970 for monitored populations [79]. For IUCN Red List marine fish species, residential and commercial development is listed as a threat for around one in five Red List species. The discharge of untreated sewage and other pollution to ocean waters may also impact many near shore marine ecosystems. Pollution is listed as a threat to one in three Red List marine fish species. The most common threat to marine fish is overfishing. Urban seafood consumption patterns drive the levels of harvesting from wild fisheries, as well as the level of production from aquaculture, with significant indirect effects to marine ecosystems.

In Figure 19 (bottom) we show the sections of coastlines that are forecast to have the greatest population density in 2020. Human population will be especially high along the coastline for much of South and Southeast Asia, West Africa, Northern Europe, and portions of the eastern United States and the Caribbean. Nearshore habitats of value for marine biodiversity include coral reefs, mangroves, salt marshes, and kelp forests. Along these stretches of coastline with high human population density, maintaining these habitats will be important to preventing marine biodiversity loss.

Urban areas also depend on coastal habitats for ecosystem services essential to human wellbeing [91]. The section of this report on climate adaptation focuses on the benefits coastal habitats provide in reducing the risks of coastal flooding and hazards. There are of course a variety of other benefits that coastal habitat provides, many of which are catalogued on the Naturally Resilient Communities website. Finally, in the Integrating Nature into Cities section we discuss how these ecosystem services can be incorporated into cities, for the benefit of biodiversity and human wellbeing.



Proximity to urban areas has been shown to have several negative impacts on ecological function and biodiversity, and their ecological integrity is increasingly jeopardized by continued urban growth.

Photo © Alex Potemkin

Impacts of urban growth on protected areas

Urban growth not only directly affects natural habitat through land conversion, it also affects protected areas in many other ways. Land protection has been the preeminent strategy for biodiversity conservation over the past fifty years, and the creation of protected areas (PAs) is the primary goal of Aichi Target 11. Arguably, the rapid increase in terrestrial protected areas over the last few decades, from 8% in 1972 to 15% today (Protected Planet Report 2016) [92], has been one of the major successes of the CBD. Proximity to urban areas has been shown to have several negative impacts on ecological function and biodiversity (*Figure 20*), and therefore the significant investment by Parties of the CBD in protected areas is increasingly jeopardized by continued urban growth.

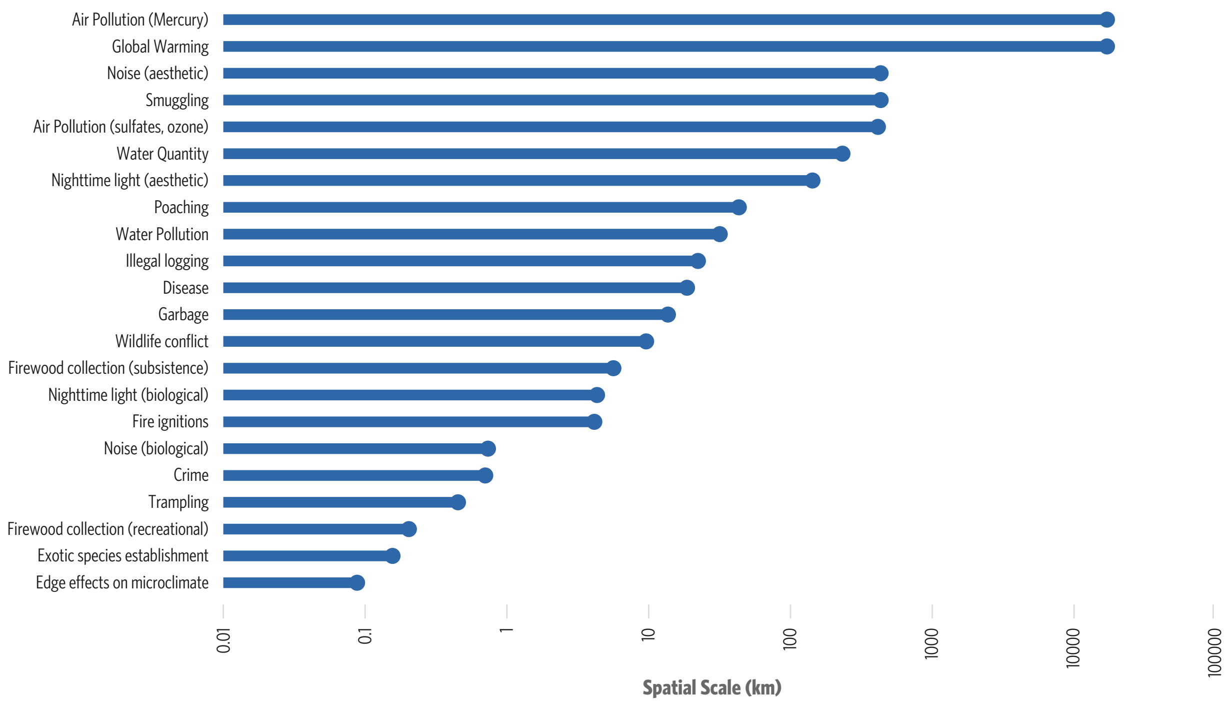


Figure 20: Impacts on protected area of being near a city, adapted from McDonald et al. (2009). A literature review identified from each study the maximum spatial scale at which negative and positive effects from urban areas propagate out and have observed to affect protected areas. Each line represents an average of the reported distances in the literature.

The scale at which urban areas affect PAs varies depending on the type of effect. Some impacts are very local, such as the alteration of temperature and other abiotic conditions along habitat edges, an effect that extends into the protected area a few tens of meters. Habitat edges also become pathways by which invasive, non-native plants and animals can spread, which often have deleterious effects on the native flora and fauna within the PA. Some actions that can severely affect protected areas include resource extraction (legal or illegal), such as hunting or logging, which can extend into the PA by tens of kilometers. Other impacts of urban areas on PAs are regional or global in scale, such as those from light and air pollution like NO_x and SO_x, spreading 100s of kilometers from cities. Greenhouse gas emissions have global impacts. Our analysis presented below follows the rule of thumb suggested by McDonald et al. [93], in which PAs within 50 km of urban areas are considered at increased risk of significant anthropogenic impacts.

As the human population has increased, there has been a significant increase in the average population density in the surroundings of protected areas. The average population density, both rural and urban in a 50 km buffer zone around strictly protected areas (IUCN categories I-IV) has increased 24% from 2000 to 2020 (estimated population), from 51 to 63 people/km^2 (*Figure 21*). Similarly, for loosely protected areas (IUCN categories V-VI), the population density has increased 28% over the same period, from 53 to 68 people/km^2. Individual countries may have much higher values. The Netherlands, for instance, is forecast to have 808 people/km^2 in 2020 in the surroundings of its PAs, while Bangladesh is forecast to have 1,265 people/km^2.

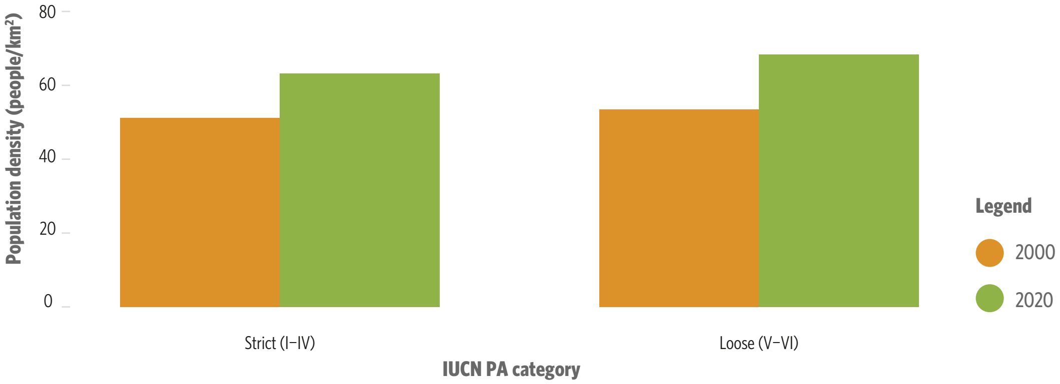


Figure 21: Population density near protected areas, in 2000 and 2020 (estimated).

Along with urban population increase often comes urban area expansion. Urban areas continue to move closer to PAs (*Figure 22*). In 1992, only 3% of strictly protected PAs (IUCN categories I-IV) were within 10 km of cities, while roughly 6% of PAs were between 10 and 20 km from cities and 20% of PAs were between 20-50 km from a city. By 2030, we project that these numbers will have increased dramatically, with 8% of strictly protected PAs within 10 km of cities, 9% between 10-20 km from cities, and 23% within 20 and 50 km from a city. Trends for loosely protected PAs (IUCN categories V-VI) are similar, although these PAs tend to be closer to urban areas than do strictly protected PAs. By 2030, more than one in three strictly protected PAs and one in two loosely protected PAs will be in the 50 km buffer zone around cities. Managing PAs near cities will be a common challenge in our urban century, and close to half of all PAs will require special management if they are to retain their ecological functions.

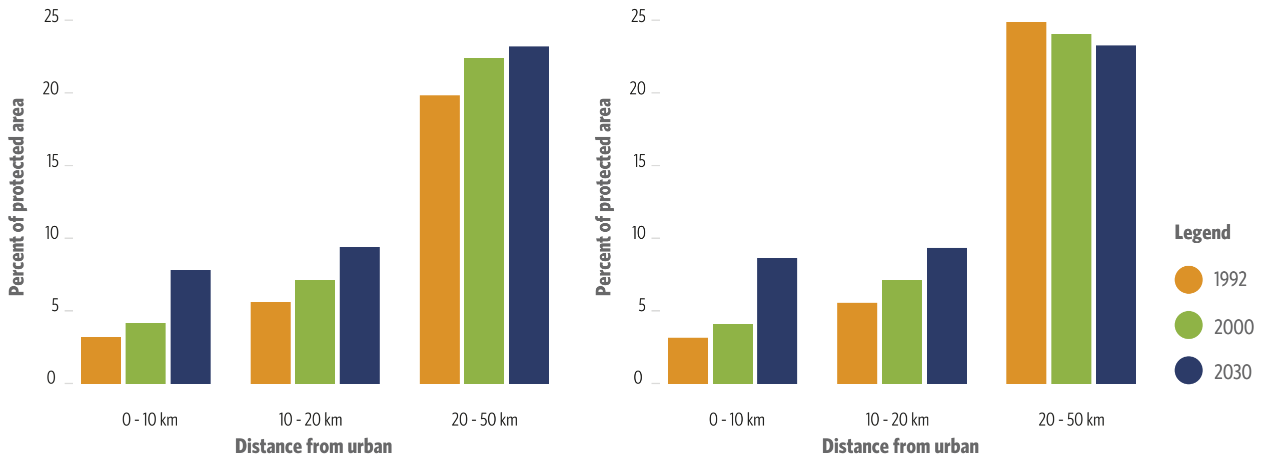


Figure 22: Distance from PA to urban area in 1992 and 2030. **Left:** Strictly protected areas (IUCN categories I-IV). **Right:** Loosely protected areas (IUCN categories V-VI).

The degree of urban impacts on protected areas vary widely from country to country (*Figure 23*). By 2000 more than 80% of PAs in most European Countries were within 50 km of a city. Conversely, countries in Latin America and Africa have relatively low fractions of PAs that are within 50 km of a city. By 2030, there will be a significant increase in proximity of PAs to cities globally. The biggest increases will be in Latin American, the Indian subcontinent, and parts of sub-Saharan Africa. While in China the fraction of PAs near cities will remain low, due to the relatively sparsely populated west of the country, PAs along the coastline will see a sharp increase in urban area-adjacency.

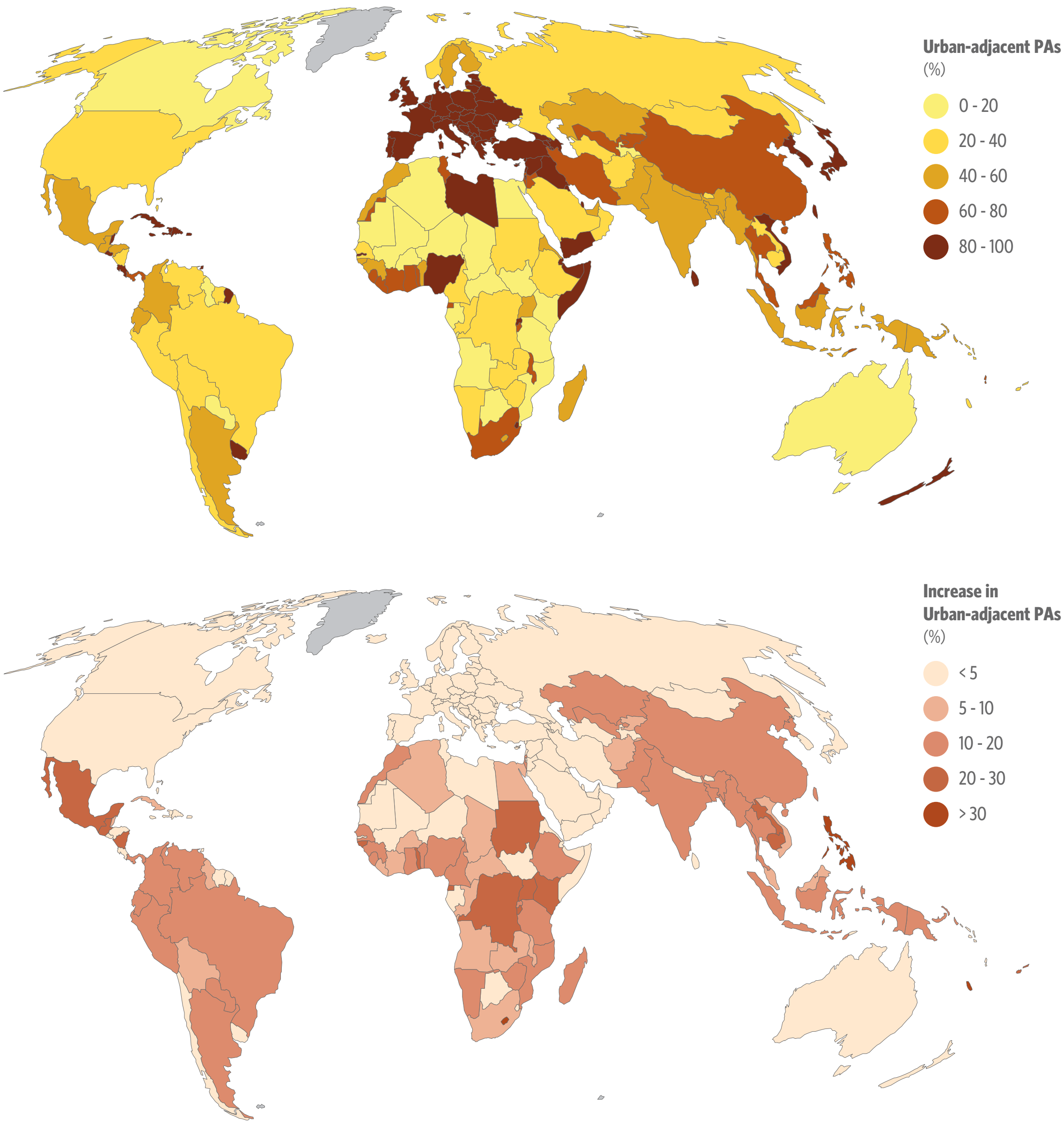


Figure 23: Country-level trends in in the fraction of all protected areas (IUCN categories I-VI) that are urban adjacent (within 50 km of an urban area). A.) Percent of protected areas that are urban-adjacent (2000), by country. B.) Increase (%) in the fraction of protected areas that are urban-adjacent (2000-2030).

Photo © Evgeny Pylayev

The same sort of analysis can be applied to individual protected areas, to examine the potential impacts of urban growth on specific PAs. Table 3 shows large (> 500 km^2), strictly protected areas (IUCN categories I-IV) that already have large amounts of urban area within 50 km. Note the multiple protected areas in already highly urbanized countries, such as Italy, Taiwan, and United States. Brazil also has two PAs on this list, both near the coastline.

The protected areas that will experience the most rapid urban growth (2000-2030) within 50 km are shown in Table 4. Protected areas in Table 4 tend to be concentrated in countries that are still urbanizing rapidly. For instance, Sundarbans National Park in India will have a significant increase in urban area in its surroundings, as Calcutta and other urban settlements rapidly expand. Many of the potentially impacted PAs highlighted in Table 4 are in developing countries, with a special concentration in sub-Saharan Africa. Importantly, inclusion in Table 4 does not mean that urban growth will necessarily occur inside PA boundaries, but just that significant urban growth is forecast within 50 km.

We find that urban growth, if unplanned, could impact natural habitat that currently stores carbon equivalent to emissions from 931 million cars on the road for one year.

Impacts of urban growth on climate change

Natural habitat and carbon storage

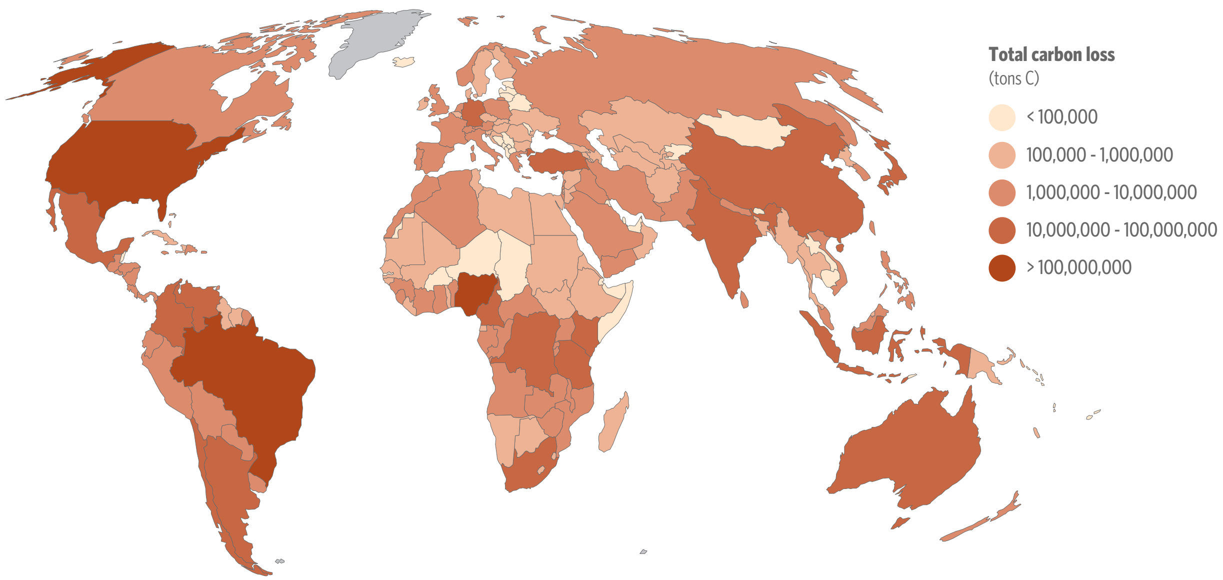
Climate change mitigation has been defined as any intervention to reduce the sources or enhance the sinks of greenhouse gases [94]. High concentrations of carbon dioxide and other greenhouse gases in the atmosphere contribute significantly to global warming and associated climate change [95]. The UNFCCC's 2015 Paris Agreement states as its long-term goal to keep the increase in global average temperature well below 2°C, relative to pre-industrial levels. The reduction of carbon dioxide emissions is one of the main mechanisms by which this goal can be achieved.

// Urban growth, if unplanned, could affect natural habitat that currently stores an estimated 4.35 billion tons of carbon dioxide.

Carbon dioxide is released into the atmosphere through a number of different processes, including the burning of fossil fuels and land use change such as deforestation. Globally, emissions from fossil fuels and industry amounted to 9.9 ± 0.5 billion tons of carbon (GtC) per year in 2016, while emissions from land use changes totaled 1.3 ± 0.7 GtC/year [96]. Natural habitat stores carbon in the form of biomass, and when it is cleared or burned to make way for urban development, carbon dioxide is released. Intact natural habitat therefore fulfills an important climate service by storing carbon. Protecting natural habitat from unplanned urban growth directly contributes to Aichi Target 15: *By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration,… thereby contributing to climate change mitigation and adaptation*.

This climate mitigation service can be quantified by calculating the amount of above- and below-ground carbon stored in biomass and converting that figure into the amount of carbon dioxide that could potentially be released if this biomass were cleared or burned for urban land use [97]. We find that urban growth, if unplanned, could impact natural habitat that currently stores an estimated 1.19 GtC, or 4.35 billion tons of carbon dioxide ($GtCO_2$) (*Figure 24*). This is the same amount of carbon dioxide emissions from 931 million cars on the road for one year [98]. Assuming the avoided emissions are spread equally over the period between 2000 and 2030, avoiding urban-caused habitat loss would prevent emissions of 0.15 $GtCO_2$/year-. Compared to the large numbers associated with cities' overall direct and indirect CO_2 emissions (see next section), the emissions of 0.15 $GtCO_2$/year that are potentially released due to expansion into natural habitat might appear relatively minor. However, this amount still represents between 2.0% and 6.6% of total annual greenhouse gas emissions associated with global land use change [96].

We find that the greatest potential overall loss of carbon from urban growth will occur in the United States, Brazil, and Nigeria. The highest rates of average carbon loss per hectare of habitat lost will occur in Central Africa and Southeast Asia, as well as Brazil and Australia, as the vegetation types which are expected to be lost due to urban growth (such as tropical forests) store large amounts of carbon.



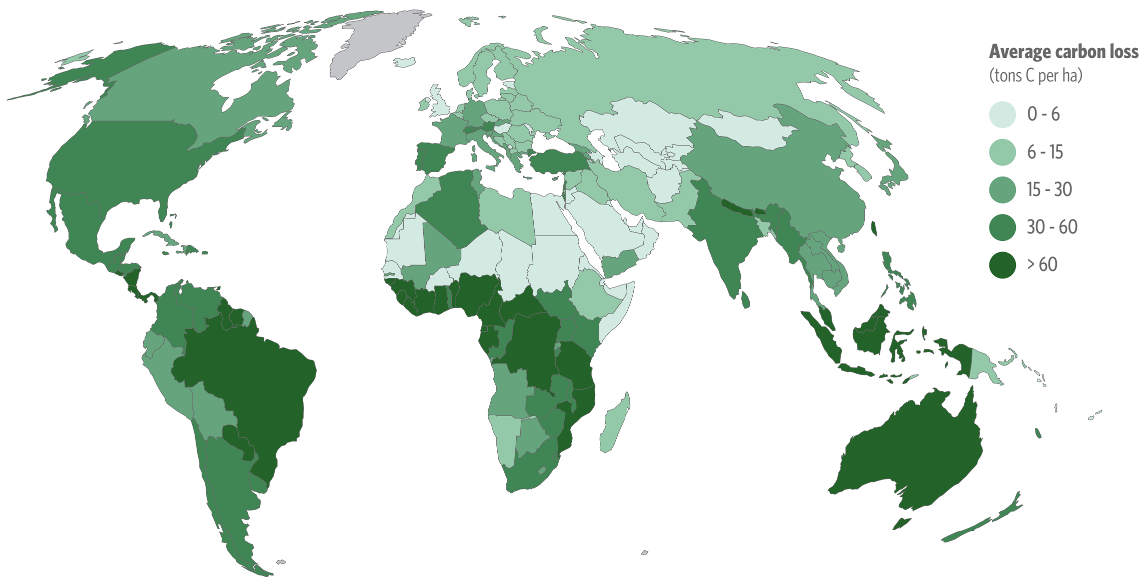


Figure 24: Country-level trends in the total carbon (in tons) (top), and average carbon (in tons per hectare) (bottom) lost due to urban growth into natural habitat.

Unlike many other impacts of urban development that play out at the local scale, the impacts of increasing carbon dioxide emissions are felt at the global scale. To quantify the severity of impacts an estimate of the social cost of carbon (SCC) can be calculated. The SCC is a measure of the economic harm caused by climate change and its consequences, such as flooding, food shortages, and the spread of diseases [99]. It is usually expressed as the dollar value of the long-term damages from emitting one ton of carbon dioxide. There are a number of integrated assessment models that can be used to calculate the SCC, though none of the models currently include the full range of important biophysical and socioeconomic impacts of climate change (mainly due to limited data availability) [95]. Here we use an estimate of the SCC based on the US Environmental Protection Agency's modeled SCC estimates (USD 42/t CO_2 eq) [100]. Our estimate of the carbon stored in natural habitat that is forecast to be lost to urban growth (2000-2030) has a potential social cost of 182.8 billion USD.

Alternatively, the value of avoided carbon emissions can be equated with the average price of carbon offsets in voluntary carbon markets, which currently trade at a much lower value than the SCC. The 2016 average price of carbon offsets on these voluntary carbon markets was USD 3.0/t CO_2 eq [101]. We estimate that the carbon stored in natural habitat that is forecast to be lost to urban growth (2000-2030) would have a value of 13.1 billion USD on voluntary carbon markets.

In the context of global greenhouse gas emissions, the emissions associated with urban growth into natural habitat may seem minor. However, for some countries protecting natural habitat on the urban fringe can meaningfully contribute meaningfully to achieving greenhouse gas emissions targets, as pledged at the Paris Climate Conference in 2015. Taking into account the potential mitigation benefits of natural habitat can be an important tool in the arsenal of urban planners to reduce the climate change impacts of their cities.

Uncertainty in estimating carbon stored in biomass

Carbon storage in vegetation can be calculated in different ways. One approach is to use globally consistent default values for biomass of different vegetation types, and then convert those biomass values to above- and below ground carbon stocks using the carbon fraction for each vegetation type [97]. Essentially, this method creates a database of carbon values for over 120 different types of carbon "zones", each associated with a different land cover, vegetation type, continental region, and forest age. This means that carbon values can be estimated for all regions of the globe, except for urban areas.

More recent methods base carbon values on remotely-sensed aboveground biomass estimates. This approach may be more accurate than the database approach described above, but so far studies have either been limited to certain vegetation types or regions, like the pan-tropics [102, 103], or have a coarse spatial resolution (>10 km) [104].

Nevertheless, comparisons between different types of data can be useful to assess the level of uncertainty associated with carbon storage values. Here we compare the global Ruesch & Gibbs [97] method with the Baccini et al. [102] approach that covers only tropical forests. Figure 25 shows the difference in carbon storage values (in kg/ha) between the two methods for the central Africa region. The Baccini et al. [102] data, based on remote-sensing technology, distinguishes more detail and variation within the forest vegetation, while the Ruesch & Gibbs [97] data covers a wider range of different vegetation and land use types.

For urban growth areas and vegetation types where the two different data sets overlap, the Ruesch & Gibbs [97] data estimates an average of 73.1 tons of carbon stored per hectare. In contrast, the Baccini et al. [102] data estimates an average of 48.0 tons of carbon stored per hectare. The Ruesch & Gibbs [97] estimates are therefore 52% higher, on average, than the Baccini et al. [102] estimates. In part, this is likely due to the fact that the Ruesch & Gibbs [97] data takes into account above- and below ground carbon, while Baccini et al. [102] focuses only on aboveground carbon. This raises an interesting question as to whether urbanization processes are likely to set free below-ground carbon, the same way that agricultural conversion of natural habitat might. Nevertheless, the difference in results might also indicate an overestimate of carbon storage values by the Ruesch & Gibbs [97] approach, at least in high-biomass areas like tropical forests.

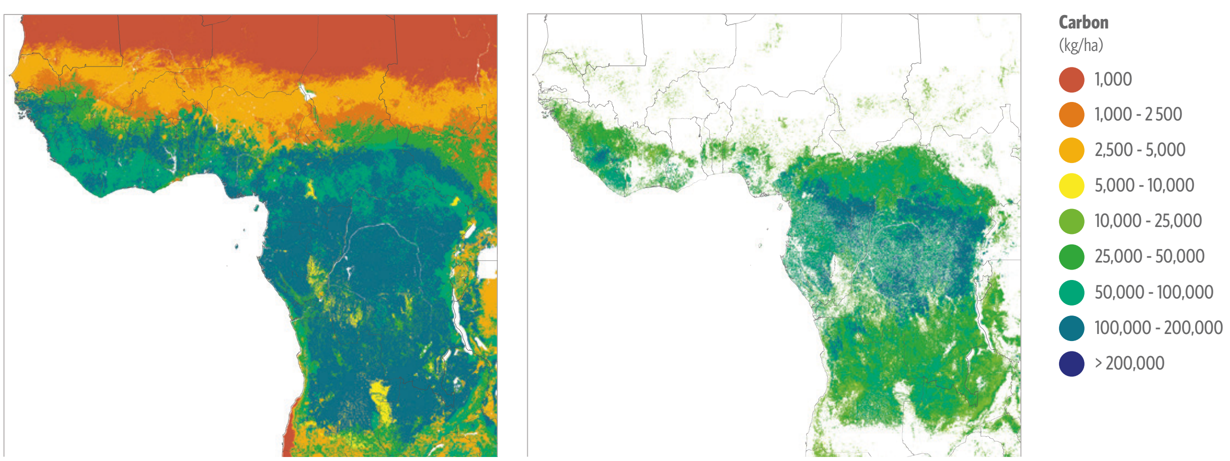


Figure 25: Comparison of results for carbon stored in biomass (kg/ha) in the central African region, as calculated using the Ruesch & Gibbs (2008) method (left) and the Baccini et al. (2012) method (right). The Baccini et al. (2012) method only considers tropical forest vegetation, while the Ruesch & Gibbs (2008) method takes into account all vegetation types.

Consumption and emissions within cities

As outlined above, 1.19 GtC stored in vegetation may be released into the atmosphere by unplanned urban expansion into natural habitat. Over the thirty year period under consideration (2000 – 2030), that translates into annual emissions of 145 million tons of CO_2. However, beyond emissions related to habitat loss, cities are responsible for a range of other greenhouse gas emissions associated with urban activities such as energy consumption, industry, transport, and waste disposal, as well as the import and export of goods.

The calculation of the total contribution of cities to greenhouse gas emissions depends on how urban emissions are defined. However, it has been estimated that cities account for as much as 70% of all human-induced greenhouse gas emissions [105]. Given the total global annual greenhouse gas emissions of 49 Gt CO_2 eq in 2010 [95], the contribution of cities would be estimated at 34 Gt CO_2 eq.

To facilitate standardized accounting, emissions are often categorized as either direct or indirect. In an urban context, direct emissions are emissions from sources within cities, such as industry. Indirect emissions are emissions that result as a consequence of a city's consumption of resources that are harvested or produced somewhere else. A recent global analysis of consumption-based (indirect) emissions estimates that emissions from the top-500 most emissions-intensive cities totaled approximately 9.9 ± 0.2 Gt CO_2 eq in 2015 [106].

Indirect emissions of urban areas are often estimated in studies that consider a city's "footprint". Urban areas consume large amounts of water, agricultural products, marine resources, and other renewable resources that are provided by areas outside of cities, and they produce waste that needs to be assimilated [107]. A city's ecological footprint can be expressed as the amount of biologically productive land that is needed to meet its demand for resources. For example, London's ecological footprint was calculated to be an area the size of Germany and Denmark combined [108]. When assessing a city's impact on biodiversity and ecosystem services, it is therefore important to consider the wider ramifications of urban consumption and growth beyond encroachment into natural habitat.

Natural habitat and climate change adaptation: a case study of coastal resilience

Climate change adaptation is the process of adjustment to actual or expected climate, with the aim of moderating or avoiding harm or exploiting beneficial opportunities [94]. Some of the most destructive consequences of climate change include increases in the frequency and severity of weather-related extreme events, such as hurricanes. In addition, global warming is causing the thermal expansion of seawater and melting of land-based ice sheets and glaciers, which results in sea level rise. Coastal communities are therefore especially vulnerable to the impacts of climate change, with increased risks of storm waves and surge, as well as sea level rise and subsidence [109]. It has been estimated that forty million people are currently living in areas that are at risk from one in one-hundred-year coastal flood events in major coastal cities around the world - a number that is projected to triple by 2070 [110]. Furthermore, extensive built infrastructure is often found close to the shore. The total value of exposed assets in major port cities was estimated at 3,000 billion USD in 2005, with the highest values recorded for the United States, Japan and the Netherlands [110]. By 2070, this figure is projected to increase tenfold. Likewise, Hallegatte *et al*. [111] estimate global flood losses in the world's largest coastal cities to reach 60-63 billion USD per year by 2050, mainly due to climate change and subsidence.

Coastal habitats such as coral reefs, salt marshes, seagrass beds, mangroves, and coastal dunes play a crucial role in reducing the impacts of coastal hazards which are expected to be exacerbated by climate change [112-114]. Coral reefs and mangrove forests dissipate wave energy. Similarly, seagrass beds and marshes stabilize sediments that help to slow down waves. Globally, it has been estimated that the topmost 1 m of coral reefs provide flood reduction benefits that result in more than 4 billion USD annually in avoided damages [91]. Coastal wetlands reduced flood damages in the northeastern United States by an estimated 625 million USD during Hurricane Sandy in 2012 [115]. Coastal habitats provide a climate change adaptation service which reduces the vulnerability of coastal communities.

Some coastlines are more at risk than others. Along with the presence or absence of natural habitats, factors such as relief, wave exposure, and surge potential play roles in determining the vulnerability of coastal communities [116]. Taking these factors into account, we have assessed the relative importance of natural habitat along the coastline by modeling the overall risk of physical exposure with and without habitat. Figure 26 (top panel) shows the resulting distribution of critical coastal habitat around the world. Areas where habitat is significantly reducing the exposure to coastal hazards and sea level rise are mainly found in the tropics, especially in the Caribbean, eastern Africa, and Southeast Asia. In many of these places, such as Indonesia, Bangladesh, Tanzania, Cuba, and the eastern United States, population densities along the coast are high, making the service provided by natural habitats even more important *(Figure 26 bottom panel)*.

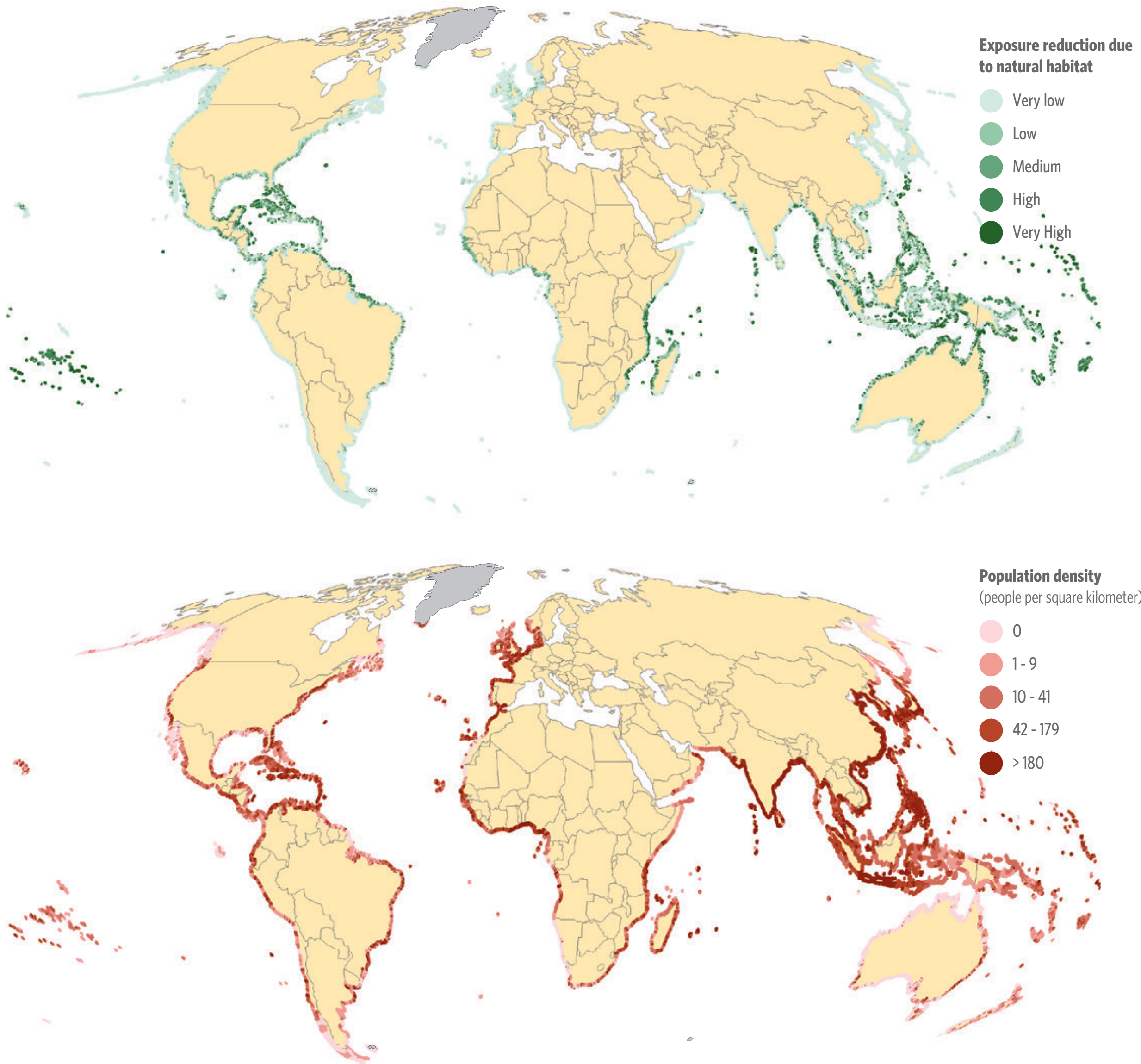


Figure 26: Distribution of coastal habitat that reduces exposure to coastal hazards such as storm waves, surges, and sea level rise (top panel). Coastal habitats considered here include coral reefs, mangroves, seagrass beds and salt marshes. The bottom panel shows population density along coastlines.

As cities on the coast expand, some of the critical natural habitats may be lost or degraded due to coastal development. As a result, many urban communities could find themselves at higher risk of damage from storm surges and sea level rise. Especially vulnerable are those communities within the low elevation coastal zone (LECZ), which is land area less than 10 m above sea level [117]. Along those stretches of coastline where natural habitat plays a critical role in reducing the risk of coastal hazards and sea level rise, 10,100 km^2 of urban area was within the LECZ in 2000. By 2030, this figure is projected to more than double to 23,000 km^2. Similarly, in 2000, 95 million people lived in rural and urban areas within the LECZ along coastlines with critical natural habitat. This number is expected to increase to 125 million by 2020. Figure 27 shows the growth in urban area in the LECZ along critical habitat stretches at the country level between 2000 and 2030. Our findings indicate that Nigeria and Brazil, followed by the US, China, and Indonesia, will have the greatest amount of urban growth along high-benefit coastlines by 2030.

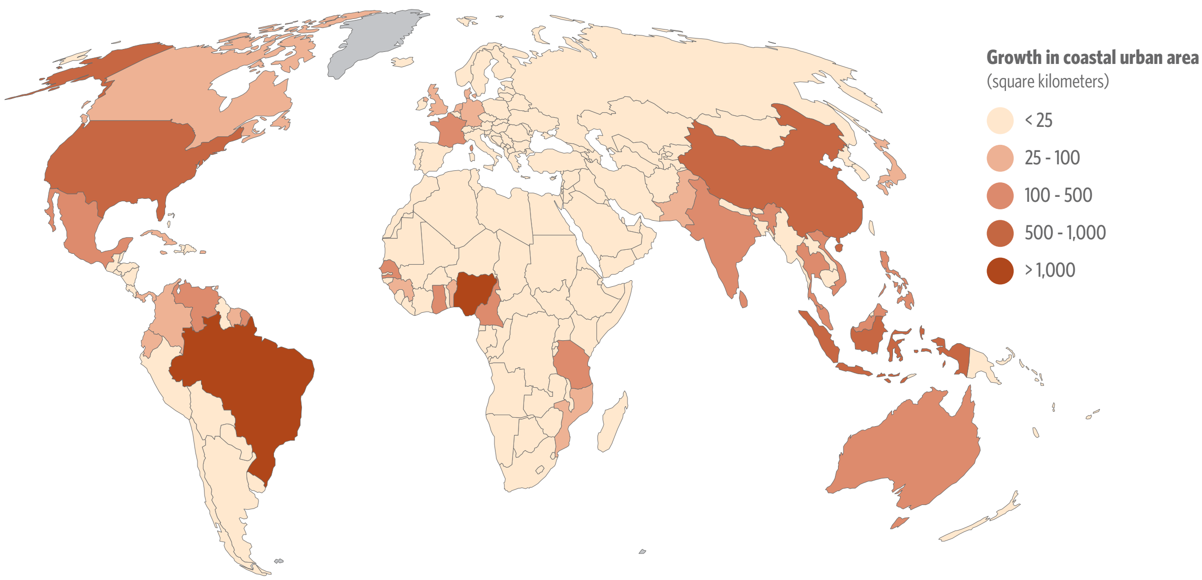


Figure 27: Country-level estimates for the growth in urban area (in km2) found within the low elevation coastal zone, along stretches of coastline where natural ecosystems provide high-levels of coastal risk-reduction services. Time period considered is 2000 – 2030.

These findings suggest that protecting natural habitat that provides this critical climate adaptation service should be a priority when planning for sustainable urban growth and risk reduction. This is especially important in cities where low-lying coastal areas are predominantly occupied by poor and marginalized residents, since these communities often have lower capacity to prepare for, respond to, and recover from extreme events [118-120]. Our results demonstrate that the protection and restoration of critical coastal habitat contributes directly to Aichi Target 14: *by 2020, ecosystems that provide essential services… are restored and safeguarded…*

In recent years, scientists and practitioners have come to recognize that nature-based solutions can be a cost-effective complement to built infrastructure to reduce risks from coastal hazards in urban areas. However, the effectiveness of nature-based solutions (NBS) can vary significantly from one urban area to the next, depending on factors such as space availability, the intensity of storms, and the distribution of vulnerable populations [121]. Strategies to urbanize coastal environments therefore require an integrated, cross-sectoral approach that accounts for these factors.

Other important climate mitigation and adaptation services

Beyond carbon storage and coastal protection, ecosystems in and around cities may provide a number of other services that contribute to climate mitigation and adaptation. For example, urban areas typically experience higher temperatures than surrounding rural areas, a phenomenon known as the urban heat island effect [122]. This effect is expected to become more intense with global warming [123]. Excessive heat is already a major cause of deaths worldwide. For example, the heat wave that struck Europe in 2003 claimed an estimated 70,000 lives [124]. In 2010, heat waves in India killed more than 1300 people in the city of Ahmedabad alone [125]. Parks, street trees, and water bodies have been shown to significantly reduce ambient temperatures, by absorbing the sun's heat energy and shading urban surfaces such as streets, sidewalks and buildings [126]. These green and blue spaces in cities therefore provide an important climate adaptation service to urban dwellers – especially to poor and vulnerable residents who cannot afford technological solutions such as air-conditioning. Moreover, the shading of buildings and general reduction of ambient temperatures by trees and other vegetation decreases the amount of energy needed to cool buildings from within, thus reducing energy costs and carbon dioxide emissions associated with energy use [127, 128]. Depending on the source of a city's energy (i.e. fossil fuel-derived vs. renewable), this may translate into a substantial climate change mitigation service provided by natural habitat.

Climate change is also predicted to increase other risks, including the frequency and intensity of wildfires and the frequency and severity of precipitation events, leading to an increased risk of flooding in some urban areas [129, 130]. Green spaces within a city, but also natural habitat on its fringes, can play an important role in adapting to these extremes by intercepting rainfall, increasing water infiltration into the ground, and slowing down the lateral flow of water [131].

These examples illustrate the many benefits associated with natural habitats in and around cities. Benefits also extend beyond climate change mitigation and adaptation. For instance, natural habitats—especially trees—have the potential to improve air quality by acting as a filter for particulate matter and other sources of pollution [132]. Green spaces and natural habitats in and around cities provide many opportunities for tourism and recreation, and they can contribute to improved physical and mental health, and can be significant for cultural and religious practices. In some parts of the world, urban dwellers depend on natural habitat on the fringes of cities for their livelihoods, through activities such as harvesting food, obtaining materials for shelter, and keeping livestock. Urban growth, if unplanned, may therefore impact benefits that city residents rely on for their everyday wellbeing.

Cities can plan for their urban growth in ways that avoid negative consequences.

Photo © Roger Lee

Exploring solutions

This report has documented the potential negative consequences of unplanned urban growth. In the next few decades, urban growth could cause significant biodiversity loss and reduce the contribution of natural habitat to both climate change mitigation and adaption. This section discusses three potential solutions. First, we discuss how cities can plan for their urban growth in ways that avoids these negative consequences. Second, we present how cities can manage urban protected areas, which are crucial for human wellbeing but pose some special management challenges. Third, we describe how nature can be integrated into cities, by restoring or creating natural infrastructure that enhances human wellbeing.

// Nature can be integrated into cities by restoring or creating natural infrastructure that enhances human wellbeing.

Planning for a natural future

One common way that cities try to harmonize urban growth and the natural world is to plan how natural habitats or natural features (e.g., street trees, public parks, open space, constructed wetlands) can be protected, restored, or created to maximally protect biodiversity and enhance human wellbeing [6]. The term *urban greenprint* was popularized in the United States in the 1990s [133], and has been widely used by groups such as the Trust for Public Land. There are many other alternative terms in use, such as *urban natural resource planning, eco-urban assessments, and urban conservation planning*. We will use the term *urban greenprinting* in this report, but we acknowledge that there are a variety of terms commonly in use for similar planning tasks (see the review in the Current Biodiversity Activities by Municipal Governments section).

Urban Greenprinting seeks to do two things:

- *Bring biodiversity and ecosystem service information into spatial planning* - By incorporating information on key natural features into plans that affect how cities develop, cities can grow while protecting biodiversity and human wellbeing.
- *Silo-busting* - In many urban areas, there is a lack of coordination between different government agencies and other stakeholders. The act of bringing together groups to craft a joint spatial vision (a greenprint) can often help overcome the lack of coordination that impairs urban areas.

This assessment has focused on analyzing how poorly planned urban growth could negatively impact natural habitat that is important for maintaining biodiversity or for climate-related ecosystem services (both mitigation and adaptation). Urban plans (such as comprehensive, sustainability, zoning, and transportation plans) formulated through a greenprinting approach can allow urban growth in certain appropriate places, while avoiding urban expansion on to habitat that is crucial for biodiversity or ecosystem services. This approach need not restrict the overall growth of a city, or prevent the achievement of other goals such as adequate, affordable housing for an increasing urban population. In most metropolitan areas, there is enough land for urban expansion that is of lesser importance for biodiversity and ecosystem services, such as degraded land (brownfields) or land already cleared for agriculture. Cities may also be able to avoid some expansion by allowing more density in new urban settlements, to the degree appropriate to a particular city's context, thus concentrating new settlements and avoiding urban sprawl.

While urban greenprints incorporate information on biodiversity and ecosystem services provided by natural habitat, they also consider a broader range of natural infrastructure including human-designed parks, planted street trees, and water management infrastructure such as bioswales and rain gardens. It is common in urban greenprints to plan for multiple ecosystem services from these natural features, including recreation, aesthetic beauty, and stormwater management. Of course, a successful urban plan must also consider many elements and processes in addition to those involving nature. Depending on the planning context, this consideration may include transportation considerations, zoning and new affordable housing construction, water management, economic development, and energy use. A recent example of a multi-objective approach is the recently published draft action plan for European Union cities, Sustainable Use of Land and Nature-Based Solutions Partnership, which promotes a compact city model aimed at reducing urban sprawl while also incorporating nature into urban life and maintaining a healthy urban environment.

Important in any successful urban planning process, including greenprinting, is the inclusion of key stakeholders [6] to ensure that local knowledge from different groups is incorporated, and that plans reflect the values of the full range of stakeholders they will affect. Local stakeholder involvement is crucial to ensuring that the plan created will be politically viable and likely to be successfully implemented. Inclusion of a representative set of local stakeholders also helps to achieve a plan that equitably distributes the costs and benefits of urban planning decisions.

The livelihood and human wellbeing benefits provided from nature are often key to securing government and public support for any greenprinting plan. A case study of the mainstreaming of biodiversity into policy in South Africa found that messaging based around the avoidance of loss of habitat and biodiversity, though factually and scientifically accurate, was not successful in motivating support. More effective was messaging that quantifies the benefits of nature to people [134].

Many tools exist to help cities incorporate biodiversity and ecosystem service information in urban planning. For biodiversity information, many countries have available geospatial data on the spatial location of rare species or habitat types, which can be incorporated into plans as exclusion layers. For example, the NatureServe Explorer includes information on the distribution of more than 70,000 plants, animals, and ecological communities and systems in the United States and Canada. For ecosystem services, there are tools that can be used to measure the ecosystem service value of natural features. For instance, the ITree toolbox is widely used to quantify ecosystem services from urban trees, while the InVEST toolbox from the Nature Capital Project is often used to quantify services in more rural landscapes, such as services that contribute to water security and the mitigatoin of coastal hazards [135, 136]. Similarly, the TEEB Manual for Cities includes methods and models to estimate the value of ecosystem services provided by single green infrastructure elements [7]. Finally, in planning contexts where budget or other constraints require spatial optimization (e.g., selecting the most important patches of natural habitat to protect out of a large set of possible sites), tools like Marxan and Zonation are often used to construct optimal conservation plans [137].

Often during a planning process, whether at the metropolitan or national scale, it is helpful to develop multiple scenarios for the future [35]. The IPBES Expert Group on Scenarios and Models promotes the development of multiscale and cross-sectoral scenarios around positive visions of the relationship of people with nature, called Nature Future for Urban Systems [138]. These scenarios identify a range of preferences from different stakeholders for how to manage biodiversity and ecosystem services, and develop scenarios representing these preferences. These visions represent a diversity of preferences that include: valuing nature for itself [139], such as for its ecological integrity and biodiversity protection; valuing nature for the services it provides to people, such as climate regulation or food provisioning; and valuing an inseparable relationship between people and nature, such as that of cultural landscapes and local knowledge. Some of the visions foresee cities with more space for biodiversity and natural processes, with the rewilding of urban parks with native species and increased connectivity to the wider landscape. Others emphasize the availability of nature-based solutions, such as green infrastructure, green roofs, and artificial wetlands, and their potential to improve climate, air quality, water quality and physical and emotional wellbeing. Finally, others emphasize a cultural relationship with nature in cities, including the possibility of urban gardening and the historical heritage of city parks and botanical gardens. This participatory modeling framework can be used by cities to explore different planning options and assess how the different preferences result in different cityscapes.

Once a greenprint is complete, governments and stakeholders will need to move to implementation. This often requires the integration of actions across multiple levels of government. While municipal governments may control zoning, national government agencies may control major decisions about infrastructure spending, and other agencies may have responsibility for natural resource management [140]. Involving these various levels of government in the design of a greenprint is key to having enough buy-in to allow later implementation of the plan. Moreover, implementation takes time and resources from government agencies. In some cities in less developed countries, it can be challenging to fund the implementation of a greenprint, and supplemental sources of funding from national or international institutions may be needed.

We hope that the Nature in the Urban Century Assessment inspires the urban areas identified as priority places in this report to take action. We hope that there will be efforts to create collaborative, locally-led greenprints in some of these priority places, which will allow for growth while maintaining habitat that is key for biodiversity or climate-related ecosystem services. The greenprints must of course also be sensitive to local context, and to the needs and desires of city residents, in order to inspire support and catalyze implementation of the greenprinting plan.

Current Biodiversity Activities by Municipal Governments

Numerous cities around the world have already initiated activities to protect biodiversity. While these efforts may not be called "urban greenprints", the terminology used in this report, many of the goals of existing urban activities to protect biodiversity share the same general goal, to incorporate information on biodiversity and ecosystem services into urban planning, decision-making, and action.

In a recent effort to compile and understand current urban biodiversity activities, the Urban Biodiversity Hub (UBHub) has identified efforts undertaken by cities around the world, building off work by Pierce [141] and Nilon *et al*. [52]. The results to date are available at ubhub.org.

Urban Biodiversity Reports and Plans

At least 123 cities from 31 countries have produced a biodiversity report and/or a biodiversity plan (*Figure 28*). A biodiversity plan is defined here as an official government strategy or a document primarily dedicated to biodiversity or ecosystem health that describes goals related to biodiversity and the actions needed to meet those goals. Biodiversity plans cover a variety of topics, including education and communications campaigns about nature, efforts to increase direct access to nature, conservation planning, habitat restoration, green and blue infrastructure, species-specific strategies, regulations to improve development impacts, and broader sustainability initiatives that reduce the impact on local or global biodiversity. These plans often mimic the National Biodiversity Strategy and Action Plans and take on the name Local Biodiversity Strategy and Action Plans (LBSAP) or some similar derivative, such as LBAP or BAP. However, a municipality often chooses a different title that reflects its own approach, such as the Ecological Vision (Ecologische Visie) from Amsterdam (Netherlands). In all, there are 129 biodiversity plans from 108 municipal governments, primarily from the United Kingdom in Europe, North America, and Asia (*Figure 28*).

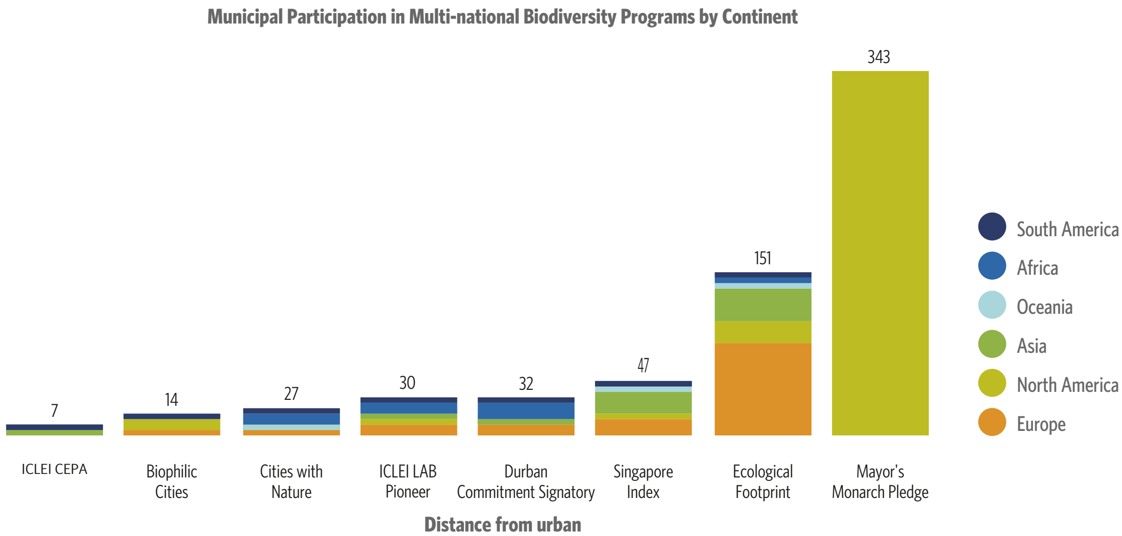


Figure 28: This graph compares municipal-level participation in some of the more popular urban biodiversity programs that span more than one country. ICLEI's programs include the Communication, Education, and Public Awareness (CEPA) program and the Local Action for Biodiversity (LAB) Pioneer program. Both the Singapore Index and Ecological Footprint data include both direct participation in the system by municipal governments themselves and assessments by other stakeholders, such as universities and NGOs.

It is interesting to note that while Europe and North America have the majority of urban biodiversity plans, this assessment has shown that some of the most significant impacts on biodiversity from urban growth between 2000 and 2030 will be in Asia, Africa, and South America. This may simply be a reflection of that fact that it takes resources to develop an biodiversity report or plan, and cities in less developed countries may find it more challenging to find such resources. Other studies have identified this governance paradox. For instance, Huang *et al*. [142] found that the countries where urban growth is most likely to affect biodiversity are also, on average, countries with lower scores as measured by Worldwide Governance Indicators. Overall, the findings of our assessment emphasize the need for initiatives that can help cities in biodiverse regions craft urban biodiversity plans.

A biodiversity report is defined here as an assessment of current ecosystem health or biodiversity, commissioned or adopted by the government and summarized in a single public document primarily focused on this topic. The production of such a biodiversity report is a key element of biodiversity planning, as it contains the baseline data needed by a city to form a strategy for biodiversity. These documents are often entitled "Biodiversity Report," but other names are often adopted by cities, such as Naturbarometer from Berlin (Germany). There are forty-six municipalities that have produced such reports thus far, over half of which are located in Europe and North America. Many of these municipalities have updated their reports over time.

Urban Biodiversity Frameworks and Programs

The Urban Biodiversity Hub has identified twenty-two frameworks and programs that are specific to urban biodiversity and used in more than one country (*Figure 29*). Frameworks primarily guide cities on their biodiversity management by offering a standardized index or measurement system that they can use. These include indices such as the Singapore Index (also known as the City Biodiversity Index or Singapore Index on Cities' Biodiversity) and the Ecological Footprint, which result in a single score reflective of biodiversity status or planning efforts. Programs often ask cities to follow particular steps for biodiversity, such as creating biodiversity documents, piloting projects, making political commitments or joining particular networks. Several of these programs are offered by ICLEI - Local Governments for Sustainability, such as the Local Action for Biodiversity (LAB) program; the Communication, Education, and Public Awareness (CEPA) program; the LAB Wetlands program; the Integrated Action for Biodiversity Project (INTERACT-Bio), and the Urban Natural Assets (UNA) program. Other programs are offered by coalitions of NGOs, such as the newly-created CitiesWithNature program.

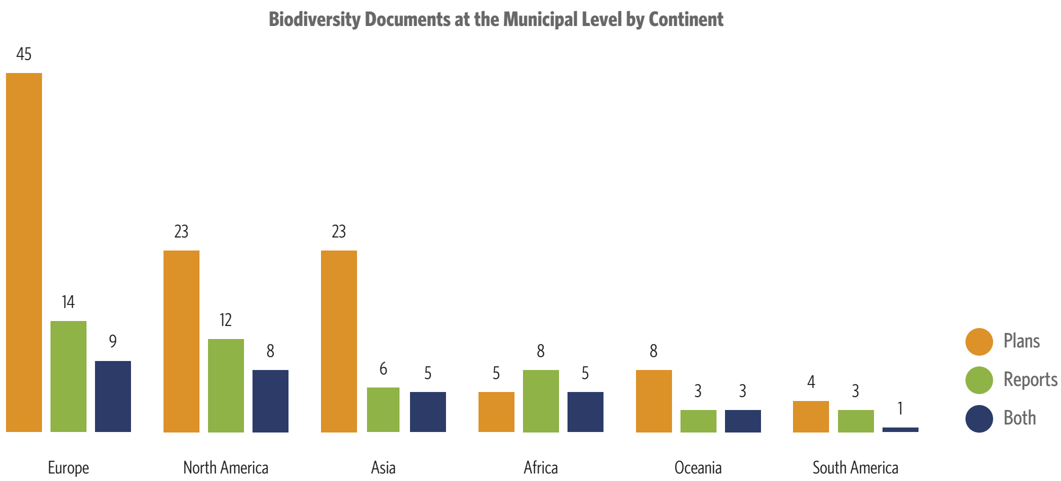


Figure 29: At least 108 cities have published biodiversity plans and at least 46 cities have published biodiversity reports. Of these cities, 31 have produced both. Most documents were produced by European cities, and most are from 34 cities in the United Kingdom. The next most common continent is North America, where most of the reports originate from 13 cities in the United States and 12 Canadian cities. Most of the documents published in Asia are from 19 Japanese cities.

The largest program, as measured by the number of participating municipalities, is the Mayor's Monarch Pledge by the National Wildlife Federation (USA), which awards points to participating cities for each action that a city takes for monarch butterflies from a predetermined list of twenty-four actions. Cities report their progress on an annual basis and earn a designation such as "Monarch Champion" or "leadership circle" for committing to a particular number of actions. Nearly all (330) of the participants in the program are in the United States, with the remainder (13) in Canada.

Managing urban protected areas

Multiple strategies can be used by cities seeking to plan for growth while protecting critical habitat for biodiversity and climate-related ecosystem services. For instance, as part of a greenprint, zoning and transportation decisions can be adjusted to reduce development pressure on critical habitat. The most common conservation tool to protect critical habitat; however, is land protection. Creating and managing protected areas has been a key strategy used by many countries to make progress toward Aichi Target 5 (limiting habitat loss) and Aichi Target 11 (increasing land protection). While they are often found in rural landscapes, many well-known and successful protected areas are in and near cities, such as Bukhansan National Park near Seoul (Korea) and Table Mountain National Park in Cape Town (South Africa).

There is a need for a new generation of urban protected areas, to address the massive urbanization of the 21st century. These protected areas would preserve habitat critical for protecting biodiversity or providing climate-related ecosystem services. Land protection would then be part of the implementation of an urban greenprint, which might include other important implementation steps (changes to transportation and zoning, for example). Research shows that, because of the spatial concentration of urbanization's biodiversity impacts of urbanization, a targeted increase in land protection could prevent extinctions of the majority of species at risk from urban growth [56]. Land protection remains the most permanent and effective way to safeguard biodiversity.

Protected areas also play an important role in maintaining ecosystem services crucial for human wellbeing. These can include the services related to climate change mitigation and adaptation that are considered in this report, but there are multiple other benefits from the proximity of people and nature. Protected areas are often used for recreation, improving physical and mental health and enhancing quality of life. Urban protected areas can be a key part of a city's economic development plans, becoming tourist attractions that give the city a worldwide reputation.

While urban protected areas supply multiple benefits, they also pose some management challenges (*see Figure 20*) [93]. Urban protected areas sustain more frequent resource harvesting and damage, such as illegal logging, firewood harvesting, poaching, and trampling of vegetation. The urban setting also often alters disturbance regimes, including the alteration of fire frequency in many landscapes and increases in the rate of establishment of non-native, invasive species. As urban protected areas are fragmented from other blocks of natural habitat, the lack of ecological connectivity can limit species migration while edge effects can degrade the quality of habitat in the protected area.

However, there are solutions to these management challenges. The IUCN WCPA Urban Conservation Strategies Specialist Group has been working since 2005 to bring together urban protected area managers and scientists. One useful report from this specialist group is Urban Protected Areas: Profiles and Best Practice Guidelines, which compiles case studies and suggests urban protected area management procedures [143]. Some of the guidelines focus on how to appropriately connect people with PAs, so that they fully benefit from proximity to the PA, while avoiding adverse impacts to the PA's natural systems. Another major focus of the guidelines is promoting collaboration among institutions, both across jurisdictions (many protected areas are in multiple jurisdictions) and across sectors (e.g., between natural resource managers and urban planners). In this urban century, governments at all levels will need to invest more money for adequate management of urban protected areas.

The IUCN is continuing to explore how it can best support urban protected areas. At the request of its members, it is creating a new IUCN Urban Alliance, which will provide a platform for debate and information-sharing among urban protected area managers. It will also catalyze new urban protected area creation and increased management. Efforts like this at institutions like IUCN, ICLEI, and The Nature Conservancy (TNC) can help support cities as a new generation of urban protected areas is created.

Integrating nature into cities

This report has focused on how urban growth can be harmonized with the preservation of existing natural habitat in and near cities. However, there are numerous other kinds of natural features that can be incorporated into urban areas, to the benefit of human wellbeing and biodiversity [6]. Urban parks often contain remnant forests and lawns that provide spaces for recreation, but also valuable habitat for some species. Street trees can shade roads, lowering the air temperature on hot days and filtering pollutants from car traffic. Constructed bioswales or wetlands can help manage stormwater. Green roofs and green walls can lower indoor temperatures during the summers and decrease the need for space heating in winter. Finally, urban gardens contribute to food production as well as being sites for environmental education.

These man-made natural features may not be as important for maintaining biodiversity as natural habitat for rare or sensitive species. But numerous studies show that cities can harbor significant biodiversity, and natural features can help make the urban landscape more hospitable for a larger variety of species. For instance, many species of migrating birds use parks, including New York City's Central Park, as temporary resting places while migrating. Some native species survive quite well in cities, such as eastern grey squirrels (*Sciurus carolinensis*) in the United States. Man-made natural features do provide important biodiversity benefits, and urban greenprints should try to plan to maximally incorporate these benefits.

Man-made natural features like parks can serve as important corridors and thus can help counteract fragmentation. Parks, even if they contain non-native habitat, can be important for wildlife movement or nesting. For instance, protected breeding birds like the European green woodpecker (*Picus viridis*) make use of park or backyard trees for feeding their offspring. Natural features can often serve as important corridors for human movement, too. Many cities strive to have "greenways" to increase walking and biking, and some cities are exploring the idea of strategically planting street trees to create "cool corridors" that allow for more comfortable movement during heat waves.

Man-made natural features are primarily designed to benefit humans, the urban residents who will interact with the natural features. The benefits that natural features provide, their ecosystem services, are often greater than the benefits provided by natural habitat, simply because the natural features are closer to where people live and work. Each ecosystem service needs to be generated within a certain distance around the people it is supposed to benefit [144]. The spatial scale at which natural features provide ecosystem services varies greatly, from the shade of a tree, which may extend up to tens of meters, to the carbon sequestration effects benefits of forests which have global impact on the atmospheric concentration of CO_2. Urban conservation and greenspace planners must balance two competing trends. Placing natural features closer to where people live increases ecosystem-service provision. However, the opportunity costs of using land for natural features is often greater near city centers, where there is so much competition from other land-uses.

This report has primarily presented urban spatial conservation planning (urban greenprinting) with regard to the preservation and maintenance of natural habitat. However, urban greenprinting can also focus on integrating man-made natural features into urban planning [6]. For instance, many cities conduct urban tree canopy assessments to map current tree cover and plan where additional trees should be planted, for maximal benefit. From a technical perspective, it can be challenging to plan for multiple types of natural features for multiple different ecosystem services. Nevertheless, there are several guidelines for how to successfully plan within this challenging urban context [7].

To aid cities in incorporating nature into their urban plans, ICLEI, in collaboration with TNC and the IUCN, has created CitiesWithNature, a global platform for cities and other subnational governments that recognizes and enhances the value of nature in and around cities. The platform builds on a decade of experience with ICLEI and the IUCN's international Local Action of Biodiversity (LAB) initiative and draws on lessons learned under the Cities' Biodiversity Index. CitiesWithNature provides an interactive, user-friendly, digital interface for cities, their communities and experts to connect, share, and learn from each other.

Through CitiesWithNature, participating cities and subnational governments can share their ambitions, policies, plans, actions and innovations and demonstrate their commitment to work, plan and live with nature; keep abreast of current global agreements and ambitions; and gain access to a wide variety of tools, projects, services and information offered by leading global organizations and city and subnational networks.

There are solutions for shaping urban growth while protecting biodiversity and climate-related ecosystem services.

Photo © Jacoblund

A call to action

Much of this assessment has focused on presenting the business-as-usual scenario, showing the negative impacts on biodiversity and climate-related ecosystem services if we continue on our current urban growth trajectory. We have tried to argue that there are solutions, ways to shape urban growth while protecting biodiversity and climate-related ecosystem services. In this last section, we list specific actions that can be taken to begin to achieve this more harmonious future. We, the individuals and institutions involved in writing this report, call on those reading this report to:

// Cities have the potential to be major catalysts of change.

1 Integrate local governments in national planning from the start

Countries use National Biodiversity Strategies and Action Plans (NBSAPs) to plan how they will achieve their commitments under the Convention on Biological Diversity. Aichi Target 17 calls for all Parties to the CBD to create NBSAPs, and since COP-10, 160 Parties have submitted such plans. Multiple documents provide guidance on how to write NBSAPs, as well as specific topics like agricultural biodiversity, gender issues, and unique issues of biodiversity for island states (https://www.cbd.int/nbsap/guidance.shtml). While there are guidance documents related to climate change and ecosystem services, two topics mentioned in this report, few are explicitly focused on urbanization or urban growth. However, decision X/22 of the CBD offered a plan of action for the engagement of subnational governments, cities and other local authorities in the work of the CBD. Furthermore, the Quintana Roo Communique on Mainstreaming Local and Subnational Biodiversity Action explicitly calls all levels of governments to action in this critical period of rapid urbanization.

There is an urgent need for many countries to more fully consider urban growth in the next iteration of NBSAPs. Currently, many NBSAPs make only slight mention of cities and urban growth. Better incorporation of urban issues into NBSAPs would allow countries to craft more efficient, effective plans to fulfill their commitments under the CBD. Many of the techniques of systematic conservation planning or *urban greenprinting* (see discussion above) can be useful during the preparation of an NBSAP.

National governments can work with their local government counterparts to incorporate urbanization and urban growth into the next iteration of the NBSAPs, and the support of cities and subnational governments allows countries to design more effective plans to fulfill their commitments under the CBD. The ICLEI Cities Biodiversity Center in collaboration with the SCBD and the Japan Biodiversity Fund, produced "Guidelines for an integrated approach in the development and implementation of national, subnational and local biodiversity strategies and action plans" [140]. These guidelines focus on vertical and horizontal integration and how the different levels of government can cooperate and coordinate their planning, actions and monitoring.

Governments will also have to set aside appropriate resources to implement the urban-focused components of their NBSAPs. The financial and resource commitments that countries make to urban conservation should match the scale of the challenge that poorly planned urban growth poses to the Aichi Targets and the goals of the CBD. If urban growth will cause 290,000 km^2 of habitat loss between 2000 and 2030, a significant portion of all habitat loss, then urban conservation work deserves a significant fraction of conservation dollars.

2 Empower cities to plan for a positive natural future

Cities have the potential to be major catalysts of change, because they can help to implement recent international agreements such as the Aichi Biodiversity Targets, the Paris Agreement, the 2030 Agenda for Sustainable Development, the New Urban Agenda, and the Sendai Framework for Disaster Risk Reduction. Actions by cities to address the implications of urban growth will make crucial contributions to the national efforts aimed at fulfilling international commitments. Empowering cities to take these actions will require planning and implementation among multiple actors, across various geographies and scales.

For instance, for urban greenprinting, much of the expertise for urban planning and zoning lies at the municipal level. However, national governments have a unique role in the CBD, being the entities that develop NBSAPs and funds their implementation. National agencies also often manage national parks and other protected areas, which may be crucial areas for biodiversity persistence in urban areas. This division of roles implies the need for greater coordination between municipal and national governments, which could work together to codesign and implement effective urban greenprints.

As important as cross-scale collaboration is the need for a change in mindset. Many urban planners still view conservation of natural resources as antithetical to planning for urban growth and economic development. A shift in perspective in urban planning is needed, toward planning for a positive natural future. Participatory methods can be used to identify such a future based on the preferences of different city stakeholders. Potential tactics to implement the vision of a positive natural future include ecological restoration and rewilding, integrated urban planning, technological solutions, nature-based solutions, and improved governance.

3 Leverage international institutions

International institutions have a key role in designing and building the cities of the future. The GEF has a role in funding projects that support achievement of the CBD and other international agreements. The GEF has a sustainable city program, and has recently broadened its focus to include conservation of urban biodiversity and ecosystem services. The Green Climate Fund and other mechanisms under the UNFCCC will finance climate mitigation and adaptation actions, which often will occur in and near cities. The World Bank and regional development banks will finance major development projects in cities, as will bilateral donors. These international institutions will collectively help shape the cities of the future.

We call for more extensive consideration of urban biodiversity impacts and ecosystem services in the funding decisions of major institutions, both multilateral and bilateral. Major international funders, such as the GEF and the Green Climate Fund, could direct appropriate funding to mitigate the impact of urban growth on biodiversity and ecosystem services, focusing especially on key priority areas where the return on investment is likely to be largest. Similarly, bilateral donors should increasingly fund projects that mitigate urban impacts on key priority areas.

4 Create a Convention on Biological Diversity for the urban century

In the past, discussion of urban growth and cities in the CBD decision-making process was relatively limited. Urban growth was often subsumed under the much broader discussion of the drivers of global habitat loss. Within that discussion, attention focused appropriately on conversion for agriculture and logging. In the next few decades, however, urban growth will be one of the major sources of habitat loss and in some countries, urban growth will be the largest driver of terrestrial habitat loss.

We call on all Parties to the CBD to ensure full integration of urban issues into the post-Aichi Targets. This could be through the creation of a new urban-focused target, in the same spirit as the current Aichi Target 7, which aims to foster agriculture-sector sustainability. Alternatively, urban issues could be considered through urban-related implementation metrics that would measure progress toward a broad goal, such as the current Aichi Target 5, which aims to halve the rate of habitat loss. Asking countries to track and report urban-related natural habitat loss could help ensure progress toward Aichi Target 5.

We urge all Parties to the CBD to view the time between now and 2020 as a period to plan what urban conservation investments are needed to meet the challenge urbanization poses to the goals of the CBD. The 2020 COP of the CBD will be a major moment when new goals are set. The meeting will be held in China, in many ways the world center of urbanization. It is our hope that the next meeting of the CBD in 2020 will be a moment when Parties to the CBD can make meaningful commitments to protect biodiversity and human wellbeing in the urban century.


It is our hope that the next meeting of the CBD in 2020 will be a moment for making meaningful commitments to protect biodiversity and human wellbeing in the urban century.
Photo © DG Wildlife

Methods

Urban growth analysis

Two primary datasets were used to define the extent of urban land. Historical urban land was defined by the CCI Land Cover dataset [145] which provides an annual estimate of global land cover for the period 1992 – 2015 at 300m resolution. Future urban land projections were defined by urban land forecasts developed by Seto *et al*. [9]. The Seto *et al*. [9] forecasts identify the probability of land becoming urban by 2030 with 5 km resolution.

The Seto *et al*. [9] urban forecasts were downscaled to the same spatial resolution as the CCI Land Cover dataset (300 m), and small pixels along the coastline that were not assigned an urbanization probability in the Seto *et al*. [9] forecasts due to its coarser resolution were assigned the urbanization probability from neighboring cells. Regional and national boundaries used in the analysis are defined in the Natural Earth 1:10m cultural vector layer (Natural Earth 2018). For any calculation that required the accurate calculation of area, we used a Mollweide equal area projection.

Urban land over time

We analyzed the amount of global urban land over time. The total urban land area was extracted from the CCI Land Cover dataset by region for each year over the period 1992 – 2015. Urban land in 2030 is taken as the combined extent of the land in the Seto *et al*. [9] forecasts with 75% or greater probability of becoming urban, and the CCI Land Cover urban extent in 2015. This harmonized land cover assumes that any land identified as urban in 2015 will remain urban in 2030.

New urban land by country

New urban land between 2000 and 2030 was calculated as the difference in total urban area per country in 2000 and the total projected urban land per country in 2030. The extent of urban land in 2000 was defined as the combined extent of the CCI Land Cover urban extent in 2000, and the baseline extent of urban land for 2000 in the Seto *et al*. [9] urban land forecasts. The extent of urban land in 2030 is defined as the combined extent of the Seto *et al*. [9] baseline urban extent in 2000, the forecasted urban land with a 75% or greater probability of becoming urban by 2030, and the land identified as urban in the 2015 CCI Land Cover data. As per the analysis of regional urban land totals, this approach assumes that urban land in 2015 will remain urban by 2030.

Habitat loss analysis

Habitat loss calculation

We began by creating a raster of what areas were protected currently, assuming that future urban growth will not directly convert habitat within protected areas. We obtained the most recent World Database on Protected Area file (July 2018) [146]. The database contains both polygon features (for PAs with known boundaries) and point features (for PAs with unknown boundaries). For both types of features, we excluded exclusively marine preserves. For polygon features, we excluded PAs that have no IUCN category protection category and were not nationally designated. For those that are nationally designated but lack an IUCN protection category, we assume they are category VI. We also excluded polygon features that were EU Sites of Community Importance, because this regional designation does not necessarily translate to land protection against urbanization. For point features, we excluded those with no listed IUCN protection category, mostly UNESCO-MAB sites and Ramsar sites that do not have an accompanying nationally designated PA. Point features were buffered to be their reported size, in a Mollweide projection.

The next step was to create a raster of natural habitat that was not protected, and thus could be lost during urbanization. This involved integrating the protected area information from the WDPA with information from the CCI Land Cover grid [145]. For this analysis, we were principally interested in the land cover from 1992 (the first year available), 2000 (the base year of the Seto *et al*. [9] forecasts), and 2015 (the most current year available). CCI Land Cover was reclassified to a simple five-level classification scheme: Agriculture (codes 10-40 in the CCI data); Urban Settlement (code 190); Water (code 210); Permanent Ice/snow (code 220); and Natural habitat (all remaining codes).

Next, we wanted, for just unprotected natural habitat, to create a map of probability of habitat loss. The harmonized urban growth forecasts (see Urban Growth Analysis methods section) was used to estimate the probability of additional habitat loss (2000-2030). These probabilities are fundamentally based upon the Seto *et al*. [9] forecasts, which have a probabilistic estimate of the likelihood of urbanization occurring. Results for habitat loss were summarized by biome, using the WWF definition of biomes [147]. We also summarized habitat loss by country, using the high-resolution country shapefile available from the Natural Earth website (ne_10m_admin_0_countries). Finally, we mapped habitat loss with metrics of biodiversity importance, such as the Alliance for Zero Extinction [148], the Biodiversity Hotspots (25 April, 2016 edition; [149]), the Global 200 Ecoregions [81], and information on vertebrate endemism [56].

Key biodiversity areas

We focused special attention in our analysis on Key Biodiversity Areas (KBAs), where the is a global standard set by IUCN by which areas of biodiversity importance can be designated as a KBA. We obtained the most current KBA layer available (January 2018) [84, 150]. This was then intersected with our habitat loss probability layer, with pixels greater than 75% likely to be urbanized assumed "urban" for this calculation. In R, we statistically analyzed the fraction of KBAs that have different % losses of area due to urban (2000-2030). We mapped KBAs that are forecasted to lose more than 5% of their area (2000-2030) for graphing. For reporting, we calculated total area of KBAs using a Mollweide protection.

Imperilment analysis

In order to understand how urban growth and natural habitat loss affected the probability of imperilment, we obtained range maps for taxa from the IUCN [151]. We focused our analysis primarily on the terrestrial mammals and amphibians (Anura, Caudata, and Gymnophiona). In ArcGIS, we calculated the fraction of each species' range that was urbanized in 2000.

Protected area analysis

We began our analysis using the same selected features from the WDPA (see discussion in Habitat Loss Analysis methods section). We analyzed separately strictly protected PAs (IUCN protected area category I-IV) and loosely protected PAs (IUCN protected area category V-VI). We wanted to compare this to distance to urban area and population density. Our population density information came from the Gridded Population of the World (Version 4, Revision 10) [152]. This comes at a base resolution of 1 km, and except the calculations involving land cover (which we done at the resolution of the CCI Land Cover), all calculations described in this section were done at 1 km resolution using a Mollweide equal-area projection.

For every point on the earth's surface, we calculated the distance to the nearest urban area in 1992, 2000 and 2030. This distance to urban areas is important since it relates to the impact of cities on ecological structure and function in protected areas (see protected area analysis in main text for more detail). Specifically, we used the Euclidean Distance command in ArcGIS to calculate distance to urban areas as defined in the harmonized land cover (see Urban Growth Analysis methods section). We then calculated, for each time period, the fraction of PA area that is in different distance classes from urban areas (0-10 km, 10-20 km, 20-30 km, etc.).

We constructed 50 km buffer around the world's protected areas. Specifically, we used the WDPA features, processing strictly and loosely protected PAs separately, to define 50 km buffer zones around each PA. The 50 km threshold was used as it was the distance after which most urban impacts on protected areas ended (see protected area analysis in main text for more detail). We then clipped out the actual PA from this buffer area, since we want the buffer zone to be only what is in the buffer zone around PAs. We then used the Zonal Statistics command in ArcGIS to calculate the population density in each buffer zone.

Finally, we ran an additional GIS analysis to determine how much some iconic, big strictly protected areas are impacted by urbanization, now and in the future. For this exercise, we selected out strictly protected areas that were greater in area than 500 km^2. This threshold was chosen to pick large, named PAs. In the 50 km buffer around these PAs, we calculated the percent urban in 2000 and 2030 (projected). We then created two tables showing most "at-risk" PAs: biggest change in urban proportion of land (2000-2030) within 50 km of PA, and biggest amount of urban area (2000).

Carbon analysis

The analysis of carbon storage as a climate mitigation service is based on the Ruesch & Gibbs [97] carbon data for above- and below-ground biomass. To calculate the global amount of carbon stored in natural vegetation that could be lost to urban growth, we transformed the Ruesch & Gibbs [97] grid to match the resolution and projection of our habitat loss probability layer, and summed the total amount of carbon stored in biomass for the pixels that had a greater than or equal to 75% likelihood of being urbanized by 2030. For the country-level analyses, the same approach was followed, but the carbon figures were summed up for each country using zonal statistics. In addition, average carbon lost per hectare was calculated at the country level by dividing the total amount of carbon by the area lost to urban growth.

For the comparison between the Ruesch & Gibbs [97] data and the Baccini *et al*. [102] data, we obtained the Baccini *et al*. [102] dataset on pantropical aboveground woody biomass and resampled it to match the resolution and projection of our habitat loss probability layer. The data is originally expressed in biomass per hectare, which we converted to carbon per hectare using the 0.47 conversion factor from the IPCC. Average values of carbon stored per hectare were calculated for both the Ruesch & Gibbs [97] data and the Baccini *et al*. [102] data, using only pixels where i) the Baccini *et al*. [102] values were non-zero (i.e., they were forested pixels analyzed by Baccinni *et al*.), ii) both data sets overlapped in extent, and iii) natural habitat is projected to be lost to urban growth.

Coastal analysis

The analyses for the case study of coastal resilience were mainly based on the InVEST Coastal Vulnerability model developed by The Natural Capital Project (www.naturalcapitalproject.org) [116, 136]. This model produces a qualitative, relative index of coastal exposure to erosion and inundation, taking into account the following bio-geophysical variables: sea level change, wind exposure, wave exposure, relief, geomorphology (shelf only, since there are no global datasets for shoreline type), surge potential depth contour, and natural habitats. The climate change adaptation service provided by natural coastal habitats (such as coral reefs, mangroves, seagrass, and salt marshes) is calculated as the difference in exposure with and without that habitat. The model was run globally, and provided service values for points spaced 1 km apart along the major coastlines of the world. These service values were classified into 5 quantiles, ranging from very low to very high, and converted into a raster. All rasters used or created in this section were projected and resampled to match our habitat probability layer.

To display population density along the coast, we downloaded the Gridded Population of the World, Version 4 (GPWv4) [152] Population Density Adjusted to Match UN WPP Country Totals, Revision 10 [153], and assigned population density values from the grid to the points from the coastal vulnerability model.

Euclidean allocation was used to extend the classified service raster out in to the low-elevation coastal zone (LECZ). A LECZ layer representing areas along the coast with elevations of 10m and lower was provided by the Center for International Earth Science Information Network [154], and overlaid with the extended classified service layer. All following calculations were limited to those areas within the LECZ where service values were medium, high, or very high.

The amount of urban area in the LECZ was calculated for 2000 and 2030, based on the Seto *et al*. [9] 2000 baseline land cover data and the 2030 urban forecasts. For the population estimates within the LECZ, we used the 1 km resolution GPWv4 data for 2000 and for 2020 (the farthest available population forecast). For areas within the LECZ that had medium to very high service values, we calculated the average population density and converted that to number of people based on the number of pixels in those areas.

Tables

Table 1. Project habitat loss for the world's biome types, 2000-2030. Data is shown for area lost 2000-2030 (square kilometers), as well as the proportion of the biome's total area that will be converted. Note that as the total area of biomes varies widely, these two quantities differ. The Mangrove biome is projected to lose around 10,000 km^2 of habitat, which amounts to 3% of the total biome area. A similar amount of habitat in Temperate Coniferous Forests will be lost to urbanization 2000-2030, but as this is a much larger biome, this urbanization amount to only 0.15% of the total biome area.

Biome Name	Urban-caused habitat loss, 2000-2030 (km2)	Urban-caused habitat loss, 2000-2030 (% of biome area)
Boreal Forests/Taiga	1,430	0.01%
Deserts	38,206	0.14%
Flooded Grasslands	3,289	0.30%
Mangroves	10,091	2.90%
Mediteranean Habitat	20,515	0.64%
Montane Grasslands	8,036	0.15%
Temperate Broadleaf Forests	78,430	0.61%
Temperate Coniferous Forests	11,135	0.27%
Temperate Grasslands	15,156	0.15%
Tropical Coniferous Forests	3,356	0.47%
Tropical Dry Forests	7,573	0.25%
Tropical Grasslands	26,636	0.13%
Tropical Moist Forests	63,439	0.32%
Tundra	72	0.00%

Table 2. Amphibians and mammals listed as threatened on the IUCN Red list that have more than 20% of their range converted to urban area. The IUCN codes species as Critically Endangered (CR), Endangered (EN), or Vulnerable (VU). Species are sorted by their Latin binomial name.

Amphibians:

Latin name	Common name	Country	IUCN category
Allobates juanii	None	Colombia	CR
Ambystoma flavipiperatum	Yellow-peppered Salamander	Mexico	EN
Dryophytes suweonensis	Suweon tree frog	South Korea	EN
Eleutherodactylus grandis	Great Peeping Frog	Mexico	CR
Eleutherodactylus lentus	Yellow Mottled Coqui	U.S. Virgin Islands	EN
Eurycea sosorum	Barton Springs Salamander	United States	VU
Eurycea tonkawae	Jollyville Plateau Salamander	United States	EN
Eurycea waterlooensis	Austin Blind Salamander	United States	VU
Heleophryne rosei	Table Mountain Ghost Frog	South Africa	CR
Hyalinobatrachium guairarepanense	None	Venezuela	EN
Hyla heinzsteinitzi	None	Israel; Palestinian Territory	CR
Hynobius tokyoensis	Tokyo Salamander	Japan	VU
Hynobius yangi	Kori Salamander	South Korea	EN
Hypsiboas cymbalum	Campo Grande tree frog	Brazil	CR

Mammals:

Latin name	Common name	Country	IUCN category
Crocidura wimmeri	Wimmer's shrew	Côte d'Ivoire	CR
Dipodomys stephensi	Stephen's kangaroo rat	United States	EN
Eumops floridanus	Florida bonneted bat	United States	VU

Table 3. Selected protected areas currently with a lot of urban area within 50 km. Protected areas near urban areas can be impacted ecologically unless properly managed, although this proximity also benefits urban dwellers by allowing greater interaction with nature. This list was created by measuring urban area in the year 2000 in the 50 km buffer around strictly (IUCN category I-IV) protected areas greater than 500 km^2 in area. This list is sorted by country name and then by the name of the protected area.

Name	
Cordon del Plata Provincial Park	Argentina
Blue Mountains National Park	Australia
Neusiedler See und Umgebung landscape protection area	Austria
Parque Estadual Da Serra Do Mar Park	Brazil
Parque Nacional Da Serra Do Itajai Park	Brazil
Golden ears park A - Park	Canada
Calanques National Park - Core Area	France
Kiskunsagi National Park	Hungary
Gunung Halimun - Salak National Park	Indonesia
Parco dell' Etna Regional/Provincial Nature Park	Italy
Parco nazionale del Gran Paradiso National Park	Italy
Parco nazionale dell'Alta Murgia National Park	Italy
Biwako Prefectural Wildlife Protection Area	Japan
Hallyeohaesang National Park	Korea, Republic of
Veluwe Nature Conservation Act	Netherlands
Ingushsky Zakaznik (Federal)	Russian Federation
Ci-lan Major Wildlife Habitat	Taiwan
Shei-pa National Park	Taiwan
Alpine Lakes Wilderness	United States of America
Merritt Island National Wildlife Refuge	United States of America
Mount Rainier National Park	United States of America
Rocky Mountain National Park	United States of America
Sespe Wilderness	United States of America

Table 4. Selected protected areas with substantial urban growth in their surroundings. This list was created by measuring urban growth (2000-2030) in the 50 km buffer around large strictly (IUCN category I-IV) protected areas greater than 500 km^2 in area. All these protected areas were forecast to have more than a 5% increase in the nearby urban area. This list is sorted by country name and then by the name of the protected area.

Name	Country
Parc national du Ruvubu National Park	Burundi
Parque Estadual Da Serra Do Mar Park	Brazil
Parque Nacional Da Serra Do Itajai Park	Brazil
Golden ears park A - Park	Canada
Mont Cameroun National Park	Cameroon
Virunga National Park	Congo (DRC)
Chingaza Natural National Park	Colombia
Farallones de Cali Natural National Park	Colombia
Las Hermosas Natural National Park	Colombia
Los Nevados Natural National Park	Colombia
Cuenca del Lago Atitlan Multiple Use Area	Guatemala
Bromo Tengger Semeru National Park	Indonesia
Gunung Halimun - Salak National Park	Indonesia
Kolleru Sanctuary	India
Sundarban National Park	India
Kolahghazi Wildlife Refuge	Iran
Biwako Prefectural Wildlife Protection Area	Japan
Aberdare National Park	Kenya
Meru National Park	Kenya
Mt. Kenya National Park	Kenya
Maduru Oya National Park	Sri Lanka
Ifrane National Park National Park	Morocco
Majete Wildlife Reserve Wildlife Reserve	Malawi
Falgore (Kogin Kano) Game Reserve	Nigeria
Okomu Forest Reserve	Nigeria
Veluwe Nature Conservation Act	Netherlands
Parsa Wildlife Reserve	Nepal
Kirthar National Park	Pakistan
Nyungwe National Park	Rwanda
Ci-lan Major Wildlife Habitat	Taiwan
Shei-pa National Park	Taiwan
Kilimanjaro National Park National Park	Tanzania
Mount Elgon National Park	Uganda
Queen Elizabeth National Park	Uganda
Sespe Wilderness	United States of America
Ugam-Chatkal National Park	Uzbekistan
Cerro Saroche National Park	Venezuela

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