Chapter 14: Nature, Risk, Resilience, and Security in the US

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Summary

Human security is inseparably tied to nature's ability to reliably provide essential ecosystem services, and there is a large and growing evidence base that establishes this connection (1–4). Features like forests, wetlands, mangroves, and coral reefs provide critical protective services against environmental disasters and provide a means for communities to adapt to a changing climate. There is a growing body of scientific evidence that conserving and restoring nature can be an effective part of strategies to reduce disaster risks (5) and support climate adaptation (6).

Human activities have reshaped ecosystems in ways that have created risks and undermined resilience in the United States. Changes in the use of land and water, overexploitation of resources, pollution, and climate change have disrupted ecological processes, reduced biodiversity, and undermined the ecosystem services that support human well-being and economic security (7,8). Abundant evidence has established that these transformations can and have increased risks from floods, droughts, storms, wildfires, and heat waves while diminishing the ability of nature and people to withstand and recover from disturbances and to adapt (9,10).

Conserving, restoring, and stewarding natural systems provide vital paths to reduce growing risks in ways that support building lasting resilience in human communities and ecosystems. Investments in the form of natural and nature-based solutions that protect and restore critical ecosystem functions can help address a wide range of problems and hazards while producing a significant array of co-benefits.

There is a growing body of evidence and practice that demonstrates that the security of individuals, communities, and nation-states depends on how well we protect and sustain nature (11). A commitment to new ways of engaging with nature could help protect people and communities against risks and drive societal resilience in a manner that strengthens individual and national security.

Background

Individuals, communities, and nations face a complex web of hazards and challenges in the 21st century.

Between 1980 and 2024, the US experienced more than 400 weather- and climate-related disasters—including severe storms, floods, drought—that produced at least $1 billion dollars (in 2020 dollars) in economic damage (12). The total damages across these 400 events was nearly $3 trillion (in 2020 dollars). In addition, almost 17,000 people have been killed by these events in the US since 1980. These impacts and the growing scale of disasters in the US and around the world are the consequence of increasing exposure and vulnerability to hazards (e.g., storms), changes in the characteristics of hazards as a result of climate change (e.g., storm intensification), weaknesses in infrastructure systems, and how people have occupied and transformed natural systems and landscapes.

Expanding development in the US during the 20th century included the construction of more than 4 million miles of roadway (13), as many as 2 million dams (14), 100,000 miles of levees (15), and the development of roughly 900 million acres of agricultural land (about 40% of all US land) (16). These actions have transformed the American landscape and how natural systems work. While this transformation fueled economic development across sectors, it has also created vulnerabilities, hazards, and risks. For example, through large-scale engineering and land conversion, the US lost half of its wetlands in 200 years, from an estimated 220 million acres in the 18th century to about 110 million acres today (17,18). Cities, neighborhoods, businesses, and farms developed and built within floodplains and on top of drained and filled wetlands are at risk of flooding, especially as repairs and upgrades to decades-old infrastructure lags, development "protected" by this infrastructure expands, and flood hazards grow. Given the role that wetlands play in regulating the movement and distribution of water, the loss of wetland and floodplain functions also has profound consequences for drought and wildfire risks, water resilience (including access to clean water), the security of the agriculture system, and vital functions provided by other species.

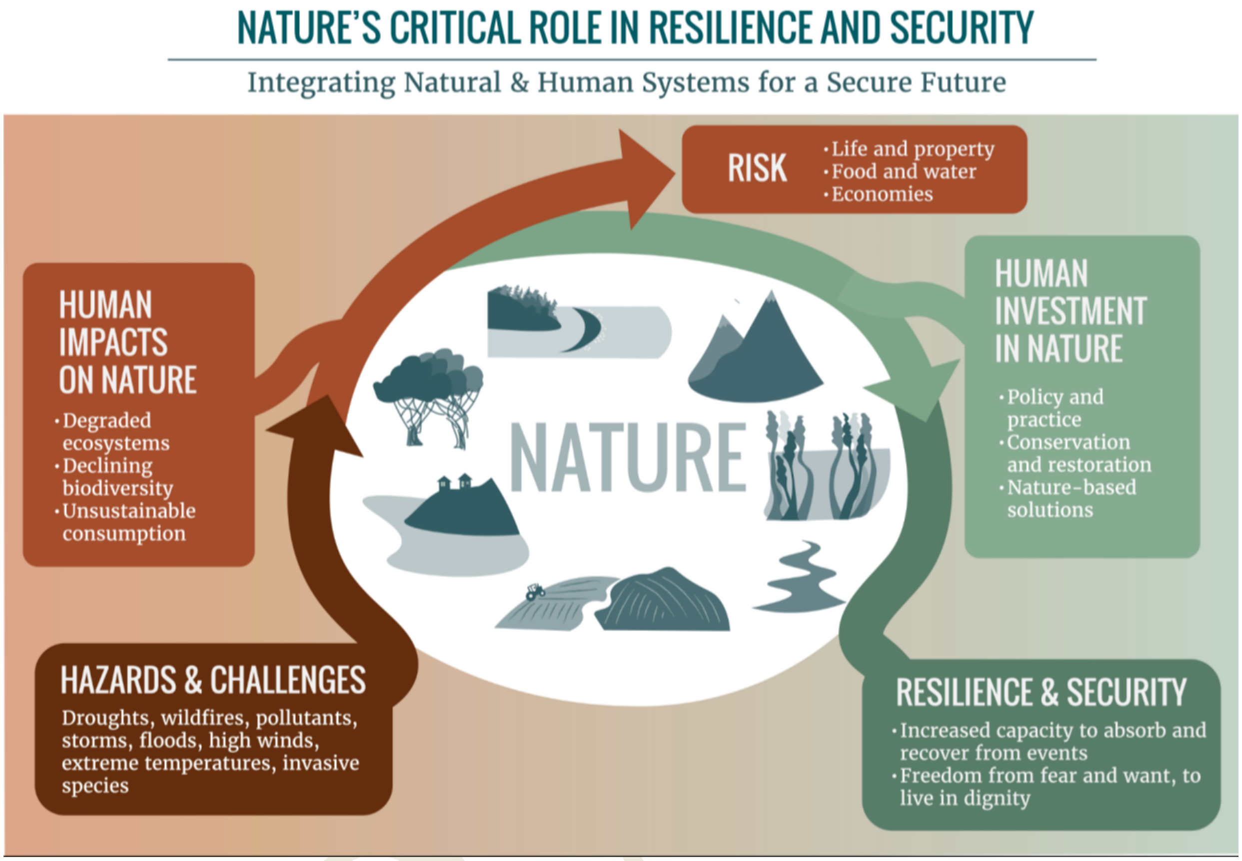
There is growing recognition that restoring Earth's natural systems and integrating them with human systems can help address many challenges and hazards facing communities and human society. Actions taken to reduce harm to people and communities, including the planned use of natural systems, can be considered in the context of three complementary concepts—risk, resilience, and security—which are used in informal and formal ways to understand potential or actual harm and to inform solutions. These concepts and their associated technical practices are being used to address complexity and uncertainty in a host of fields, including engineering, ecology, economics, and human health and safety (19–26).

The focus here is on the application of these concepts to hazards and challenges at the intersection of human and natural systems. The technical field of risk analysis has developed over the last 40–50 years (27,28) to assess the "uncertainty about and severity of the consequences of an activity with respect to something that humans value" (29). For example, risk assessments can be performed to describe the probability that homeowners will experience economic damages from flooding over the period of a 30-year mortgage. The concept of resilience and its application has an equally long history across multiple disciplines (25,26,30–33). Across these domains, resilience is defined as the ability of a system to absorb, recover, and adapt to disturbances or adverse events (19,29,32,34). For example, communities that plan and organize cooling shelters and then adapt their future land use to incorporate more green space can be more resilient during periods of extreme heat (which contributes to the deaths of approximately 10,000 people in the US, annually (35)). In the domain of security, increasing focus is being placed on human security. The United Nations Commission on Human Security notes the movement away from a predominant focus on “traditional, state-centric conceptions of security that focused primarily on the safety of states from military aggression to one that concentrates on the security of the individuals, their protection, and empowerment” (36). Human security is “a people-centered approach focused on individual human beings and their rights and needs; specifically, freedom from fear, freedom from want, and freedom to live in dignity” (24). As many as seven related dimensions of human security (and related threats) have been proposed: economic (e.g., unemployment), food (e.g., crop failure), health (e.g., infectious disease), environmental (e.g., disasters), personal (e.g., violence), community (e.g., ethnic conflict), and political (e.g., human rights abuse) (37). Viewed from the perspective of the individual, human security can be understood as a precondition of national security (24).

Human decisions and actions, through their effects on nature, can create, increase, or reduce risks, resilience, and security. People who build their homes on low-lying ground near a river expose themselves to future flooding. A community that expands development across floodplains reduces its ability to absorb and recover from a flood. By contrast, a community that invests in restoring floodplains and wetland functions across its landscapes can increase its resilience and security with respect to future flooding, drought, and access to clean water. Nations that organize their institutions in ways that reduce tensions and conflict between human activities and natural systems can sustain their **natural capital** and the flow of **ecosystem services** that support their long-term security.

The accumulation of human actions have reshaped and disrupted natural systems. While these actions have largely been taken in pursuit of economic benefits, they have also created risks for people and society that have compromised the long-term resilience and security of the US economy and communities across the country (Figure 14.1). Developing positive relationships between people and nature, in which human systems and natural systems are aligned in ways that are mutually beneficial, can reduce risks, create resilience, and develop comprehensive security.

Figure 14.1. Social–Ecological Conceptual Diagram



Informed decision-making and nature-based interventions can reduce risk and enhance resilience.

Many of the risks facing individuals, communities, organizations, and the country are the result of a combination of hazards and past human decisions and actions, particularly human decisions that have degraded nature's systems and the ecosystem services upon which society depends. Therefore, human decision-making and interventions that support and restore natural systems provide an important pathway for reducing risks and building long-term resilience and security. Figure original to The Nature Record.

Key Message 14.1. Healthy ecosystems support the security of communities and the Nation

Healthy ecosystems are essential to human security, offering protection from hazards and supporting reliable supplies of food, water, and energy (virtually certain). Degradation of soils, forests, wetlands, and other natural systems undermines livelihoods, increases disaster risks, and threatens the physical and mental well-being of people (virtually certain). Investments in ecosystem protection, conservation, and restoration—such as watershed and wetland conservation and management—can yield multiple benefits, *strengthening community resilience and long-term economic stability (virtually certain). The security of communities and the country depends on cultivating nature's capacity to support human safety and well-being (virtually certain).*

State of Knowledge 14.1

Human security is inseparably tied to nature's ability to reliably provide essential ecosystem benefits and services, and there is a large and growing evidence base that establishes this connection (1–4). Some of the critical benefits provided by nature are tangible, such as food, water, energy, and safety, while others are less tangible, such as recreational and aesthetic experiences (see Ch. 11: Culture) (10,38).

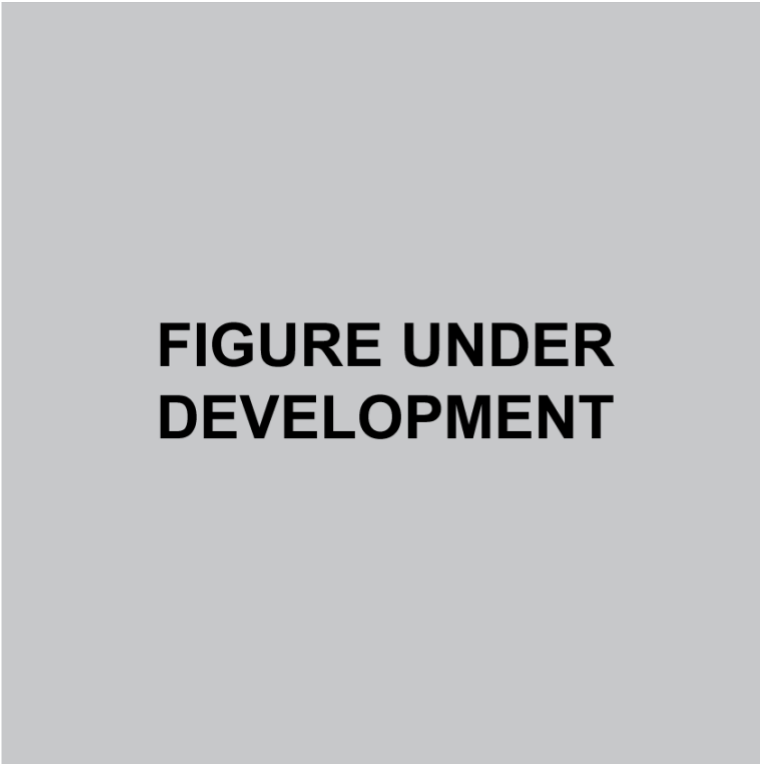
Healthy ecosystems underpin food security by sustaining fisheries, aquaculture, and agriculture, while the degradation of ecosystems undermines livelihoods and nutrition (39–42). For instance, soil health is the foundation for the production of nutritious food and is therefore fundamental to both local and global food security (43,44). Sustainable soil and **ecosystem management** are thus essential to human security. Recent findings indicate that a 60% increase in global food production will be needed by 2050. This will require increased support from many related ecosystem services related to water, pollination (45), pests, and plant diseases. However, one-third of global soils are already experiencing moderate to severe degradation due to erosion, nutrient depletion, salinity, sealing, and contamination (46).

Healthy ecosystems in forests, rivers, streams, wetlands, coasts, and oceans provide services that influence both the quantity and quality of freshwater supply (38) and water management goals of storage, flow regulation, filtering, and flood and drought protection (see Ch. 7: Inland Waters) (47). Forests, wetlands, and grasslands regulate water quality and supply, reducing treatment costs and buffering communities against droughts and floods, as demonstrated by New York City's watershed protection program (Box 14.1) (48,49). Water services also include supplies for agriculture and fish production and the ability to store and retain floodwaters (38,50).

Box 14.1. The New York City Watershed Program

New York City's water system, serving nearly nine million people, fundamentally relies on functioning ecosystems in the Catskill, Delaware, and Croton watersheds (51) (Figure 14.2). The city protects water quality by preserving the ecosystem services provided by forests, soils, and wetlands in these watersheds, enabling a significant reduction in treatment costs for drinking water.

Figure 14.2. NYC Watershed Map and Photo



(Authors' note: This figure will include a map of the watershed program across the Catskill, Delaware, and Croton watersheds (including infrastructure components) combined with a photograph of the natural system within one of those watersheds)

To safeguard the watersheds, the city and state established the landmark 1997 New York City Watershed Agreement. This pioneering partnership agreement has become a global model of how ecosystem protection can provide essential public services. By protecting upstream ecosystems, the city not only secures high-quality drinking water at relatively low cost but also supports biodiversity, rural economies, and climate resilience.

The program invests in land conservation, sustainable agriculture and forestry practices, and wastewater management to maintain watershed health. These watershed management efforts represent a total cost of about $1.5–$2 billion (in 1997 dollars) over several decades, and they have allowed New York to avoid building treatment systems estimated at $8–$10 billion (in 1997 dollars) to construct and $365 million (in 1997 dollars) annually to operate, delivering financial benefits of four- to fivefold in addition to the environmental benefits provided by the conserved ecosystems.

The ecosystem services provided by the watersheds was the basis for the Environmental Protection Agency (EPA) granting a waiver that allowed the city to avoid building costly water filtration plants while reliably delivering safe water at far lower cost.

In addition to avoiding filtration costs, the watersheds contain some of the greatest recreational and sporting opportunities in the region—such as boating (kayaking, canoeing, and other nonmotorized boating), hiking, hunting, fishing—thus generating rural economic value as well as cultural ecosystem services (52).

[END BOX 14.1 HERE]

Energy security is also tied to ecosystem health, with hydropower and other renewable systems depending on stable watershed functions (53,54). Healthy soils and effective land management, which support ecosystem services, can prevent damaging events like landslides and flooding that could disrupt energy infrastructure. By sustaining vegetation with strong root systems, healthy soils directly reduce erosion potential, landslide risk, and negative impacts from windstorms (55).

Ecosystems provide significant, direct support to the well-being and safety of people. The economic benefits of the variety and richness of life across landscapes and ecosystems are now widely recognized by economists (56,57). Beyond material needs, green spaces and healthy ecosystems also support human mental and physical well-being and cognitive function (10,58–60).

Ecosystems also provide vital protective services. Features like forests, salt marshes, mangroves, and coral reefs provide critical protection against environmental disasters and provide a means for communities to adapt to a changing climate. There is a growing body of scientific evidence that conserving and restoring such features in ecosystems can be an effective part of strategies to reduce disaster risks (5) and support climate adaptation (6). The economic value of such **natural infrastructure** and **nature-based solutions** (NBS) in enhancing resilience is increasingly recognized by researchers, policymakers, and decision-makers. A growing body of research shows that natural systems are cost-effective in reducing disaster risks, prompting extensive global analyses of the economic value of these systems (61). For example, coastal wetlands, mangroves, and coral reefs can buffer communities against waves from coastal storms and sea level rise in ways that reduce disaster risks and prevent billions of dollars in economic damages (62–65).

Evidence has been building over many years regarding the protective services provided by ecosystems. A 2008 analysis of economic damages from 34 major hurricanes striking the US coast since 1980 found that the presence of coastal wetlands explained about 60% of the differences in observed damages across coastal communities (62). The same study estimated that the loss of 1 hectare of wetland corresponded to an average increase of $33,000 (in 2008 dollars) in storm damage from specific storms. The estimated value of storm protection from wetlands varied by event, ranging from as little as $23 per hectare (in 2009 dollars) for Hurricane Bill (2009) to as much as $463,730 per hectare for Hurricane Opal (in 1995 dollars), with a median value of just under $5,000 per hectare. In a more recent study, coastal wetlands have been estimated to reduce annual flood damages in the US by over $23 billion (in 1995 dollars) (63).

Coastal habitats, particularly mangroves, coral reefs, and salt marshes, can provide more cost-effective approaches for reducing wave heights and providing protection at the shoreline compared to conventional engineering solutions (e.g., levees, floodwalls, etc.) (64,66). For example, a global study that looked at mangroves and salt marshes—including sites in the US—found that these natural systems can provide the same level of coastal protection as conventional structures like breakwaters, but at a much lower cost. (66). An analysis of property damage caused by 88 tropical storms and hurricanes hitting the US between 1996 and 2016 shows that counties with more wetland coverage experienced significantly less property damage (65). The same study estimated that the expected economic value of the protective effects of wetlands varies widely across coastal US counties, averaging about $1.8 million per square kilometer, with a median value of $91,000 per square kilometer (in 2016 dollars).

Box 14.2. The Mississippi River

(Photo(s) to be included)

The Mississippi River is the backbone of a vast river basin that encompasses 40% of the US and all or portions of 31 US states and two Canadian provinces (Figure 14.3.). The basin and its 7,000 rivers and streams cover 1.2 million square miles and provide a large array of ecosystem services and economic value related to agriculture, transportation of goods, and drinking water. Its ecological processes generate critical local, regional, and national benefits. The river supports 1.3 million jobs and serves as a vital artery of economic security and ecological resilience for the Nation.

Figure 14.3. Mississippi Basin Map and Photo

(Authors' note: This figure will include a map of the Mississippi River and Basin combined with a photograph of the river showing aspects of the natural system and human activity related to the infrastructure.)

The Mississippi River and its tributaries have been significantly modified and engineered for two primary reasons: to limit the spread of water across the rivers' floodplains during high flows (i.e., flooding) and to support the commercial navigation system that operates on the river network. The great flood of 1927 inundated more than 27,000 acres of land along the Mississippi and displaced hundreds of thousands of people. The Flood Control Act of 1928 began a great campaign of engineering that included building thousands of miles of levees, creating river diversions, and shortening the river by 150 miles by dredging cutoffs through the river's meandering loops. One thousand miles of articulated concrete mat has been placed along the banks in an effort to keep the Mississippi from changing course, which it did for millennia prior to human intervention. These interventions—in combination with building 62 locks and dams and other structures that comprise the navigation system—enable agricultural development across the basin's floodplains and the movement of nearly 700 million tons of cargo each year. This engineering has created risks as well as benefits. For example, dams and levees on the Mississippi River have greatly reduced the delivery of sediments to the Mississippi River Delta, substantially contributing to the loss of 1,800 square miles of land in coastal Louisiana, thereby exacerbating flood risks, including from hurricanes.

Key economic benefits of the Mississippi River including the following (67):

- Total ecosystem service value of the Mississippi River Delta estimated between $12–$47 billion per year (in 2007 dollars).
- 700 million tons of cargo moves on the Mississippi River navigation system annually, saving $6 billion (in 2010 dollars) in transportation costs compared to other modes of transportation.
- Storm protection: coastal wetlands in the Mississippi Delta reduce storm damages, with avoided costs valued at billions of dollars annually (62).
- Hurricane protection: wetlands provide an estimated $23,000 (in 2008 dollars) per hectare per year in storm protection benefits.
- Commercial and recreational fisheries: Mississippi Delta ecosystems support fisheries worth $2–$3 billion (in 2010 dollars) annually, providing jobs and food security.
- Carbon sequestration: wetlands and forests in the basin store large amounts of carbon, valued at hundreds of millions of dollars annually in avoided damages.
- Water supply and quality: the Mississippi watershed provides drinking water and industrial water supply for 20 million people, valued in billions when accounting for treatment cost savings and economic productivity.
- Tourism and recreation: recreational activities (fishing, hunting, boating, wildlife viewing, etc.) contribute tens of billions annually. The Upper Mississippi alone supports a $55 billion (in 2025 dollars) tourism and recreation industry, built on the river's scenic landscapes, fishing, and hunting. (67–71)

[END BOX 14.2 HERE]

Description of Evidence Base

There is a large and growing evidence base that establishes the connection between human security and nature's ability to reliably provide essential ecosystem benefits and services (1–4). The robust evidence base has developed over several decades and includes fundamental research and synthesis across a broad range of fields and disciplines, including ecology, engineering, economics, agriculture, oceanography, hydrology, forestry, and many others. The high level of confidence—*virtually certain*—for all statements in this Key Message is based on the overwhelming amount of evidence establishing nature's support to human well-being and the functioning of human society. Ongoing research and scholarship on ecosystem processes and services, across a range of disciplines, is focused on quantifying the nature of these services, how they are disrupted, and the consequences of their disruption for society and nature.

Major Uncertainties and Research Gaps

Evaluating the economic benefits of ecosystem services is essential for creating public support for nature conservation and investment, but it can be challenging to accomplish given the complexity and dynamic nature of ecological and economic systems (57,72). Despite significant advances, major limitations continue to constrain the economic evaluation of nature-based solutions. Long-term monitoring of the ecosystem services of NBS and their socioeconomic outcomes is particularly scarce (61). Standardized monitoring frameworks for NBS effectiveness have yet to be developed or implemented (6).

The technical literature on economic benefits also reveals important thematic gaps. Research examining the protective services of ecosystems has focused heavily on mangroves, forests, and coastal ecosystems, while coral reefs, riparian zones, and urban ecosystems—often directly linked to highly populated areas—remain underexplored (5,61). Similarly, droughts are dramatically understudied with respect to the value of nature-based approaches, despite being the second most widespread hazard after floods (61). The number of recorded droughts has increased by 29% over the past 20 years, and, from 2007 to 2017, droughts have affected at least 1.5 billion people and cost $25 billion (in 2021 dollars) globally (73). These impacts are especially acute for marginalized groups, including children. As of 2025, over 920 million children (over one-third of the global child population) were highly exposed to water scarcity, which in turn impacts their nutritional access.

The economic benefits of ecosystems are understudied, and when studied they are underestimated. While NBS provide hazard protection, their additional long-term co-benefits, such as food provision, cultural services, and improved well-being, are often underestimated. Data on implementation costs are typically more available than benefits, which require resource-intensive socioeconomic analysis and costly survey data collection (61).

Equity and distributional impacts of ecosystem services are also understudied. Most comparative studies conclude that NBS are more cost-effective than engineered alternatives, with no evidence to the contrary. However, equity, inclusivity, and distributional impacts are often overlooked in NBS design and evaluation, limiting their transformative potential (74). Fewer than 30% of scientific studies considered social and distributional impacts of NBS across income, gender, race, Indigenous groups, or local communities (61).

The absence of policy and procedural guidance for evaluating benefits and costs of NBS and ecosystem services will present obstacles for incorporating evidence into decision-making in both the public and private sectors. There are examples of progress being made in the development of relevant policy (75). As such policy is translated into procedures and then applied to decisions that affect actions and the nature of interventions in ecosystems and communities, the experience gained will provide learning opportunities for refining and expanding practice.

Key Message 14.2. Human activities have undermined nature's capacity to support the resilience of communities and the Nation

The cumulative impact of human actions over time has transformed ecosystems and processes in ways that have created significant and growing risks for communities, businesses, and governments (virtually certain). Changes in natural resources, landscapes, habitats, and plant and animal populations have decreased the resilience of human and ecological systems by reducing the capacity of systems to absorb disturbances and adapt to threats (virtually certain).

State of Knowledge 14.2

Human activities have reshaped ecosystems in ways that have created risks and undermined resilience in the US. Changes in the use of land and water, overexploitation of resources, pollution, and climate change have disrupted ecological processes, reduced biodiversity, and undermined the ecosystem services that support human well-being and economic security (7,8) (see Ch. 9: Drivers and Ch. 10: Climate Change).

People depend on nature for water, food, energy, and other natural resources Over time, the size of the human population and the scope of human resource extraction, agriculture, and other forms of development—shaped by a prevailing worldview about humanity's relationship with nature—have had significant impacts on resilience of people and ecosystems. A telling example of this worldview can be found inscribed in the limestone of the Engineering Building at the University of Wyoming, built in 1926: "Strive on—the control of nature is won, not given." This ethos of "control" has underpinned a century of interventions in landscapes and ecosystems across the country (76). Gilbert White, widely regarded as the father of floodplain management, famously cautioned against attempts to control nature and reminded practitioners that engineered solutions often create new vulnerabilities: "Every intervention of man in the environment around him incurs some risk as to both favorable and unfavorable consequences. Every intervention is taken in the face of partial ignorance as to what its effects will be and involves uncertainty as to the ultimate outcome" (77).

Infrastructure

The scale of human activity has had a profound impact on both the physical structure and living systems of the planet. Infrastructure development has grown to the point that the amount of material used to develop that infrastructure (e.g., concrete, asphalt, rock, and steel) now exceeds the total mass of all living things on the planet (78). In fact, over the last 100 years, the total mass of this infrastructure material doubled every 20 years (78). Some of the consequences of the growth of impervious surfaces (e.g., roads, parking lots) include the retention of urban heat (79) and the prevention of water infiltration into soil. Rapid surface runoff from more than 40,000 square miles of impervious surface in the US is the source of a range of problems, including increased flood risks (80).

The physical reshaping of landscapes and processes resulting from infrastructure development has brought about large-scale change in how things move, including water, people, and animals. When rain falls on land, water flows in rivulets, then streams, and then into rivers. When it rains heavily in unaltered systems, streams and rivers swell, water flows over the rivers' natural banks and spreads across adjoining wetlands and floodplains. In the US, 90,000 large dams (14), as many as 2 million small dams (81), and 100,000 miles of levees (82) were built—in most cases many decades ago—to control the flow of water for several purposes, including the building of farms, cities, businesses, and homes on floodplains. Through these actions and other modifications to the landscape, the contiguous US lost half of its inventory of wetlands in 200 years—from an estimated 220 million acres in the 18th century to about 110 million acres today (17,83,84). And wetland loss continues: From 2009 to 2019, the US lost another 670,000 acres.

US infrastructure also includes more than 25,000 miles of navigation channels along rivers and coasts and nearly 4 million miles of roadways that crisscross the country—affecting the flow of goods, people, animals, and more. Approximately 250 million cubic yards of sediment is dredged every year from US waterways to maintain the economic engine of commercial navigation. Nationally, only about 30% of this sediment is beneficially used to restore landscape features, land, and habitats. In recognition of the need to improve this situation, first the US Army Corps of Engineers in 2023 and then the US Congress in 2024 created national goals to beneficially use a minimum of 70% of dredged sediment to create habitats, NBS, and other benefits (85,86). While roads also affect the flow of water and sediment, one conflict in particular affects a large number of people and animals. There are 1–2 million collisions between vehicles and wildlife on US roadways every year, resulting in more than 200 human fatalities, 26,000 injuries, $8 billion (in 2021 dollars) in property damage, and the death of more than 300 million vertebrate animals (87). The field of road ecology and investments in wildlife passages and crossings are helping to reduce risks for people and wildlife (88).

Agriculture

Development of the agriculture sector in the US has reshaped the rural American landscape. Roughly 900 million acres (1.4 million square miles) of land—about 40% of the contiguous US—is dedicated to farmland (89,90). Soils are a vital form of natural capital, and soil degradation and land conversion are global threats to food and water security. The world's food systems rest on fragile ground: 95% of our food relies on healthy soils, but one third of farmland is already degraded (91). In the US, one-third of agricultural soils are experiencing moderate to severe degradation, threatening productivity and increasing vulnerability to droughts and floods (43,44). In the West, declining snowpack and watershed health reduce both water supply reliability and hydropower generation, impacting energy and agricultural systems (54,92). In the Mississippi River Basin, nutrient runoff from agriculture has created one of the largest hypoxic (low oxygen) zones in the world, undermining fisheries and imposing high economic costs on coastal communities (67,93).

Wildfires

The growing impacts on wildfire further illustrate the systemic risks of degraded ecosystems. In California and across the western US, decades of fire suppression, combined with climate change and land-use pressures, have increased the frequency and severity of catastrophic fires. These events not only destroy property and ecosystems but also impair air quality, disrupt supply chains, and impose public health costs measured in billions of dollars annually (94,95).

Box 14.3: The Dust Bowl

In the early 20th century, federal policies promoting homesteading and farming led to massive land conversion across the Great Plains. Farmers in the southern plains plowed up nearly 50,000 acres of native prairie grass every day around 1929. By the mid-1930s, 33 million acres of prairie had been turned over, leaving soils vulnerable to erosion (96). When drought struck, the result was the Dust Bowl: catastrophic dust storms that stripped away over 1 billion tons of topsoil, impacting 100 million acres of land and forcing 2.5 million people to migrate out of the region (96) (Figure 14.4).

Figure 14.4. Dust Bowl Map and Photograph

FIGURE UNDER DEVELOPMENT

(Authors' note: This figure will include a map of the Dust Bowl region and a photograph illustrating the scale of the environmental impact.)

The Dust Bowl is a reminder of the consequences of unsustainable land management and the fragile balance between agriculture and the environment. Today, US agriculture faces renewed pressures from a variety of sources, including intensifying droughts, soil degradation, aquifer depletion, and climate volatility. These stressors echo the vulnerabilities of the 1930s. US soil degradation is worsened by climate change, which intensifies erosion through extreme weather events. Erosion accelerates the breakdown of organic matter and the release of stored carbon. This degradation of the soil system threatens crop yields and national food security (17,96,97).

[END BOX 14.3 HERE]

Hydrology

The hydrology of the US has been substantially changed through human intervention and engineering.

Human activity and development have changed the way water moves over and under the land. Impervious surfaces and drainage infrastructure capture 90% of the rainfall in urban environments as runoff, which can lead to both local water scarcity (e.g., by preventing infiltration into soil and groundwater aquifers) and urban flooding (when undersized stormwater systems are overwhelmed) (98). Projected trends in both the size of urban populations and rainfall intensity have led to calls for new approaches for managing urban stormwater, including the use of NBS (98). Deforestation in suburban and rural areas associated with human development, agriculture, and other processes can have large and consequential effects on hydrology (99). There were an estimated 53.2 million acres of tile-drained cropland in the US in 2022 (100). These below-ground piping systems move water more quickly from the land to streams, increasing peak flows and the threat of flooding (101).

Approximately 100,000 miles of rivers in the US have been disconnected from their floodplains, largely through the use of engineered levees. For example, the Mississippi River is disconnected from 80% of its floodplains, confining the river's flow primarily to its main channel (102). A river's floodplains and associated wetlands provide space for high flows to spread out, reducing the height of flood peaks and water on the river. In 2019, the Mississippi River was at flood stage for more than 200 days. Such high flows over such long periods threaten the structural integrity of confining levee systems, resulting in levee breaches and flooding. Flooding in the Midwest in 2019 produced more than $20 billion (in 2019 dollars) in damage (103), particularly along the Mississippi and Missouri Rivers, including more than $1 billion (in 2019 dollars) needed to repair damage and hundreds of breaches in levees over several hundred miles of levee system (104). The nature of future flood (and drought) risks will be determined by a combination of factors, including climate change and approaches to managing the connections between rivers and floodplains.

Urban rivers have been substantially modified as a consequence of development. The Los Angeles River, which runs across the second-largest city in the US for more than 50 miles, exemplifies the challenge. A large flood along the river in 1938 resulted in the deaths of 100 people and the destruction of 5,000 homes across the floodplain. Subsequent engineering of the river to reduce future flood risks involved installing a concrete channel to increase the capacity of the river to carry high flows within its channel (105). The Los Angeles river retains few of the ecosystem services of a natural river, including hydrological processes supporting groundwater recharge in a region where access to sufficient water supply presents a significant challenge (106). Nearly one million people live within one mile of the river. The Los Angeles County Department of Public Works is currently pursuing a strategy to restore some ecosystem services, including through NBS, to provide a range of benefits to communities across the basin (107).

Biodiversity

Impacts on the abundance, distribution, and diversity of plants and animals can and have had cascading consequences for human risk and security. Beavers, once numbering more than 200 million across North America, were hunted nearly to extinction by the end of the 19th century (108). The near-total loss of this keystone species altered hydrology and fire regimes across an entire continent, as demonstrated by recent research showing that beaver ponds help slow wildfires and store water in drought-prone landscapes (109). Pollinators, too, have suffered major declines, with significant economic costs and security implications for US agriculture, which relies on pollination for a substantial share of crop production. Factors implicated in pollinator declines include habitat loss, pesticide exposure, climate change, and disease (110–113). In North America, approximately 22.6% of 1,579 assessed vertebrate and insect pollinator species are at elevated risk of extinction (114). This includes all three pollinating bat species. Bees represent the most vulnerable insect group, with an estimated 34.7% of the 472 species assessed at risk (114). Numbers of North American bumblebees have fallen nearly 50 percent since 1974 (115). In 2025, total economic value of pollinators worldwide amounted to $178 billion, which represented 9.5% of the value of the world agricultural production (including in North America) used for human food (116).

These cumulative alterations underscore how human-driven changes in landscapes and ecosystems have amplified risks and reduced resilience. From the Dust Bowl to wetland loss along the Gulf Coast, the consequences of large-scale landscape and ecosystem transformations reveal a consistent pattern: Human interventions designed to control nature and maximize short-term benefits have often undermined the very ecosystem services that underpin long-term security.

Description of Evidence Base

An abundant evidence base from a range of geographic contexts and sectors of society has established that human-caused transformations in nature can and have increased risks from floods, droughts, storms, wildfires, and heat waves while diminishing the ability of ecosystems and people to withstand and recover from disturbances and to adapt (e.g., (9,10). The evidence establishing the connection between human impacts on natural systems and risks to human safety and security was part of the growing awareness of environmental challenges in the 1960's and before. Fundamental research and synthesis across the physical, natural, and social sciences and engineering over the last 40 years and more has documented the growing cumulative effect of human development on nature and the consequent risks for people and communities. The high level of confidence—*virtually certain*—for both statements in this Key Message is based on the overwhelming amount of evidence establishing the scope of human effects on nature over the last 100 years and more and consequent risks at multiple levels, from individual communities and regions to whole sectors of the economy.

Major Uncertainties and Research Gaps

Progress in conserving and sustaining the ecosystem services of nature can support the resilience and security of communities and the country.

Understanding and Managing Natural Assets and Infrastructure

People in the US are beneficiaries of a diversity of natural assets: oceans, rivers, forests, grasslands, wetlands, and coastal islands, among many other ecosystems, features, and habitats. These assets provide physical structures and processes that provide habitat that supports biodiversity while also providing protective and other services that support the resilience and security of communities, businesses, and entire sectors of the US economy. When the condition of these assets declines, the risks faced by communities, businesses, and the economy can be expected to increase.

Asset management has become standard practice for private and public organizations. The American Society of Civil Engineers grades the condition of US infrastructure every four years and publishes a report card with the purpose of raising awareness and prompting intervention to address weaknesses in the system of infrastructure on which the country depends. No comparable comprehensive effort exists for assessing the condition of US nature, natural infrastructure, and NBS. Developing a system to track natural assets and accounts at the national level—and their implications for human risks—could be used to inform and guide investments in resilience and security (117).

Sharing Information About Nature and Resilience

Access to general information about nature at all levels of education and popular entertainment is probably greater now than at any time in history. While awareness is growing regarding the close connections between threats to nature and threats to people, developing ways of sharing practical knowledge about how human security depends on the condition and services that nature provides could create broader understanding about resilience. Sharing positive examples of nature's contributions to human security in different contexts—designed for a wide range of contexts and audiences, from the general public to practitioners—could foster the dialogue, creativity, and engagement that leads to progress in building comprehensive resilience and security (118–123).

Coordinating and Governing for Resilience at Scale

The accumulation of relatively small, local interventions over long periods can result in large-scale change to systems. A few miles of levee along an otherwise unregulated river will have localized effects, whereas thousands of miles of levee will affect the hydrology, ecosystems, and the distribution of risks across an entire river basin. The gulf hypoxic zone—an area of low oxygen in water encompassing several thousand square miles along the coast of Louisiana that has caused ecological and fisheries harm totaling billions of dollars—is the result of fertilizer application and runoff from agricultural lands across the Mississippi River Basin, changes in hydrology, and widespread loss of riparian habitats and wetlands. A hypoxia task force was established in 1997, but the problem has only grown in scale since then, highlighting the governance challenges associated with such large-scale change in the nature–human system (124).

In a related way, environmental offsets and mitigation programs in the US represent a significant opportunity to create future resilience, if these programs—a large-scale market with $6–$9 billion (in 2020 dollars) in annual transactions—could be organized to conserve and contribute to protective services related to flooding and other hazards (125). The development of markets and financial resources and flows for nature and nature-based solutions is a growing topic and opportunity for progress (126,127).

Finally, large-scale conservation commitments and programs such as 30x30—a global initiative aimed at conserving 30% of land and coastal waters by 2030—provide opportunities to create portfolios of investment in NBS, at full scale, to address a diversity of hazards and risks (128).

Key Message 14.3. Restoration and integration of natural systems can build resilience

Efforts to conserve, restore, and steward natural systems can help reduce growing risks from flooding, wildfire, extreme heat, and other hazards in ways that support lasting resilience in communities and ecosystems (well established). Integrating nature-based approaches into infrastructure design enhances the reliability and cost-effectiveness of protective systems, complementing conventional engineering solutions (well established). As climate impacts and development pressures intensify, combining natural and built infrastructure provides a flexible and enduring path toward community safety, economic stability, and ecological health (well established).

State of Knowledge 14.3

Natural systems and processes provide many vital services, including protective services. Investments in the form of NBS can help address a wide range of problems and hazards while producing a significant array of co-benefits. In general, nature-based and conventionally engineered solutions can be used and combined in complementary ways (Figure 14.5). For example, risks from extreme heat can be reduced both by painting roofs white and by planting trees, which provide shade and cooling through evapotranspiration. While both approaches can mitigate risks from heat waves, trees provide additional aesthetic, health, carbon storage, and biodiversity benefits.

Figure 14.5. The Resilience Process and Value of Infrastructure Systems

Combining nature-based and conventional infrastructure improves community resilience and recovery.

Two hypothetical infrastructure scenarios are presented: C, a single-layer system (e.g., a levee to address flood risk) and C+N, a multilayered system (e.g., a levee setback that includes a restored floodplain). Compared to a conventional solution used alone, integrating NBS can result in reduced loss and quicker recovery. Examples of C+N include a levee setback and restored floodplain, building code upgrades for fire resistance combined with prescribed burning as a part of ecological forest management, and improved water conservation technologies combined with restored wetlands to facilitate groundwater aquifer recharge. Adapted from Linkov et al. (2018) (129).

Flooding

Flooding can occur from tides, rivers rising, and ponding of rainfall and snowmelt, as well as from coastal tides and surge and waves during storms. Maintaining and restoring natural features and nature's ability to convey floodwaters, slow storm surges, and dampen waves before they hit shore can meaningfully reduce the impacts of storms and floods on people and the built environment. Many of the actions that help reduce flood risk in both riverine and coastal systems have additional ecosystem service benefits for biodiversity, habitat, carbon storage, recreation, and more.

The size or intensity of a flood can be described in multiple ways that are reflected in its probability of occurring. Bigger floods occur less frequently than smaller floods. A flood that has a 1% chance of occurring in any given year is commonly referred to as a "hundred-year" flood.

Flooding from Rivers and Inundation

An estimated 41 million people in the US are currently exposed to floods from rising rivers and ponding, based on maps that define areas that are expected to be inundated during a hundred-year flood (130). Current damages in the US from these floods are about $32 billion (in 2022 dollars) per year. Climate change is expected to increase these damages by 26% by 2050 (131), and ongoing development in floodplains is expected to further increase such damages.

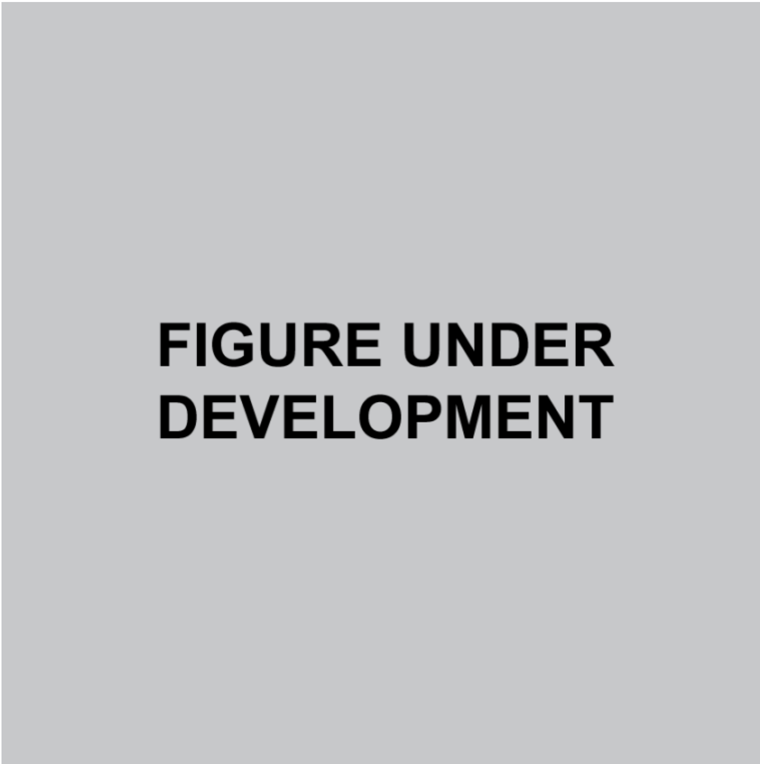
Nature can help alleviate flooding by increasing infiltration and reconnecting floodplains (132). Given the volume of floodwaters associated with damaging floods, it is generally challenging to meaningfully reduce flood peaks and associated damages by increasing the flood storage capacity in upland watersheds (133–135). Rather, successful examples of using NBS to avoid significant flood damages typically involve increasing the "getaway capacity" of floodwaters via spillways or expanding floodplains via levee setbacks (i.e., reconnecting rivers to their adjacent floodplains by moving the levee away from the river) (136). For example, where levees have created pinch points that prevent drainage of a watershed and thus cause upstream flooding, targeted levee setbacks can facilitate drainage and alleviate the flooding.

There are 24,000 miles of levees in the national levee database and more than 100,000 miles of levees across the US, representing millions of acres of disconnected floodplain (15,137,138). The American Society for Civil Engineers gave levees a grade of D+ in their 2025 Infrastructure Report Card (139), and in 2021 the organization estimated it would cost $70 billion (140) to address the maintenance backlog, a cost that is expected to increase with time. When levees are set back from the river channel, they are exposed to less frequent and slower-moving floodwaters, with lower flood heights, which significantly reduces both maintenance needs and risk of failure (141). The floodplains that are restored through setbacks represent NBS integrated with conventional solutions (i.e., a levee) that reduces risks, damages, and costs to people and infrastructure (Figure 14.2).

Box 14.4. The Yolo Bypass in Sacramento, California

People and communities in the US have long recognized the importance of nature to their physical security. The Yolo Bypass project is a prime example (Figure 14.6).

Figure 14.6. Yolo Bypass Map and Photo



(Authors' note: This figure will include a map of the Yolo Bypass system and a photograph that includes both infrastructure and nature components in the system.)

Following a series of large floods in California in the 1800s, including catastrophic flooding in 1861–1862, the US Congress authorized what today is known as the Yolo Bypass along the Sacramento River. It was recognized at the time that levees alone could not address the highest flows in the river and its tributaries. The system includes a series of weirs and other structures that deflect high river flows onto 60,000 acres of the native floodplain, reducing flood risks for Sacramento and its surrounding communities (142). The project has been successfully operating and growing for more than a century. Of the 60,000 acres in the bypass, 75% are privately owned farmland that is inundated through agreements with landowners, while 16,000 acres are included within the Yolo Bypass Wildlife Area, which provides habitat for wildlife and recreation opportunities for people. As this project demonstrates, strengthening nature's contributions to risk reduction can support long-term resilience in the United States.

[END BOX 14.4 HERE]

Coastal Flooding

An estimated 2.5 million people will be exposed to severe coastal flooding in the US by 2050 (143), and tens of millions of people currently live in low-elevation coastal zones that are vulnerable to flooding. The protection and restoration of coastal habitats (e.g., mangroves, reefs, and salt marshes) can reduce risks by reducing wave energy (144–146). Salt marshes can reduce wave energy by up to 72%, and mangroves can reduce wave height by up to 66% (147).

The flood protection benefits of coral reefs have been quantified for the United States (64,148). Coral reefs have been estimated to prevent flooding for 53,800 people, $2.7 billion in damage to property, and $2.6 billion in indirect economic impacts due to economic interruption (in 2021 dollars). Given the current probabilities of flooding across the US, the hazard risk reduction benefit of US coral reefs has been estimated at $1.8 billion annually.

The flood protection benefits of mangroves have also been quantified globally, including in the United States (149). In the US in 2020, mangroves provided flood-reduction benefits to more than 64,000 people. Mangroves provide $2.4 billion in flood-reduction benefits annually (in 2020 dollars). This is double the benefit that mangroves provided in 2010, as more people and structures are located in coastal areas.

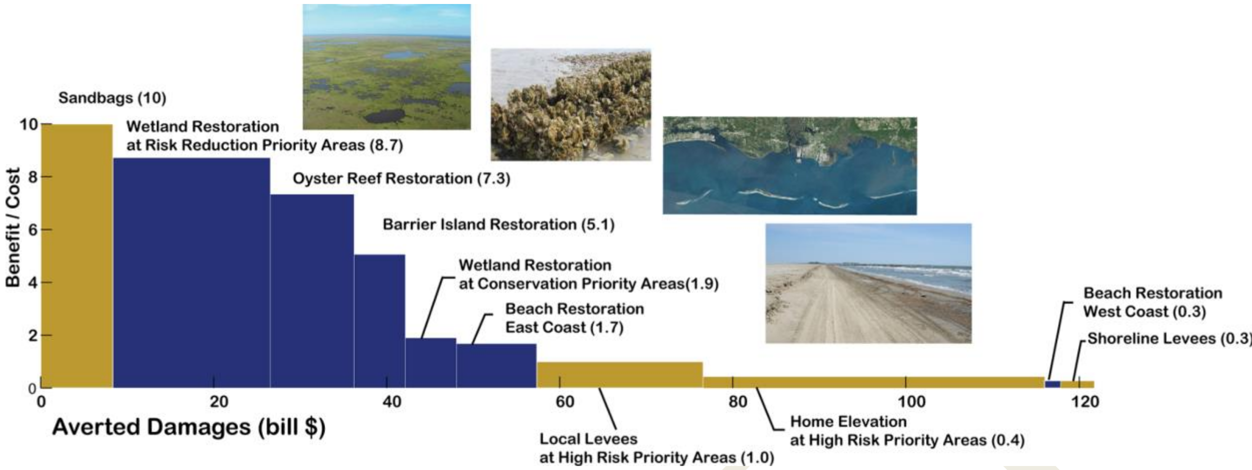
Regional analyses for salt marshes found that coastal wetlands avoided $625 million in direct flood damages during Hurricane Sandy (2012) (63) and $934 million during Hurricane Ike (2008) (150).

These benefits are provided by existing nature; however, many of these remaining ecosystems are greatly reduced from their former extent and could be restored. For example, oyster reefs in the US have declined by 64% in extent and 88% in biomass over the last 100 years (151), while mangroves in the US increased by 13.5% between 1980 and 2020 (152) (see Ch. 6: Marine Ecosystems).

About 70% of coral reefs in Florida are eroding (153). The restoration of coral reefs in Florida and Puerto Rico could significantly reduce flooding risk (154) by reducing the area flooded from a 100-year event by 20 square kilometers, avoiding flooding to more than 14,700 people, and avoiding $1billion in damages to buildings and $800 million in indirect economic effects due to economic interruption (2025). Given the current probabilities of flooding, the flooding risk-reduction benefits of coral reef restoration in Florida and Puerto Rico would be $391 million annually (in 2025 dollars) (154).

Both wetland and oyster reef restoration are highly cost-effective practices for flood-risk reduction in the Gulf of Mexico (155). The benefits of flood-risk reduction, including NBS, increase as more development is built in harm’s way and as climate change increases the frequency of flooding events (Figure 14.7).

Figure 14.7. Cost–Benefit Analysis of Adaptation (figure to be adapted)



Compared to conventional measures, nature-based solutions offer a more cost-effective approach to adaptation.

The y-axis shows the benefit to cost ratio. Numbers greater than one indicate that averted damages exceed the cost of implementing the practice. The x-axis shows the total potential averted damages if the practice were to be fully adopted across the US Gulf Coast. Note that while sandbagging is the most cost-effective intervention, nature-based solutions are more cost effective than levees or home elevation. Adapted from Reguero et al. 2018 (155). CC-BY-4.0.

Fire

Maintaining and restoring the ability of fire-prone ecosystems to experience low-severity fire (e.g., through the reduction of fuel loads) can lower the risk of severe wildfires that threaten human lives, communities, and drinking water supplies.

The area burned by wildfires in the United States has increased, on average, by about 150,000 acres every year from 1983 to 2024 (156). While fire is a natural process, historic suppression and climate change have altered fire regimes, shifting from frequent low-intensity fires—in which most mature trees survive—to systems with thick forests and brush that tend to burn at high severity, killing most or all the trees.

Ecological forest management that restores forest structure (accomplished by thinning and prescribed fire) can reduce the risk of severe fires (157) and infrastructure loss (158,159). Shifting back to a more frequent, low-severity fire regime often requires reducing current fuel loads through thinning and/or prescribed fire. Once fuel loads have been reduced, prescribed fire or managed wildfire can maintain lower fuel load and reduce the severity of wildfires when they do occur. Restoring historic fire regimes can also benefit biodiversity. For example, old-growth forests are now at greater risk of being lost to wildfire than to logging (160). Consequently, preserving habitat for species that depend on old growth, such as spotted owls, requires management for wildfire resilience (161).

Extreme Heat

Heat waves kill approximately 10,000 people in the US each year (35). Heat waves are particularly damaging in urban areas due to the urban heat island effect, in which the built environment amplifies the ambient temperature compared to nearby rural areas. Trees and other plants have a cooling effect through evaporative cooling (water evaporates from photosynthesizing leaves) and, depending on the height of the plants, through casting shade. Compared to more natural areas, cities have relatively more impervious surfaces (asphalt, concrete, and rooftops) and less plant cover, making them warmer than surrounding areas. But cities are not as warm as they would be without any trees: On average, cities in the US are 5.5° F cooler because of urban trees (162). Planting more trees would help cities stay cooler; for example, a study of 93 European cities found that 40% of heat-related deaths could be avoided with adequate tree cover (163).

There is substantial variation in tree canopy even within cities, which means that the impacts of heat are not evenly distributed throughout cities. Disparities among neighborhoods in access to nature have a long history. In the 1930s, the Federal Home Loan Bank Board developed four classes of real estate risk, from A (best) through D (hazardous), commonly referred to as redlining (164). Redlined areas are, on average, 4.7° F hotter (165). Depending on the city, redlined areas can be as much as 12.6° F hotter (165). Despite the clear benefits of urban trees, tree canopy is decreasing in the US at a rate of about 175,000 acres per year (164). Recently, there has been increasing awareness of this issue (166), and there are now many tree-planting initiatives (167).

Water Quality

Water quality—the suitability of water for human and environmental uses based on its physical, chemical, and biological characteristics— is foundational for security and resilience because it directly underpins health, food production, economic stability, and environmental sustainability (168). Suitable water quality is essential to public water supplies, agriculture, recreation, propagation of fish and wildlife, energy production, and many other industrial processes. Agriculture is both heavily dependent on water quality for irrigation and other uses and also a major contributor to water-quality degradation (169,170). For example, heavy fertilizer use combined with extensive land-use conversion of wetlands and riparian areas in the Mississippi River basin has resulted in a “dead zone” of about 7,000 square miles in the Gulf of Mexico, leading to major economic losses from reduced catches and revenues for commercial and recreational fishing industries, lower seafood availability, and declines in tourism (171). Water-quality degradation can lead to waterborne diseases and public-health risks, as well as corrosion of water pipes and consequent toxicity, leaks, and contamination (172). Social conflicts arise, particularly in regions that share water bodies, when access to clean water is limited or when uncompensated economic injuries result from pollution. Water quantity and quality are interrelated. Droughts, streamflow depletion, ineffective irrigation management, and overdrafting of groundwater can lead to increased concentrations of pollutants, salinization, and long-term economic impacts over large regions (170,173).

Water-quality degradation and its consequent risks and impacts can be reversed through a wide range of NBS, including restoration of wetlands and riparian corridors, as well as conserving and sustainably managing forested and grassland watersheds (174,175). Harnessing nature to complement traditional water resources infrastructure can reduce future risks to water supplies needed by communities and businesses, help water providers keep costs down, enhance resilience to climate change, and provide a wide range of other benefits, including protection against flooding and erosion, improved air quality, recreational opportunities, wildlife habitat, and numerous other benefits (176).

Integration: Engineering with Nature, Not Engineering Against Nature

Comprehensive resilience and security can be achieved through the integration of natural and human-built systems. Conventional and nature-based solutions can be combined to develop practical, scalable, and adaptable risk-management systems that sustain themselves over time. Realizing this potential would entail a shift in mindset away from either/or framing that presents a false choice between purely engineered and purely nature-based solutions. Substantially reducing risks while enhancing resilience in the US would require transformational change in thinking in regard to nature. The last 400 years of history in America is filled with examples and lessons regarding the need to respect nature’s seniority and relevance to human security. People and human institutions will continue to develop their surroundings for economic and other purposes. Approaches to development that increase value in nature, rather than impairing or depleting it, would enable innovative solutions for human security.

Description of Evidence Base

A significant and rapidly growing evidence base from fundamental research and practical applications of NBS has been fueling the development of technical tools, policies, and full-scale implementation of NBS. The types of evidence being produced varies based on the hazard and ecosystem. For example, the benefits from reduced coastal flooding have been demonstrated using hydraulic engineering models that account for the influence of the height and roughness of natural systems (reefs, mangroves, and salt marshes) and their effects on storm surge and waves (e.g., (154)). The benefits of nature for heat reduction come from studies that have correlated canopy cover with surface temperatures, both from field measurements and remote sensing (e.g., (162)). Numerous epidemiological studies have correlated heat waves with increases in adverse health outcomes such as emergency room visits (e.g., (35)). The high level of confidence in this Key Message is based on decades of evidence from fundamental and synthesis research and technical guidance (including engineering guidance) being used to inform designs for a broad range of NBS applications.

Major Uncertainties and Research Gaps

Progress in deploying nature-based solutions to reduce risks, make systems more reliable, and increase the resilience of systems could be advanced by developing standards of practice to guide the development of multipurpose solutions and infrastructure.

Facilitating Multipurpose, Multibenefit Solutions, Land Use, and Infrastructure

Developing multipurpose approaches for addressing risk and resilience challenges involves a range of means and tools, including policy, legal, regulatory, and financial instruments. Examples of such approaches include Flood-Managed Aquifer Recharge in California, an approach for conserving water resources by using working lands (e.g., farms and ranches) and floodplains to hold flood waters for recharging the groundwater aquifers below (177,178). Obtaining required permits for restoration and NBS projects can take years and consume up to a third of a project's budget (179). Research that advances understanding of how NBS work and sharing of best practices across regions and programs could help to improve, modernize, and streamline federal and state regulatory processes governing the implementation of NBS (180–182).

Many opportunities to advance NBS implementation lie at the intersection of sectors. For example, ports and navigation infrastructure are exposed to a range of hazards for which NBS are relevant, including storms, flooding, and sea level rise (183). One example is the federal goal, noted above, to use at least 70% of dredged sediment to create habitats and features relevant to NBS. Another emerging area of cross-sector collaboration on NBS relates to the insurance industry. Both physical and financial risks are growing. Investments in nature, in the form of NBS, provide a means for reducing insured losses, and insurance for NBS provides a means for sustaining the protective services provided by nature (184).

Guiding Practice

Developing and sharing evidence-based technical guidance for a diversity of contexts, audiences, and users is key to advancing successful NBS implementation. The landscape contexts range from coasts to rivers, deserts to wetlands, mountain forests to grassland plains, and wilderness to working lands. A range of guidance is being developed and shared to inform the work of communities, decision-makers, planners, engineers, construction companies, and professional organizations and agencies associated with building, operating, and maintaining combinations of conventional and natural infrastructure (123,149,185–187). In 2024, the American Society of Civil Engineers, which develops standards of practice for designing and implementing infrastructure projects, issued a policy statement on nature-based solutions that expressed its support for "expanding infrastructure and community resilience through protection, restoration, prioritization, and implementation of NBS and processes to achieve societal, environmental, and economic benefits” (188). Expanding and accelerating collaborative development of guidance could increase the pace of effective implementation of NBS. Collaborative efforts to organize and share the rapidly growing evidence base for NBS would support the development of needed guidance (189).

Key Message 14.4. Human security depends on partnering with nature

The security of individuals, communities, and nation-states depends on integrating natural and human systems to ensure they exist in better balance (well established). Population growth, economic development, and technological change are intensifying pressure on the environment and contributing to the unsustainable consumption of natural resources (very well established). These dynamics are disrupting ecosystem services, climate stability, and access to natural resources that are vital to human, economic, and national security (very well established). A commitment to new ways of engaging with nature would help protect people and communities against risks and improve societal resilience in ways that strengthen individual and national security (well established).

State of Knowledge 14.4

In January 1941, as the United States stood on the brink of major war, President Franklin D. Roosevelt declared in his State of the Union Address a vision for the “Four Freedoms” that people “everywhere in the world” should enjoy. He spoke at a time when the US was grappling not only with economic depression and the specter of world war but also unprecedented environmental calamities. Deforestation and drought had exposed the country to nature’s extremes. Widespread floods had inundated communities, from the Great Plains to the Northeast. The Dust Bowl had stripped fertile land down to barren soil, displacing millions of people in one of the largest forced migration events in American history. Against this backdrop, President Roosevelt’s vision of four freedoms—freedom of speech, freedom of religion, freedom from want, and freedom from fear—offered a broader conception of security rooted in human dignity and resilience. President Roosevelt’s vision of freedom followed from his “New Deal” approach to government, which reimagined the role of government as a positive force in people’s lives.

From Conflict to Security

Freedom from fear and want are fundamental to human security. Such a framing—that security includes feeling safe from harm and having access to the necessities of life, including food, water, shelter—resonates strongly with the value of resilient ecosystems, clean air and water, and natural infrastructure. Much as the New Deal reimagined government’s role in lifting the nation out of crisis, reframing our relationship with nature—not as an adversary to fight, but as a partner to be embraced—provides a path to unleashing the benefits that nature can provide in building healthier individuals, stronger communities, and a more secure Nation.

Human actions can pose a threat to vital ecosystem services that produce fresh food, water, and livable habitats and security at multiple levels (Figure 14.8). What is more, the institutional capacity of the modern state to cope with severe environmental change and restore access to or substitute what nature provides may be limited or nonexistent (190). The effectiveness of a government's response heavily influences its legitimacy with the public. Inadequate responses could exacerbate the conditions of want that breed socioeconomic instability and, in extreme cases, contribute to conflict.

Figure 14.8. The Relationship of Human, National, International, and Nature Security

Nature-related threats and restoration actions influence human security across local, national, and international scales.

Human security—at every scale—is deeply connected to nature security. For example, drought and degraded soil conditions caused by poor management practices could have security implications at multiple scales, from local hunger to national famine or an international humanitarian crisis. Conversely, actions taken to restore and sustain natural resources and ecosystem services can reduce human security threats in multiple ways and levels. Adapted from Securing an Open Society (2004) (191).

Lessons of Nations and Neighborhoods

Much of the work tracing the link between natural resources, environmental pressure, and conflict has largely focused on states in the global south where the institutional capacity of governments to absorb shocks to ecosystems and natural resource availability is insufficient to prevent socioeconomic and political instability. In East Africa, for example, foreign exploitation of fisheries off Somalia—which was embroiled in a civil war in the 1990s and early 2000s—contributed to the collapse of coastal livelihoods and the rise of piracy that has disrupted global maritime traffic and prompted a US-led international response (192,193). In Syria, years of government mismanagement around water resources collided with a multiyear drought that is partly responsible for driving farmers into urban communities, where the regime's failure to effectively contain the environmental crisis fueled discontent (194). The result is one of the longest civil wars in recent memory and the resurgence of violent extremism that has undermined US interests in the greater Middle East. While the pathway between ecological stress and any conflict is hotly debated among those who study the root causes of war, it is undeniable that nature is inextricably linked to other drivers of violence and conflict—including ineffectual leadership, historical grievances, and territorial disputes—and can contribute to instability that has direct implications for US national security and foreign policy interests.

Environmental pressures and natural-resource constraints need not result in armed conflict to affect national security. Indeed, in the global north, environmental degradation, including deforestation and contamination of land and freshwater resources, has exacerbated health inequality, worsened financial hardships, and exacerbated historical grievances in some communities. In the United States, water scarcity — driven in part by drought and developmental pressure—has contributed to substantial economic damage and threatens livelihoods. According to the CDC Foundation, the US economy loses an estimated $8.58 billion annually because of water scarcity, largely due to declines in labor and productivity, reduced household earnings, and higher healthcare costs (195). In the US West, acute drought and tensions around water rights have deepened political faultlines between federal authorities and antigovernment groups, worsening concerns about long-term governance over constrained water resources (196). Across the US, invasive species—plants, insects and other organisms—are displacing native ones and harming ecosystems, putting domestic food supplies at increased risk, and undermining key parts of the economy. By one estimate, invasive species cost the US economy $4.5 trillion (in 2017 dollars) from 1960 to 2020 (197).

Urban sprawl—particularly the growth of low-density development—has also contributed to the expansion of US communities into areas exposed to hazards and future disasters, such as floodplains and forest areas vulnerable to wildfire. Climate-driven changes to precipitation patterns and socioeconomic development in flood zones have exposed more urban areas to costly disasters (198). Similar socioeconomic patterns have driven the exposure of communities to wildland fire hazards near forests (199). In 2024, the US experienced 27 major environmental disasters with damages totaling $182.7 billion (12).

These events exacerbate financial hardship in marginalized communities and undermine confidence in domestic institutions (200).

The Nature of National Security

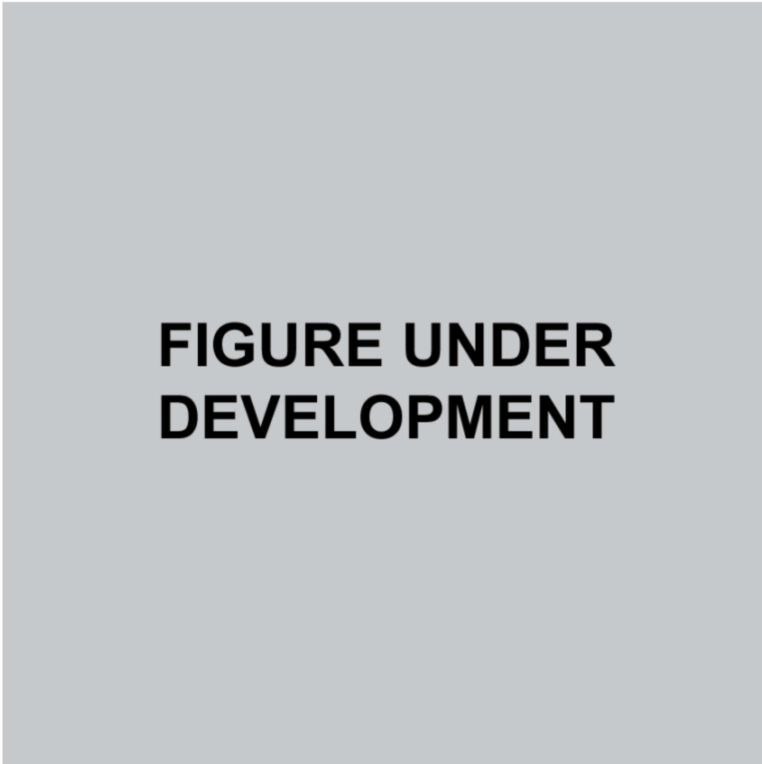
The US military’s limited adaptive capacity in land management, particularly its reliance on hard infrastructure and legacy land-use practices, has exposed many of its installations, training areas, and ranges to extreme weather and other climate-driven hazards that cost billions of dollars in infrastructure damage and undermine defense readiness. In 2018, Hurricane Michael struck Tyndall Air Force Base, Florida, destroying nearly 99% of the installation (201). The Air Force estimated that rebuilding the installation would cost $5 billion (202). In 2019, Offutt Air Force Base in Nebraska experienced significant flooding from the Missouri River, inundating one-third of the installation, displacing 3,200 personnel, and destroying $230 million in simulators (203). The Department of Defense estimated that the cost to rebuild the flooded portion of the installation would total as much as $1 billion (204). These disasters are not only financially costly for the US military—diverting funding away from core mission requirements to repair or reconstruct damaged facilities—they also undermine military preparedness and training by preventing access to ranges that may be flooded or exposed to other hazards and displace troops and military families for significant periods of time.

Global and domestic examples show how environmental degradation can undermine security, reminding us that the security of individuals, communities, and nation-states depends on how well we protect and sustain nature. There is also a growing body of evidence and practice that demonstrates how embracing nature can promote peacebuilding and stability (11). Globally, environmental fragility and natural resource pressure have encouraged a new movement focused on the creation of peace parks and ecological corridors, with states establishing protected transboundary areas that seek to preserve biodiversity and natural resources in an effort to reduce the risk of conflict between humans and wildlife (205). In the US, the Sentinel Landscapes Partnership is a similar enterprise focused on building coalitions between federal, state, and local governments and private landowners to protect natural areas for the benefit of future use and to avoid encroachment upon national security missions, particularly near military installations (206). These concepts exemplify the benefits to individuals, communities, and nation-states that can come from a new way of relating with nature—moving away from treating nature as a threat and recognizing it as a potential partner in addressing security risks.

Natural infrastructure—or nature-based engineering—is a good example of this paradigm shift. The approach integrates natural principles in design and construction processes to help strengthen the capacity of the built environment to absorb environmental shocks and maximize protections for communities against ecological stress, particularly extreme weather and severe environmental change. The US Army Corps of Engineers, which has long-held responsibility for building infrastructure projects to address hazards, has been leading efforts to integrate human and natural systems that advance economic, community, and national security (207). This includes implementing natural infrastructure—such as wetlands, dunes, and islands—or hybrid elements that integrate nature-based and traditional engineering techniques—such as seawalls with oyster reefs or mangroves—to mitigate floodwaters, reduce wave energy, and stabilize shorelines while also improving local biodiversity and the health of ecosystem services.

The US military has embraced the transformative potential of natural infrastructure to help manage environmental change, increase natural resource availability, and mitigate risks from future extreme weather events (Figure 14.9). In 2019, the rebuilding program at Tyndall Air Force Base organized an effort focused on developing coastal resilience through investment in natural infrastructure, which subsequently received both national and international recognition (208–210). Efforts are now underway, through multiple programs, to develop NBS that support resilience for the base and the surrounding communities. In addition, the Defense Advanced Research Projects Agency is investing more than $50 million through its Reefense program in the science and engineering of nature-based approaches, some of which are being demonstrated and tested at Tyndall Air Force Base (211). At Fort Huachuca, Arizona, the Army has collaborated with Cochise County and local groups to designate conservation areas and employ natural infrastructure principles to reduce stormwater evaporation and improve infiltration into the groundwater, enhancing the natural recharge of the one the largest watersheds in the Southwest and an area that is increasingly prone to drought (212). At Fort Benning, Georgia, the Army is collaborating with the University of Georgia to restore a creek to its original floodplain and thereby reduce risks at an airfield that supports special operations and other strategic airlift missions (213).

Figure 14.9. Nature-Based Solutions at US Military Installations



(Authors' note: Figure will include photographs and descriptions of NBS that have been implemented on US military installations.)

As the US military and others are discovering, there are opportunities to embrace nature to protect against environmental stress and manage risks from drought, floods, and other challenges. Yet the speed and scale of action to engage with nature may not yet be sufficient to overcome the challenges that the US and other nation-states will confront as the global security environment continues to evolve in the decades ahead (214). Lessons from early adopters of natural infrastructure concepts show the benefits to communities across the US. In the near term, fostering the necessary cross-disciplinary collaboration (215), integrating natural infrastructure into appropriate resilience policy and implementation guidance, funding strategies, and workforce training curricula (216) could help unleash the positive benefits that nature can deliver in securing our individual well-being and national security (217).

Box 14.5 Agricultural Security

(Authors' note: Figure will be an infographic that includes a map showing the distribution of agricultural land across the US with photographs illustrating NBS with agriculture.)

To understand the agricultural and food system of today, we must understand the past. Many of the current criticisms of our agricultural systems stem from the primary goal of increasing yields and productivity to satiate a rapidly expanding population. The Green Revolution of the mid-20th century was focused on eradicating global hunger and mass famines. The development of agricultural technologies, synthetic fertilizers, pesticides, herbicides, and new varieties of crops helped to increase crop production two- or threefold while increasing crop acreages by only 30% (218). Subsequent observation, research, and science have highlighted the multitude of instances in which agricultural production, when favored over other ecosystem services, is detrimental to the agricultural systems themselves (219).

Since agricultural security is intrinsically tied to the land and environment, disruptions to either can severely impact the health and well-being of people. Agricultural security is strongly linked with climate security; there are numerous examples every year of droughts, floods, fires, and other disasters disrupting production and transportation of agricultural commodities. The loss of fertilizers into groundwater and surface waters has led to many examples of eutrophication-related impacts, such as the hypoxic zone in the Gulf of Mexico, harmful algal blooms in Lake Erie, and more. This loss of fertilizers also represents direct economic loss to farmers themselves, as well as an intrinsic loss of the energy used to create those fertilizers. Synthetic nitrogen is created from the highly energy-intensive Haber-Bosch process that converts gaseous nitrogen into ammonia that can then be used to create nitrogen fertilizers. Synthetic phosphorus is mined from rocks, a process that is also energy intensive and subject to geopolitical threats.

There is a strong and growing effort within the agricultural community to create more resilient and secure agroecosystems. Conservation efforts on working lands such as farms and ranches, as well as the use of best management practices, have been ways for farm owners and operators to enhance the inherent ecosystem services provided by agricultural ecosystems while still maintaining production. Working with agriculture to enhance these services on the approximately 900 million acres of farmland in the US will be key not only to agricultural security but also to national security as a whole (Figure 14.10).

Figure 14.10. Agriculture Map and Photos

FIGURE UNDER DEVELOPMENT

(Authors' note: An infographic that includes a map showing the distribution of agricultural land across the US with photographs illustrating NBS with agriculture.)

[END BOX 14.5 HERE]

Description of Evidence Base

Over the past 40 years, the discipline of security studies has developed a considerable evidence base relating the relationship of nature to human security. Beginning with the environmental crisis of the 1970s and continuing through the end of the Cold War, international security scholars have observed the toll of human activity on global biodiversity and atmospheric systems, as well as situations where competition over natural resources has instigated, perpetuated, and reignited conflict (220–222). Scholars have generally concluded that although humans depend on the natural world, human behavior and actions threaten the existence of the world as we know it. The high level of confidence in this Key Message is based on decades of domestic and international security research and scholarship relating impacts on natural systems to human security.

Major Uncertainties and Research Gaps

Progress in developing resilience and security will involve gleaning lessons from current efforts, measuring outcomes, and innovating through technological advancement.

There is a need to understand and apply lessons from the performance of existing policies, plans, and programs that leverage natural systems for human security in order to inform future policy and action at national, state, and local levels (223). Examples include the US Department of Defense's Readiness and Environmental Protection and Integration Program, which has been supporting natural infrastructure and NBS associated with military installations and neighboring communities, including a $10 million investment in 2021 at Tyndall Air Force Base (224). The California Department of Water Resources Central Valley Flood Protection Plan (225) recognizes both the social vulnerabilities present in Central Valley and the role of NBS in comprehensive flood-risk management. The US Federal Emergency Management Agency and its partner organizations across the public and private sectors have supported guidelines called(187)�. These and other efforts point to the need to assess and share experiences across a wide range of activities to shape and sustain successful efforts.

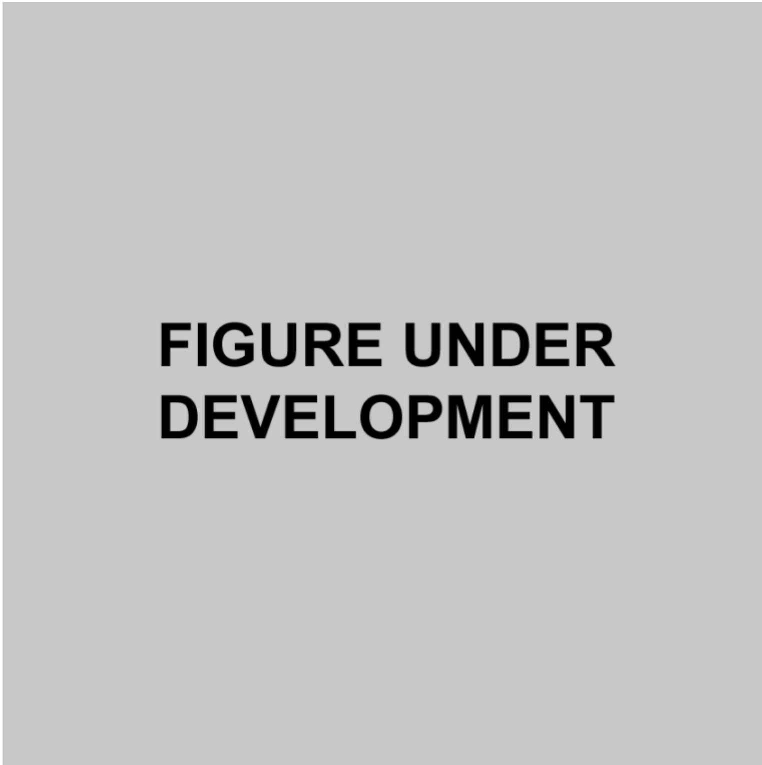
Making progress in developing resilience and security at national and community levels depends, in part, on advancing ways of measuring and quantitatively describing resilience and security and the factors contributing to these system-scale attributes. Practical metrics and tools are needed to plan and design for resilience and security outcomes for conventional as well as nature-based solutions (31,33,226).

The innovation in practice needed to develop solutions for stubborn problems related to resilience and security will be fueled by research in many areas, including in the materials and technologies supporting durable NBS. One example is the US Defense Advanced Research Projects Agency's Defense Program, which is supporting research in novel materials and structures to develop oyster and coral reefs as NBS that support resilient shorelines at military installations and elsewhere (227).

Environmental Justice and Equity Highlights

Risks are not evenly distributed across communities and people (Figure 14.11). Communities of color, people with lower incomes, and socially vulnerable people (including older people and individuals with physical disabilities) are disproportionately exposed to and harmed by hazards, including heat, flooding, and wildfire (228–230). When socially vulnerable people and communities experience a disaster, they are less able to deal with and recover from the harm.

Figure 14.11. Risk and Environmental Justice



(Authors' note: an infographic that includes the use of FEMA Risk Index Maps, https://hazards.fema.gov/nri/ to illustrate spatial variation in the nature of hazards and risks across the US)

The relationship between communities, people, and infrastructure varies across the US. Levees have been widely used to address flooding. Twenty-three million people live and work on the land behind levees in the US (15,138), and Hispanic, Native American, Asian, and Black communities are overrepresented in these low-lying areas (231). In addition, communities in leveed areas are characterized as having higher levels of social vulnerability, poverty, and disability (231). The condition of levees in the US is poor and worsening, as the American Society of Civil Engineers reported in its 2025 report card. Improving the condition of levees to a state of good repair would require an estimated investment of $70 billion (139). Historically, investment decisions for infrastructure like levees have been driven by benefit–cost analyses that compare the estimated costs of a new infrastructure project with the economic benefits that would be provided by the project, for example, in the case of a levee, the flood damages to physical assets and property that the levee would prevent. Using such an approach puts poorer communities at a disadvantage given that the total economic value of physical assets and property in poor communities is lower than in wealthier communities.

Given the economic obstacles to upgrading levees for vulnerable communities across the US, nature-based solutions represent a way to develop durable, cost-effective ways to reduce risks (61,66). For example, levee setbacks, which reconnect rivers to their adjacent floodplains by moving the levee away from the river, can reduce risks of flooding and future damage to levees during high water events. At the same time, such projects can restore habitat for fish and wildlife and create recreational opportunities for people (232). The opportunity moving forward is to tailor combinations of conventional and natural infrastructure to provide a range of benefits that match the needs of communities.

Substantive engagement between public agencies and communities is a prerequisite for developing infrastructure systems that address the diverse needs of communities (233). The need for communication and engagement across communities is reflected in plans and standards that have been developed to inform practice for nature-based solutions (216,234). Collaborating with communities on problems and solutions provides opportunities to learn and improve practice while working toward solutions that create shared value for diverse communities and the Nation (235).

Emerging Issues

Progress on several fronts will be needed to integrate human and natural systems in beneficial ways in regard to risks, resilience, and security.

Communicating to Meet the Challenge

Efforts to optimize human activities in relation to nature—minimizing harm to nature and people while creating value for people and nature—are at the core of many disciplines and fields of practice, including environmental science, ecosystem restoration, design and architecture, and engineering. This diversity has given rise to a large and growing communication challenge as communities of practice share their ideas and intentions using different but related concepts and language (e.g., ecosystem-based approaches, ecological engineering, nature-based solutions, natural infrastructure). This is just one aspect of the boundaries between disciplines that can pose challenges to the collaboration needed to improve how human and natural systems interact. Such differences also affect the quality of communication among groups, such as researchers, practitioners, decision-makers, and the public. Convenings, programs, and projects that are designed with the intention of bridging disciplines, professional networks, and sectors can be used to address this challenge.

Stakeholder engagement presents serious challenges for government agencies, the private sector, and the public. There is a gap between the expectations of stakeholders for engagement and the level and quality of engagement commonly offered by the government and private organizations taking actions and pursuing projects that will affect stakeholder interests, risks, and nature. While standards of practice exist for guiding effective engagement (236), they have not been widely or uniformly implemented by government agencies. Nature-based solutions present opportunities for engaging early and broadly with stakeholders because NBS are unfamiliar to many, require different ways of thinking about problems and solutions, and provide a diversity of benefits that can motivate compromise and partnership. New commitments and approaches would be needed for scaling up quality stakeholder engagement.

Partnering at New Levels

The persistent risks facing communities and institutions are the product of a complex array of factors that call for new levels of partnering across organizations and sectors. Public agencies at the state and federal level have been authorized, through law, to engage in specified missions and areas of work. There is a growing need for public agencies to creatively partner with each other to combine their authorities and work to solve cross-cutting problems. One example illustrating the value of NBS partnerships is the collaboration between the US Army Corps of Engineers and the US Department of Agriculture's Natural Resources Conservation Service to implement floodplain reconnection projects through levee setbacks along the Missouri River (232). In some cases, partnering will require overcoming decades of traditional practices and even tensions, such as those between agencies charged with developing infrastructure and environmental and natural resource agencies charged with the conservation of habitat and species.

The complexity and scale of risk management problems also highlight the need for the public and private sectors to work together. Public–private partnerships have been developed to address infrastructure needs and other opportunities that generate public good while supporting business and economic development. Nature-based solutions have been supported through engagement with the insurance sector, which is reflective of the value NBS can provide in the form of risk reduction.

Developing Capacity

The sharing of knowledge and experience across communities and organizations is a critical accelerator for making positive use of nature to address risk and resilience challenges. Focused investment in programs of research and practice can produce new science, engineering, and construction methods (207,237). Learning networks that operate across regions, organizations (e.g., public and private), levels of government (e.g., local, state, federal), and communities of practice (e.g., environmental conservation and engineering) provide opportunities to share experience, best practices, and resources (238,239). Education and professional training that emphasizes cross-disciplinary training would be needed to develop a workforce that can combine engineered, natural, and social systems to build long-term resilience and security (one example is the Graduate Certificate in Natural Infrastructure from the University of Georgia Institute for Resilient Infrastructure Systems (240)).

Fostering Innovation

Progress can be achieved in reducing risks, building resilience, and advancing security by making a collective commitment to innovation. Implementing new approaches to solve stubborn problems will require change, and change is hard for everyone—individuals, communities, and organizations. Stimulating the innovation in policy and practice that is needed to enlist nature's support in reducing the potential for future harm to people and the planet represents a grand challenge. Accepting and organizing around this challenge could stimulate the creativity that leads to progress.

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