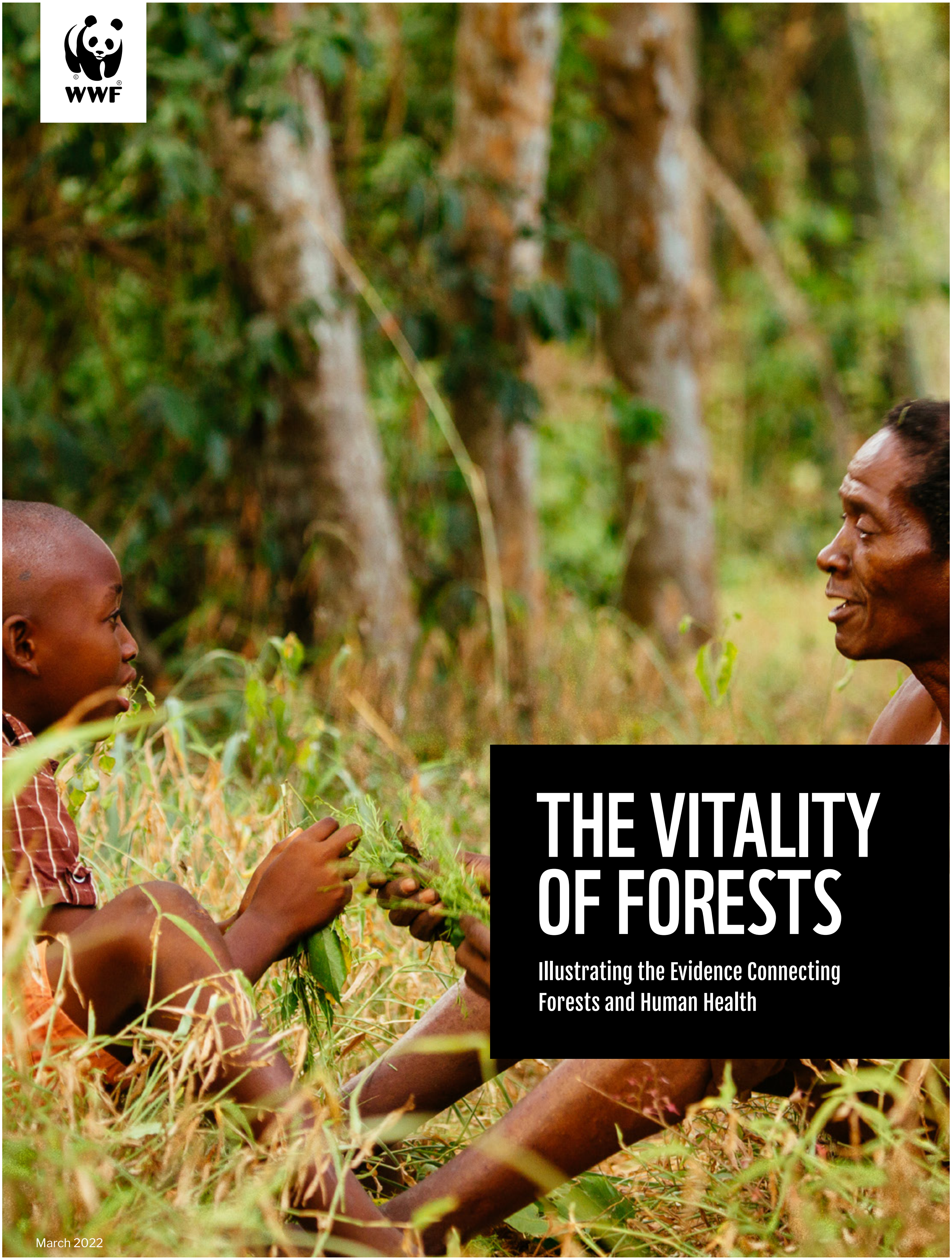

THE VITALITY OF FORESTS

Illustrating the Evidence Connecting Forests and Human Health

March 2022

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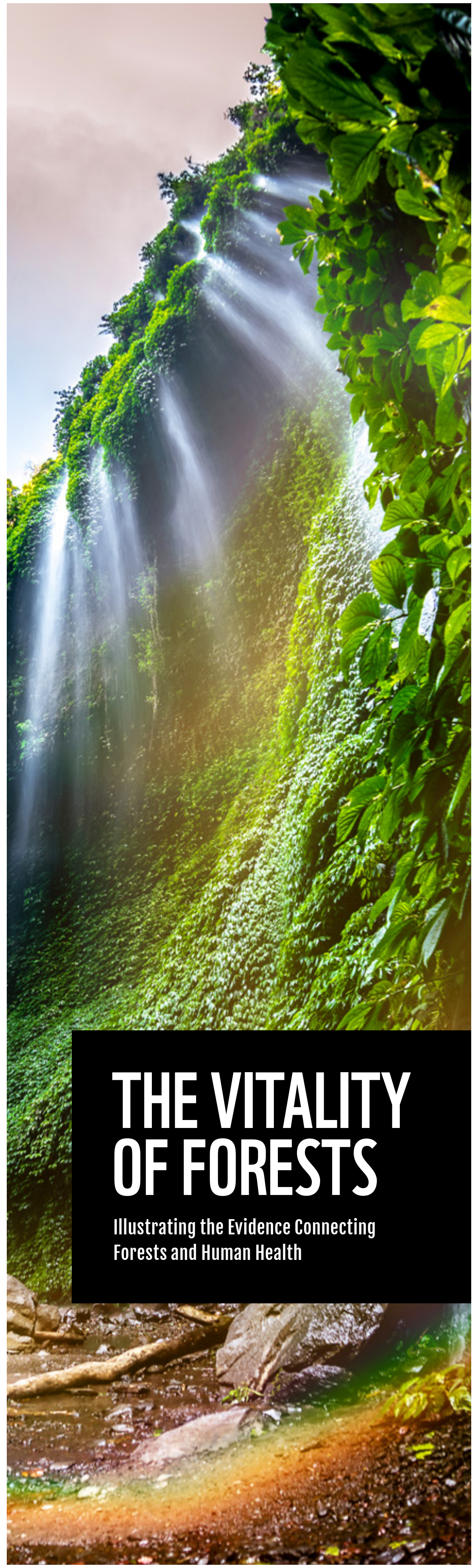
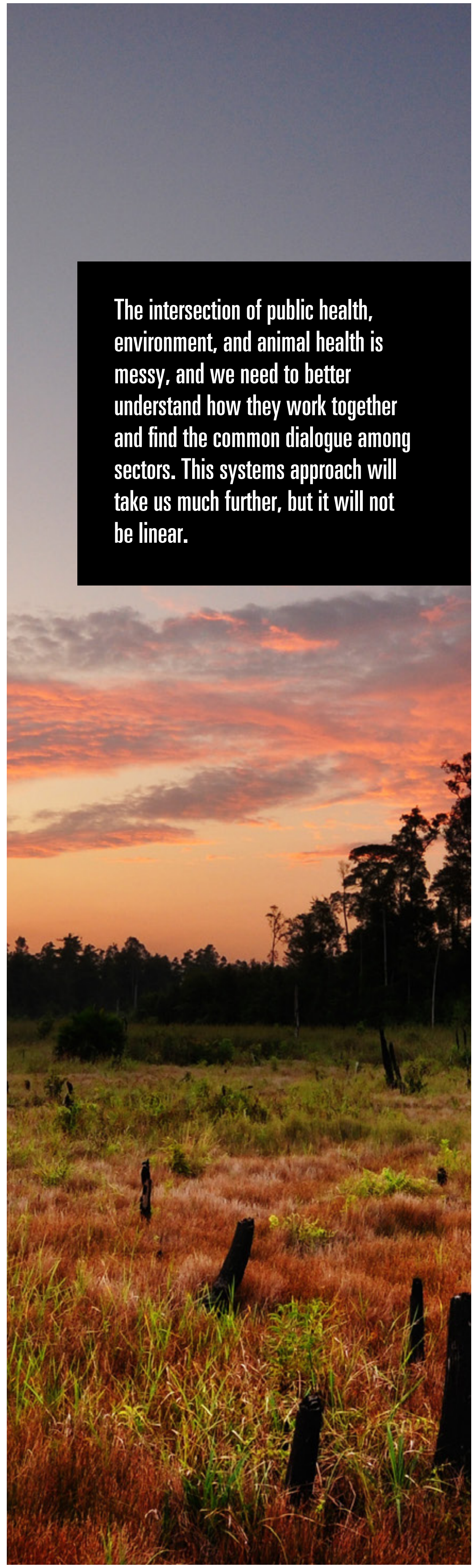


Contents


The intersection of public health, environment, and animal health is messy, and we need to better understand how they work together and find the common dialogue among sectors. This systems approach will take us much further, but it will not be linear.

Key Terms

Environmental exposure – Includes the health risk associated with degradation of environmental quality. Air and water pollution impact both NCDs and infectious diseases. Through filtering air and water, forests can reduce the risks of infectious diseases and NCDs.

Infectious diseases – Diseases caused by organisms such as bacteria, viruses, fungi, or parasites that can be spread, directly or indirectly, from one organism to another.

Noncommunicable diseases (NCDs) – Noncommunicable diseases are noninfectious diseases that cannot be transmitted between people. NCDs constitute the leading cause of mortality and disability globally.

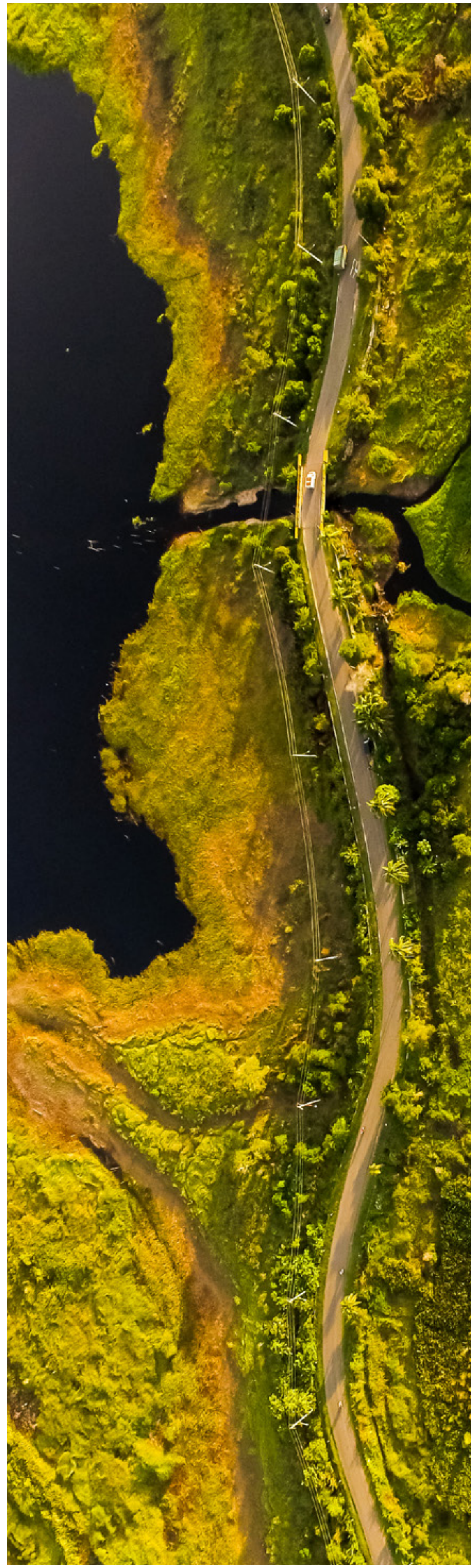
- Forests provide both mental and physical benefits associated with risk reduction for some NCDs, including cardiovascular diseases, cancers, chronic respiratory diseases, and diabetes.
- Forests positively impact nutrition and food security for many communities, influencing health outcomes—including those related to NCDs (e.g., cardiovascular diseases, cancer, and diabetes).

Physical hazards – Physical hazards include environmental and natural hazards (e.g., storms, flooding, drought, extreme temperatures, landslides, and wildfires). Forests can provide protection against physical hazards in a variety of ways that can prevent death and protect human health.

Spillover – Also known as pathogen spillover, zoonotic spillover, or spillover infection, spillover refers to a single event during which a pathogen from one species moves into another species; such movement can result in an outbreak.

Systems approach – A systems approach shifts the focus from individual parts to how the parts are organized, recognizing that interactions of the parts are not static and constant but dynamic and fluid. Systemic change is where relationships between different aspects of the system have changed toward new outcomes and goals.

Zoonotic infectious disease – Also called a zoonosis, a disease transmitted to humans from other animals that can be caused by bacteria, viruses, fungi, or parasites; approximately half of all infectious diseases are zoonotic including recent outbreaks and pandemics that threaten global health and economies, such as COVID-19, SARS, MERS, avian influenza, Ebola, and HIV.



Executive Summary

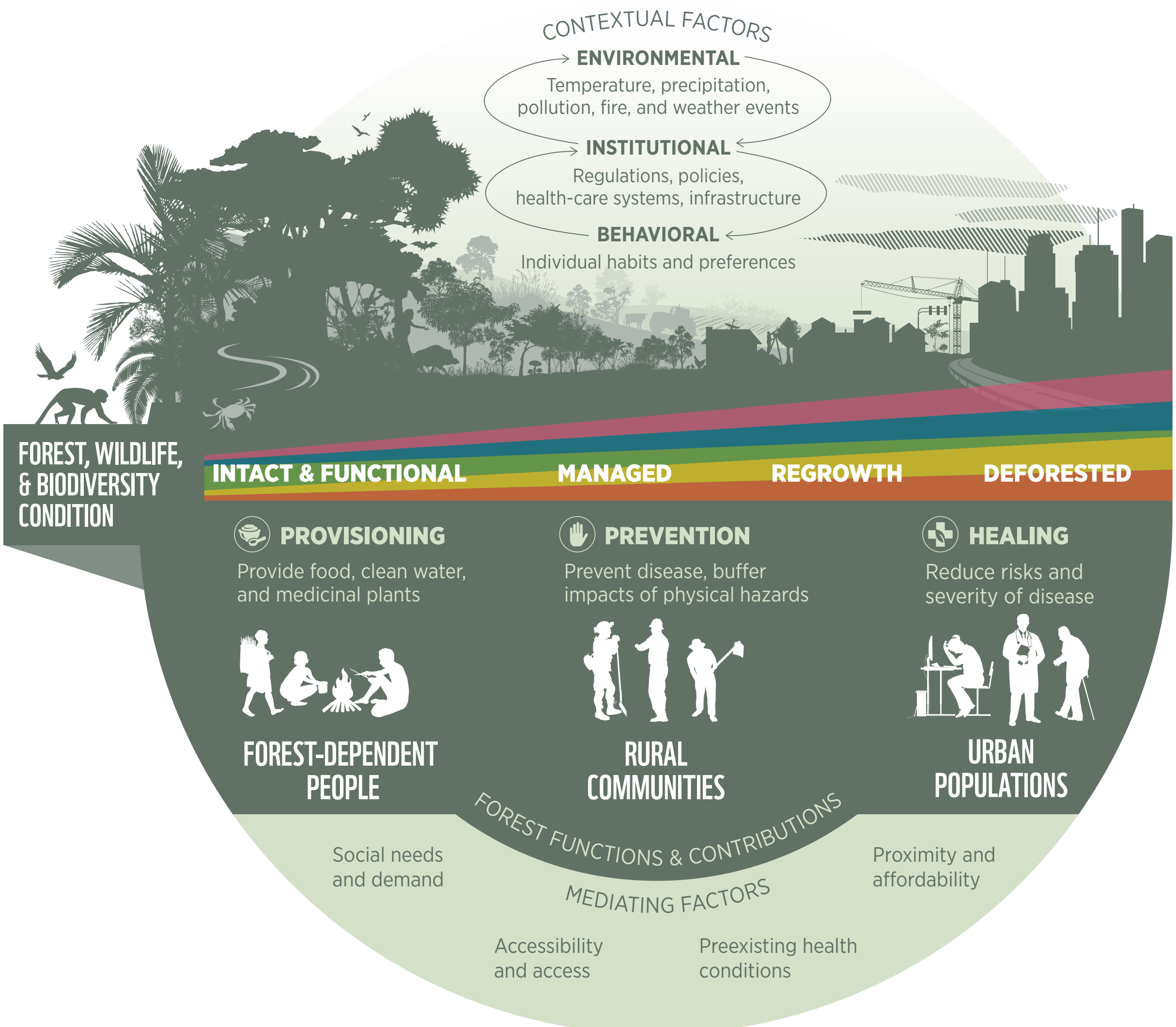
There is a growing interest in understanding the role forests play in human health. This has increased dramatically due to the escalating risks associated with forest loss and degradation and the spread of zoonotic infectious diseases, especially COVID-19, which has impacted nearly every community on Earth. The unprecedented attention to and interest in the links between nature and human health have illuminated the critical function of forests in individual, community, and global human health. The recognition of the interconnections between forests and human health elevates an urgent call to bridge the health and conservation sectors while looking at the numerous components of human health related to diverse forest functions across a variety of situations, contexts, and solutions.

There is a mounting body of literature exploring the multidimensional links between forests and health including food and nutrition; the risks of communicable and noncommunicable diseases (NCDs) (including mental health); and natural hazards. In addition to the food, fuel, and fiber provided by forests that support people's health and well-being, forests also act to regulate water cycles and filter air pollution that indirectly but substantially affect human health. Climate warming and its compounded effects on these cycles and the provisioning roles of forests, combined with associated droughts and longer dry seasons, may increase the likelihood that forests act not only as a benefit to human health but also as a risk.

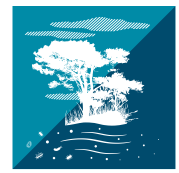
Overall, the balance of the literature reviewed in this report substantiates forests as important in contributing to human health. The most direct negative impacts on human health often result from deforestation and forest degradation, which limit the ability of forests to provide what people need to live healthy lives, prevent illness and injury, and heal when called upon. As outlined below, deforestation leads to a cascade of negative health implications for people that occur across geographic scales and timelines. A comprehensive understanding of forests and human health must look not only at the direct interactions but also at how forest loss indirectly impacts human health in many ways (e.g., air quality and climate change). While the evidence base for this is still growing, it is clear that forests are vital to human health and well-being.

Embracing a holistic framework linking forests and human health

Figure ES.1. Forest and human health interactions and the factors that shape them




Noncommunicable diseases


Environmental exposure


Food and nutrition


Physical hazards


Infectious diseases

The recognition of the interconnections between forests and human health should encourage the adoption of a holistic framework to understand the direct and indirect interactions and to elicit actions to maintain and restore the vitality of forests. This framework, set forth in this report, acknowledges that forests—from intact to those degraded or regrown—sustain various nature-society interactions involving different people along a continuum, from dispersed rural households to densely populated urban settings. These interactions are defined by the three major functions forests provide with respect to human health: (1) provisioning functions of food, medicinal plants, and water; (2) prevention functions including reducing the risk of spillovers of zoonotic infectious diseases and the risks of natural hazards (e.g., flooding, landslides, storms, and heat); and (3) healing functions, mainly by reducing the risks of NCDs. However, the results of these interactions and the actions people might take to support human health through the protection, management, and restoration of forests depend on a wider set of contextual factors (i.e., environmental, institutional, and behavioral) and are influenced by a plethora of mediating factors including the prevalence of preexisting health conditions; social demands; access, accessibility, and proximity to forests; and the time or financial resources that allow people to afford the benefits that forests can provide.

Nature's Contributions to Human Health

Nature's contributions to human health include both positive and negative impacts of nature (i.e., diversity of organisms and ecosystems and their associated ecological and evolutionary processes) on human health and quality of life.

Adapted from Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)

This report provides a synthesis of key research around multiple forest and health interactions defined by different forest functions and beneficiary social groups by illustrating these interactions through many specific cases across multiple locations. Building on this knowledge base, it also identifies major information gaps and suggests a path for the environmental and health sectors to unite and investigate, identify, and implement joint solutions that support both forests and human health. This report is intended to reach a wide audience of decision-makers in the public and private sectors in the development, health, and environmental fields. It should also inform both conservation and health practitioners and civil society organizations in rural and urban settings, all of which have an important role in protecting the vitality of forests while ensuring healthy lives and promoting well-being for all.

Our main goal is to provide an evidence base and framework that demonstrates the role that forests play in human lives and to bring this into the foreground of global health. The dialogue around forest conversion, and thereby deforestation, is often mischaracterized as an either/or scenario—environment versus economy; saving forests versus safeguarding communities; or protecting animals versus protecting children. While perhaps helpful in politics, this framing has the effect of dividing a complex array of stakeholders that share many of the same challenges, including governments, Indigenous peoples and local communities, industry, business, investors, ranchers, farmers, engineers, environmentalists, community activists, academics, scientists, and health professionals. Human health perspectives and goals can offer a platform for understanding common ground and exploring the potential for collaboration among many stakeholders with seemingly opposing goals.

The interactions between forests and human health

Forests provide

Forests supply food and help define the cultures of Indigenous peoples, local communities, and all those who consume forest-dependent foods, generally with positive health outcomes. Forests contribute to soil and habitat conservation (especially for pollinators) and sustain the water cycle, thus playing a pivotal role in agriculture and food security.[1] Forest provisioning of food, medicinal plants, and water is critical for people who depend more heavily on forests. Forests provide a critical safety net by supplying micronutrients and protein from wild sources. Conserving and restoring forests while maintaining local farming systems can also have a positive effect on reducing NCD risk related to malnutrition, especially related to reductions in child mortality associated with malnutrition.[2]

Forests prevent

Forests mediate the emergence and spread of zoonotic infectious diseases. Deforestation threatens this protective role. Research on infectious diseases shows that deforestation can increase disease risk for humans by improving and altering the biology of disease vectors' habitats (e.g., insects, mammals, and snails). The populations benefiting from the preventive functions of forests can be localized depending on the capacity of a disease to spread, but such pathogens can impact billions when they become pandemics like COVID-19. In some cases, forests and the biodiversity they host dilute the effect of disease transmission. However, forests can also host a greater number of pathogens because of the broader variety of animal species.

Forests also protect people from natural hazards, including flooding, landslides, avalanches, wildfires, storms, and heat, that contribute to human deaths, injury, and illness. The people benefiting from these preventive impacts of forests tend to be localized in vulnerable places, yet millions can be affected in urban settings. Forests also have a cooling effect that reduces the likely health consequences of extreme heat and other events connected to climate change, particularly for the most vulnerable people, including rural and industrial workers exposed to heat.[3] Additional effects are associated with the exposure of people to haze fires, which can spread over long distances.[4]

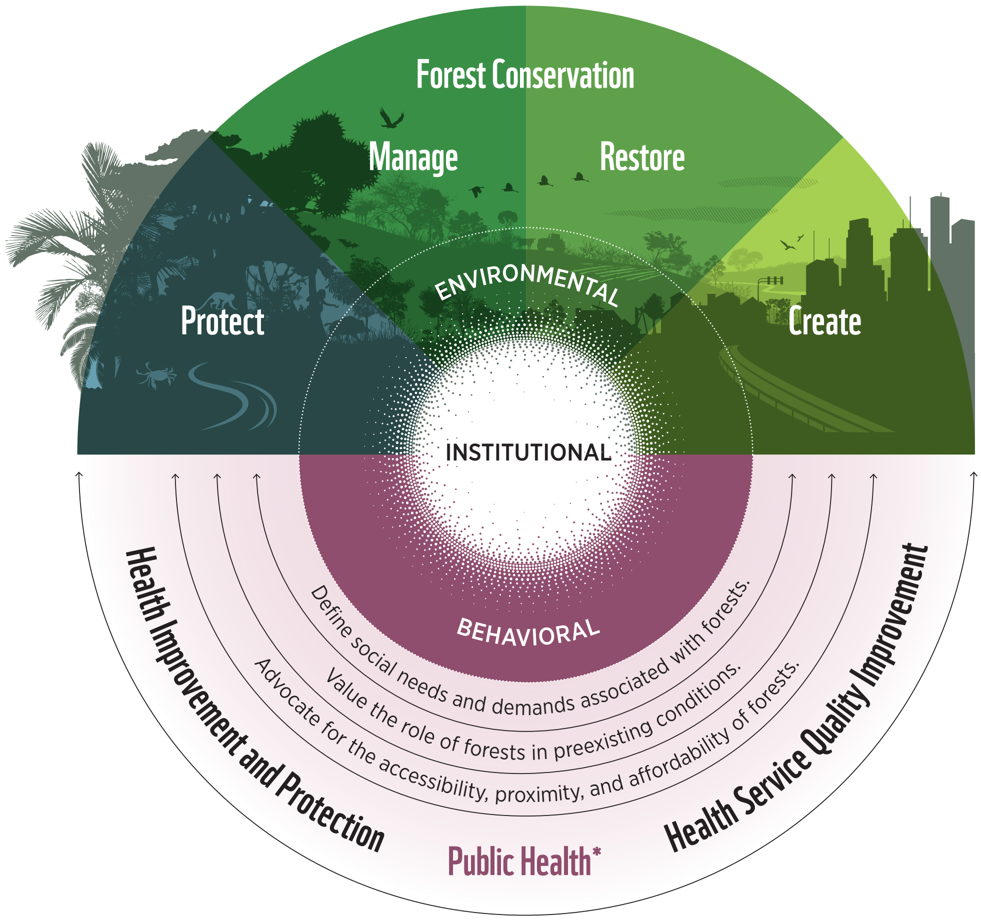
Forests heal

Human interaction with forests reduces risks associated with some major NCDs, including cardiovascular diseases, chronic respiratory diseases, and diabetes. Exposure to forests contributes to improved mental health, and access to forests also promotes increased physical activity, which is associated with reduced obesity and stress levels—factors that are linked to reduced risk of NCDs. But forests are not accessible to all people, particularly in urban settings. Indirectly, forest restoration can contribute to reduced incidence of NCDs by filtering pollutants from the air. Forests also mitigate the health impacts of water pollution, especially from diarrheal disease, which is a leading cause of mortality for children aged under 5 years.[5] The contribution of forests to pollution reduction has the potential to positively impact children's immediate and lifetime health. Further, the drivers of climate change and air pollution (including deforestation) are intrinsically connected to the burden of NCDs.

What is needed? Embracing a systems approach

There are many potential societal responses to sustain and/or enhance the positive impacts of forests on human health including the protection, management, and restoration of forests.[6] Additionally, urban forestry and other novel approaches have emerged as possible responses largely due to the growing focus of public and private sector decision-makers on nature-based solutions to climate change.[7]

Figure ES.2. Responses required to sustain and enhance the positive impacts of forests on human health



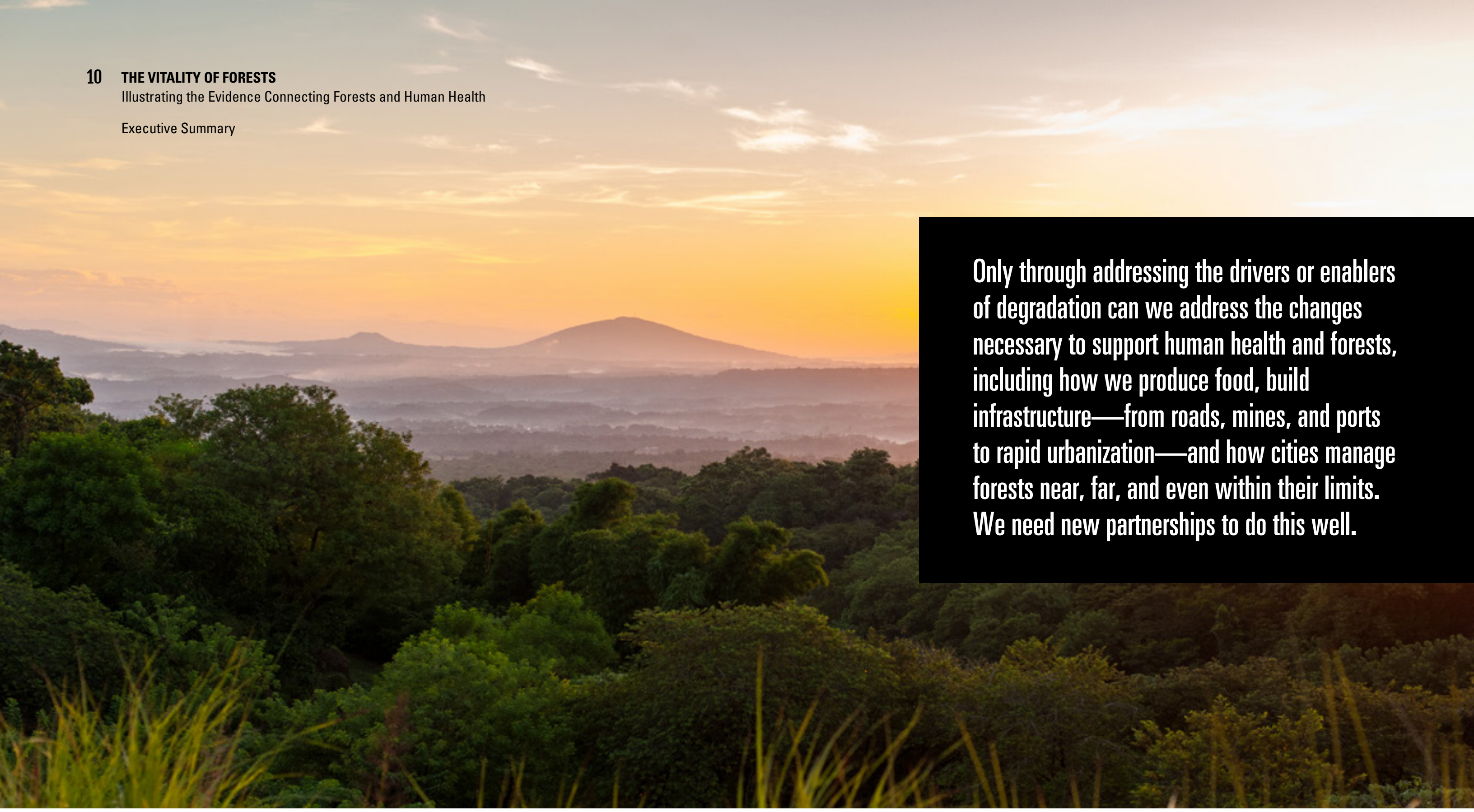
*The practice of public health spans but is not exclusive to the three core domains of health improvement, health protection, and health service quality improvement as originally coined by Griffiths, Jewell, and Donnelly (2005).

Protect forests and avoid their conversion

It is critical to protect remaining forests, particularly intact and primary forests, and to reduce the pressures leading to future deforestation and degradation by reducing threats. Yet for these measures to achieve scale, institutional factors should be addressed, such as formalizing tenure rights for local populations; increasing permanent finance for protected areas; improving yields on agricultural lands; and halting the expansion of agriculture and infrastructure into intact forest landscapes. Monitoring systems that consider the interactions between forests, food, and zoonotic infectious disease spillover risks are of critical importance for adaptive decision-making, especially related to the frequency and intensity of interactions among wildlife, livestock, and people.

Improve forest management of working lands

Reducing the environmental impacts of forestry and land use and restoring degraded lands should be given priority in working lands, where both intact and small forest fragments play a critical role in sustaining landscape-scale biodiversity as well as regulating water cycles and preserving soil quality. Improving forest management and supporting regenerative agriculture require the removal of perverse economic incentives that reward forest conversion and perpetuate inefficient agriculture and weak governance systems unable to control illegal logging and other types of forest and land degradation. In addition to preserving these forests, urban and semiurban populations can advocate for the value and the role forests play in preventing physical hazards and the emergence of disease.



Only through addressing the drivers or enablers of degradation can we address the changes necessary to support human health and forests, including how we produce food, build infrastructure—from roads, mines, and ports to rapid urbanization—and how cities manage forests near, far, and even within their limits. We need new partnerships to do this well.

Take a diversified approach to forest restoration

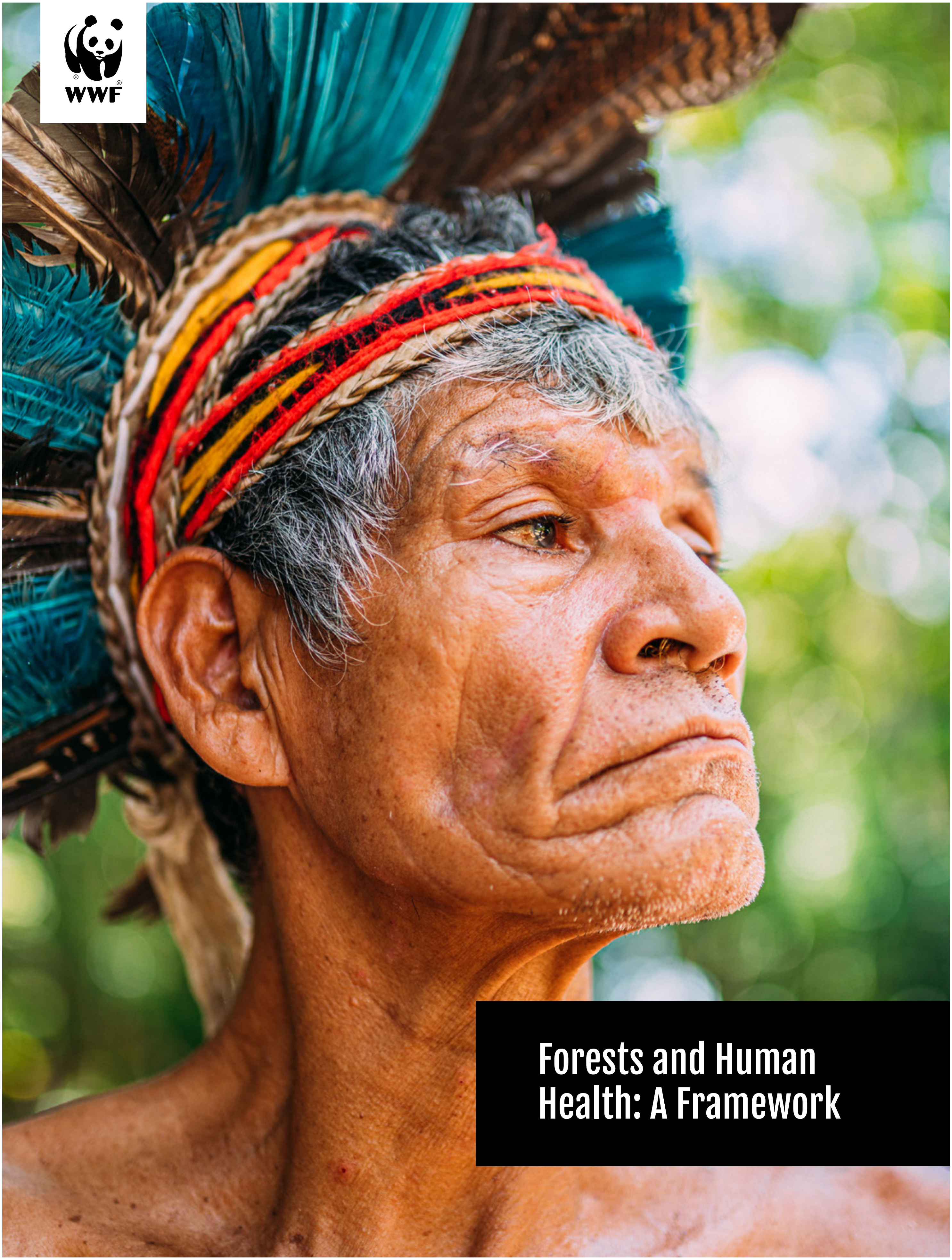
There are multiple ways to restore forests and eliminate the drivers that lead to their degradation both within forests themselves and across multiuse landscapes (e.g., assisted natural regeneration, agroforestry, timber plantations, and agrisilvicultural systems). Each may have different implications for food security, biodiversity recovery, hydrological cycles, and local climate variability. Different contextual conditions must be addressed to make forest and landscape restoration possible and permanent. These include mobilizing long-term finance, securing tenure rights, and ensuring mechanisms for equitable benefit sharing with local populations. Restoration must also make sense at a local scale where effort must have clear social, cultural, and economic value and direct impacts on human health. In addition, restored forests must be made more accessible and affordable for urban populations.

Create urban forests

Creating forests in urban areas and planting trees may lead to cooling and, depending on the case, flood abatement. In addition, more trees and forests in urban areas may contribute to reductions in air pollution and provide recreational benefits as well as positive impacts on those with a high incidence of NCDs who may also have limited contact with forests.

Foster learning between the conservation and health fields

To make the potential synergy between forest vitality and human health a reality, we need deeper connection, exchange, and action between the conservation and health communities. This will benefit both people and nature while reducing the unintended consequences. “Best practice” in both fields needs to expand to adopt each other’s objectives. Lives depend on it.



Forests and Human Health: A Framework

Investing in forests creates jobs, reduces zoonoses, and delivers on climate and biodiversity goals. Not only do you minimize the risk of new pathogens, but you also generate all sorts of other benefits for people.

Worldwide, 750 million people—60 million of whom are Indigenous—inhabit forests.[8] An estimated 1.6 billion people depend directly on forests for their livelihoods.[9] Forests are also home to more than three-quarters of the world's life on land.[10]

Yet these essential forests are under significant threat. Human impacts have led to the loss of about 40% of the Earth's forests.[11] Increasing agricultural areas; poorly planned infrastructure and land management; and illegal logging have led to substantial forest loss and degradation—17% of the Amazon has been converted from forest in the past 50 years.[12] Deforestation continues today at an alarming rate: Between 2015 and 2020, the world lost 10 million hectares of forest per year (of the approximately 4 billion hectares of existing forest in 2015).[13] Tropical rain forests experienced their greatest reduction in tree cover between 1992 and 2015.[14] In addition, there is growing evidence suggesting that for the forests that remain, their degradation is also extensive.[15]

While little noticed until now,[16] human health is entwined with forests, not only wherever forests grow but also remotely in places far removed from forests. The concepts of forests themselves, what is included in human health, and how they might be connected have been evolving. This includes changes in our understanding of the factors that mediate how people and forests interact. Just as a forest is more than its trees, human health is more than its clinical "vital signs."

How people live and interact with their environments can support or impair their health and the health of others. This report illustrates the positive role of forests in supporting human health. However, there are instances when the relationship is not win-win and where forests can contribute to human health risks (from fires, infectious diseases, etc.) or where their existence may seem to impede development objectives. For example, deforestation often enables more people to live in areas and can provide important, if not equitable, income streams and livelihoods through the land uses (typically agriculture) that replace forests. There are significant local and economic incentives that drive forest loss, often supported by regional and national economic systems. However, forest loss and degradation affect more than the local people whose livelihoods, health, and cultures can be tied to forests and deforested land. Their loss and degradation also impact regional and global commons that rely on forests to mediate clean air and water, sequester carbon, and support most terrestrial species. As a result, the analysis of interactions between forests and human health must embrace multiple levels of understanding given how these interactions influence local autonomy and sovereignty, environmental and social power dynamics, and human lives.

This report explores the evidence regarding the role forests play in human health across multiple dimensions: infectious diseases; NCDs (including those related to mental health); nutrition and food security; environmental pollution; and physical hazards. The literature, though complex, generally confirms that forests offer a positive balance of benefits by providing services, preventing spread of diseases, and supporting other types of healing. Human health is most directly impacted by the loss and degradation of forests, which cause many compounded and interacting maladies across the spectrum of human health. However, it should also be noted that forests pose human health risks for people in some cases. They are often the reservoirs of animal populations that host novel infectious disease; can harbor dangerous animal populations; can include noxious, poisonous, and dangerous plant species; and may cause a range of physical and infrastructure hazards. Despite these risks, this report demonstrates that the conservation, protection, and restoration of the world's forests are critical to safeguarding and promoting human health while also making indispensable contributions to managing climate change and biodiversity loss.

A holistic framework depicting main interconnections

That human health is responsive to our environment, including forests, is not novel. Yet a comprehensive analysis that describes the existing evidence base and relates human health outcomes to the existence and function of forests, while also looking at the direct and indirect effects of the interactions, is generally lacking. Here we provide a response to this need and develop a framework that helps to better classify and understand interactions between forests and human health.

The framework recognizes that the interactions between forests and human health have many nuances and scales. People and forests are influenced by other environmental, institutional, and behavioral contexts that affect how groups, whose health is affected in various ways, differentially benefit from forests. Yet how people are impacted by forests also depends on the resilience of individual forests to varying types of degradation. How intact or fragmented forests respond and the underlying contexts that mediate human heath in places will influence human health outcomes.

The provisioning, preventative, and healing functions of forests are not necessarily exclusive categories (e.g., provisioning of medicinal plants can contribute to healing), and they are associated with each other across time and place. Each of these functions generates outcomes that vary depending on how and when people interact with forests and the forest with which they interact. Some will be based on individual actions like procuring forest foods but will also be impacted by community and landscape factors (e.g., population density, seasonality, and cultural cues). The relationships between people and forests are strongly influenced by an individual person's current and accumulated life experiences (i.e., mediating factors) that include preexisting health conditions; social needs and demands; access and accessibility to forests; forest proximity; and the affordability of a person's exposure to forests.

Our approach

This report is based on a synthesis of existing literature exploring the multiple dimensions of forests and human health. A literature review across a broad range of sources (e.g., academic literature, white papers, gray literature, and conference proceedings) used key search terms related to the contributions of nature to human health outlined in section 2.3.4.5 of the *Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Global Report*.[17] This framework identified six contributions of nature to human health: (1) dietary health; (2) environmental exposure; (3) exposure to communicable diseases; (4) hazard risk reduction including exposure to extreme weather, drought, or fire; (5) psychological health; and (6) use of natural compounds in medicinal products and biochemical compounds. Here we focus on the first five impacts and exclude use of natural compounds in medicinal products due to its technical complexity. This report primarily details the existing evidence across these five dimensions of human health. Furthermore, we recognize that there are limitations in the current research between forests and human health. We also acknowledge the need for continued exploration of the interconnections between forests and human health and provide suggestions on key knowledge gaps to aid future exploration of these topics.

To complement the literature review and to ensure diverse perspectives, 15 interviews were conducted with experts of varying backgrounds in the environmental and health sectors. Interview questions focused on gathering additional evidence related to the interactions between forests and human health and identifying how the health sector has worked in collaboration or engaged with forest ecosystems to date. While interviewees did not contribute to the drafting or review of this report, they discussed opportunities for strategic engagement and answered targeted questions about human health that helped inform the content of this report.

Embracing a holistic framework linking forests and human health

Figure 1. Forest and human health interactions and the factors that shape them

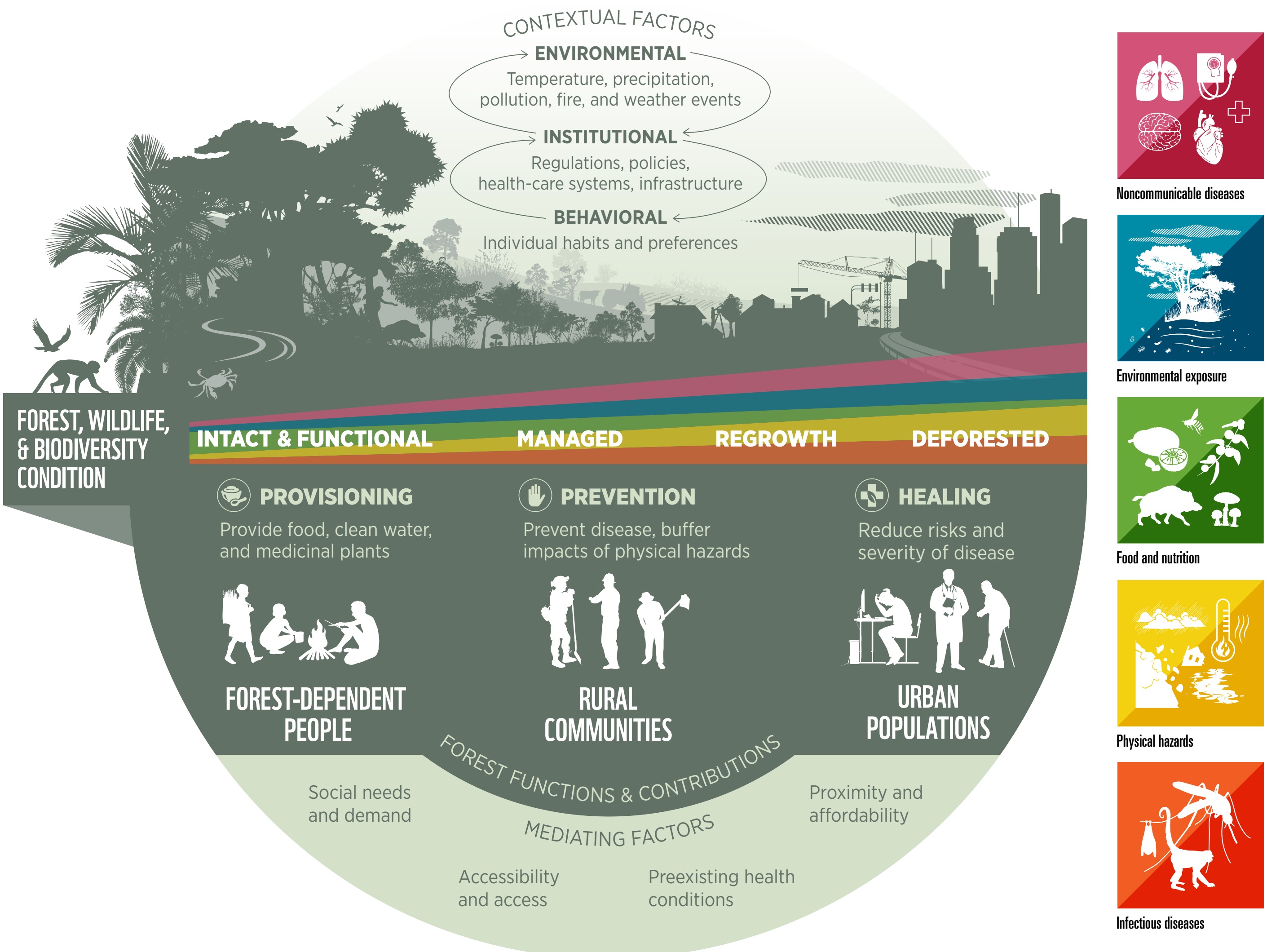


Figure 1 depicts different dimensions of forest and human health interactions: (1) forest types and functions that span intact and functional forests to deforested urban areas;[18] (2) population groups or beneficiaries along a spectrum from forest-dependent people to urban populations; and (3) forest contributions to human health as influenced by contextual factors and mediating factors. It demonstrates that across the range of nature's contributions to human health, intact forests have a greater potential to support people locally, regionally, and remotely. Forests provide food and nutrition, clean air and water, and fiber. Forests influence human health through many preventative functions by reducing the risks of zoonotic infectious disease spillovers; buffering the impact of physical hazards like heat or storm intensity; and benefiting many people in both rural and urban settings. In addition, all types of forests play a healing role related to NCDs and can sustain the mental and physical health of people living in urban, peri-urban, or suburban settings with access to forests.

Nature's Contributions to Human Health

Nature's contributions to human health include both positive and negative impacts of nature (i.e., diversity of organisms and ecosystems and their associated ecological and evolutionary processes) on human health and quality of life.

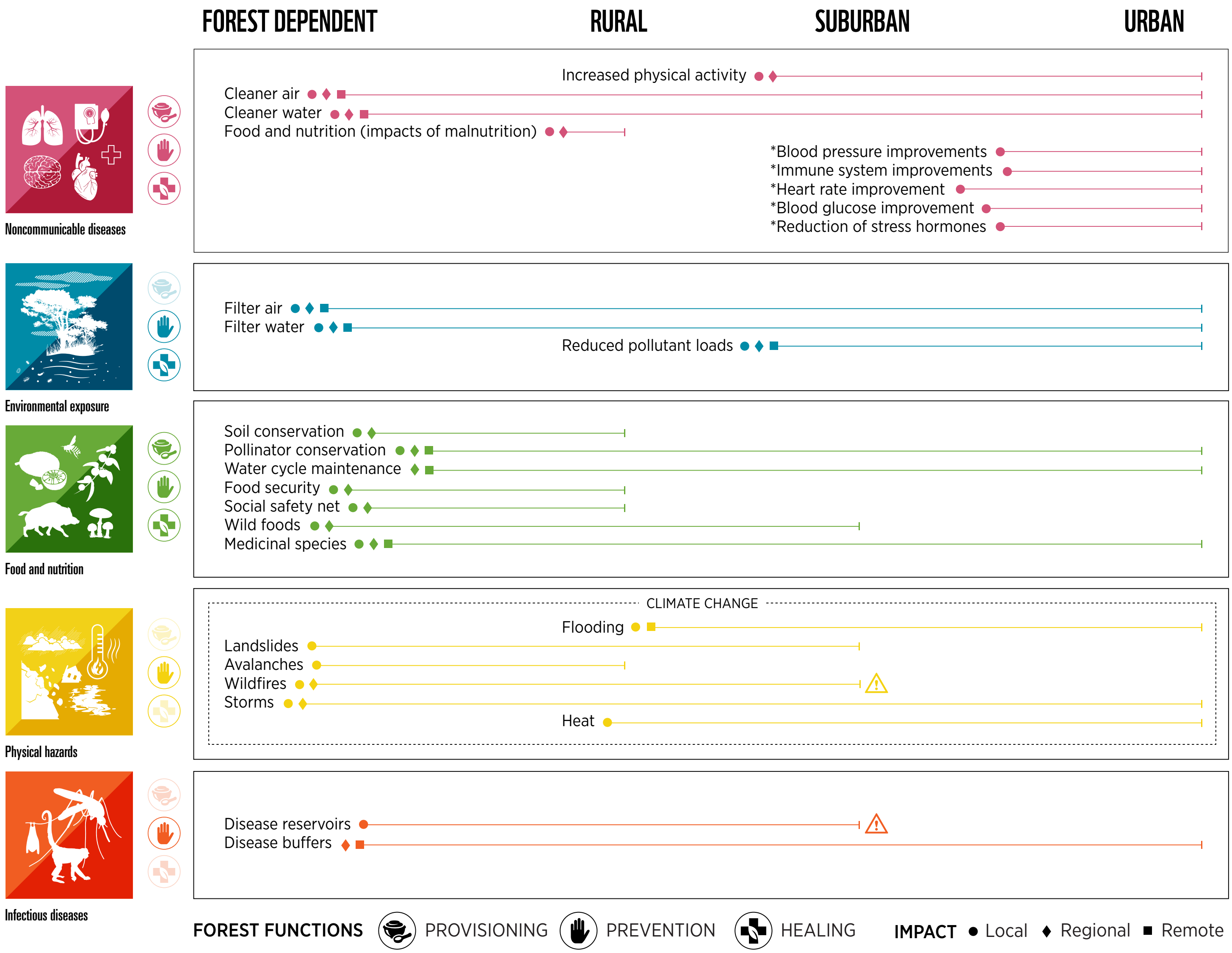
Adapted from IPBES

Forest and human interactions are shaped by three place-specific underlying conditions:

1. **Environmental**, specifically linked to biophysical factors like ecology, heat, water and air pollution, and weather events that impact human health;
2. **Institutional**, resulting from governance and other collective processes of decision-making and the implementation linked to regulations, policies, service systems, and physical infrastructure; and
3. **Behavioral**, which is linked to individual preferences and habits including diets and physical activity that can predispose people to certain health outcomes.

In addition, these underlying conditions tend to be influenced by a person's individual circumstances, which mediate the impacts of forests on human health. This can include the prevalence of preexisting health conditions across different populations, ranging from those living near or in forests to those residing far from forests. The combinations of individual circumstances and the proximity and capacity of forests create social demands and needs that influence the use of forest goods and services for satisfying the material or nonmaterial needs that contribute to human health. For example, in contexts where there is a greater incidence of NCDs, there may be a growing demand or need for the healing effects of forests. Yet all people do not have the same access to forests. For many people living in dense urban settings or deep within nonforested landscapes, accessibility to the healing effects of forests may not be possible. However, even with access and accessibility constraints removed, social dynamics often mean that not all people can afford the time and resources to increase their exposure to forests in ways that lead to meaningful health outcomes. These same mediating factors also play an important role when looking at the provisioning and prevention functions of forests.

Figure 2. Forest functions with impacts on human health along the rural-urban continuum



*These NCDs have not been studied in the literature for forest-dependent or rural people.

Negative impacts on human health.

This figure illustrates several detailed forest functions within each of nature's contributions to human health. The provisioning, prevention, or healing roles of the forest functions within each human health category are indicated by the associated icons. Many of these functions depend on the community to which a person belongs, and others are nearly universal. The lines extending from each forest function depict the range of influence of each within human communities from forest dependent to urban. Some functions, like those associated with reducing risks of NCDs, are more relevant for suburban/urban people at local scales. Other functions, such as those associated with food and nutrition, are more relevant as people become more dependent on forests for food and nutritional needs. These functions have direct and indirect impacts across spatial scales from locales to areas remote from forests themselves. The extent to which each of these functions is directly or indirectly relevant to human health locally, regionally, or remotely is indicated by the shapes (circle, diamond, square).

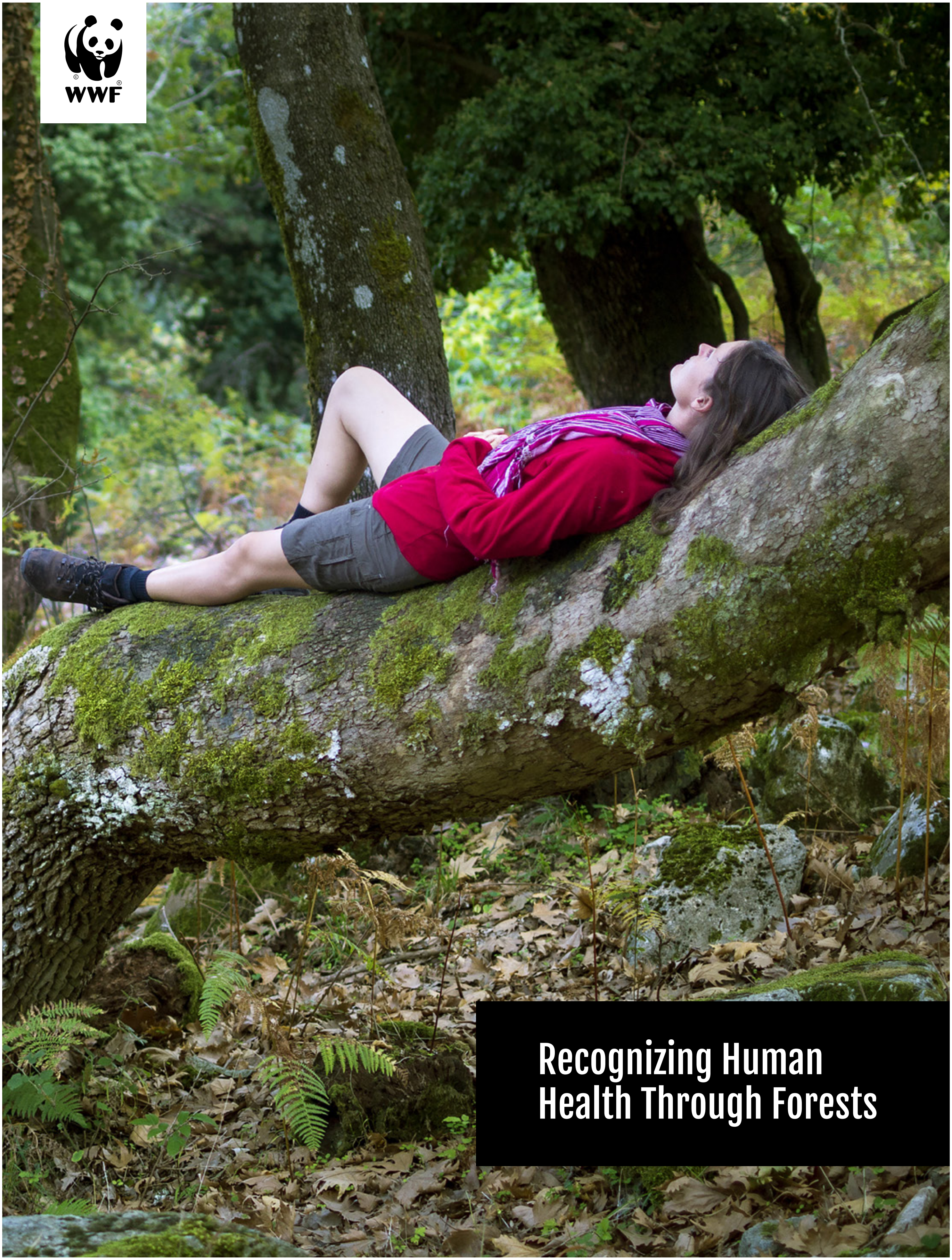
- **Forests reduce risks associated with some major NCDs,** especially for people residing in urban settings affected by such diseases. These illnesses include cardiovascular diseases, cancers, chronic respiratory diseases, diabetes, and mental health. Although evidence related to the intersection of NCDs and forests is relatively nascent, a growing body of research suggests that exposure to forest environments can provide benefits that positively affect the body's immune system, blood pressure, heart rate, blood glucose, and stress hormones. Access to forests also contributes to increased physical activity, which is associated with obesity prevention and reduced stress levels—both of which are factors that are linked to reduced risk of NCDs. Further, the drivers of climate change and air pollution (including deforestation) are intrinsically connected to the global burden of NCDs.

- **Forests clean air and water** and reduce the risks of infectious and noncommunicable diseases. By filtering pollutants from the air, forests play an important role in reducing NCD risks linked to air pollution, including heart disease, stroke, pulmonary disease, and lung cancer. Forests also help mitigate the health impacts of water pollution—a driver of infectious diarrheal diseases—through reducing soil erosion and sediment load, filtering pollutants from water, and reducing pollutant inputs associated with human land use. With diarrheal disease being a leading cause of mortality for children aged under 5 years,[19] the contribution of forests to pollution reduction holds the potential to have an important impact on children's immediate and lifetime health.

- **Forests positively impact nutrition and food security,** particularly for forest-dependent and adjacent Indigenous peoples and local communities, improving health outcomes. Through soil and habitat conservation (especially for pollinators) as well as the water cycle, forests play a pivotal role in underpinning landscape function and the sustainable agriculture necessary for increasing food security.[20] For communities that rely on forests for food, including those with limited market access to purchase food and in times of conflict or severe food insecurity, forests can provide a critical safety net by supplying micronutrients and protein from wild sources, which is especially important for children.

- **Forests can protect people from the harsh impacts of natural hazards,** including flooding, landslides, avalanches, wildfires, storms, and heat, that contribute to human deaths, injury, and illness. With climate change exacerbating many of these risks, a focus on the role that forests can play in resilience to natural hazards could offer life-saving solutions. Those protected by the preventive role of forests tend to be localized in vulnerable places, yet millions in urban settings also benefit. In addition, extreme heat, physical risks from accelerated storm activity, and other events connected to climate change not only pose health risks for the most vulnerable people, such as children and older adults, but also impact economic productivity and financial investments. The effects of climate warming can result in rural and industrial workers' exposure to excessive heat, which has clear implications on their health and productivity.

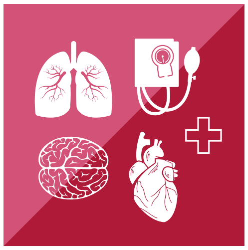
- **Forests mediate the emergence and spread of zoonotic infectious disease** and are thereby the first line of defense against the emergence and spread of new infectious diseases. Deforestation threatens this protective role.[21] Research on infectious diseases shows that deforestation can increase disease risk for humans by improving and altering the biology of disease vectors' habitats. Deforestation and degradation of forests also amplify disease risk by increasing the chance of disease spillover from animals to humans due to closer contact; increasing the densities of disease host and vector populations; and decreasing the biodiversity that can help to dilute disease-vector infection rates. The populations benefiting from the preventive functions of forests can be localized depending on the capacity of pathogens to spread, but billions can be impacted when localized pathogens become epidemics or pandemics like COVID-19.



Recognizing Human Health Through Forests

Commodities that replace forests, like cattle, tobacco, or corn, are often used to make products that increase noncommunicable disease risks, and these risks are compounded by poor management decisions to maintain these new land uses.

Noncommunicable diseases



Noncommunicable diseases or NCDs are the fastest-growing and largest health burden globally. Worldwide, NCDs account for about 70% of deaths.[22] The four primary NCDs are cardiovascular diseases, cancers, chronic respiratory diseases, and diabetes. The four primary NCDs, together with a host of other NCDs—including neurologic, endocrine, gastrointestinal, renal, allergic, and autoimmune disorders—are not only the leading cause of mortality but also comprise 21 of the principal 30 causes of age-standardized years lived with disability.[23] The burden of NCDs is growing disproportionately in low- and middle-income countries (LMICs), with more than 70% of deaths occurring in these countries.[24]

The primary NCDs share common risk factors, including poor diet, air pollution, and physical inactivity, all of which contribute to morbidity and mortality. Since air pollution is a primary risk factor for NCDs, there are close ties to environmental pollution, which will be addressed in more detail below. Additionally, while mental health was long overlooked as an NCD, the global health and development community has now recognized mental health conditions as one of the main groups of NCDs.[25]

NCDs AND HUMAN HEALTH

41 million people die each year from NCDs globally

71% of all deaths globally are attributed to NCDs

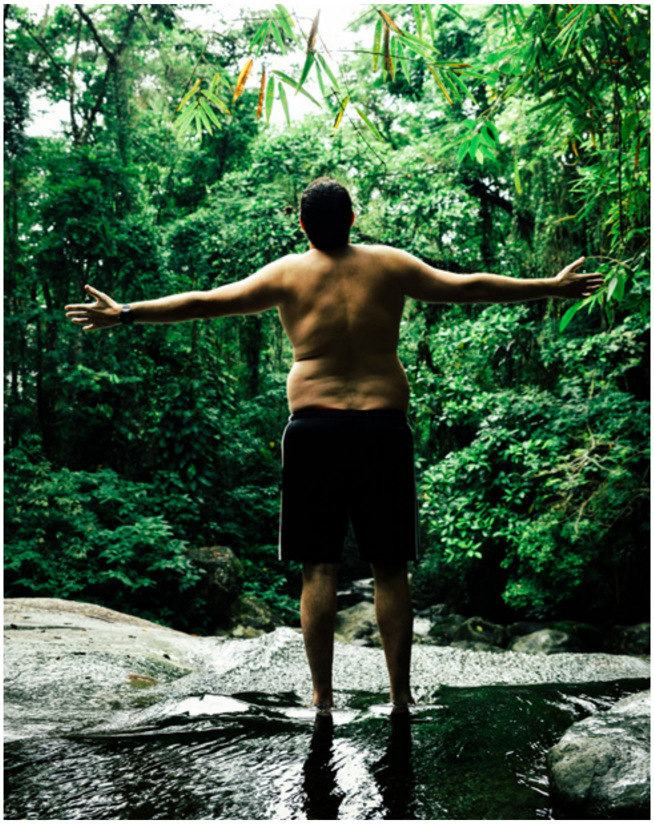
77% of NCD deaths are in low- and middle-income countries

80% of premature NCD deaths are cardiovascular disease, cancers, respiratory disease, and diabetes

World Health Organization (WHO)

Understanding the linkages between NCDs and the psychological and physiological responses and benefits of exposure to physical forest environments would benefit from further exploration. The number of studies evaluating the benefits of forests for NCDs is limited in this report for several reasons. First, this area of study is relatively nascent, and there is not a substantial body of literature from which to draw. Historically, there has been more research and greater attention paid to cultural loss because of deforestation than on the impacts of deforestation on NCD incidence. While cultural loss has clear, important, and devastating impacts on mental health, those linkages fall outside the scope of this paper. Finally, several studies reviewed had other constraints that limited the ability to draw robust correlations or conclusions (e.g., small sample sizes).

It is well established that access to green space leads to increased physical activity, reduced risk of obesity, and decreased stress levels.[26, 27] A number of studies that have examined the effects of forest exposure have identified a wide range of benefits, including improving the body's immune system; potentially increasing resistance to cancer; decreasing diastolic blood pressure, stress and anxiety, and serum cortisol levels; increasing relaxed feelings; and lowering heart rates and levels of blood glucose (which suggest important implications for diabetic patients).[28, 29, 30]



Box 1. Physiological and psychological effects of forest bathing[31]

A study aiming to explore forest bathing as a natural therapy with physiological benefits assessed the biological indicators of Japanese male adults in a forest setting. The subjects participated over the course of three days and two nights. Physiological responses and self-reported psychological reactions to forests and urban environments were measured. Salivary cortisol levels and pulse rates—biological markers for stress—significantly decreased in the forest compared with the urban environment. The study found that participants self-reported significantly more positive feelings and fewer negative feelings following stimuli in the forest compared with the urban environment. Heart rate variability analysis also indicated that the forest setting considerably increased parasympathetic nervous activity, increasing digestion and decreasing heart rate and respiration.[32] The authors suggested that forest bathing has a positive impact on physical and mental health and may be a useful strategy for health promotion.

Impact of forest exposure on hormones and stress[33,34]

To date, researchers in Japan have led investigations into the physical effects of exposure to forests compared to exposure to urban settings. Several stress and sexual hormones have been measured in forest versus urban settings, and a number of researchers have demonstrated that cortisol reached considerably lower values in forest settings. Likewise, noradrenaline, adrenaline, and progesterone displayed significantly lessened concentrations after individuals spent time in a forest. For example, a study was conducted in Japan to assess the impact of forests versus urban landscapes. Participants were exposed to a forest and an urban environment while salivary cortisol concentration, diastolic blood pressure, and pulse rates were measured. The study found that each of these three stress measures decreased significantly within 15 minutes of the subjects being physically present in a forest. The same results were not replicated in the urban setting.

Cardiovascular health

Numerous studies have measured indicators tied to the cardiovascular system, including blood pressure, heart rate variability, and pulse rate following exposure to forests. Several studies in Japan have demonstrated that forest exposure can result in significantly lower pulse rates, diastolic blood pressure, and/or systolic blood pressure. Similarly, researchers in other countries have found lower values of blood pressure among study participants who have been exposed to forests compared with urban settings. Thus, researchers have concluded that exposure to forests may be beneficial through a reduction in the levels of parameters that elevate the risk of cardiovascular disease.[35]

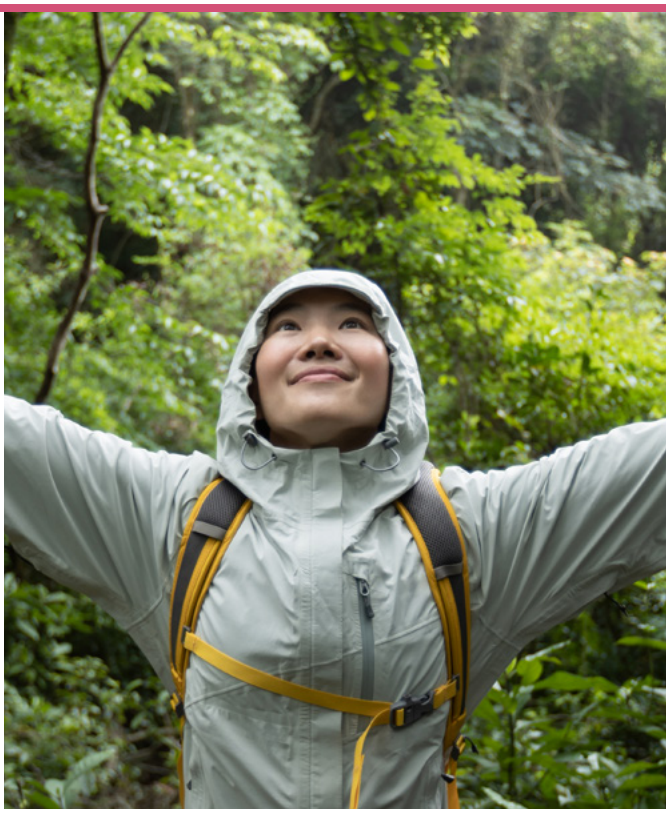
Mental health and well-being[36]

A systematic review of 25 studies examining health and/or well-being in natural versus synthetic environments suggests that natural environments might have a direct and positive impact on well-being but concluded that there is a need for additional research to better understand the public health implications. The authors did identify a number of pathways in which natural environments can be advantageous, including providing an environment for physical exercise and activity, which has well-established benefits in terms of mental health and risk reduction for several other NCDs. The authors also reference the innate qualities of natural environments (e.g., spatial openness), which can prompt positive emotional responses. Additionally, in a systematic literature review on the benefits of exposure to nature among children under 12 years of age, the authors found that exposure to nature is an essential component of healthy development in children and contributes to positive values and perspectives on the environment. Further, the study suggests that this exposure can contribute toward more "playful" engagement.[37] Play is a well-established cornerstone of healthy social and emotional development among children.

Finally, while there has been less research and advocacy focused explicitly on deforestation as a driver of NCD risk factors, there is a limited body of studies, which suggests this is an important area to explore further.

Knowledge gaps

- **Forests as a prescription:** Understanding the linkages between NCDs and psychological and physiological responses and benefits of exposure to physical forest environments merits further exploration.
- **Contextual NCDs from rural to urban:** Expanding the scope of studies looking at the interactions between NCDs and forests beyond simple green spaces in urban settings would also be worthwhile. There is a need for more data comparing different types of human populations in the continuum from urban to rural and how they are affected by different types of NCDs.
- **NCDs attributable to forest loss:** Additional information on the impacts of deforestation and forest degradation on NCDs through different modes of transmission (e.g., haze fires, water cycles, and heat) would be valuable.
- **Physiologies of forest exposure:** Exposure to forests (or forest bathing) has demonstrated a wide range of benefits, including improving the body's immune system. However, more robust evidence is needed on the associated factors that influence these effects (e.g., severity of NCDs and exposure time).



Environmental exposure

In a 2018 paper, The Lancet Commission on pollution and health declared that "pollution is the largest environmental cause of disease and premature death in the world today," with NCDs accounting for the majority of this disease burden.[38] The commission paper notes that the vast majority of mortality associated with pollution is in LMICs, particularly those that are rapidly developed and industrializing, with the poor and vulnerable disproportionately affected. The preservation of healthy forests or their restoration can be an important strategy to help lessen disease risk associated with pollution and address institutionalized environmental inequities and injustice.[39] By filtering pollutants from air and water, forests help reduce the threats of pollution-related infectious diseases and NCDs. This section explores the research demonstrating this vital contribution of forests to human health.

ENVIRONMENTAL EXPOSURE AND HUMAN HEALTH[40]

9 million premature deaths linked to pollution in 2015

16% of all deaths worldwide

92% of deaths are in low- and middle-income countries

254 million years of life lost and 14 million years lived with disability from disease caused by pollution

The Lancet Commission on pollution and health

Table 1. Impacts of environmental exposure on human health

Environmental exposure	Related global burden of disease
Pollution	• Pollution is the largest environmental cause of disease and premature death in the world, attributable to 9 million premature deaths in 2015 and 16% of all deaths worldwide, the large majority (92%) of which were in LMICs. Disease caused by pollution was responsible for 254 million years of life lost and 14 million years lived with disability.[41] • NCDs such as cardiovascular disease, stroke, pulmonary disease, and lung cancer account for most of the total disease burden attributed to pollution.[42]
Air pollution	• Data from the *2015 Global Burden of Disease* study show that air pollution (ambient and household) accounted for 6.5 million deaths, with NCDs accounting for a majority of the disease burden.[43] • Household air pollution is a cause of cardiovascular disease (coronary heart disease and stroke); chronic obstructive pulmonary disease; acute lower respiratory infections; lung cancer; and cataracts. In 2017, household air pollution contributed to 2.9% of all deaths (1.6 million) globally and 2.4% of Disability Adjusted Life Years (59 million), with India, China, and countries in sub-Saharan Africa facing the highest number of deaths and women and children most acutely affected.[44] • The World Health Organization (WHO) estimates that nearly half of the deaths of children aged under 5 years due to pneumonia are linked to household air pollution.[45]
Water pollution	• Data from the *2015 Global Burden of Disease* study show that water pollution (unsafe water source, inadequate sanitation, and inadequate hand-washing) accounted for 1.8 million deaths globally in 2015, with 1.3 million of those deaths attributable to unsafe water sources.[46] • Diseases linked to water pollution comprise gastrointestinal diseases—including diarrheal disease, typhoid fever, paratyphoid fever, and lower respiratory tract infections.[47] • Children aged under 5 years are most likely to be affected by diseases associated with unsafe water.[48]

Ambient air pollution

Trees and forests play an important part in mitigating the negative impacts of air pollution on human health by removing pollutants from the air. Nowak et al. conducted a study of these impacts in the contiguous United States. They found that the total amount of pollution removed by trees in 2010 was 17.4 million tons, with the estimated effects of a national reduction in human mortality of 850 incidences; reductions of 670,000 incidences of acute respiratory symptoms; 430,000 incidences of asthma exacerbation; and 200,000 school days lost.[49] Using estimates of health-care expenses and productivity losses, Nowak et al. valued the effect of pollution reduction on human health at $6.8 billion. The authors note several limitations to the study. These include not accounting for the negative effects of trees on air quality, such as reduced wind speeds; the emissions of volatile organic compounds that contribute to pollutants, such as ozone; or trapping pollutants under tree canopies in proximity to sources of emissions. They suggest that effects of trees on pollution removal will differ locally based on variations in tree cover; pollution concentration; length of growing season; percent of evergreen leaf area; and meteorological conditions. While this study provides strong evidence that pollution removal by trees has positive impacts on air quality—and thus human health—it also highlights the need to consider local variables when assessing the impacts.

When forests are lost or degraded, they contribute to air pollution that negatively impacts human health. Deforestation and forest degradation lead to the release of CO_2 emissions from the burning of trees and the decomposition of the remaining biomass and soil. Estimates show that deforestation and forest degradation account for approximately 12% of global CO_2 emissions originating as a result of human activity. This is the largest source of CO_2 emissions in at least 30 developing countries.[50] Demonstrating the serious health effects of fires associated with forest clearing, a study by Johnston et al. using data from 1997 to 2006 found that the average mortality attributed to landscape fire smoke exposure was 339,000 deaths annually (range of 260,000–600,000), with low-income regions of the world, particularly in sub-Saharan Africa and Southeast Asia, disproportionately affected.[51] The findings of this study affirm that reducing fires associated with deforestation could have significant benefits to human health.

Box 2. Deforestation and air pollution in Brazil[52]

Between 1976 and 2010, about 15% of the Brazilian Amazon was deforested, with fire serving as the primary method for forest clearing. Using mortality data for cardiopulmonary disease and lung cancer associated with exposure to particulate matter[53] from fires, researchers estimated an average of 2,906 premature mortalities annually across South America from 2002 to 2011 due to deforestation fires. Forty percent of the mortality was related to particulate emissions from all fires. Since 2004, Brazil has witnessed significant reductions in deforestation rates. Since 2017, however, deforestation and fires have dramatically increased. The researchers demonstrated that when fire emissions related to deforestation decreased (between 2001 and 2012), air quality improved, which resulted in benefits to human health. Specifically, the study found that the mean particulate matter concentrations decreased by 30%, with the researchers estimating the prevention of between 400 and 1,000 premature adult deaths annually in South America.

Household air pollution

Research also notes linkages between deforestation and forest degradation and the harvesting of fuelwood, though not as a primary driver of large-scale, global deforestation.[54, 55] More than 2.4 billion people, primarily in the developing world, rely on biomass (e.g., wood, crop residues, and charcoal) to cook and heat their homes.[56] The production of charcoal—the use of which is on the rise by households in Africa—has a significant impact on deforestation. Charcoal production contributed to approximately 7% of deforestation rates in tropical countries with high degrees of deforestation, with the level of impact dependent on factors such as the use of clear-cutting versus selective cutting; the size of trees and their densities; and tree species composition.[57]

The burning of fuelwood, a major driver of forest degradation, contributes to air pollution, both at the ambient and household levels, leading to negative health outcomes. Household (indoor) air pollution, primarily caused by the use of biomass for cooking and heating, is closely linked to early death and disease, with impacts disproportionately affecting people in LMICs that are more reliant on these biomass sources. Research shows that exposure to household air pollution is a cause of cardiovascular disease (coronary heart disease and stroke); chronic obstructive pulmonary disease; acute lower respiratory infections; lung cancer; and cataracts. In 2017, such exposure contributed to 2.9% of all deaths (1.6 million) globally and 2.4% of Disability Adjusted Life Years (59 million), with India, China, and countries in sub-Saharan Africa facing the highest number of deaths and women and children most acutely affected.[58] WHO estimates that nearly half of the deaths of children aged under 5 years due to pneumonia are linked to household air pollution.[59] The organization suggests that a shift from solid fuels to cleaner technologies, such as biogas, electricity, or solar power, and to improved designs of stoves (clean cookstoves) that are more efficient can help to mitigate indoor pollution. In addition, stemming forest loss and degradation linked to fuelwood harvesting would prove beneficial.

Water pollution

Forests play a critical role in protecting the quality and safety of drinking water, which is closely tied to the prevention of water-related diseases. Research shows that forests impact water quality by reducing soil erosion and sediment load and filtering pollutants. They also reduce pollutant inputs because forests are not associated with high development land uses such as agriculture, industry, or human settlements, which are linked to elevated pollution levels.[60, 61]

There has been growing recognition that water and land management are closely tied and that activities humans carry out on land (e.g., agriculture) have a direct impact both on the use and pollution of water resources.[62] When rain falls directly on bare land, the soil can easily erode and be carried into rivers. Large-scale forests reduce this process and filter contaminants from being washed from land into rivers and streams, thus protecting vital sources of drinking water in rural areas.[63]

Unsafe water contributes to a variety of waterborne diseases, including typhoid and diarrheal disease, which are caused by ingestion of contaminated water that contains bacteria or viruses.[64] Inadequate hygiene, including a lack of access to clean water for hand-washing, contributes to the spread of respiratory infections. Hand-washing removes respiratory pathogens from hands, preventing them from entering the body or being passed on to others.[65]

Box 3. Diarrhea and acute respiratory infections are two of the leading causes of morbidity and mortality globally among children aged under 5 years.

- Diarrhea accounts for about 8% of all deaths among children aged under 5 years worldwide. The majority of deaths from diarrhea occur among children aged under 2 years living in South Asia and sub-Saharan Africa.[66]
- Acute respiratory infections are the leading cause of mortality in children aged under 5 years worldwide, and most of these deaths are due to bronchiolitis and pneumonia. Pneumonia kills more children than any other infectious disease.[67]

A study of 35 developing countries focused on waterborne diarrheal disease showed that tree cover plays a role in drinking water quality by filtering pollutants and pathogens in places where people rely on surface water, primarily in rural areas.[68] The researchers found that in the rural areas studied, upstream tree cover was associated with a lower prevalence of diarrheal disease (linked to water pollution) in children downstream, with a 30% increase in upstream tree cover linked to a 4% reduction in the probability of diarrheal disease—similar to the effects of an improved sanitation facility. Testing whether the impact of tree cover was associated with the filtration and dilution of pollutants or the displacement of human activities polluting the watershed, the researchers found that positive impacts stayed constant in areas of high- and low-upstream human activity, suggesting that even with higher levels of development upstream, the positive effects of tree cover remain. The findings of this study support the conclusion that the influence of forests on drinking water quality has positive impacts on the prevalence of diarrheal disease for people who rely on surface water. With diarrheal disease being the second-leading cause of death and the leading cause of malnutrition in children aged under 5 years worldwide, measures to prevent this disease are critical for the health and well-being of children around the globe.[69]

Box 4. Tropical forests and children's health[70]

A study of the public health benefits of forest conservation in Cambodia—which reviewed Demographic and Health Survey data from 2005, 2010, and 2014—analyzed the association between incidence of diarrhea and acute respiratory infections in children aged under 5 years within protected land areas and in areas with forest destruction.[71] The study found that loss of dense forest was associated with increased incidence of diarrhea and acute respiratory infections. Protected area coverage (not by type) was associated with decreased incidence of both ailments. The researchers acknowledge that the causal mechanisms behind the association of these childhood diseases with the extent of local loss of dense forest are yet to be determined.

Knowledge gaps

- **Forests and air pollution:** Evidence suggests pollution removal by trees improves air quality—and thus reduces the impacts of poor air quality on human health. It will be important to better understand how these impacts are affected by local conditions, including variations in tree cover; pollution concentration; length of growing season; percent of evergreen leaf area; and meteorological conditions.
- **Environmental justice:** When assessing the impacts of forests on water and air pollution, more knowledge is needed about the people who benefit based on their proximity to forests and other factors related to different local institutional and socioeconomic conditions.
- **Health priorities related to forests:** There is a need to systematically identify the range of forest-water-health interactions and determine how different places can fit within these conditions in both space and time.

Conversations around nutrition, forest health, and local communities don't pay enough attention to nutrition as opposed to calories. The forest really delivers for communities. Agriculture can provide calories through crops but not the same level of nutrition that wild food from forests can provide. The inequities of the trade-offs can be stark.

Nutrition and food security

Forests provide a source of livelihoods, food, fuel, and medicine for many different human communities across geographies. Forests directly supply many healthy foods, including fruits, leafy vegetables, seeds, nuts, and edible oils. Forests also provide the habitat for bushmeat, fish, and insects.[72] Globally, about 1.6 billion people depend directly on forests for their livelihoods.[73]

For many Indigenous peoples and forest-dependent communities, forest species (plants, animals, mushrooms) are a significant lifeline, and the inequities and trade-offs of repurposing forestland for pastures and crops can be stark. Human food security and dietary health rely on sufficient access to diverse, quality foods. Nonetheless, forests can also expose humans to dangerous wildlife, toxic fruits and foliage, and flora and fauna that cause allergic or irritant reactions.[74]

FOOD SECURITY AND HUMAN HEALTH

1.6 billion people globally depend on forests for their livelihoods

3.1 million children worldwide die from undernutrition

50% of a woman's total daily energy intake is sourced from wild foods in some extreme poverty communities

Food and Agriculture Organization of the United Nations (FAO) and United Nations Environment Programme (UNEP). *The State of the World's Forests 2020*

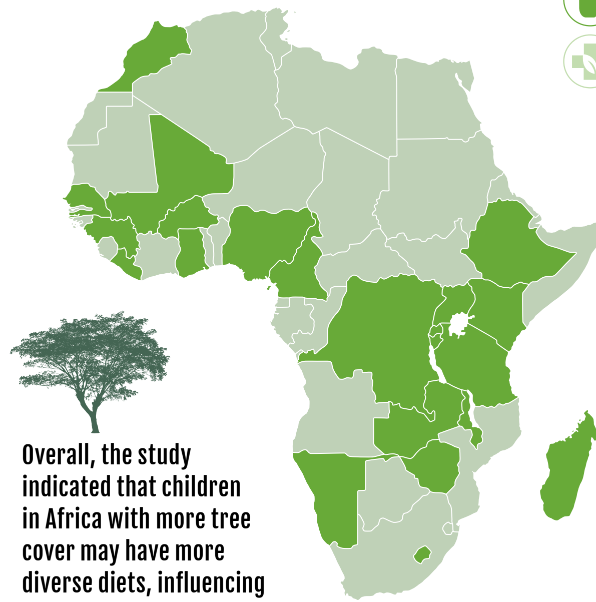
Adequate nutrition is crucial for the health and well-being of all people and has implications for people's susceptibility to disease and their short- and long-term health. Foods, diets, and the nutritional status of individuals are significant determinants of NCDs, including cardiovascular diseases, some types of cancer, and diabetes.[75] While the evidence is still limited, several studies suggest links between tree cover and the quality of children's diets. Several studies also acknowledge that key household indicators and sociodemographic factors (e.g., mother's education, household size, and market access) present variables that make it challenging to determine a linear causal pathway between tree cover and children's diets.[76]

Each year, childhood undernutrition kills 3.1 million children.[77] Of particular importance is the nutrition of women prior to and during pregnancy and over the first two years of a child's life, which has far-reaching implications for the survival, health, and development of mothers and their children. Poor nutrition during this critical window—the first 1,000 days of life—can leave those children who survive with long-term health, social, and financial challenges. Both the quality and diversity of a child's diet have a significant impact on their nutritional status; children with adequate nutrition will have improved cognitive and physical development as well as lower risk of morbidity and mortality. If children do not have access to the vital nutrients they need to grow and develop their brains and bodies, they are far more likely to become ill and to die from diseases over the course of their lifetimes (e.g., acute respiratory disease and diarrheal disease).[78] Malnutrition, in all its forms, has serious and lasting developmental, economic, social, and medical effects for individuals.

Box 5. Forest cover and child health and nutrition[79]

A 2019 *Lancet* study explored the intersection of forests, poverty, and human health—which connect with the UN Sustainable Development Goals (SDGs) 1, 2, 3, 6, and 15—looking specifically at the effects of forests on three of the conditions that most significantly impact childhood health among the poorest and most vulnerable children. These include anemia, stunting, and diarrheal disease. The study found that forest cover is associated with reduced prevalence of all three conditions among the poorest households in the 35 countries studied. Children living with the most forest cover who fell within the two lowest wealth quintiles were significantly less likely to have or develop these maladies when compared with children with less forest cover. Conversely, the study found that for children in the highest wealth quintiles, no association was found between forest cover and prevalence of these health outcomes.[80] The authors underscore the critical importance of building on emerging data at the nexus of environmental and human health and identifying the co-benefits of forest conservation and human health to identify opportunities to deliver on multiple SDGs.

Box 6. Forest cover and dietary quality among children in 21 African countries[81]



Overall, the study indicated that children in Africa with more tree cover may have more diverse diets, influencing their nutrition and, ultimately, their food security.

Countries in the study

One study drew from Demographic and Health Survey data on food consumption and Global Land Cover Facility tree cover data in 21 African countries to examine the relationship between tree cover and three significant indicators of the nutritional quality of children's diets: (1) dietary diversity; (2) fruit and vegetable consumption; and (3) animal source food consumption. The study assumes that markets in these settings are insufficient or inaccessible. Given that households can access diverse and nutritious food through two pathways (i.e., production or purchase), a household with sufficient access to a "perfect" market would not be impacted by vegetation cover. However, the study concluded that households with access only to limited markets might be impacted from low tree cover in a number of ways, including poorer access to wild, nutritious foods (e.g., wild fruit). The study found a statistically significant positive relationship between tree cover and dietary diversity specific to fruit and vegetable consumption. There was increased consumption with tree cover up to a peak of 45% tree cover. However, no statistically significant relationship was established between tree cover and animal food consumption. Overall, the study indicated that children in Africa with more tree cover may have more diverse diets, influencing their nutrition and, ultimately, their food security.

Box 7. Forest contribution to dietary intake and relationship to household food insecurity in Cameroon[82]

A study of rural forest-dependent households in 12 villages in eastern and southern Cameroon was carried out to determine the extent to which forest foods contribute to a diversity of diet and household food security. Household food consumption data were gathered from women to generate a dietary diversity score, food variety score, and forest food consumption score. The study found that forest foods accounted for roughly half of women's total daily energy intake, indicating a deep dependence on forest foods. Further, forest foods significantly contributed to critical vitamin intakes (e.g., 98% of vitamin A, 88% of zinc, and 89% of calcium). A significant inverse correlation was observed between the Household Food Insecurity Access Scale score and the forest food consumption score, which implies that forest foods play a vital role in food security for forest-dependent communities, such as these 12 villages, and by extension for a proportion of the 1.6 billion people who directly depend on forests for their livelihoods. The authors concluded that forest foods are widely consumed by forest-dependent communities and that, given the abundance of nutrients in wild fruits and vegetables, these foods offer important contributions to improving nutritional outcomes and addressing food insecurity.

The extent of the role that forests play in supporting human nutrition and food security is insufficiently substantiated and, historically, has been largely unrecognized.[83] It is important to note that there has also been considerable debate around the nutritional value of forest foods. Some have argued that the small physical stature of forest-dwelling communities is due to poor nutrition, while others contend that wild meats, obtained by hunter-gatherers, are in fact nutritionally superior to domesticated meats. There is substantial agreement that forests can offer a nutritional safety net in times of conflict or environmental or household-level crises.[84] It is equally important to recognize that the most extreme poverty and hunger is found primarily among rural, smallholder farmers, and increasing food production, agricultural productivity, and associated rural incomes are widely seen as crucial to eradicating hunger and extreme poverty.[85]

Forest conservation clearly has potentially important implications for nutrition-sensitive interventions in LMICs to safeguard the health and development of vulnerable populations—particularly women of childbearing years and young children. Yet conservation efforts, including reforestation and restoration, must consider the roles of both forests and trees, as well as productive agriculture and smallholder agriculture, in ensuring food security and nutrition-sensitive approaches for the world's growing population, particularly for those most vulnerable to extreme hunger, poverty, and inadequate nutrition.[86]

The wild foods produced by forests and trees are a critical source of food security and nutrition for millions of people, especially those living in poverty. This is particularly true for rural communities with limited access to markets and where wild or semiwild fruits, vegetables, wild meats, and mushrooms are often an important source of micronutrients and protein. For example, in remote regions of Tanzania, wild foods account for between 19% and 30% of vitamins A and C and iron and contribute to 2% of energy intake. Forests are also a crucial source of fuel for cooking in rural communities and cities.[87]

Knowledge gaps

- **Nutritional trade-offs of land-use change:** The nutritional capacity of wild, forest-derived foods has received insufficient attention. There is a need to better understand the level of nutrition (per area of productivity) provided by forests versus pastures or row crops to fully comprehend the nutritional implications of land-use change.
- **Tree cover and child nutrition:** The causal pathways between tree cover and children's diets require greater evidence across diverse contexts because there are other factors shaping these interactions linked to mitigating and contextual factors (e.g., mother's education, household size, and market access).
- **Dietary preferences, agroforestry, and forest foods:** More knowledge is needed on local preferences for wild forest foods and forest-based agricultural systems (e.g., agroforestry and silviculture). A better understanding of the institutional conditions that lead to diet shifts in communities that previously preferred or used forest foods is needed. It is also important to understand how changes to markets and human health outcomes are linked.

Physical hazards

Forests generally mitigate physical risks to human health. The United Nations estimates that more than 1.3 million people died as a direct result of natural hazards (e.g., storms, flooding, drought, extreme temperatures, landslides, and wildfires) from 1996 to 2015—with an acceleration in weather and climate-related disasters from the previous decade.[88] Natural ecosystems, especially forests and mangroves, can provide protection from these physical hazards in a variety of ways, preventing death and safeguarding human health. Below, Dudley et al. detail how forests and natural ecosystems offer a defense against some of these physical hazards. Additionally, we have included heat as another physical hazard based on its emergence in the literature as something that can be mediated by forest cover.[89]

PHYSICAL HAZARDS AND HUMAN HEALTH

1.3 million average number of fatalities from natural hazards from 1996 to 2015[88]

$1,700 yearly loss of worker income from stoppages due to extreme heat†

4x increase in days with hazardous heat affecting outdoor workers†

†Union of Concerned Scientists. https://doi.org/10.47923/2021.14236

- **Flooding:** Forests can slow the pace of water flow by buffering and absorbing floodwaters and contributing to groundwater intrusion.
- **Landslides:** Vegetation helps to stabilize soil, and trees can provide a barrier to the movement of soil, snow, or rocks down steep slopes.
- **Wildfires:** Well-managed forests are better able to withstand wildfires.
- **Hurricanes and storms:** Green infrastructure (e.g., forests, marshes, and mangroves) can help buffer the physical impacts of stormwater.[90]
- **Heat:** Forested landscapes and cities, as well as trees themselves, provide relief and shade to people and animals and reduce ambient temperatures.[91]

Interventions to preserve and restore the world's forests often acknowledge the benefits forests afford human and planetary health. However, they must also acknowledge the potential physical hazards that can stem from forests and trees. Forests themselves tend not to generate physical risks to human health, but trees certainly can in the context of physical hazards as a part of floods, landslides, and storms. The distinction here between forests and trees is less important if it can be understood that there are trade-offs inherent in the protection, management, and restoration of forests. Therefore, comprehensive risk assessments to determine the various physical risks to people associated with forests and the impacts of trees in different physical hazard and disaster risk-planning scenarios, especially in a changing climate, are essential to balanced forest conservation and management strategies.

Flooding and landslides

The role of forests in limiting the impacts of flooding or landslides typically depends on the scale, intensity, and duration of precipitation. For the types of changes in precipitation that are associated with climate change, wet places will tend to get wetter, leading to increased risk of flooding and landslides.[92] The extent that forests can mitigate the most drastic impacts of these hazards seems bound by scale. Forest cover can improve the peak discharges for small to moderate floods but has little effect on large floods.[93] Additionally, Bathhurst et al. report that at the catchment scale, it appears that forest cover must be at least 20%–30% to generate any flood reduction benefits. How forest cover can mitigate peak flow during rainfall events is the primary metric that determines the role forests can play in preventing dangerous floods.

In addition to forest cover, soil properties and groundwater intrusion also impact the likelihood and/or intensity of small or moderate flooding events. These events appear less dependent on forest cover than on the compaction potential of different soil types, even following afforestation. Water that can infiltrate soil in catchments is obviously less risky than water that cannot and remains on the surface. Key to this risk is the establishment of road networks, especially within forests, that reduce subsurface water flow and contribute to flood generation.[94]

Forests, especially those with deep-rooted trees, have long been entrusted to lessen the occurrence of landslides by improving drainage and securing soils. This protection, however, only extends to shallow landslides. Forests are unable to prevent landslides that result from deep geological movement (e.g., earthquakes) or extended heavy rainfall.[95]

Not only does deforestation contribute to increased flood or landslide risk, it also places people in harm's way. Infrastructure developed without appropriate drainage or precautions against potential erosion predisposes it to failure and places the people who use roads and other infrastructure prone to enhanced flooding and landslide risk in physical danger.[96]

Wildfires

Wildfires have emerged as a formidable physical hazard to people, and the largest and most intense wildfires burn forests. In this context, the existence of forests produces human health risks, both physically from the fires themselves as well as the smoke and haze that can even cross continents. Massive fires in the Amazon, the western United States, and Australia have demonstrated a significant and life-altering risk to human well-being. Yet these threats are balanced by the importance of forests to human health in other capacities. The economic contributions of forests as well as the physical perils that they pose have led most countries that contain forests to create forestry departments that manage the benefits and risks of forests, including the threats of wildfires.

Wildfire suppression is a typical fire management strategy, especially as residential development expands into forested areas. The fuel load of forests managed for residential development predisposes such forests to more intense fires, especially when droughts set in. However, the management required for fire-adapted forests, namely prescribed burning, is at odds with the human health implications of smoke, haze from such fires, and the potential hazards given limited firefighting resources. While the intent is to avoid the human health impacts of smoke, which are well documented, there is a trade-off between fire suppression and the more substantial and disastrous impact of wildfires. These physical risks can often extend beyond the fires to include landslides and debris flows, many of which can be catastrophic in the wake of tragic fire events.[97]

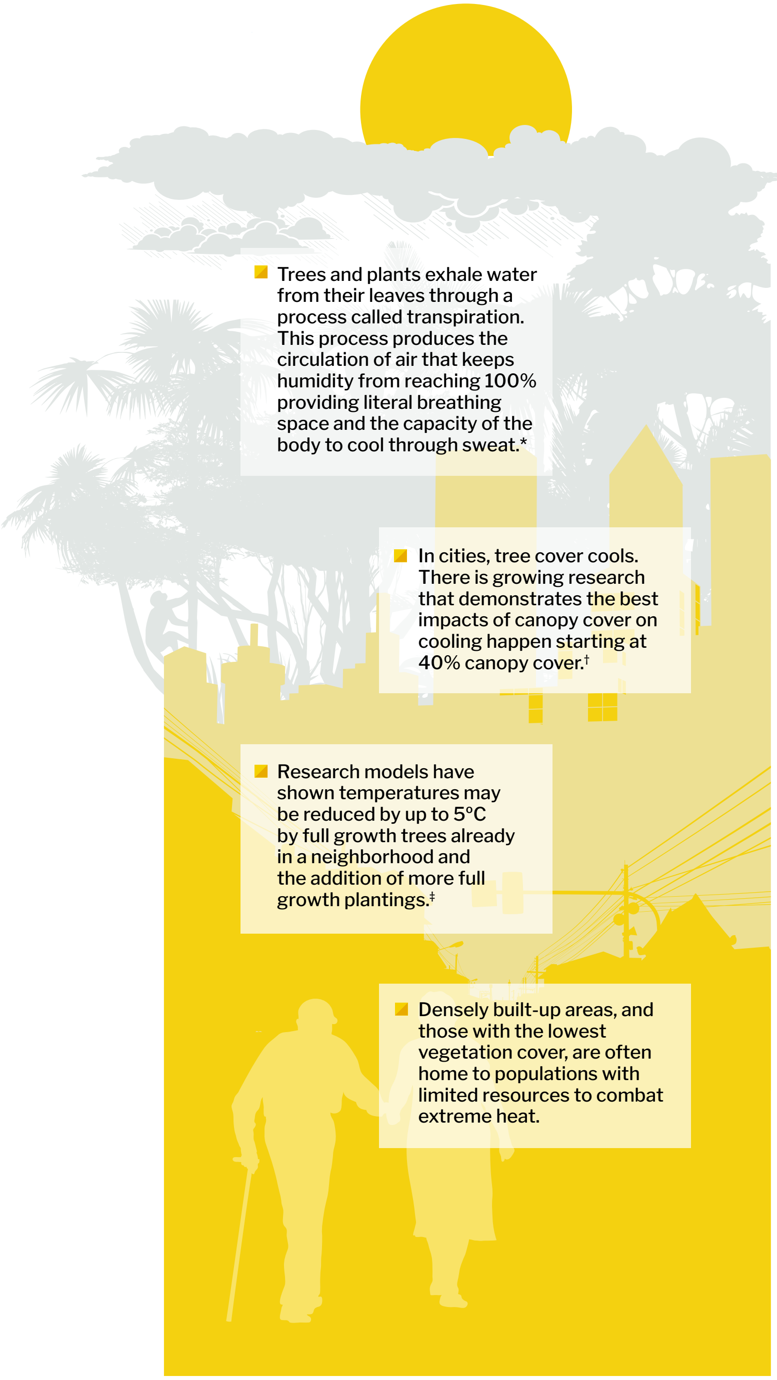
Hurricanes and storms

Forests can positively affect human health by minimizing the impacts of rain, wind, and water associated with storms. Tide and water level surges from tropical storms represent some of the most destructive and dangerous features of such storms.[98]
In many cases, wave energy and flooding are lessened by mangrove and coastal forests, and planting mangroves has become a proven disaster risk reduction strategy in the coastal tropics. However, in other cases, large waves and storms have uprooted trees and mangroves that then become significant physical hazards on top of flooding and wind. In this sense, forests reduce risks to human health while the trees themselves pose a risk.

Husrin et al. demonstrate a series of contexts for how coastal trees and forests can weaken storm energy in waves based largely on root depth and the width of forests perpendicular to coastlines.[99] When it comes to minimizing the physical risks to human health from coastal storms, the most important factor in whether trees and forests will be an asset or a liability during a storm is the integrity and width of the forest itself, where increased forest width seems to grant greater protection. It should be noted, however, that during storms, forests can also pose a threat to human health from falling limbs and trees that cause physical harm as well as the disruption of life-supporting infrastructure.

Heat exposure and related diseases

Figure 3. Forests circulate and cool the atmosphere
Extreme heat exposure has increased nearly 200%, affecting 1.7 billion people from 1983 to 2016, and extreme humid heat overall has more than doubled in frequency since 1979.* Forests can not only mitigate temperature extremes but can also limit the ability of humidity to climb to 100% where temperatures of 35°C exceed the capacity of the human body to cool itself, suggesting the increasing importance of urban forests.



*https://doi.org/10.1073/pnas.2024792118
†https://doi.org/10.1073/pnas.1817561116
‡https://doi.org/10.1016/j.compenvurbsys.2021.101655

Heat is a growing threat to human health as climate change subjects more people to extreme temperature events. According to WHO, exposure to excessive heat not only carries direct risk for illnesses such as heat exhaustion and heatstroke but also exacerbates chronic cardiovascular, respiratory, and diabetes-related conditions.[100] In addition, WHO notes that small variations in temperature are linked to increases in illness and mortality, and additional research demonstrated that heat waves are associated with increases in intimate partner violence, police reports, and help line calls.[101]

Forests provide natural protection from heat. The cooling effects of shade and the release of moisture from soil into the air can lessen the impacts of excessive temperatures.[102, 103] However, the combination of heat and humidity can also present significant risks to people. In extreme conditions where humidity is 100% and heat approaches 35°C, humans reach the physiological limit for survival. Due to climate change, extreme heat and humidity combinations are already appearing more frequently, having doubled globally since 1979.[104]

Much of the research on the effects of heat stress on health has focused on extreme events, particularly in urban areas in developed countries. In urban settings, the largest cooling potential increases nonlinearly as canopy cover approaches and exceeds 40%.[105] This threshold may be important in urban design to adapt to more frequent and intense events in cities.

A study by Wolff et al. using surveys of inhabitants of nearly 500 villages in rural Indonesia provides insights into the linkages between deforestation, heat, and health in rural areas in LMICs.[106] When asked whether forests were important for health, most respondents cited the role of forests in the maintenance of cooler temperatures, with inhabitants of recently deforested or fragmented landscapes most likely to provide this answer. These results affirm the potential of forests in regulating local climate and add evidence to a phenomenon that many people have personally experienced.

Knowledge gaps

- **Forests and flooding:** Forest cover of 20%–30% appears to mitigate peak flows in small or moderate flooding if considered at the catchment scale. Understanding other types of land cover that could support flood mitigation would be beneficial.
- **Extreme heat and humidity:** What is the role of forests in managing landscape-scale humidity in relation to temperature? Does the presence of forests increase relative humidity, placing forest-adjacent communities in greater risk of experiencing heat/humidity maximums, or do forests regulate humidity and heat to safer levels?
- **Rural, suburban, and urban forest fire management:** There are trade-offs between managing forests with residential uses and controlling fuel loads in fire-adapted forests. Prescribed burns generate smoke that can impact human health, and wildfires can be catastrophic. It would be useful to know more about the human health trade-offs between fire suppression strategies and the disastrous effects of wildfires.

Infectious diseases

Infectious diseases are the leading cause of death in low-income countries and the leading cause of death of children aged under 5 years globally.[107] While established infectious diseases account for most of the infectious disease burden, emerging infectious diseases (EIDs) are on the rise globally, many tied to zoonoses (diseases transmissible from animals to humans). WHO estimates there are about 40 infectious diseases that were not present one generation ago. These include: severe acute respiratory syndrome (SARS); avian influenza; Ebola virus disease (EVD); Middle East respiratory syndrome (MERS); and Nipah. According to WHO, 75% of all EIDs originate in animals.[108,109] With the number of EIDs increasing significantly over time, zoonotic EIDs pose a serious threat to global health. Interactions between humans and nature have changed dramatically over the last century. In the past 50 years, the increasing emergence of zoonotic infectious diseases corresponds with unprecedented rates of tropical deforestation and degradation.

INFECTIOUS DISEASES AND HUMAN HEALTH

75% of new or emerging infectious diseases are zoonotic

2.5 billion estimated cases of human illness of zoonotic origin

2.7 million human deaths from zoonoses worldwide each year

44% of infectious disease deaths are in poor countries

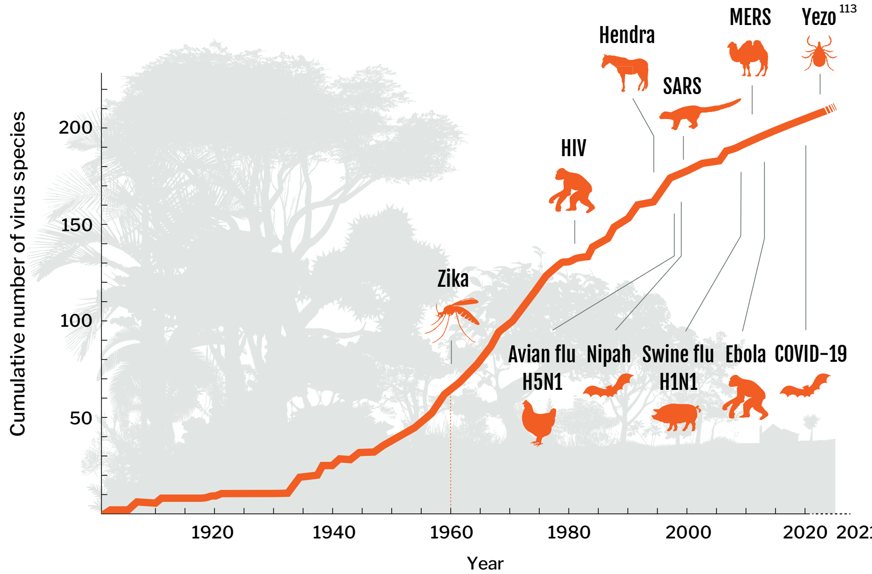
Centers for Disease Control and Prevention.
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5711306/

The linkages between deforestation and infectious diseases are complex and are influenced by a variety of interconnected factors. These include: varied ecological systems; human behavior; changing interactions with and among wildlife; and the unique biology of wildlife and pathogens. A growing body of research suggests that deforestation can increase the risk of the emergence and spread of infectious diseases. A 2015 study found that nearly one in three outbreaks of new and emerging diseases is linked to land-use change, including deforestation.[110] By shrinking and fragmenting habitats (especially forests), deforestation promotes greater concentrations and interaction among disease pathogens, vectors, and hosts, leading to greater opportunities for disease transmission to people.[111]

Deforestation and infectious disease risk

Understanding the intersections between pathogens and people is necessary to determine the impact that conservation efforts might have on disease emergence and control. Hosseini et al. classify the risk of the emergence and spread of pathogens to people from wildlife into the following components: hazards, exposure, and vulnerability.[112] These researchers define hazards as "potential sources of harm from microbes, such as viruses, bacteria, and other pathogens"; exposure as "the likelihood of contact, including vector-borne transmission, between humans and hazards"; and vulnerability as "the possibility given exposure that the microbial hazard can actually cause harm."

Figure 4. Cumulative increase in zoonotic infectious diseases



Research shows examples in which deforestation is linked to both increases and decreases in the risk of the emergence and spread of infectious disease. This linkage is due to unique interactions between disease hosts, pathogens, and their environment. For example, forests are associated with greater biodiversity. Pathogen diversity when proportional to forest biodiversity often increases the existence of a greater number of infectious diseases because more species (hosts) carry more pathogens. However, greater host biodiversity can also effectively decrease the risk of spillover of individual pathogens from animals to humans because it reduces the prevalence of pathogens among a diversity of less-competent host species.[114] Some species are hosts but do not transmit pathogens to people (noncompetent hosts), while other species can pass an infectious disease to people (competent hosts). Biodiversity can be critical in diluting local populations of competent hosts with noncompetent hosts, reducing the probability of a competent host transmitting a pathogen to a person.

Below are examples of ways in which deforestation both increases and decreases risk of spillover:

Increased infectious disease risk associated with deforestation

- Fragmentation of forests shrinks wildlife habitats, often bringing animals and humans closer together, increasing the risk of spillover of diseases from animals to humans.[115]
- Deforestation can concentrate host and vector animal populations in fragmented habitats at unnaturally high densities. Disease vectors interact with a greater variety of pathogens and other potential hosts (e.g., livestock, wildlife, and humans), which can lead to new foci of transmission or novel sources of zoonotic infections.[116] Many vector species, like people, are also habitat generalists.
- Deforestation is associated with a loss of biodiversity, which plays a protective role for humans through the "dilution effect." The dilution effect hypothesizes that vector infection rates, and thus human infection risk, are lower in areas with a wider variety of wildlife where noncompetent hosts dilute disease transmission between vectors and highly competent hosts.[117] Biodiversity loss of apex predators also compromises nature's mechanism for reducing the prevalence of host and vector animals within prey populations.[118]

Decreased infectious disease risk associated with deforestation

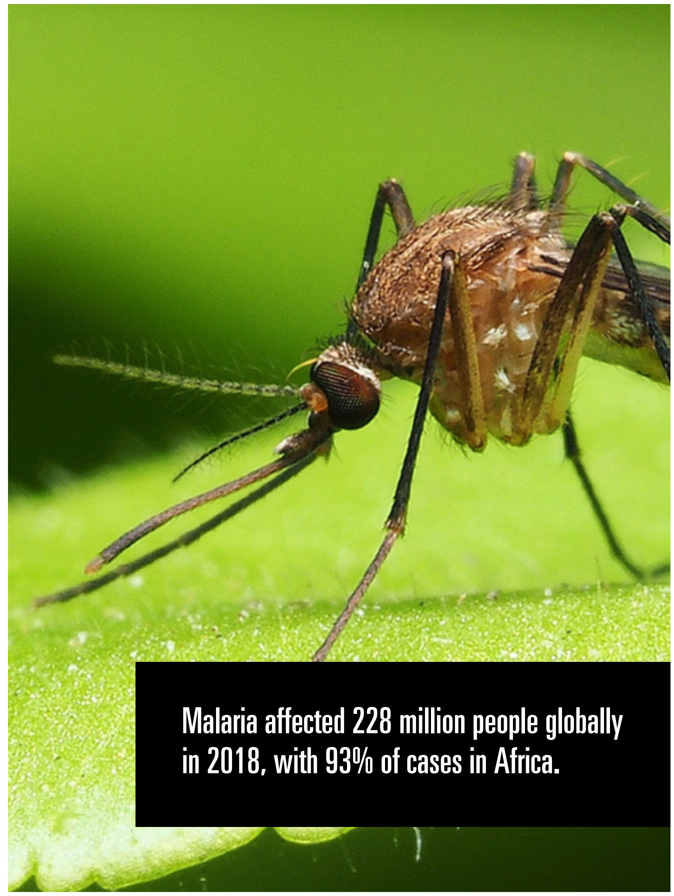
- Counter to the dilution effect, the biodiversity associated with forested areas can mean a higher number of competent disease hosts, increasing disease prevalence (i.e., the amplification effect). Areas with high biodiversity could also host novel pathogens, leading to an emergence of new diseases that could enter the human population.
- Deforestation can eliminate select disease vector species through the destruction of their habitats.[119]

Research across established pathogens and EIDs demonstrates the complexity of the relationship between deforestation and the emergence and spread of infectious diseases. While causality is challenging to determine, research on established diseases such as malaria, yellow fever, and Lyme disease, along with research on emerging diseases such as EVD and COVID-19, provide strong evidence of the deep linkages between deforestation and human health. Understanding the effects of deforestation on the risks of disease transmission between wildlife and humans provides an opportunity to better predict and mitigate the emergence of new infectious diseases as well as the spread of existing infectious diseases.

Malaria

Although the disease ecology of forests is an emerging area of study, malaria is one of the infectious diseases with the most robust research on linkages to deforestation and may offer insights into other mosquito-borne and zoonotic diseases. Malaria affected 228 million people globally in 2018, with 93% of cases in Africa, and resulted in an estimated 405,000 associated deaths.[120] Several studies have shown that deforestation is connected to an increased prevalence of malaria. However, these studies have also found that regional and local ecological variables, the characteristics of different mosquito species, and environmental variables affect mosquitoes' ability to develop and transmit the malaria parasite (vector competence).

An analysis by Austin, Bellinger, and Rana of 67 developing nations where malaria is endemic showed that deforestation is associated with increased prevalence of malaria—across different regions and different species of mosquitoes.[121] The study cites several ways in which deforestation can impact malaria prevalence, including increases in sunlight and standing water that provide favorable breeding sites for competent mosquito vectors; loss of biodiversity; and increases in human exposure to vector mosquitoes. While the study identifies a broad pattern linking deforestation to malaria, it also notes that the analysis does not consider regional or local ecological factors and mosquito species characteristics that may affect malaria prevalence.



Malaria affected 228 million people globally in 2018, with 93% of cases in Africa.

Within Austin, Bellinger, and Rana's analysis, a review of a set of regional and local studies offers insights into the variations of the impacts of forests on malaria transmission. These studies reveal that while some vector mosquitoes require deep forest shade (and benefit from forest conservation), certain mosquitoes require partial shade and can thrive on forest edges or in areas with reduced tree cover.[122] The researchers note that mosquito distribution; the ecology of a locality or region; characteristics of different mosquito species; and patterns of human-mosquito contact affect regional and local variations in the impacts of forests on malaria transmission. Other factors, such as soil conditions, level of rainfall, and temperature variations, also affect the prevalence of malaria.

A study of 795 municipalities in the Amazon across 13 years found that a 10% increase in deforestation led to a 3.3% increase in malaria incidence, with deforestation effects on malaria the greatest during the early stages of deforestation as forest edge habitat increased.[123] In Africa, three of the four most competent malaria vectors are mainly nonforest species.[124] Deforestation provides the ecological conditions that allow these competent vectors to proliferate.

A study by Guerra, Snow, and Hay showed that in Central Africa—where all four of the most competent malaria vectors are present—deforestation has been linked to increases in malaria transmission by creating suitable habitats for breeding of nonforest-dependent mosquitoes.[125] The researchers also found that because Southeast Asia and the western Pacific have a wider diversity of vector mosquito species, deforestation is associated with both reductions and increases in malaria transmission across the regions. Closed forests provide favorable ecological conditions for the lifespan and breeding sites of some mosquito species, while forest-fringe and deforested areas create favorable breeding habitats for others. The researchers note that some vectors in the regions are highly adaptable to habitat changes caused by deforestation, which could also lead to increases in transmission after deforestation activities. These variables make the impacts of deforestation on malaria transmission in Asia unlikely to be unidirectional. This study reveals the complexity of the relationship between deforestation and malaria transmission and underscores the need to better understand the regional, local, and microdynamics of these linkages.

Lyme disease

Lyme disease is the most reported vector-borne disease in the United States, with prevalence highest in areas in the Northeast where suburban and exurban development infringe on forested areas.[126] Each year, approximately 30,000 cases[127] of Lyme disease are reported in the United States, although some estimates suggest that the actual infection rate is nearly 300,000. Lyme disease is a species of bacteria that can be passed to humans through a tick vector after it feeds on animals during its successive life stages. Several studies have concluded that fragmentation of forests increases the risk of human exposure to Lyme disease.[128, 129]

An analysis by Larsen et al. examined the hypothesis that increases in tick density, infected ticks, and the prevalence of infected ticks, combined with increased opportunities for zoonotic spillover due to human development associated with fragmented forests, would increase Lyme disease incidence.[130] Several studies cited in this analysis found that linking human incidence of Lyme disease to forest fragmentation yielded ambiguous results. One study showed that areas with forests that were smaller and more fragmented had fewer cases of Lyme disease than areas with more contiguous forest. Additional studies cited in the analysis suggested no impact from forest fragmentation on disease incidence. Larsen et al. posit that an explanation for these inconsistent findings is that disease risk modifies human settlement patterns—with higher Lyme disease incidence resulting in fewer people residing in the forest fringes.

Box 8. Lyme disease in the coastal dunes of California[131]

Until recently, the issues surrounding tick-borne pathogens like Lyme disease were primarily confined to the northeastern United States. The forests of New England have been the epicenter of Lyme disease cases and research. However, a study by Salkeld et al. examined the prevalence and diversity of tick-borne pathogens in multiple coastal woodland and grassland ecosystems in California. This research uncovered a wide diversity of tick-borne pathogens with relatively high infection rates among collected ticks. This included high densities of infected ticks in coastal grassland habitats, which do not conform to the habitat risks or geography most people would associate with Lyme disease.

Box 9. Lyme disease in New York State

Borrelia burgdorferi, bacteria that causes Lyme disease

A study in southeastern New York State found that forest fragmentation leads to diminished species diversity in forested areas, resulting in higher risk of human exposure to Lyme disease.[132] The findings of this study upheld the "dilution effect" hypothesis that species diversity of vector hosts, some of which are noncompetent disease hosts, dilutes the effects of the most competent disease reservoir, the white-footed mouse (which infects 40%–90% of larval ticks), in spreading disease. Because the white-footed mouse has a wide habitat tolerance, it can survive in degraded forests, leading to more mice in species-poor communities. The study further found that tree squirrels demonstrated the strongest dilution potential by reducing infection prevalence by 58% (when compared with ticks feeding on mice alone). Several other studies have concluded that fragmentation of forests increases the risk of human exposure to Lyme disease.[133, 134]

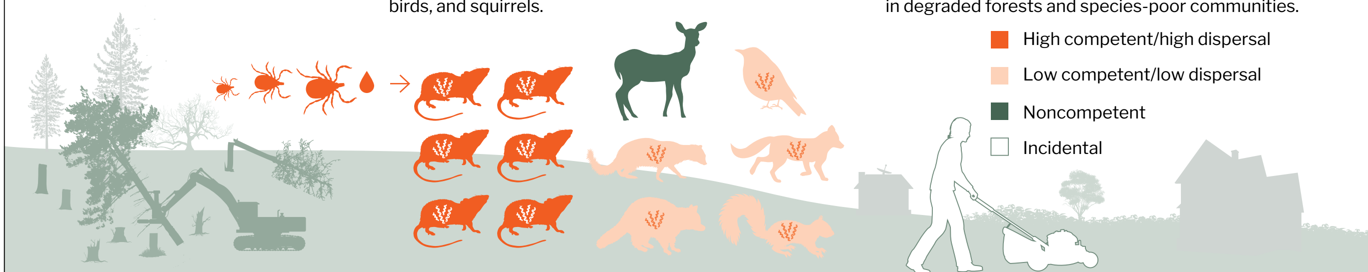
Degraded forests

Vector hosts

Ticks feed on a variety of wildlife, including mice, deer, birds, and squirrels.

Level of competency

Mice are high-competent disease hosts and thrive in degraded forests and species-poor communities.



Ticks transmit and/or become infected with *Borrelia burgdorferi* bacteria from blood meals of infected hosts, but not all hosts have the same level of competency to become infected or transmit disease. A greater diversity of species lowers the probability of human exposure to disease.

Other vector-borne diseases

Deforestation has also been linked to other mosquito-borne diseases, such as dengue (96 million clinical cases annually);[135] Japanese encephalitis (68,000 clinical cases annually);[136] and yellow fever (200,000 cases annually);[137] among many others. While research on the intersection of deforestation and disease is more limited for these infectious diseases, studies by Mondet (yellow fever); Vanwambeke et al. (dengue); and Mackenzie and Williams (Japanese encephalitis) indicate that land-use changes—including deforestation—can impact the abundance of infected mosquitoes and increase human contact with infected mosquitoes and other host animals, thus increasing infection risk.[138, 139, 140]

In addition, diseases passed to humans through other vectors have linkages to deforestation. A report by the Center for International Forestry Research cites dozens of vector-borne diseases with linkages to deforestation.[141] These include Lassa virus, passed through rodents; schistosomiasis, passed through snails; leishmaniasis, passed through sand flies; and Chagas disease, passed through triatoma bugs. Studies that focus on the effects of malaria transmission due to mosquito habitat changes caused by deforestation offer insights into the impacts of deforestation on the transmission of these diseases and mosquito-borne diseases beyond malaria. However, these studies may not capture how deforestation or forest degradation affect the unique biology and ecology of other vector species.

Emerging infectious diseases

The US National Institute of Allergy and Infectious Diseases defines EIDs as those that "have nearly appeared in a population or have existed but are rapidly increasing in incidence or geographic range."[142] EIDs include SARS, MERS, EVD, avian flu, swine flu, Zika, and COVID-19 and are likely to include the appearance of established infectious diseases in new areas as climate change expands vector habitats. As travel between countries becomes less expensive and easier, infectious diseases are spreading further and faster than at any other time in human history.

A driver behind the increased incidence of EIDs spilling over into human populations and then rapidly spreading is the global demand for live exotic animals (for pets as well as consumption). Historically, the impact of EIDs was limited to communities near forested or deforested areas containing pathogen-carrying animals. Hunters would bring infected animals out of the forest into their communities, but the disease would not spread widely beyond those communities. With greater migration to urban areas and cross-border expansion of regional and international markets, the demand for wildlife is increasingly dispersed, and the globalized supply chain allows for species harboring pathogens to be in contact with humans along all points of these more complex and lengthy supply chains.

With 75% of EIDs originating in animals, the understanding that human health is connected to the health of wildlife, which is inextricably linked to forest health, is gaining greater attention not only in the research community but also among policymakers and the general public.[143] There is a growing body of research on the linkages between EIDs and deforestation that may further substantiate these connections.

Ebola virus disease

EVD is a rare but severe and often fatal disease, with a mortality rate of 50%. The virus is zoonotic in origin, and fruit bats are the most probable natural host. Transmission likely occurs from wildlife (fruit bats, porcupines, or nonhuman primates) to humans and then spreads among people.[144] Recent research also indicates that humans can now act as intermediate hosts and can serve as long-term Ebola virus reservoirs that trigger new EVD outbreaks.[145]

Since its identification in 1976, EVD has killed more than 13,000 people, with all cases originating in Africa.[146] The outbreak in West and Central Africa between 2014 and 2016 was the most severe, with more cases and deaths than all other outbreaks combined. During this outbreak EVD also spread across countries in the region. In August 2018, the 10th outbreak of EVD was announced in the Democratic Republic of the Congo, in the northeastern part of the country. This was the world's second largest EVD outbreak, which lasted almost two years, and was declared over on June 25, 2020. However, just a few weeks prior to this announcement, the country confirmed its 11th outbreak (unrelated to the 10th) in the northwest.[147]

A study by Olivero et al. of 27 sites in West and Central Africa with EVD outbreaks occurring between 2001 and 2014 showed an association between outbreak locations within the rain forest biome in the region and forest loss within the previous two years.[148] While the findings also note high human population density and favorable viral conditions at EVD outbreak sites, the relative importance of forest loss was found to be greater than 60% independent of these factors. The findings of the study support the researchers' hypothesis that the underlying reason for the link between forest loss and EVD is increased contact between humans and infected wildlife.

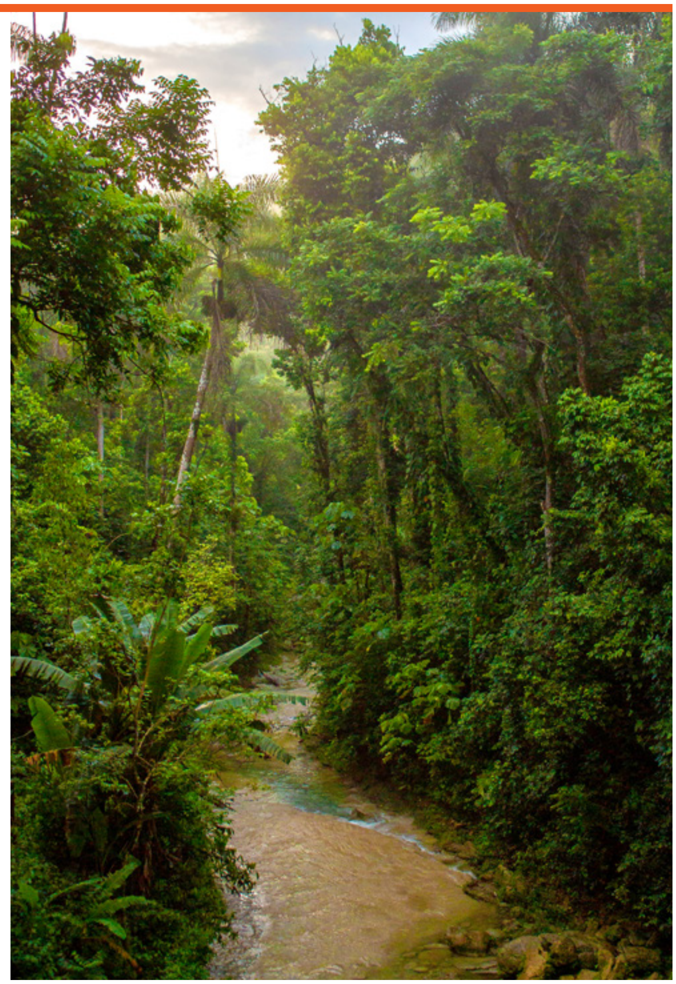
Another study of EVD outbreak sites in West and Central Africa by Rulli et al. had similar results. The research supports the hypothesis that EVD transmission to humans is more likely to occur in highly disturbed forest areas.[149] Using land-use cover change data and EVD outbreak records for years 2004–2014, Rulli et al. found that most index cases of EVD in humans (the point where spillover occurs from wildlife to humans) in the region happened in forest fragmentation hot spots. Although the reservoir host for EVD remains uncertain, an African bat species is the most likely zoonotic host and is a habitat generalist. Rulli et al. found that population density of ape species (e.g., chimpanzees and gorillas) prone to EVD infections also increased after forest disturbance. The researchers concluded that biodiversity loss associated with forest fragmentation may enhance the likelihood of EVD infections in humans.

COVID-19

COVID-19 (or SARS-COV-2) is an infectious disease caused by a novel coronavirus. The outbreak of the disease has become a pandemic that has spread rapidly throughout the world since the first case was reported in December 2019, with nearly 376 million confirmed cases and 5.6 million confirmed deaths as of February 2022.[150] The origins of COVID-19 are far from certain, though current research suggests that the virus itself is zoonotic, likely hosted by bats.[151] Advances in genome sequencing helped researchers quickly identify its likely origin and provide tools that are critical for environmental screening for this disease and for preventing the emergence of new diseases in the future.[152] While the science around COVID-19 is still evolving, the disease's likely zoonotic origins indicate the potential for linkages with destruction of animal habitats. Recent evidence suggests that SARS-COV-2 has circulated among human populations in Yunnan, China's most biodiverse province, for decades. During the same time frame, Yunnan has lost more than a quarter of its natural forest. The current outbreak, however, is the result of its introduction to a new, hyperconnected, and immunologically naive group of people following the spillover event(s) that likely occurred closer to forest edge habitat years ago.[153] Researchers are continuing to investigate the origins of the disease and the method of spillover into human populations.

Knowledge gaps

- **Deforestation and spillover:** Research suggests that deforestation can increase the risk of the emergence and spread of infectious diseases. Yet zoonotic disease outbreaks do not occur in all places where deforestation takes place. There is a need to better understand the risk factors leading to zoonotic infectious disease outbreaks and spillovers.
- **Relationships between forests, pathogens, and vectors:** Understanding the effects of deforestation and forest degradation on the risks of disease transmission between wildlife, livestock, and humans provides an opportunity to better predict and mitigate the emergence of new infectious diseases as well as the spread of existing infectious diseases.
- **Disease responses to forests:** Understanding the intersections between pathogens, people, and transmission pathways across different types of zoonotic infectious diseases and regions will be critical in determining the impact of conservation efforts on disease control and the most effective interventions to prevent spillover.
- **Roles of biodiversity:** We need improved knowledge regarding how forest disturbance changes biodiversity such that the transmission of infectious diseases is altered—especially in the context of the dilution and amplification effects.



What Is Needed? Embracing a Systems Approach

The analysis of the relationship between human health and forests is only done one way in conservation. How do we improve the state of the environment to improve human health? Alternatively, how can improving human health benefit forests?

Overall, the balance of the literature reviewed in this report substantiates forests as an important contribution to human health. The societal responses to sustain and/or enhance the positive impacts of forests, which may also contribute to reducing health risks, are multiple. They can be organized into four major action domains: protect, restore, manage, and create. We based these domains on the existing forest conservation framework of protect, restore, and manage.[154] In addition, we included a new category drawing on the increased interest in nature-based solutions. This "creation" category is primarily linked to urban forests.[155] The interventions to protect, manage, or restore forests and the myriad benefits they contribute to planetary and human health must also recognize and respond to the potential hazards that can stem from deforestation and degradation. Therefore, actions aimed at reducing likely risks associated with forest loss and degradation are also necessary in a health context.

Moreover, responses to improve human health through forest interventions should look at specific interventions or the implementation of initiatives at different scales. Responses must also consider the underlying environmental, institutional, and behavioral factors of a place that can enable or hinder their success, as well as some of the mediating factors identified in Figure 1, by either removing constraints or amplifying their benefits. These constraints include access to and accessibility of forests; the affordability of forest interactions either through financial or time commitments; the proximity of people to forests and forest benefits; and the range of other social needs and demands that accompany local social-forest interactions.

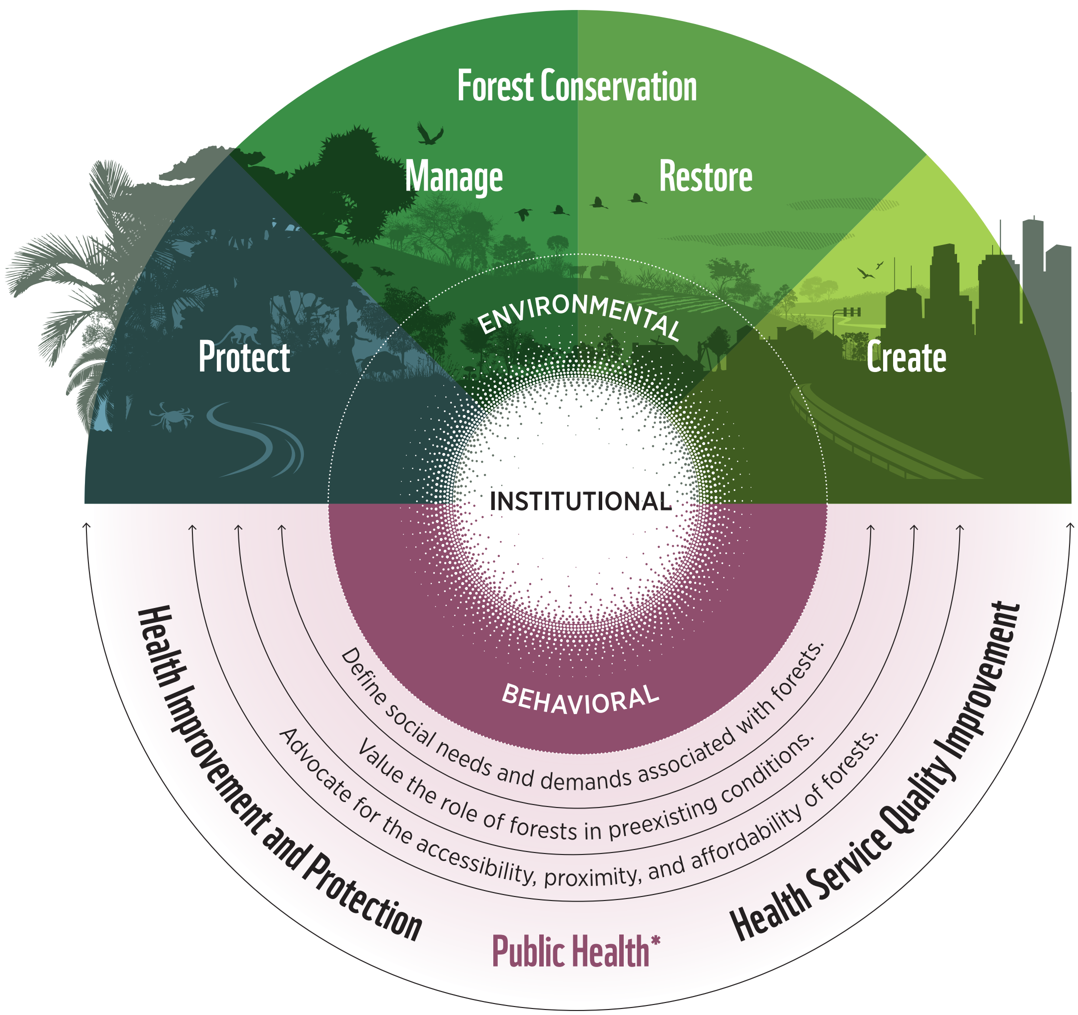
Protect forests and avoid their conversion

It is critical to protect the world's remaining forests, particularly intact forests, and to reduce the pressures leading to future deforestation. This protection has benefits for sustaining forests' provisioning role by supplying forest foods to local people as well as clean water and medicinal plants, among many other functions. Forest protection can decrease carbon emissions and thus the indirect impacts of climate warming on human health. Avoiding deforestation also lessens the potential for water and air pollution. In addition, it supports the preventative role of forests in relation to zoonotic infectious disease spillover and minimizes the risks from exposure to physical hazards. However, for these measures to achieve scale, institutional factors must be addressed. These include ensuring long-term finance for protected areas; formalizing tenure and the social and economic rights of local populations; and halting the expansion of agriculture, urban areas, and infrastructure (mainly roads) into forests.

Specific interventions to support human health and protect forests are shown in Table 2. For example, sustaining forest food supply can preserve local cultivars and phenotypes as well as local cultural heritage and traditional knowledge in economies where forest food is important to nutrition. Safeguarding forests on slopes, coastal forests, and mangroves and sustaining forest hydrology and high-risk geology/soils can help reduce or prevent risks of physical hazards. In addition preserving Indigenous and traditional knowledge and customs, wild forest foods, and traditional natural medicine can lead to a reduction in NCD incidence.

Systems to monitor interactions between forests, food, and nutrition as well as threats of zoonotic infectious disease spillovers are critical. Given the variability of physical hazards to humans associated with forests and deforestation in a changing climate, comprehensive risk assessments are essential to forest conservation and management strategies to optimize benefits to human health.[156] Knowledge gained from risk monitoring must also be applied to local and subnational decision-making through co-adaptive risk management to inform national adaptation strategies to enhance resilience.

Figure 5. Responses required to sustain and enhance the positive impacts of forests on human health



*The practice of public health spans but is not exclusive to the three core domains of health improvement, health protection, and health service quality improvement as originally coined by Griffiths, Jewell, and Donnelly (2005).

Figure 5 details the different elements that should be assessed across the forest protection, management, restoration, and creation responses to sustain or enhance the contributions forests can make to human health while reducing existing hazards. However, each action taken to support forests to promote human health outcomes must be weighed against its feasibility and the balanced contribution to environmental, institutional, and behavioral contexts. Understanding these contexts and effectively considering the benefits and some of the risks of forests to human health, especially the risks associated with deforestation and forest degradation, will determine locally appropriate strategies. In this case, we refer to the forest conservation and public health domains of practice generally, including but not limited to the formalized sectors.

Improve forest management of working lands

Reducing the environmental impacts of land use and management while ensuring the vitality of all forests and forest fragments on working lands should be a priority, especially where forests and forest fragments play a critical role in sustaining biodiversity, regulating water cycles, and preserving soil quality. Yet beyond forests, stimulating more sustainable and regenerative agriculture can support the social and ecological functions of forest landscapes. This includes moving to perennial crops, practicing no-till agriculture, and implementing agrosilvopastoral systems that cooperate with natural processes and seasonality. This may also reduce forests' exposure to fire, maintain their cooling/shading effects, and minimize physical hazards.

By contrast, commercial-scale logging and extraction of nontimber forest products tend to generate new local road networks that facilitate hunting, increasing interactions between humans and wild species. This can lead to exposure to novel zoonotic infectious diseases. Forest fragmentation also tends to precede deforestation, which impacts warming and heat exposure of local people, including rural workers, and global warming that stresses forests due to climate variability and droughts.

Improving forest and land management requires removing economic incentive structures and policies that reward forest conversion and weak governance systems unable to control illegal logging and forest conversion. In addition to preserving these forests, urban and semiurban institutions need to better value the services forests provide that prevent physical hazards and sustain key environmental services by filtering water and air pollution.

Forest management interventions that contribute to human health are detailed in Table 2. For example, managing agricultural catchments and bushmeat populations impacts food and nutrition as does supporting agricultural area-bound intensification and seasonal availability of crops and wild foods. Zoonotic infectious diseases can be prevented by controlling access to protected areas; regulating wildlife markets and bushmeat access; instituting agricultural and wildlife quarantines; and improving community health care. Management strategies to reduce human health risks associated with forests include forest fire prevention; supervision of recreational forests; actions to enhance forest access and accessibility; and improved infrastructure design that supports forests.

Existing forest and land management monitoring can inform best practices, from the plot or management unit to the landscape. However, we need more information on how to scale up some of these practices and the contextual changes required to more effectively contribute to the uptake of better land management for human health outcomes. In addition, management plans and strategies must include traditional and local knowledge.

Finally, studying the thresholds and tipping points at which forests are unable to recover from various threats should be a priority. These indicate irreversible ecological processes that land managers ought to avoid and the associated social and economic impacts with strong implications for human health.

Alternative land management such as goat grazing can be a cost-effective, environmentally sound way to clear combustible vegetation and promote the growth of native grasses and beneficial plants, particularly in steep or difficult terrain.

Take a diversified approach to forest restoration

There are multiple ways of restoring forests and the landscapes they occupy, and each may have different implications for biodiversity recovery, hydrological cycles, and local climate variability. Most importantly, restoration needs to look forward to support current and future generations and should use many different approaches to improve the ecological productivity of landscapes in line with conservation and human health and well-being objectives. For example, impacts on local food supply and nutritionally diverse diets may be achieved through the expansion of agroforestry systems while also providing environmental benefits from shade and reduced heat exposure. Forest restoration, if undertaken in a landscape context, may also reduce physical hazards linked to flooding, landslides and avalanches, and storms. More importantly, forest regeneration closer to semiurban and urban areas may increase the exposure of people with different types of NCDs, including mental illness, to forests. This outcome may be independent of the restoration type.

Preserving natural forest remnants is critical to facilitating regeneration processes that rely on local native species, as these are often the last remnants of locally adapted species. Different contextual conditions must be addressed to make restoration possible. These include mobilizing long-term finance; securing tenure rights; ensuring mechanisms for equitable benefit sharing with local populations; and compensating local restoration efforts while acknowledging that Indigenous peoples and local communities place unique social, cultural, and spiritual values on forests. Finally, we must remove access and affordability barriers to encourage urban populations to benefit from forestlands and advocate for their conservation even if they seem remote.

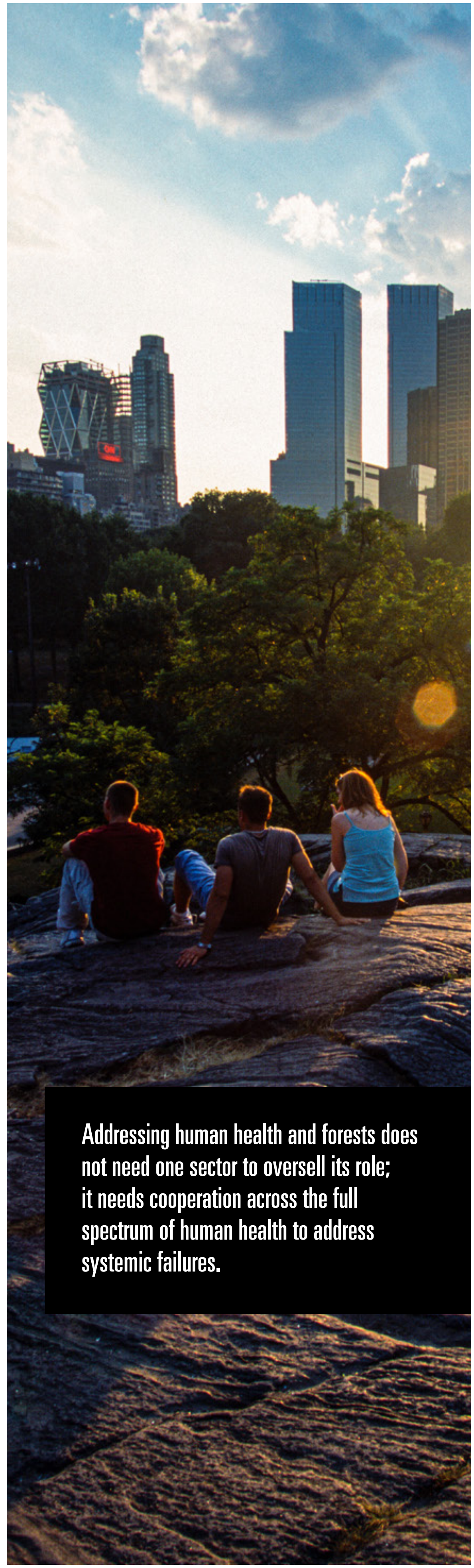
It all starts with nutrition—childhood nutrition is fundamental for lifetime health, and there is evidence of forests providing a safeguard for local communities by supplying wild harvested foods. Facing hunger, people turn to forest foods like nuts, roots, bushmeat, and berries. This is a safeguard during times of hunger.

Restoration initiatives that sustain forests' contributions to human health are detailed in Table 2. These entail regenerating the capacities of forests to provide food of high nutritional value in places experiencing forest degradation. This can be accomplished by incentivizing agroforestry systems, especially those that allow local cultivars and phenotypes to persist alongside more diversified agricultural farming systems. Interventions with the potential to decrease the risks of physical hazards include restoration of mangroves, aquifers, floodplain forests, catchment forest cover, and deep-rooting trees on slopes. In addition, preserving urban green spaces and restoring forest landscapes may contribute to reducing the incidence of NCDs and preventing spillovers of zoonotic infectious diseases. Forest restoration also has an important role to play in mitigating environmental pollution through regenerative agriculture; recovery of riparian forests; and drained land and modified watercourses. Thus, restoration actions are important for reducing—directly and indirectly—the risks pollution poses to human health.

Create urban forests

Creating urban forests may have important positive contributions to human health, particularly for those living in dense urban settings. Designating forests in urban areas, increasing green space, and planting trees may lead to cooling and, depending on the case, flood abatement. More trees in urban areas can also filter air pollution and provide recreation benefits, with positive impacts on populations with a high incidence of NCDs that may also have limited contact with forests. These actions, however, depend on significant institutional policy changes, especially regarding urban planning and budget allocations for preserving green areas or creating green corridors in urban landscapes—developments that tend not to increase a city's tax base. Several mediating factors affecting access, accessibility, and affordability must be addressed, particularly aimed at removing discriminatory regulations and urban planning working against greening underserved communities. Efforts should focus on upgrading physical infrastructure as well as options for improving these communities' overall well-being and living standards in ways that enhance health systems and exposure to forests.

Table 2 includes specific interventions in the "create" domain. For example, urban orchards along with diet shifts incorporating foods with higher nutritional value can improve nutrition and food. As already mentioned, building green urban corridors will help enhance accessibility to forests, with impacts on NCDs and mental health, especially if accompanied by campaigns to explain the health benefits of time spent in forests.



Addressing human health and forests does not need one sector to oversell its role; it needs cooperation across the full spectrum of human health to address systemic failures.

Table 2. Specific interventions within the forest landscape responses framework (protect, manage, restore, create) that may contribute to human health (e.g., to support human health through nutrition and food and protect local cultivars and varieties)

	PROTECT ...	MANAGE ...	RESTORE ...	CREATE ...
To reduce the incidence of noncommunicable diseases	• Rural livelihoods • Indigenous and traditional knowledge and customs • Intact forests and protected areas I-V • Wild forest foods • Sustainable homeopathic and natural medicine	• Fires, fuel loads, fire frequency and intensity • Protected areas category VI • Recreational forests • Forest access and accessibility • Infrastructure design that supports forests	• Green spaces • Forest landscapes • Institutional reliance and acceptance of forest-based health solutions	• Forest bathing • Urban forests • Urban orchards • Conservation for public health • Nature prescriptions
To reduce the health impacts of pollution	• Minimum catchment forest cover • Protected areas • Riparian forests • Intact forests • Grievance mechanisms	• Fires and smoke • Tree cover in urban areas • Charcoal reliance • Agricultural and livestock encroachment • Industrial and agricultural effluents • Overconsumption • Transboundary pollutants • Harmful agricultural practices • Pollution standards and testing	• Regenerative agriculture • Riparian forests • Forest landscapes • Indigenous rights and decentralized control • Drained land and modified watercourses	• Urban forests • Conservation for public health
To support human nutrition and food security	• Strict protected areas • Local cultivars and varieties • Cultural heritage and traditional knowledge • Indigenous autonomy • Nutritionally diverse landscapes • Forest food and culture • Precapitalist economies	• Forests and agroforestry systems • Catchment agricultural diversity • Bushmeat populations • Access to food and nutrition • Impacts of commodity subsidy systems • Forest rights and access • Seasonal availability of crops and wild foods • Agricultural area-bound intensification	• Forests and agroforestry systems • Traditional forest food culture • Local cultivars and phenotypes • Indigenous/ traditional rights • Communal land management • Agriculturally diverse areas	• Climate-resilient crops • Diet shifts • Novel food sources • Urban orchards • Long-term successional agricultural systems
To mitigate the impacts of physical hazards	• Forests on slopes • Coastal forests and mangroves • Fire regiments in fire-adapted forests • Forest hydrology • High-risk geology/soils • Existing forests and natural land cover	• Forest fuel load and wildfires • Soil compaction • Infrastructure development • Urban and residential development • Irrigation needs and capacities	• Forests and mangroves • Aquifers • Floodplain forests • Catchment forest cover • Deep-rooting trees on slopes	• Forests as disaster risk reduction solutions • Nature-based solutions
To limit the emergence and spread of infectious diseases	• Sustainable use of protected areas • Biodiversity of Key Biodiversity Areas • Habitat of taxa associated with emerging disease • Wildlife populations from people • Forest cover and intact areas	• Tourism and access to protected areas • Wildlife markets and bushmeat access • Disease vector habitat • Livestock density and transport • Infected wildlife and people • Land-use change • Agricultural and wildlife quarantine • Community health care	• Intact forest areas • Forest and agricultural diversity • Functional landscapes • Environmental and epidemiology partnerships	• Vaccines and vaccine dissemination protocols for wildlife and people • Wildlife assays and monitoring programs • EID monitoring programs

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References

Executive Summary

[1] FAO and UNEP. 2020. *The State of the World's Forests 2020. Forests, biodiversity and people*. Rome. https://doi.org/10.4060/ca8642en

[2] Raiten, D.J. & Aimone, A.M. (2017). The intersection of climate/environment, food, nutrition and health: crisis and opportunity. *Current Opinion in Biotechnology*, 44, 52–62. http://dx.doi.org/10.1016/j.copbio.2016.10.006

[3] Alves de Oliveira, B.F., Bottino, M.J., Nobre, P., & Nobre, C.A. (2021). Deforestation and climate change are projected to increase heat stress risk in the Brazilian Amazon. *Communications Earth & Environment*, 2, 1–8.

[4] The World Bank. 2016. The Cost of Fire: An Economic Analysis of Indonesia's 2015 Fire Crisis. Jakarta, Indonesia. https://documents1.worldbank.org/curated/en/776101467990969768/pdf/103668-BRI-Cost-of-Fires-Knowledge-Note-PUBLIC-ADD-NEW-SERIES-Indonesia-Sustainable-Landscapes-Knowledge-Note.pdf.

[5] Children: Improving survival and well-being. (2020, September 8). *World Health Organization.* https://www.who.int/news-room/fact-sheets/detail/children-reducing-mortality

[6] Sayer, J., Elliot, C., & Maginnis, S. (2003). Protect, manage and restore: Conserving forests in multi-functional landscapes Paper Submitted to the XII Forest Congress, Quebec, Canada. http://www.fao.org/3/XII/0484-C3.htm

[7] Seddon, N., Smith, A., Smith, P., Key, I., Chausson, A., Girardin, C., . . . Turner, B. (2021). Getting the message right on nature-based solutions to climate change. *Global Change Biology*, 27(8), 1518-1546. https://doi.org/10.1111/gcb.15513

Forests and Human Health: A Framework

[8] We Need to Safeguard Our Forests. (n.d.). World Wildlife Fund. https://wwf.panda.org/our_work/our_focus/forests_practice/importance_forests/importance_forests_test.cfm

[9] Managing Forest Resources for Sustainable Development: An Evaluation of World Bank Group Experience. (2013). Independent Evaluation Group. https://openknowledge.worldbank.org/handle/10986/35158

[10] Deforestation and Forest Degradation. (n.d.). World Wildlife Fund. https://www.worldwildlife.org/threats/deforestation-and-forest-degradation

[11] Millennium Ecosystem Assessment (Program). (2005). Ecosystems and human well-being. Washington, D.C: Island Press.

[12] Lovejoy, T. E., & Nobre, C. (2019). Amazon tipping point: Last chance for action. *Science Advances*, 5(12), eaba2949. https://doi.org/10.1126/sciadv.aba2949

[13] FAO and UNEP. 2020. *The State of the World's Forests 2020. Forests, biodiversity and people.* Rome. http://www.fao.org/documents/card/en/c/ca8642en

[14] Ibid.

[15] Vancutsem, C., Achard, F., Pekel, J. F., Vieilledent, G., Carboni, S., Simonetti, D., . . . Nasi, R. (2021). Long-term (1990–2019) monitoring of forest cover changes in the humid tropics. *Science Advances*, 7(10), eabe1603. doi:10.1126/sciadv.abe1603

[16] See for example, Colfer, C. J. P. (2008). *Human Health and Forests: A Global Overview of Issues, Practice and Policy.* London: Routledge. https://doi.org/10.4324/9781849771627

[17] Brauman, K. A., Garibaldi, L. A., Polasky, S., Zayas, C., Aumeeruddy-Thomas, Y., Brancalion, P., DeClerck, F., Mastrangelo, M., Nkongolo, N., Palang, H., Shannon, L., Shrestha, U. B., and Verma, M. (2019). Chapter 2.3. Status and Trends–Nature's Contributions to People (NCP). Zenodo. https://doi.org/10.5281/zenodo.5519476

[18] These forest functions on human health aligns with the components of human health outlined in Chapter 2.3 of the IPBES global report – " (1) dietary health, (2) environmental exposure, (3) exposure to communicable diseases, (4) hazard risk reduction including exposure to extreme weather, drought or fire, (5) psychological health, and (6) use of natural compounds in medicinal products and biochemical compounds" (p. 32), see S, D., J, S., E.S., B., H.T., N., & M., G. (2019). IPBES Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES Science and Policy for People and Nature. https://ipbes.net/global-assessment

[19] Children: Improving survival and well-being. (2020, September 8). *World Health Organization.* https://www.who.int/news-room/fact-sheets/detail/children-reducing-mortality

[20] FAO and UNEP. 2020. *The State of the World's Forests 2020. Forests, biodiversity and people.* Rome. https://doi.org/10.4060/ca8642en

[21] Morens, D.M. & Fauci, A.S. (2020). "Emerging pandemic diseases: How we got to COVID-19. *Cell*, 182, 1077–1092

Recognizing Human Health Through Forests

Noncommunicable diseases

[22] The NCD Alliance: Why NCDs. https://ncdalliance.org/why-ncds

[23] Frumkin, H., & Haines, A. (2019). Global environmental change and noncommunicable disease risks. *Annual Review of Public Health,* 40(1), 261–282. https://doi.org/10.1146/annurev-publhealth-040218-043706

[24] NCD mortality and morbidity. (n.d.). *World Health Organization.* https://www.who.int/gho/ncd/mortality_morbidity/en/

[25] Mendis, S., & World Health Organization. (2014). Global status report on noncommunicable diseases 2014.

[26] Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Forns, J., Plasència, A., & Nieuwenhuijsen, M. J. (2015). Mental health benefits of long-term exposure to residential green and blue spaces: A systematic review. *International Journal of Environmental Research and Public Health,* 12(4), 4354–4379. PubMed. https://doi.org/10.3390/ijerph120404354

[27] Björk, J., Albin, M., Grahn, P., Jacobsson, H., Ardö, J., Wadbro, J., Östergren, P.-O., & Skärbäck, E. (2008). Recreational values of the natural environment in relation to neighbourhood satisfaction, physical activity, obesity and wellbeing. *Journal of Epidemiology and Community Health,* 62(4), e2. https://doi.org/10.1136/jech.2007.062414

[28] Li, Q. (2010). Effect of forest bathing trips on human immune function. *Environmental Health and Preventive Medicine*, 15(1), 9–17. https://doi.org/10.1007/s12199-008-0068-3

[29] Park, B.-J., Furuya, K., Kasetani, T., Takayama, N., Kagawa, T., & Miyazaki, Y. (2011). Relationship between psychological responses and physical environments in forest settings. *Landscape and Urban Planning,* 102(1), 24–32 https://doi.org/10.1016/j.landurbplan.2011.03.005

[30] Ohtsuka, Y., Yabunaka, N., & Takayama, S. (1998). Shinrin-yoku (forest-air bathing and walking) effectively decreases blood glucose levels in diabetic patients. *International Journal of Biometeorology*, 41(3), 125–127. https://doi.org/10.1007/s004840050064

[31] Lee, J., Park, B.-J., Tsunetsugu, Y., Ohira, T., Kagawa, T., & Miyazaki, Y. (2011). Effect of forest bathing on physiological and psychological responses in young Japanese male subjects. *Public Health,* 125(2), 93–100. https://doi.org/10.1016/j.puhe.2010.09.005

[32] Park, B. J., Tsunetsugu, Y., Kasetani, T., Kagawa, T., & Miyazaki, Y. (2010). The physiological effects of Shinrin-yoku (taking in the forest atmosphere or forest bathing): Evidence from field experiments in 24 forests across Japan. *Environmental Health and Preventive Medicine,* 15(1), 18–26. https://doi.org/10.1007/s12199-009-0086-9

[33] Furness, J. B. (2009). Parasympathetic Nervous System. In *Encyclopedia of Neuroscience* (pp. 445–446). Elsevier. https://doi.org/10.1016/B978-008045046-9.01990-2

[34] Lee, J., Park, B.-J., Tsunetsugu, Y., Kagawa, T., & Miyazaki, Y. (2009). Restorative effects of viewing real forest landscapes, based on a comparison with urban landscapes. *Scandinavian Journal of Forest Research,* 24(3), 227–234. https://doi.org/10.1080/02827580902903341

[35] Furness, J. B. (2009). Parasympathetic Nervous System. In *Encyclopedia of Neuroscience* (pp. 445–446). Elsevier. https://doi.org/10.1016/B978-008045046-9.01990-2

[36] Bowler, D. E., Buyung-Ali, L. M., Knight, T. M., & Pullin, A. S. (2010). A systematic review of evidence for the added benefits to health of exposure to natural environments. *BMC Public Health,* 10(1), 456. https://doi.org/10.1186/1471-2458-10-456

[37] Tim Gill. (2014). *The benefits of children's engagement with nature: A systematic literature review,* 24(2), 10. https://doi.org/10.7721/chilyoutenvi.24.2.0010

Environmental exposure

[38] Landrigan, P. J., Fuller, R., Acosta, N. J. R., Adeyi, O., Arnold, R., Basu, N. (Nil), Baldé, A. B., Bertollini, R., Bose-O'Reilly, S., Boufford, J. I., Breysse, P. N., Chiles, T., Mahidol, C., Coll-Seck, A. M., Cropper, M. L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., … Zhong, M. (2018). The Lancet Commission on pollution and health. *The Lancet,* 391(10119), 462–512. https://doi.org/10.1016/S0140-6736(17)32345-0

[39] McDonald, R.I., Biswas, T., Sachar, C., Housman, I., Boucher, T.M., Balk, D., et al. (2021). The tree cover and temperature disparity in US urbanized areas: Quantifying the association with income across 5,723 communities. *PLOS ONE,* 16, e0249715.

[40] Landrigan, P. J., Fuller, R., Acosta, N. J. R., Adeyi, O., Arnold, R., Basu, N. (Nil), Baldé, A. B., Bertollini, R., Bose-O'Reilly, S., Boufford, J. I., Breysse, P. N., Chiles, T., Mahidol, C., Coll-Seck, A. M., Cropper, M. L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., … Zhong, M. (2018). The Lancet Commission on pollution and health. *The Lancet,* 391(10119), 462–512.

[41] Landrigan, P. J., Fuller, R., Acosta, N. J. R., Adeyi, O., Arnold, R., Basu, N. (Nil), Baldé, A. B., Bertollini, R., Bose-O'Reilly, S., Boufford, J. I., Breysse, P. N., Chiles, T., Mahidol, C., Coll-Seck, A. M., Cropper, M. L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., … Zhong, M. (2018). The Lancet Commission on pollution and health. *The Lancet,* 391(10119), 462–512. https://doi.org/10.1016/S0140-6736(17)32345-0

[42] Ibid.

[43] Forouzanfar, M. H., Afshin, A., Alexander, L. T., Anderson, H. R., Bhutta, Z. A., Biryukov, S., Brauer, M., Burnett, R., Cercy, K., Charlson, F. J., Cohen, A. J., Dandona, L., Estep, K., Ferrari, A. J., Frostad, J. J., Fullman, N., Gething, P. W., Godwin, W. W., Griswold, M., … Murray, C. J. L. (2016). Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: A systematic analysis for the Global Burden of Disease Study 2015. *The Lancet,* 388(10053), 1659–1724. https://doi.org/10.1016/S0140-6736(16)31679-8

[44] *State of Global Air/*2020 *A Special Report on Global Exposure to Air Pollution and its Disease Burden.* (2019). Health Effects Institute and State of Global Air. https://www.stateofglobalair.org/sites/default/files/documents/2020-10/soga-2020-report-10-26_0.pdf

[45] Household air pollution and health. (2018, May 8). *World Health Organization.* https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health

[46] Forouzanfar, M. H., Afshin, A., Alexander, L. T., Anderson, H. R., Bhutta, Z. A., Biryukov, S., Brauer, M., Burnett, R., Cercy, K., Charlson, F. J., Cohen, A. J., Dandona, L., Estep, K., Ferrari, A. J., Frostad, J. J., Fullman, N., Gething, P. W., Godwin, W. W., Griswold, M., … Murray, C. J. L. (2016). Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: A systematic analysis for the Global Burden of Disease Study 2015. *The Lancet,* 388(10053), 1659–1724. https://doi.org/10.1016/S0140-6736(16)31679-8

[47] Ibid.

[48] Landrigan, P. J., Fuller, R., Acosta, N. J. R., Adeyi, O., Arnold, R., Basu, N. (Nil), Baldé, A. B., Bertollini, R., Bose-O'Reilly, S., Boufford, J. I., Breysse, P. N., Chiles, T., Mahidol, C., Coll-Seck, A. M., Cropper, M. L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., … Zhong, M. (2018). The Lancet Commission on pollution and health. *The Lancet,* 391(10119), 462–512. https://doi.org/10.1016/S0140-6736(17)32345-0

[49] Nowak, D. J., & Van den Bosch, M. (2019). Tree and forest effects on air quality and human health in and around urban areas. Santé Publique, 13;S1(HS):153-161. doi: 10.3917/spub.190.0153 S1(HS), 153–161.

[50] van der Werf, G. R., Morton, D. C., DeFries, R. S., Olivier, J. G. J., Kasibhatla, P. S., Jackson, R. B., Collatz, G. J., & Randerson, J. T. (2009). CO_2 emissions from forest loss. *Nature Geoscience,* 2(11), 737–738. https://doi.org/10.1038/ngeo671

[51] Johnston, F. H., Henderson, S. B., Chen, Y., Randerson, J. T., Marlier, M., Defries, R. S., Kinney, P., Bowman, D. M. J. S., & Brauer, M. (2012). Estimated global mortality attributable to smoke from landscape fires. *Environmental Health Perspectives,* 120(5), 695–701. https://doi.org/10.1289/ehp.1104422

[52] Reddington, C. L., Butt, E. W., Ridley, D. A., Artaxo, P., Morgan, W. T., Coe, H., & Spracklen, D. V. (2015). Air quality and human health improvements from reductions in deforestation-related fire in Brazil. *Nature Geoscience,* 8(10), 768–771. https://doi.org/10.1038/ngeo2535

[53] The US Environmental Protection Agency defines particulate matter as "a mixture of solid particles and liquid droplets found in the air. Some particles such as dust, dirt, soot, or smoke are large or dark enough to be seen with the naked eye. Others are so small they can only be detected using an electron microscope." Particulate Matter (PM) Pollution. (n.d.). *United States Environmental Protection Agency.* https://www.epa.gov/pm-pollution/particulate-matter-pm-basics

[54] Knight, K. W., & Rosa, E. A. (2012). Household dynamics and fuelwood consumption in developing countries: A cross-national analysis. *Population and Environment,* 33(4), 365–378. https://doi.org/10.1007/s11111-011-0151-3

[55] Hofstad, O., Köhlin, G., & Namaalwa, J. (2009). How can emissions from woodfuel be reduced. https://www.cifor.org/publications/pdf_files/Books/BAngelsen090219.pdf

[56] Indoor air pollution and household energy. (n.d.). *World Health Organization.* https://www.who.int/heli/risks/indoorair/indoorair/en/

[57] Chidumayo, E. N., & Gumbo, D. J. (2013). The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis. *Energy for Sustainable Development,* 17(2), 86–94. https://doi.org/10.1016/j.esd.2012.07.004

[58] *State of Global Air/2020 A Special Report on Global Exposure to Air Pollution and its Disease Burden.* (2019). Health Effects Institute and State of Global Air. https://www.stateofglobalair.org/sites/default/files/documents/2020-10/soga-2020-report-10-26_0.pdf

[59] Household air pollution and health. (2018, May 8). W*orld Health Organization.* https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health

[60] Stolton, S., & Dudley, N. (2007). *Managing forests for cleaner water for urban populations.* FAO. http://www.fao.org/3/a1598e/a1598e10.pdf
[61] Herrera, D., Ellis, A., Fisher, B., Golden, C. D., Johnson, K., Mulligan, M., Pfaff, A., Treuer, T., & Ricketts, T. H. (2017). Upstream watershed condition predicts rural children's health across 35 developing countries. *Nature Communications,* 8(1), 811. https://doi.org/10.1038/s41467-017-00775-2
[62] United Nations (2018). Sustainable Development Goal 6 Synthesis. Report 2018 on Water and Sanitation. New York.
[63] International Union of Conservation of Nature (IUCN): How forests help cities manage water. 2018.
[64] Gleick, P. H. (2002). Dirty Water: Estimated Deaths from Water-Related Diseases 2000–2020. https://www.researchgate.net/publication/252788649_Dirty_Water_Estimated_Deaths_from_Water-Related_Diseases_2000-2020
[65] *The Global Handwashing Partnership.* (n.d.). Retrieved October 4, 2020, from https://globalhandwashing.org/about-handwashing/why-handwashing/health/
[66] Diarrhoea. (2019, October). *UNICEF*. https://data.unicef.org/topic/child-health/diarrhoeal-disease/
[67] The World Health Organization: The Global Impact of Respiratory Disease Second Edition
[68] Herrera, D., Ellis, A., Fisher, B., Golden, C. D., Johnson, K., Mulligan, M., Pfaff, A., Treuer, T., & Ricketts, T. H. (2017). Upstream watershed condition predicts rural children's health across 35 developing countries. *Nature Communications,* 8(1), 811. https://doi.org/10.1038/s41467-017-00775-2
[69] Diarrhoeal disease. (2017, May 2). *World Health Organization*. https://www.who.int/news-room/fact-sheets/detail/diarrhoeal-disease
[70] Pienkowski, T., Dickens, B. L., Sun, H., & Carrasco, L. R. (2017). Empirical evidence of the public health benefits of tropical forest conservation in Cambodia: A generalised linear mixed-effects model analysis. *The Lancet Planetary Health,* 1(5), e180–e187. https://doi.org/10.1016/S2542-5196(17)30081-5
[71] Note: Dense and mixed forest coverage were derived from Open Development Cambodia, and forest loss was calculated from 2000 to 2004, 2004 to 2009, and 2009 to 2014.

Nutrition and food security

[72] Jamnadass, R., McMullin, S., Iiyama, M., Dawson, I. K., Powell, B., Termote, C., & Serban, A. (2015). Understanding the Roles of Forests and Tree-based Systems in Food Provision. In B. Vira, C. Wildburger, & S. Mansourian (Eds.), *Forests and Food: Addressing hunger and nutrition across sustainable landscapes*: Open Book Publishers. http://books.openedition.org/obp/2756
[73] *State of Global Air/2020 A Special Report on Global Exposure to Air Pollution and its Disease Burden.* (2019). Health Effects Institute and State of Global Air. https://www.stateofglobalair.org/sites/default/files/soga_2019_report.pdf
[74] Karjalainen, E., Sarjala, T., & Raitio, H. (2009). Promoting human health through forests: Overview and major challenges. *Environmental Health and Preventive Medicine*, 15(1), 1. https://doi.org/10.1007/s12199-008-0069-2
[75] Healthy Diets. (n.d.). *NCD Alliance* https://ncdalliance.org/why-ncds/ncd-prevention/healthy-diets
[76] Johnson, K. B., Jacob, A., & Brown, M. E. (2013). Forest cover associated with improved child health and nutrition: Evidence from the Malawi Demographic and Health Survey and satellite data. *Global Health: Science and Practice,* 1(2), 237–248. https://doi.org/10.9745/GHSP-D-13-00055
[77] Ibid.
[78] Improving Nutrition and Health for Pregnant and Lactating Women. (n.d.). *Scaling Up Nutrition Movement.* https://scalingupnutrition.org/news/improving-nutrition-and-health-for-pregnant-and-lactating-women/
[79] Fisher, B., Herrera, D., Adams, D., Fox, H. E., Gallagher, L., Gerkey, D., Gill, D., Golden, C. D., Hole, D., Johnson, K., Mulligan, M., Myers, S. S., Naidoo, R., Pfaff, A., Rasolofoson, R., Selig, E. R., Tickner, D., Treuer, T., & Ricketts, T. (2019). Can nature deliver on the sustainable development goals? *The Lancet Planetary Health,* 3(3), e112–e113. https://doi.org/10.1016/S2542-5196(18)30281-X
[80] Note: controlling for key variables (e.g., rainfall and education).
[81] Ickowitz, A., Powell, B., Salim, M. A., & Sunderland, T. C. H. (2014). Dietary quality and tree cover in Africa. *Global Environmental Change*, 24, 287-294. https://doi.org/10.1016/j.gloenvcha.2013.12.001
[82] Fungo, R., Muyonga, J., Kabahenda, M., Kaaya, A., Okia, C. A., Donn, P., Mathurin, T., Tchingsabe, O., Tiegehungo, J. C., Loo, J., & Snook, L. (2016). Contribution of forest foods to dietary intake and their association with household food insecurity: A cross-sectional study in women from rural Cameroon. *Public Health Nutrition,* 19(17), 3185–3196. https://doi.org/10.1017/S1368980016001324
[83] Sunderland, T., Powell, B., Ickowitz, A., Foli, S., Pinedo-Vasquez, M., Nasi, R., & Padoch, C. (2013). *Food security and nutrition: The role of forests.* https://www.cifor.org/publications/pdf_files/WPapers/DPSunderland1301.pdf
[84] Colfer, C., Sheil, D., & Kishi, M. (2006). *Forests and Human Health: Assessing the Evidence.* https://doi.org/10.17528/cifor/002037
[85] Food security and nutrition and sustainable agriculture. (n.d.). United Nations. https://sustainabledevelopment.un.org/topics/foodagriculture
[86] Rasolofoson, R. A., Ricketts, T. H., Jacob, A., Johnson, K. B., Pappinen, A., & Fisher, B. (2020). Forest Conservation: A potential nutrition-sensitive intervention in low- and middle-income countries. *Frontiers in Sustainable Food Systems,* 4(20). https://doi.org/10.3389/fsufs.2020.00020
[87] Powell, B., Maundu, P., Kuhnlein, H. V., & Johns, T. (2013). Wild foods from farm and fest in the East Usambara Mountains, Tanzania. *Ecology of Food and Nutrition*, 52(6), 451–478. https://doi.org/10.1080/03670244.2013.768122

Physical hazards

[88] *Poverty & Death: Disaster Mortality, 1996-2015.* The Centre for Research on the Epidemiology of Disasters (CRED) and the UN Office for Disaster Risk Reduction. http://cred.be/sites/default/files/CRED_Disaster_Mortality.pdf
[89] Haesen, S., Lembrechts, J.J., De Frenne, P., Lenoir, J., Aalto, J., Ashcroft, M.B., et al. (2021). Forest temp-sub-canopy microclimate temperatures of European forests. *Global Change Biology*, doi: 10.1111/gcb.15892.
[90] Dudley, N., Buyck, C., Furuta, N., Pedrot, C., Renaud, F., and K. Sudmeier-Rieux (2015). Protected Areas as Tools for Disaster Risk Reduction. A handbook for practitioners. Tokyo and Gland, Switzerland: MOEJ and IUCN.
[91] Alves de Oliveira, B.F., Bottino, M.J., Nobre, P. & Nobre, C.A. (2021). Deforestation and climate change are projected to increase heat stress risk in the Brazilian Amazon. *Communications Earth & Environment*, 2, 1–8.
[92] Chou, C., Chiang, J.C.H., Lan, C.-W., Chung, C.-H., Liao, Y.-C. & Lee, C.-J. (2013). Increase in the range between wet and dry season precipitation. *Nature Geosci,* 6, 263–267.
[93] Bathurst, J.C., Birkinshaw, S.J., Cisneros Espinosa, F. & Iroumé, A. (2017). Forest Impact on Flood Peak Discharge and Sediment Yield in Streamflow. In: *River System Analysis and Management* (ed. Sharma, N.). Springer, Singapore, pp. 15–29.
[94] Hümann, M., Schüler, G., Müller, C., Schneider, R., Johst, M. & Caspari, T. (2011). Identification of runoff processes – The impact of different forest types and soil properties on runoff formation and floods. *Journal of Hydrology*, 409, 637–649.

[95] Bischetti. (2018). Forests and landslides: the role of trees and forests in the prevention of landslides and rehabilitation of landslide-affected areas in Asia. G.B. & FAO Regional Office for Asia and the Pacific. (2013).
[96] Laurance, W.F. & Arrea, I.B. (2017). Roads to riches or ruin? *Science*, 358, 442–444. doi: 10.1126/science.aao0312
[97] Cannon, S.H. & DeGraff, J. (2009). The Increasing Wildfire and Post-Fire Debris-Flow Threat in Western USA, and Implications for Consequences of Climate Change. In: *Landslides – Disaster Risk Reduction* (eds. Sassa, K. & Canuti, P.). Springer, Berlin, Heidelberg, pp. 177–190.
[98] Liu, Q., Ruan, C., Zhong, S., Li, J., Yin, Z. & Lian, X. (2018). Risk assessment of storm surge disaster based on numerical models and remote sensing. *International Journal of Applied Earth Observation and Geoinformation*, 68, 20–30.
[99] Husrin, S., Strusińska, A. & Oumeraci, H. (2012). Experimental study on tsunami attenuation by mangrove forest. *Earth Planet Sp*, 64, 15.
[100] Information and public health advice: Heat and health. (n.d.). *World Health Organization.* https://www.who.int/globalchange/publications/HeatstressAnnouncement_250818.pdf?ua=1
[101] Sanz-Barbero, B., Linares, C., Vives-Cases, C., González, J.L., López-Ossorio, J.J. & Díaz, J. (2018). Heat wave and the risk of intimate partner violence. *Science of The Total Environment*, 644, 413–419.
[102] Wolff, N. H., Masuda, Y. J., Meijaard, E., Wells, J. A., & Game, E. T. (2018). Impacts of tropical deforestation on local temperature and human well-being perceptions. *Global Environmental Change,* 52, 181–189. https://doi.org/10.1016/j.gloenvcha.2018.07.004
[103] Haesen, S., Lembrechts, J.J., De Frenne, P., Lenoir, J., Aalto, J., Ashcroft, M.B., et al. (2021). ForestTemp – Sub-canopy microclimate temperatures of European forests. *Global Change Biology*, doi: 10.1111/gcb.15892.
[104] Raymond, C., Matthews, T. & Horton, R.M. (2020). The emergence of heat and humidity too severe for human tolerance. *Science Advances,* 6, eaaw1838.
[105] Ziter, C.D., Pedersen, E.J., Kucharik, C.J. & Turner, M.G. (2019). Scale-dependent interactions between tree canopy cover and impervious surfaces reduce daytime urban heat during summer. *Proceedings of the National Academy of Sciences* USA, 116, 7575–7580.
[106] Wolff, N. H., Masuda, Y. J., Meijaard, E., Wells, J. A., & Game, E. T. (2018). Impacts of tropical deforestation on local temperature and human well-being perceptions. *Global Environmental Change*, 52, 181–189. https://doi.org/10.1016/j.gloenvcha.2018.07.004

Infectious diseases

[107] The top 10 causes of death. (2018, May 24). *World Health Organization.* https://www.who.int/news-room/fact-sheets/detail/the-top-10-causes-of-death
[108] Global public health threats in the 21st century. (2013, July 29). *World Health Organization.* https://www.imf.org/external/pubs/ft/fandd/2014/12/pdf/jonas.pdf
[109] Neglected Zoonotic Diseases. (2011, April 7). *World Health Organization.* https://www.who.int/news-room/facts-in-pictures/detail/neglected-zoonotic-tropical-diseases
[110] Loh, E. H., Zambrana-Torrelio, C., Olival, K. J., Bogich, T. L., Johnson, C. K., Mazet, J. A. K., Karesh, W., & Daszak, P. (2015). Targeting transmission pathways for emerging zoonotic disease surveillance and control. *Vector-Borne and Zoonotic Diseases,* 15(7), 432–437. https://doi.org/10.1089/vbz.2013.1563
[111] Patz, J. A., Daszak, P., Tabor, G. M., Aguirre, A. A., Pearl, M., Epstein, J., Wolfe, N. D., Kilpatrick, A. M., Foufopoulos, J., Molyneux, D., Bradley, D. J., & Members of the Working Group on Land Use Change Disease Emergence. (2004). Unhealthy landscapes: Policy recommendations on land use change and infectious disease emergence. *Environmental Health Perspectives*, 112(10), 1092–1098. https://doi.org/10.1289/ehp.6877
[112] Hosseini, P. R., Mills, J. N., Prieur-Richard, A.-H., Ezenwa, V. O., Bailly, X., Rizzoli, A., Suzán, G., Vittecoq, M., García-Peña, G. E., Daszak, P., Guégan, J.-F., & Roche, B. (2017). Does the impact of biodiversity differ between emerging and endemic pathogens? The need to separate the concepts of hazard and risk. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 372(1722), 20160129. https://doi.org/10.1098/rstb.2016.0129
[113] Kodama, F., Yamaguchi, H., Park, E., Tatemoto, K., Sashika, M., Nakao, R., et al. (2021). A novel nairovirus associated with acute febrile illness in Hokkaido, Japan. *Nat Commun*, 12, 5539.
[114] Hosseini, P. R., Mills, J. N., Prieur-Richard, A.-H., Ezenwa, V. O., Bailly, X., Rizzoli, A., Suzán, G., Vittecoq, M., García-Peña, G. E., Daszak, P., Guégan, J.-F., & Roche, B. (2017). Does the impact of biodiversity differ between emerging and endemic pathogens? The need to separate the concepts of hazard and risk. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 372(1722), 20160129. https://doi.org/10.1098/rstb.2016.0129
[115] LoGiudice, K., Ostfeld, R. S., Schmidt, K. A., & Keesing, F. (2003). The ecology of infectious disease: Effects of host diversity and community composition on Lyme disease risk. *Proceedings of the National Academy of Sciences*, 100(2), 567–571. https://doi.org/10.1073/pnas.0233733100
[116] Olivero, J., Fa, J. E., Real, R., Márquez, A. L., Farfán, M. A., Vargas, J. M., Gaveau, D., Salim, M. A., Park, D., Suter, J., King, S., Leendertz, S. A., Sheil, D., & Nasi, R. (2017). Recent loss of closed forests is associated with Ebola virus disease outbreaks. *Scientific Reports,* 7(1), 14291. https://doi.org/10.1038/s41598-017-14727-9
[117] Pfaeffle, M., Littwin, N., & Petney, T. N. (2015). The relationship between biodiversity and disease transmission risk. *Research and Reports in Biodiversity Studies,* 9. https://doi.org/10.2147/RRBS.S52433
[118] O'Bryan, C. J., Braczkowski, A. R., Magalhães, R. J. S., & McDonald-Madden, E. (2020). Conservation epidemiology of predators and scavengers to reduce zoonotic risk. *The Lancet Planetary Health*, 4(8), e304–e305. https://doi.org/10.1016/S2542-5196(20)30166-2
[119] Guerra, C. A., Snow, R. W., & Hay, S. I. (2006). A global assessment of closed forests, deforestation and malaria risk. *Annals of Tropical Medicine and Parasitology*, 100(3), 189–204. PubMed. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3204444/
[120] World Health Organization. (2019). *World Health Organization.*
[121] F. Austin, K., O. Bellinger, M., Rana, P., & 1 Department of Sociology and Anthropology, Lehigh University. (2017). Anthropogenic forest loss and malaria prevalence: A comparative examination of the causes and disease consequences of deforestation in developing nations. *AIMS Environmental Science,* 4(2), 217–231. https://doi.org/10.3934/environsci.2017.2.217
[122] F. Austin, K., O. Bellinger, M., Rana, P., & 1 Department of Sociology and Anthropology, Lehigh University. (2017). Anthropogenic forest loss and malaria prevalence: A comparative examination of the causes and disease consequences of deforestation in developing nations. *AIMS Environmental Science*, 4(2), 217–231 https://doi.org/10.3934/environsci.2017.2.217
[123] MacDonald, A. J., & Mordecai, E. A. (2019). Amazon deforestation drives malaria transmission, and malaria burden reduces forest clearing. *Proceedings of the National Academy of Sciences*, 116(44), 22212. https://doi.org/10.1073/pnas.1905315116
[124] Guerra, C. A., Snow, R. W., & Hay, S. I. (2006). A global assessment of closed forests, deforestation and malaria risk. *Annals of Tropical Medicine and Parasitology,* 100(3), 189–204. PubMed. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3204444/#!po=58.9286
[125] Ibid.

[126] Ostfeld, R., Canham, C., Oggenfuss, K., Winchcombe, R., & Keesing, F. (2006). Climate, deer, rodents, and acorns as determinants of variation in Lyme-disease risk. *PLOS Biology*, 4, e145. https://doi.org/10.1371/journal.pbio.0040145
[127] Lyme Disease: Data and Surveillance. (n.d.). *Centers for Disease Control and Prevention*. https://www.cdc.gov/lyme/datasurveillance/index.html
[128] Allan, B. F., Keesing, F., & Ostfeld, R. S. (2003). Effect of forest fragmentation on Lyme disease risk.. *Conservation Biology*, 17(1), 267–272. https://doi.org/10.1046/j.1523-1739.2003.01260.x
[129] Brownstein, J. S., Skelly, D. K., Holford, T. R., & Fish, D. (2005). Forest fragmentation predicts local scale heterogeneity of Lyme disease risk. *Oecologia,* 146(3), 469–475. https://doi.org/10.1007/s00442-005-0251-9
[130] Larsen, A. E., MacDonald, A. J., & Plantinga, A. J. (2014). Lyme disease risk influences human settlement in the wildland-urban interface: Evidence from a longitudinal analysis of counties in the northeastern United States. T*he American Journal of Tropical Medicine and Hygiene,* 91(4), 747–755. PubMed. https://doi.org/10.4269/ajtmh.14-0181
[131] Salkeld, D.J., Lagana, D.M., Wachara, J., Porter, W.T. & Nieto, Salkeld, D.J., Lagana, D.M., Wachara, J., Porter, W.T. & Nieto, N.C. (2021). Examining Prevalence and Diversity of Tick-Borne Pathogens in Questing *Ixodes pacificus* Ticks in California. Applied and Environmental Microbiology, 87, e00319-21.
[132] LoGiudice, K., Ostfeld, R. S., Schmidt, K. A., & Keesing, F. (2003). The ecology of infectious disease: Effects of host diversity and community composition on Lyme disease risk. *Proceedings of the National Academy of Sciences,* 100(2), 567–571. https://doi.org/10.1073/pnas.0233733100
[133] Allan, B. F., Keesing, F., & Ostfeld, R. S. (2003). Effect of forest fragmentation on Lyme disease risk. *Conservation Biology*, 17(1), 267–272. https://doi.org/10.1046/j.1523-1739.2003.01260.x
[134] Brownstein, J. S., Skelly, D. K., Holford, T. R., & Fish, D. (2005). Forest fragmentation predicts local scale heterogeneity of Lyme disease risk. *Oecologia,* 146(3), 469–475.
[135] *Dengue and severe dengue.* (n.d.). Retrieved October 5, 2020, from https://www.who.int/news-room/fact-sheets/detail/dengue-and-severe-dengue
[136] *Japanese encephalitis.* (n.d.). Retrieved October 5, 2020, from https://www.who.int/news-room/fact-sheets/detail/japanese-encephalitis
[137] *Global health– Newsroom – Yellow fever.* (2019, February 19). https://www.cdc.gov/globalhealth/newsroom/topics/yellowfever/index.html
[138] Mondet, B. (2001). [Yellow fever epidemiology in Brazil]. *Bulletin De La Societe De Pathologie Exotique* (1990), 94(3), 260–267.
[139] Vanwambeke, S. O., Lambin, E. F., Eichhorn, M. P., Flasse, S. P., Harbach, R. E., Oskam, L., Somboon, P., van Beers, S., van Benthem, B. H. B., Walton, C., & Butlin, R. K. (2007). Impact of land-use change on dengue and malaria in northern Thailand. *EcoHealth,* 4(1), 37–51. https://doi.org/10.1007/s10393-007-0085-5
[140] Mackenzie, J. S., & Williams, D. T. (2009). The Zoonotic zoonotic flaviviruses of southern, south-eastern and eastern Asia and Australasia: the potential for emergent viruses. *Zoonoses and Public Health,* 56(6–7), 338–356. https://doi.org/10.1111/j.1863-2378.2008.01208.x
[141] Colfer, C., Sheil, D., & Kishi, M. (2006). *Forests and Human Health: Assessing the Evidence.* http://www.cifor.org/publications/pdf_files/OccPapers/OP-45.pdf
[142] NIAID Emerging Infectious Diseases/ Pathogens. (n.d.). NIH: National Institute of Allergy and Infectious Diseases Logo. https://www.niaid.nih.gov/research/emerging-infectious-diseases-pathogens
[143] Fauci, A. S. (2005). Emerging and reemerging infectious diseases: the perpetual challenge. *Academic Medicine,* 80(12). https://journals.lww.com/academicmedicine/Fulltext/2005/12000/Emerging_and_Reemerging_Infectious_Diseases__The.2.aspx
[144] Ebola virus disease. (n.d.). *World Health Organization.* https://www.who.int/health-topics/ebola/#tab=tab_1
[145] Keita, A.K., Koundouno, F.R., Faye, M., Düx, A., Hinzmann, J., Diallo, H., et al. (2021). Resurgence of Ebola virus in 2021 in Guinea suggests a new paradigm for outbreaks. *Nature,* 597, 539–543.
[146] Ebola Virus Disease Distribution Map: Cases of Ebola virus disease in Africa since 1976. (n.d.). *Centers for Disease Control and Prevention.* https://www.cdc.gov/vhf/ebola/history/distribution-map.html
[147] *DRC Ebola outbreaks Crisis update – September 2020*. (2020, September 4). https://www.msf.org/drc-ebola-outbreak-crisis-update
[148] Olivero, J., Fa, J. E., Real, R., Márquez, A. L., Farfán, M. A., Vargas, J. M., Gaveau, D., Salim, M. A., Park, D., Suter, J., King, S., Leendertz, S. A., Sheil, D., & Nasi, R. (2017). Recent loss of closed forests is associated with Ebola virus disease outbreaks. *Scientific Reports,* 7(1), 14291. https://doi.org/10.1038/s41598-017-14727-9
[149] Rulli, M. C., Santini, M., Hayman, D. T. S., & D'Odorico, P. (2017). The nexus between forest fragmentation in Africa and Ebola virus disease outbreaks. *Scientific Reports,* 7(1), 41613. https://doi.org/10.1038/srep41613
[150] *WHO coronavirus disease (COVID-19) dashboard.* (n.d.). Retrieved February 2, 2022, from https://covid19.who.int
[151] Salata, C., Calistri, A., Parolin, C., & Palù, G. (2019). Coronaviruses: A paradigm of new emerging zoonotic diseases. *Pathogens and Disease,* 77(9), ftaa006. https://doi.org/10.1093/femspd/ftaa006
[152] Salata, C., Calistri, A., Parolin, C., & Palù, G. (2019). Coronaviruses: A paradigm of new emerging zoonotic diseases. *Pathogens and Disease,* 77(9), ftaa006. https://doi.org/10.1093/femspd/ftaa006
[153] Chaw, S.-M., Tai, J.-H., Chen, S.-L., Hsieh, C.-H., Chang, S.-Y., Yeh, S.-H., Yang, W.-S., Chen, P.-J., & Wang, H.-Y. (2020). The origin and underlying driving forces of the SARS-CoV-2 outbreak. *Journal of Biomedical Science,* 27(1), 73. https://doi.org/10.1186/s12929-020-00665-8

What Is Needed? Embracing a Systems Approach

[154] Sayer, J., Elliot, C., & Maginnis, S. (2003). Protect, manage and restore: Conserving forests in multi-functional landscapes. Paper Submitted to the XII Forest Congress, Quebec, Canada. http://www.fao.org/3/XII/0484-C3.htm
[155] Seddon, N., Smith, A., Smith, P., Key, I., Chausson, A., Girardin, C., . . . Turner, B. (2021). Getting the message right on nature-based solutions to climate change. *Global Change Biology*, 27(8), 1518-1546. https://doi.org/10.1111/gcb.15513
[156] Hanewinkel, M., Hummel, S., & Albrecht, A. (2011). Assessing natural hazards in forestry for risk management: A review. *European Journal of Forest Research*, 13

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Illustrating the Evidence Connecting Forests and Human Health