IUFRO World Series Vol. 41

FORESTS AND TREES FOR HUMAN HEALTH: PATHWAYS, IMPACTS, CHALLENGES AND RESPONSE OPTIONS

A Global Assessment Report

Editors: Cecil Konijnendijk, Dikshya Devkota,
Stephanie Mansourian and Christoph Wildburger

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Funding support for this publication was provided by the German Federal Ministry for Economic Cooperation and Development, the Ministry for Foreign Affairs of Finland, the United States Forest Service and the Austrian Federal Ministry of Agriculture, Forestry, Regions and Water Management. The views expressed within this publication do not necessarily reflect the official policy of the governments represented by these institutions/agencies or the institutions to whom the authors are affiliated.

Publisher:
International Union of Forest Research Organizations (IUFRO)

Recommended catalogue entry:
Cecil Konijnendijk, Dikshya Devkota, Stephanie Mansourian & Christoph Wildburger (eds.), 2023.
Forests and Trees for Human Health: Pathways, Impacts, Challenges and Response Options.
A Global Assessment Report.
IUFRO World Series Volume 41. Vienna. 232 p.

ISBN 978-3-903345-20-1

Published by:
International Union of Forest Research Organizations (IUFRO)

Available from:
IUFRO Headquarters
Secretariat
Marxergasse 2
1030 Vienna
Austria

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www.iufro.org

Layout: Eugénie Hadinoto
Illustrations: Karin Grönberg, pp.20, 21, 203, 204, 205, 206, 207
Cover photographs: Olya Humeniuk, John Parrotta, Sital Uprety
Printed in Austria by Eigner Druck, Tullner Straße 311, 3040 Neulengbach, Austria

Preface

Since its establishment in 2007, the Global Forest Expert Panels (GFEP) initiative of the Collaborative Partnership on Forests (CPF) has been effectively linking scientific knowledge with political decision-making on forests. GFEP responds to critical forest-related policy concerns by consolidating available scientific knowledge and expertise on these issues at the global level. It provides decision-makers with the most relevant, objective and accurate information and thus makes essential contributions to increasing the quality and effectiveness of international forest governance.

This report titled, “Forests and Trees for Human Health: Pathways, Impacts, Challenges and Response Options”, presents the results of the eighth global scientific assessment undertaken within the framework of GFEP. All GFEP assessments are prepared by internationally recognized scientists from varied professional backgrounds and geographical contexts. The publications are presented to stakeholders across relevant international policy fora to support more coherent policies on the role of forests in addressing the environmental, social and economic challenges reflected in the United Nations Sustainable Development Goals (SDGs).

In recent years, global public health challenges have taken centre stage. The COVID-19 pandemic has created severe healthcare disruptions and reversed decades of health and economic improvements. In addition to infectious diseases, the surge of non-communicable diseases has also become a major public health threat. Global factors, including urbanisation and climate change, further exacerbate such adverse effects on human health.

Forests have immense potential to contribute to the mental, physical and social health and wellbeing of humans. Forests, trees and green spaces can provide nutritious food and medicines, support climate change mitigation and adaptation, filter air and water pollutants and offer areas of recreation. At the same time, poor practices of conservation and management of forests can result in adverse effects on human health with the emergence of zoonotic diseases, forest fires and allergic outcomes. This report consolidates available scientific evidence on the interlinkages between forests and human health and identifies trade-offs, synergies, and opportunities for strengthening policies, programmes and activities to enhance the positive health impacts of forests in diverse populations and settings.

The vast potential of forests, and nature, to contribute to positive health outcomes is increasingly recognised and promoted by policy processes at the international level. For example, the recently agreed Kunming-Montreal Biodiversity Framework calls for the adoption of integrative approaches such as One Health and ‘Good health and wellbeing for all’ is the third goal of the 2030 Agenda for Sustainable Development. Scientific reports like this are important tools for supporting policymakers and stakeholders in their ambition to ensure sustainable development that takes into consideration the health of humans, other species and the planet as a whole.

I would like to thank the Chair of the Global Forest Expert Panel on Forests and Human Health Cecil Konijnendijk, GFEP Coordinator Christoph Wildburger, GFEP Editor Stephanie Mansourian, and GFEP Project Manager Dikshya Devkota for their excellent work in guiding the assessment process and in leading the development of this publication. It is my sincere hope that those with a responsibility for implementing the SDGs at all levels will find this report a useful source of information and inspiration.

Alexander Buck
IUFRO Executive Director

Acknowledgements

This publication is the product of the collaborative work of scientific experts within the framework of the Global Forest Expert Panel (GFEP) on Forests and Human Health, who served in different capacities as panel members and authors. We express our sincere gratitude to all of them:

Thomas Astell-Burt, Nicole Bauer, Agnes van den Berg, Gregory N. Bratman, Matthew H.M.E. Browning, Matilda van den Bosch, Victoria Bugni, Payam Dadvand, Djibril S. Dayamba, Geoffrey Donovan, Xiaoqi Feng, Elaine Fuertes, Emma Gibbs, Nelson Grima, Sarah Laird, Serge Morand, Cristina O'Callaghan-Gordo, Unnikrishnan Payyappallimana, Ranaivo Rasolofoson, Roseline Remans, David Rojas-Rueda, Giovanni Sanesi, Joshitha Sankam, Charlie Shackleton, Patricia Shanley, Shureen Faris Abdul Shukor, Giuseppina Spano, Margarita Triguero-Mas, Liisa Tyrväinen, Sjerp de Vries and Bo-Yi Yang.

Without their continued efforts and commitments, the preparation of this publication would not have been possible. We are also grateful to the institutions and organisations to which the authors are affiliated for enabling them to contribute their expertise to this assessment. At the same time, we wish to note that the views expressed within this publication do not necessarily reflect the official policy of these institutions and organisations.

We acknowledge and sincerely thank the reviewers of the report, whose valuable comments have greatly improved this publication: Christos Gallis, Christopher Golden, Qing Li, Michelle Kondo, Kjell Nilsson, Abi Tamim Vanak, Benedict Wheeler, Maxine Whittaker, Kathleen Wolf and the Food and Agriculture Organization of the United Nations (FAO).

We also gratefully acknowledge the generous financial and in-kind support provided by the German Federal Ministry for Economic Cooperation and Development, the Ministry for Foreign Affairs of Finland, the United States Forest Service and the Austrian Federal Ministry of Agriculture, Forestry, Regions and Water Management.

Our special thanks go to the IUFRO Secretariat for providing indispensable administrative and technical support. Furthermore, we would like to thank the member organisations of the Collaborative Partnership on Forests (CPF) for their in-kind contributions and overall guidance to the assessment.

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Panel Chair

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Content Editor

Christoph Wildburger
GFEP Programme Coordinator

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GFEP Project Manager

Contents

ACRONYMS, UNITS AND SYMBOLS

AD	Alzheimer's Disease
ADHD	Attention Deficit-Hyperactivity Disorder
AIDS	Acquired Immunodeficiency Syndrome
AMR	Antimicrobial Resistance
ART	Attention Restoration Theory
ASD	Autism Spectrum Disorders
BMD	Bone Mineral Density
BMI	Body Mass Index
CBD	Convention on Biological Diversity
CD	Communicable Diseases
CICES	Common International Classification of Ecosystem Services
CITRO	Center of Tropical Research Investigations
CNS	Connectedness to Nature Scores
COP	Conference of the Parties
COPD	Chronic Obstructive Pulmonary Disease
CPF	Collaborative Partnership on Forests
CRF	Climate Resilience Framework
CVD	Cardiovascular Disease
DALYs	Disability-Adjusted Life Years
DEFRA	Department for Environment, Food and Rural Affairs
DOHaD	Developmental Origins of Health and Disease
EEG	Electroencephalography
EFI	European Forest Institute
EIA	Environmental Impact Assessment
ES	Ecosystem Service
EU	European Union
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization of the United Nations
FLR	Forest Landscape Restoration
fMRI	functional Magnetic Resonance Imaging
FRA	Forest Resources Assessment
GBD	Global Burden of Disease
GBF	Global Biodiversity Framework
GBIF	Global Biodiversity Information Facility
GHQ	General Health Questionnaire
GPS	Global Positioning System
HIA	Health Impact Assessment
HDI	Human Development Index
HeReS-C	Health Restoration Soundscapes Criteria
HIC	High-Income Country
IPAQ	International Physical Activity Questionnaire
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IPLC	Indigenous Peoples and Local Communities
IQ	Intelligence Quotient
IUCN	International Union for Conservation of Nature
LDL	Low-Density Lipoproteins
LiDAR	Light Detection and Ranging
LMICs	Low- and Middle-Income Countries
MEA	Millennium Ecosystem Assessment
MERS	Middle East Respiratory Syndrome
MT	Metric Tonnes
NCD	Noncommunicable Disease
NDVI	Normalised Difference Vegetation Index
NiV	Nipah Virus
NLCD	National Landcover Database
NTFP	Non-Timber Forest Product
NWFP	Non-Wood Forest Product
NYC	New York City
OECM	Other Effective area-based Conservation Measure
OHHLEP	One Health High-Level Expert Panel
PES	Payment for Ecosystem Services
PM	Particulate Matter
POMS	Profile of Mood States
PSD	Perceived Sensory Dimension
PTSD	Post-Traumatic Stress Disorder
QoL	Quality of Life
RCT	Randomised Controlled Trial
RRI	Rights and Resources Initiative
RS	Remote Sensing
SARS	Severe Acute Respiratory Disease
SAVI	Soil Adjusted Vegetation Index
SDG	Sustainable Development Goal
SES	Socio-Economic Status
SESH	Social-Ecological System Health
SRT	Stress Reduction Theory
TEK	Traditional Ecological Knowledge
TNC	The Nature Conservancy
UK	United Kingdom of Great Britain and Northern Ireland
UNDP	United Nations Development Programme

UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFF	United Nations Forum on Forests
USA	United States of America
UV	Ultraviolet
VCF	Vegetation Continuous Fields
WEF	World Economic Forum
WHO	World Health Organization
WHOQOL	WHO Quality of Life
WOAH	World Organisation for Animal Health
WWF	Worldwide Fund for Nature
ZIKV	Zika Virus

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Chapter 1

Introduction

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1.1 Importance of Forests and Trees for Human Health

Forests, trees and green spaces[1], hereinafter 'forests and trees' for short, provide multiple goods and services that contribute to *human health*. These include medicines, nutritious foods and other *non-wood forest products* (NWFPs). Globally, at least 3.5 billion people use NWFPs, including medicinal plants (FAO, 2020a; 2020b) which are particularly important for vulnerable groups and Indigenous Peoples and local communities (IPLCs). During periods of crises, such as the COVID-19 *pandemic*, demand for forest products typically increases amongst these groups (FAO, 2020a; Kuuwill et al., 2022). Forests and trees also contribute to better health by playing a role in *climate change mitigation* and *adaptation*, contributing to regulating the carbon cycle, but also moderating the micro-climate, filtering pollutants from the air and protecting settlements against the effects of extreme events such as droughts and flash floods. They offer areas for recreation, contributing to our overall mental and physical wellbeing and make the places where we live, work, study and play, healthy and liveable. In *urban areas*, not having access to forests, trees and other green spaces can result in poor mental, physical, social, as well as spiritual, health (van den Bosch and Bird, 2018).

The link between forests, trees and health can also be negative, for example, when *zoonotic diseases* emerge from forests or when forest fires threaten people's health. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) stressed the intricate links between *biodiversity* in general and pandemics, with overexploitation of forests and wildlife as an important contributing factor (IPBES, 2020). According to global data released by WHO, wildfires and volcanic activity affected 6.2 million people between 1998 and 2017 causing 2,400 deaths from suffocation, injuries and burns (WHO, 2022b).

The relationship between forests and health is multifaceted and often modulated by other factors such as the ways in which humans manage forests and wildlife, or the presence of forest roads which open up access to forests and increase human-wildlife encounters. Pandemics such as the recent COVID-19 one can be traced back to microbes carried by animal reservoirs, but their emergence as pandemics is the result of human activities leading to global environmental changes that drive biodiversity loss and climate change, including land-use change, agricultural expansion and intensification, and wildlife trade and consumption (IPBES, 2020). Land-use change alone (which includes *deforestation*) is estimated to have caused the emergence of more than 30% of new diseases since 1960 (IPBES, 2020).

Figure 1.1

A visualisation of the benefits and contributions to the Sustainable Development Goals (SDGs) of inner forests, nearby forests and faraway forests

Source: Cities4Forests, 2022

1 All terms that are defined in the glossary of this report (Appendix 1) appear in italics the first time they are mentioned.

1.2 Public Health Challenges

According to the United Nations' estimates, less than half of the global population is covered by essential health services (WHO, 2022c). In addition, the COVID-19 pandemic has created further healthcare disruptions, which could reverse decades of health improvements, particularly in low-income countries where healthcare systems and populations are more vulnerable. Although the overall *morbidity* and *mortality* related to infectious diseases have declined over the last decades, there has been a recent surge in zoonotic diseases, such as COVID-19, Severe Acute Respiratory Disease (SARS), Middle East Respiratory Syndrome (MERS), Ebola, malaria and the avian flu due to environmental and climate disruptions. Illness and deaths from such diseases are likely to spike in the future. For instance, the range of the malaria-bearing mosquito (*Anopheles spp.*) is expected to greatly increase in the next decades due to climate change (Rupasinghe et al., 2022). Even with global warming staying under 2°C, the potential occasions for transmission of diseases from wildlife to humans are liable to double by 2070 (Carlson et al., 2022).

In addition to infectious diseases, non-communicable diseases are a major *public health* threat. Due to a shift in risk factors for poor health, the prevalence of chronic diseases such as diabetes, cancer, cardiovascular conditions, immune system disorders and depression has increased across the world (GBD 2017 Risk Factor Collaborators, 2018). Contemporary risk factors, especially in high- and middle-income countries but increasingly also in low-income areas, are dominated by lifestyle related behaviours, such as insufficient physical activity, chronic stress, social isolation and poor diets (The Lancet, 2019). Environmental factors, such as urbanisation, biodiversity loss and climate change have resulted in major threats to human health, through air pollution, noise and extreme weather events, such as heatwaves, floods, hurricanes and periods of drought (which in turn threaten food supplies) (WHO, 2022a) among others. A WHO (2016) assessment on the links between human health and environment highlights that premature death and disease can be prevented through healthier environments. No less than 24% of global deaths (and 28% of deaths among children under five) are due to modifiable environmental factors (WHO, 2016).

Climate change is an issue of major concern also from a public health perspective. Many extreme weather events and their consequences on human health can be linked to climate change (WHO, 2020).

1.3 Current State of Forests

The loss and *degradation* of forests have a negative impact on the provision of crucial *ecosystem services* (i.e., the direct and indirect benefits humans derive from *ecosystems* – MEA, 2005; FAO, 2020b). The most recent Global Forest Resources Assessment (FRA) observed that 10 million ha of forests continued to be lost each year between 2015 and 2020 (FAO, 2020b). Although forest loss continues at a significant rate, a general decrease in the overall rate of net forest loss has been observed over the decade 1990-2020 (from 7.8 million ha per year in the decade 1990-2000 to 5.2 million ha per year in 2000-2010 to 4.7 million ha per year in 2010-2020) due to reduced levels of deforestation in some countries combined with increases in *afforestation*, *reforestation* and natural expansion of forests in other areas. Global figures hide regional differences, with for example, the rate of forest loss in Africa steadily rising since 1990 (FAO, 2020b). Furthermore, changes in the amount of forest area do not paint the full picture, as the integrity and quality of forests, and their functional capacity are crucial for the provision of ecosystem services. *Forest degradation*, which is much harder to define and measure, is assumed to be much higher than deforestation. Estimates suggest that human-induced degradation affects 34% of agricultural land globally (FAO, 2022). Moreover, with the world's human population continuing to grow, the per capita area of forest is decreasing. According to the FRA (FAO, 2020b), based on data from 2015, the world has a total forest area of 4.06 billion hectares, representing 31% of the total global land area. At the time of publication, this amounted to 0.52 ha per person – although forests are not distributed equally among the world's peoples or geographies. There is often a lack of forests in urban areas where most of the world's population live (and where forest benefits are invaluable), typically because urbanisation often results in forest loss and degradation, notably, through urban sprawl.

The predominant drivers of forest loss differ by geographical region. However, the main drivers around the globe are the production of commodities (in particular soy, cattle and palm oil), forestry, shifting cultivation and fire (Curtis et al., 2018), and climate change accentuates the impact of these drivers. Ongoing urbanisation is also, to a lesser extent, a driver of forest loss, although some cities across the world have made attempts to enhance their forest and tree cover in recognition of the benefits these provide to urban dwellers.

The FRA 2020, and the recent State of the World's Forests report (FAO, 2022), also highlight that forests are exposed to many disturbances that can adversely affect their health and vitality and reduce their ability to provide a full range of goods and ecosystem services. Disturbance and threats include, for example, insects, diseases and extreme weather events – with the latter damaging 40 million ha of forests in 2015, primarily in the temperate and boreal regions. That same year, forest fires affected about 98 million hectares of forests (FAO, 2022). Tropical forests were especially hard hit, with 4% of their total area being burnt that year alone.

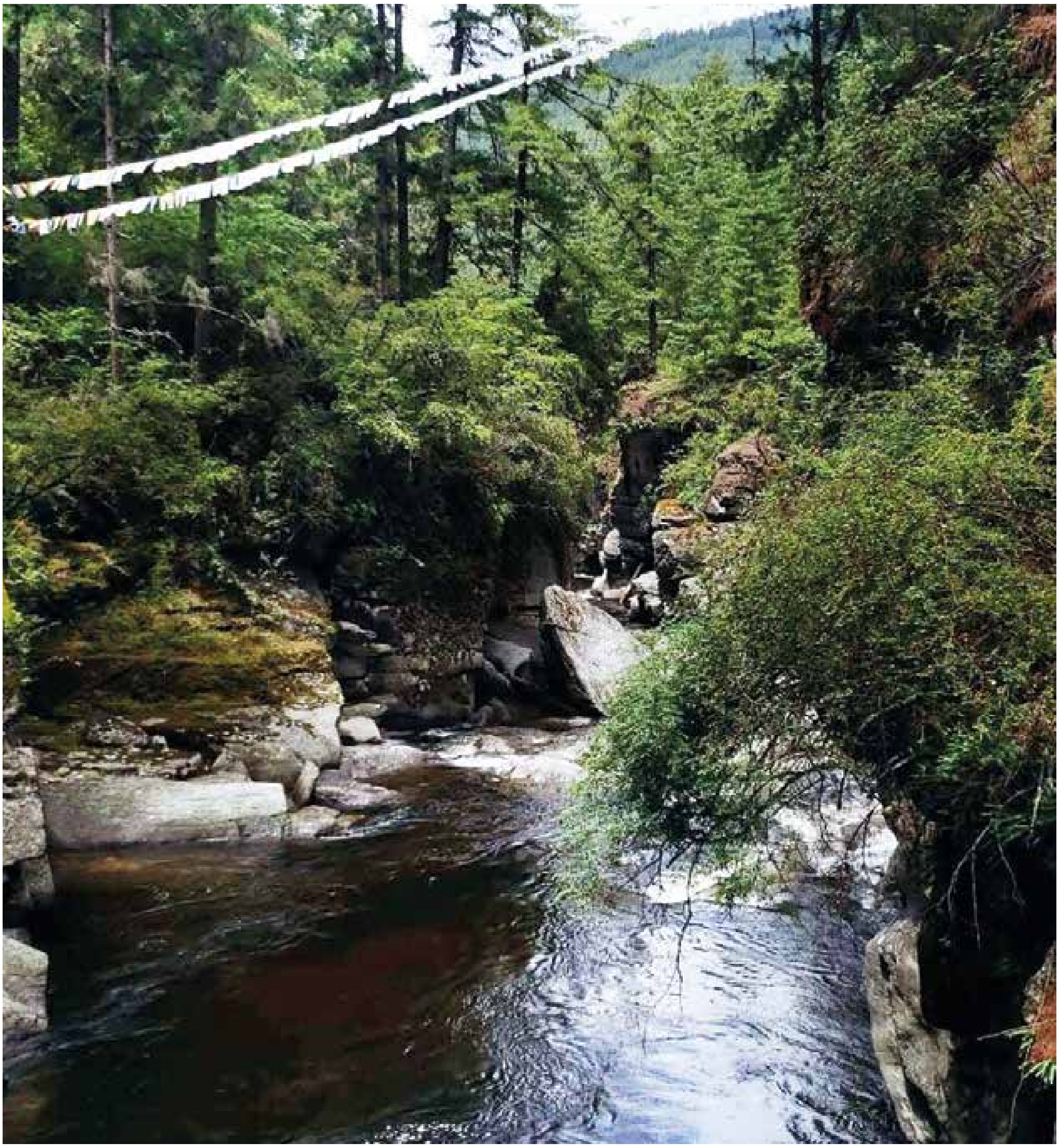
1.4 Global and Policy Context

The Millennium Ecosystem Assessment (MEA) released in 2005, set the stage for a better understanding of the contributions that nature provides people (MEA, 2005; Diaz et al., 2018). Since then, the Inter-governmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) was established in 2012 to "strengthen the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human *well-being* and sustainable development" (IPBES online; Diaz et al., 2018). Through its research outputs, the IPBES has contributed to improving our understanding of the role of nature in providing benefits to humans, and consequently, the role that ongoing nature destruction is playing in increasing health hazards, notably through forest fires and the spread of pathogens (IPBES, 2018).

There is growing research in, and recognition of, the impacts of forests, trees and green spaces on human health. A 2015 state-of-knowledge report highlighted the important links between biodiversity more broadly and human health, discussing for example, zoonotic diseases, impacts at different scales and for different parts of the human population, and the many linkages between biodiversity and health (Romanelli et al., 2015). The World Health Organization (WHO) is increasingly calling for actions that address the essential links between human health, environmental factors and climate change. A report from the 72nd World Health Assembly, held in 2019, introduced a new global strategy on health, environment and climate change aiming to transform the way environmental health risks are tackled by accounting for health in all policies, and scaling up disease prevention and health promotion (WHO, 2020). The State of the World's Forests report (FAO, 2022) is one of the first higher-level assessments and policy reports that pays more than fleeting attention to the important human health impacts of forests. The report states that trees, forests and sustainable forestry can help the world recover from the COVID-19 pandemic and combat looming environmental crises, such as climate change and biodiversity loss. It also highlights that for this to happen, societies must better recognise the considerable value of forests and their crucial roles in building inclusive, resilient and sustainable economies. The report recognises that the application of a broader framework for understanding human health in a wider planetary context is still in its infancy. Beatty et al. (2022) recently released a scientific report that illustrates the evidence connecting forests and human health. The report explores five categories of potential interactions between forests and human health: noncommunicable diseases like cancer and diabetes; environmental exposures; food and nutrition; physical hazards; and infectious diseases.

Several international policy processes and commitments have called for the inclusion of forests to contribute to *human wellbeing*, although the focus has often been more broadly on biodiversity. In 2012, the report 'Our Planet, Our Health, Our Future' jointly issued by several United Nations organisations and conventions, called for joint consideration of biological diversity, climate change and desertification from a human health perspective (Patz et al., 2012). The Convention on Biological Diversity (CBD) states that it is "alarmed by the continued loss of biodiversity and the threat that this poses to human well-being" and the recently adopted Kunming-Montreal Global Biodiversity Framework (GBF) highlights the urgent need to reduce environmental degradation to reduce health risks and the implementation of holistic approaches such as the One Health Approach (CBD, 2022). Target 12 specifically aims to increase the area, quality, connectivity, access and benefits of urban green spaces in improving human health and well-being. Additionally, the Quadripartite partnership on One Health between the Food and Agriculture Organization of the United Nations (FAO), the WHO, the World Organization for Animal Health (WOAH) and the United Nations Environment Programme (UNEP) advocates for the implementation of a One Health approach and addresses the health risks of deforestation and land degradation in several activities of its Joint Plan for Action (FAO et al., 2022). In 2020, a group of experts convened under the IPBES to assess the state of knowledge and provide policy options on COVID-19 and other zoonoses, including on the role of forests, reduced deforestation and increased *restoration* (IPBES, 2020). In other global processes, the 16th session of the UN Forum on Forests (UNFF 16) expressed concern that biodiversity loss and ecosystem degradation were driving zoonotic diseases for which we have no resistance, and issued a call to build momentum to halt illegal and unsustainable forest practices to reduce the risk of future threats to human wellbeing (ECOSOC, 2021).

The Global Forest Goals (United Nations, 2021) highlight that forests in different settings, from urban areas to natural *landscapes*, provide *livelihoods* and multiple products and services to communities. For example, the initiative Cities4Forests developed an overview of the forest continuum, from urban centres, through peri-urban and rural areas, to remote natural areas, calling these inner, nearby and faraway forests, and linking them to various benefits and Sustainable Development Goals (SDGs; see Figure 1.1). The State of the World's Forests report (FAO, 2022) highlights three pathways for securing and enhancing the essential roles of forests: halting deforestation and maintaining forests; restoration; and sustainable use. The latter also relates to the need for a broader integrated sustainable land management perspective.



Forests can enhance and maintain water quality, which is crucial for human health
Photo © Dikshya Devkota

The implementation of the United Nation's Agenda 2030 for Sustainable Development and its 17 SDGs aim to strengthen the momentum for combatting pressing challenges to enable a sustainable development for all. The third SDG specifically focuses on health and aims to "Ensure healthy lives and promote well-being for all at all ages". Linkages between human health and forests can be found in several SDG targets, for example: target 3.3 "end the epidemics of AIDS [Acquired Immunodeficiency Syndrome], tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases"; target 3.4 "reduce by one third premature mortality from noncommunicable diseases through prevention and treatment and promote mental health and well-being"; target 3.9 "substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination"; and target 11.7 "universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities" (United Nations, 2015). Moreover, promoting the interlinkages between forests and human health can directly or indirectly contribute to achieving all SDGs (FAO, 2020a). A recent study (Katila et al., 2019) analysed potential impacts of SDG implementation on forests and forestry. The authors state that understanding the potential impacts of SDGs on forests, forest-related livelihoods and *forest-based* options to generate progress towards achieving the SDGs, as well as related trade-offs and synergies, is crucial for reaching these goals. Another study on forest landscape restoration (FLR) demonstrated how the broadening agenda of FLR meant that it could support the achievement of many SDGs (Mansourian, 2018). Although global environmental *governance* systems have increasingly acknowledged the health-environment nexus, explicit interlinking of forests and human health is still limited.

To tackle health challenges by recognising that human health is closely related to the health of other species, ecosystems and the planet as a whole, novel and more integrative health frameworks have been developed. The State of the World's Forests 2022 report notes that the implementation of novel frameworks is still not optimal and that "it has become apparent, however, that addressing the ecosystem-health dimension through responsible land-use planning and the greater involvement of the forest and wildlife sectors as well as natural-resource managers is equally important. Continuous monitoring and surveillance, data-sharing and evidence-based decision-making are essential for minimising impacts and adjusting policies over time and as conditions change" (FAO, 2022). The report introduces a 'One Health' perspective, in recognition of the interlinkages between the health of humans and that of other living beings, and ecosystems.

1.5 Scope of the Assessment

Understanding of the net impacts of forests on human health is still incomplete and only a few policies and initiatives have made a tangible effort to prioritise the multifaceted role of forests in maintaining or improving human health in a sustainable manner. In urban areas, especially in *high-income countries*, it has become increasingly common to consider the positive impacts of forests, trees and green spaces on mental, physical and social health, even though the evidence base is still not complete. Elsewhere, aspects such as zoonotic diseases and food and nutrition have received more, although still insufficient, attention. Initiatives are often fragmented, unsustainable and not always evidence-based, or focus on only one or a few aspects of the many forest-health relations.

This assessment highlights that although the various impacts – often positive, but in some cases potentially negative – of forests on human health and wellbeing are increasingly being studied and acknowledged, these impacts are not reflected in relevant policies, programmes and activities, thus preventing adequate integration in ongoing and future strategies. In addition, despite a recent surge in research, there are still substantial knowledge gaps on the impacts that forests have on human health and wellbeing. The present Expert Panel aims to assess the current state of knowledge and highlight knowledge gaps, while also identifying trade-offs, synergies and opportunities for strengthening policies, programmes and specific activities to enhance positive health impacts of forests on urban, rural and *forest-dependent* communities.

The purpose of this assessment is to assess existing evidence on the linkages between forests, trees outside forests and green spaces on the one hand, and human health on the other.

This assessment takes a multi-layered perspective to the human-forest relationship in urban, rural and forest-dependent communities. It aims to assess and interpret the evidence around the interdependence between the health of forests and that of people. The focus is on forest and tree-based environments, considered broadly, and including trees outside forests and green spaces in urban areas. In this assessment, we take a pragmatic *social-ecological systems* approach based on the concept that social and ecological systems are interrelated and interdependent (Berkes and Folke, 1998). We build upon three influential interconnecting concepts that are particularly relevant for assessing the forest-human health interaction: *One Health*; *Planetary Health*; and *EcoHealth*.

1.6 Introducing the Global Forest Expert Panel on Forests and Human Health

This report presents the findings of the GFEP assessment on Forests and Human Health, which was in operation from mid-2021 through early 2023. In the frame of the IUFRO-led Joint Initiative of the Collaborative Partnership on Forests (CPF), the GFEP on Forests and Human Health had as its task to carry out a comprehensive global assessment of available scientific information on the interactions between forests and human health and to prepare a report to inform relevant international policy processes and the discussions on the 2030 Agenda for Sustainable Development.

More specifically, the assessment addresses the following main thematic elements:

- The different dimensions of the relationships between forests and human health, including benefits and challenges;
- Synergies and trade-offs between human health, and the conservation, restoration and sustainable management of forest ecosystems, their biodiversity (including wildlife), as well as trees in other land-uses; and
- Response options relevant to policy context, including governance frameworks, in economic, health, socio-cultural and environmental domains at various levels (sub-national, national, regional and international).

The GFEP on Forests and Human Health comprises 16 scientists from various disciplines with recognised expertise in the assessment topics, including forestry, ecology, landscape design, environmental psychology, and medicine and public health. The Expert Panel was further supported by 16 contributing authors. Panel members and contributing authors are from across the globe and represent different genders.

The Expert Panel decided to take a broad view of forests, trees and green spaces, and to look at these in diverse contexts. The focus is on urban, rural, as well as forest-dependent communities. Equally the Panel takes a broad perspective of human health, including all aspects of physical, mental, spiritual and social health and wellbeing of people, while also considering links to the health of other beings and ecosystems.

1.7 Structure of the Report

The next chapter offers a framework for the remainder of the report and introduces relevant transdisciplinary concepts, such as One Health and Planetary Health. It also provides an overview of key health aspects and pathways through which forests and trees are linked to human health. Next, Chapter 3 provides a comprehensive overview of the current evidence on the impacts of forests and trees on human health at different life stages. It also provides insights into current knowledge gaps and research needs. Chapter 4 investigates how specific forest types, settings and characteristics are linked to different health impacts. This chapter also discusses synergies and trade-offs between human health impacts of forests and other ecosystem services and benefits provided by forests. Although health benefits may go hand-in-hand with other benefits of forests, there are also cases where different benefits may be in conflict. Chapter 5 offers an overview of different response options that can enhance the positive health impacts of forests and trees, while also minimising negative impacts. The chapter presents response options related to accessibility and management, spatial aspects, design, governance and economics, and communications. Chapter 6, presents a summary and conclusion of the report, while also providing key messages for decision-makers and identifying important knowledge gaps.


GLOBAL
TRENDS/DRIVERS


ONE HEALTH
PLANETARY HEALTH
ECOHEALTH

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2

Chapter 2

Framing the Interrelations between Forests and Human Health

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Abstract

There is no such thing as human health without a healthy planet. Forests are a central part of the planet's ecosystems and, as such, understanding human-forest interdependence is central to achieving optimal health for all, now and for future generations.

Contemporary human health challenges differ across the globe. In high-income countries, there is a dominance of non-communicable diseases that, to some extent, are related to a disconnect from, and unhealthy interactions with, forests. In other parts of the world, health is related to interactions with forests through, for example, nutrition and other services provided by forests or through infectious diseases, such as malaria, that are in turn all impacted by forest management and practices.

Planetary health approaches provide a way of considering environmental protection as an inherent part of the solution to health. In this context, forests play an important role. Positive interactions with healthy forest ecosystems can contribute to various services, such as promotion of healthier lifestyles, prevention of disease and livelihoods.

This chapter defines common concepts and discusses the need for systems thinking when addressing the complex and dynamic relationships between forests and human health, including the importance of acknowledging voices and knowledge from Indigenous peoples and local communities. It outlines the consequences of urbanisation and humans' disconnect from nature as well as various theories, pathways and mechanisms that support evidence on positive health impacts of forests. Finally, it provides a framework that brings together the information provided in the remainder of the report.

2.1 Introduction

In many parts of the world, humans are increasingly disconnected from nature. This disconnect has resulted in a loss of recognition that, as a species, we are merely one small element in a much larger system. In so-called modern societies there also seems to be a lack of understanding that if any part of this system is broken, everything, including humans, will be affected. In many parts of the world, we are now starting to see the dire consequences of this failed understanding. Ironically, the harmful consequences of Western lifestyles are predominantly experienced by those populations who have remained connected to their surrounding natural environments, for example, forest-dependent communities[2].

In an influential review from 2012 entitled "A symbiotic view of life: we have never been individuals" – Gilbert et al. (2012) argue that human beings should not be considered as individual entities but rather as ecosystems living in continuous symbiotic and interactive relations with animals and plants around us. For example, we carry at least 300-fold more microbial genes than human genes, and microbial cells clearly outnumber the human cells of a body (O'Hara and Shanahan, 2006). Nevertheless, over the last centuries an increasingly *anthropocentric* worldview has come to dominate, influencing how we consider ourselves and how we relate to the environment around us (Kortenkamp and Moore, 2001; Goralnik and Nelson, 2012). This has resulted in major achievements in economics, human health and social welfare, but this progress has come at the cost of natural resource depletion and global environmental change (Whitmee et al., 2015). In turn, these environmental changes are affecting human health. A paradigm shift in our thinking and our collective worldview is therefore urgently needed, including to better recognise the interrelation between forests and human health. Acknowledging this interrelation to its full extent signifies that when we discuss impacts on the health of forests and ecosystems in this report, we implicitly connect them to a direct or indirect impact on human health. We use a multi-layered perspective reflecting our understanding of the human-forest relationship in urban, rural and forest-dependent communities as multidimensional. By doing so, we provide the best possible assessment and interpretation of the evidence around the interdependence between the health of forests and the health of people as it stands today.

This chapter provides a framework for the remainder of the report (Figure 2.1), introducing various concepts that will be used throughout the text.

2 All terms that are defined in the glossary of this report (Appendix 1) appear in italics the first time they are mentioned

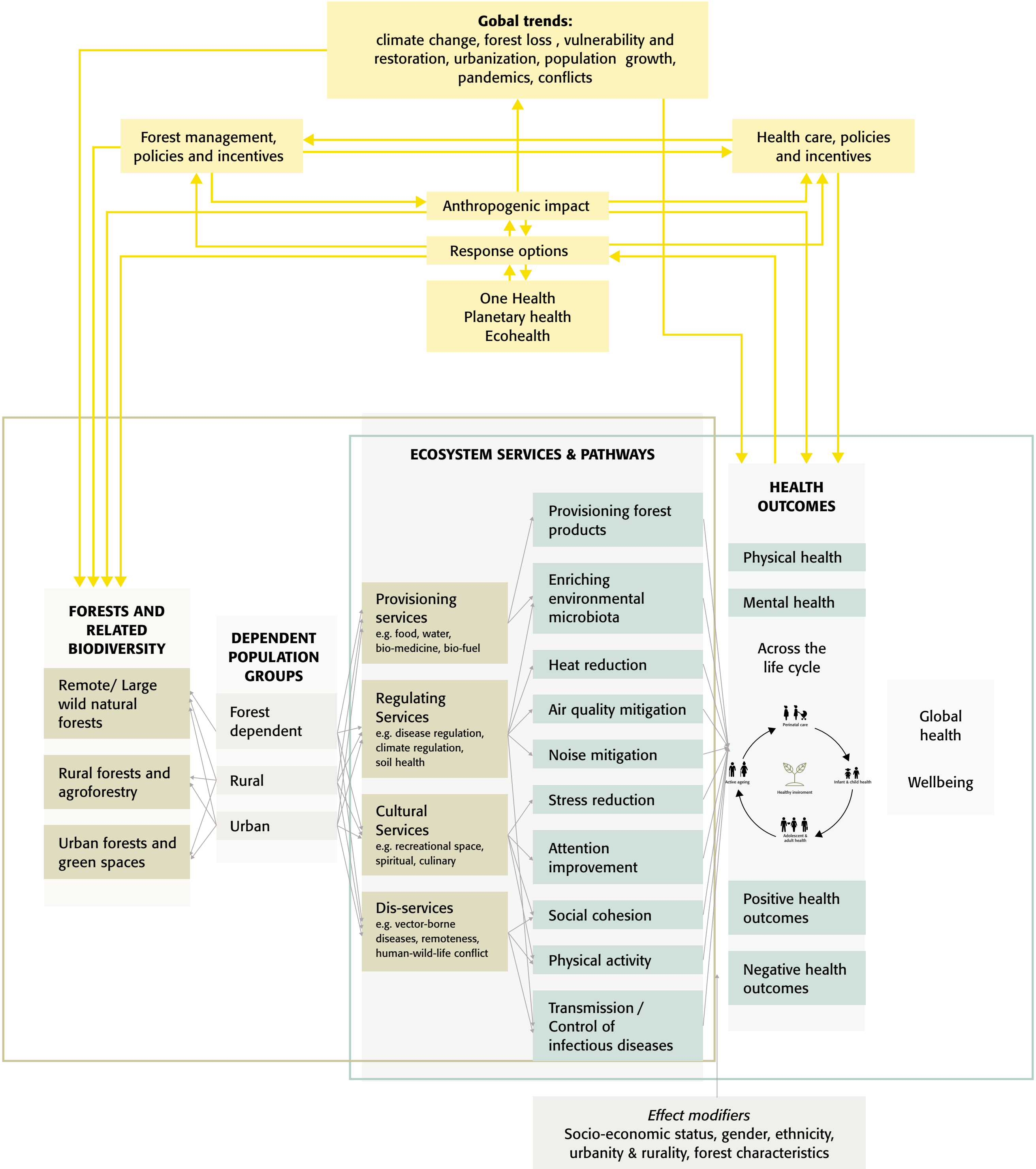
A boy and a girl sitting on a tree stem in the forest on a sunny summer day
Photo © Olya Humeniuk

The chapter addresses the need for a paradigm shift in our scientific thinking around forests and human health. It outlines definitions of human and *forest health*, and modifiers that act in the relation between them. Further information on such modifiers is provided in Chapter 3. We introduce central frameworks, such as Planetary Health, One Health, and EcoHealth. These frameworks, and interactions between them, are referred to throughout the report. Adding to this system thinking, we also present *resilience* approaches as they relate to forest and human health interactions, including drivers and solutions, which are further discussed in Chapter 4. Finally, to provide a background to the evidence presented in this report, the chapter reviews the history and development of forest and human health research, including aspects of nature disconnection. In Appendix 2 we outline common research designs, methods, measurements and indicators.

Figure 2.1 introduces a model for the rest of the report, including the synthesis of our findings and expert assessment. The framework builds upon a systems approach related to Planetary Health, One Health and Ecohealth, and brings together a diversity of pathways that connect forests and human health from an ecological and human health perspective. The model thereby brings together key elements that are used across the report, including: (1) the use of typologies to note that different characteristics of forests and of population groups can influence the types, directions and extent of forest-human health interactions in multiple ways; (2) the concept of ecosystem services and how they connect to different pathways that affect human health; (3) a life cycle approach to consider multiple and diverse influences on human health and wellbeing across the life course; and (4) a clear two-way, dynamic nature of interactions between forests and human health where forests influence human health and where human health-related behaviours and response options also influence forests and ecosystems.

Figure **2.1**

Model framework for the complex interactions between forests and human health, and related synergies, trade-offs and practices.



The figure shows types of forests and populations on the left, and health outcomes on the right. The overlap represents pathways between forests and human health, and the yellow arrows and boxes represent feedback dynamics.

2.2 Multidimensional States of Forests and Human Health

Neither humans nor forests are homogenous entities. This means that while the inherent interdependence between humans and forest environments is universal, the type and consequence of the interdependence are multidimensional. Many 'natural' forests have been set aside as reserves, wilderness areas or national parks (Li and Bell, 2018). These areas can present opportunities for entering a different 'universe' and provide unmediated, direct contact with nature.

There are also large areas of managed natural forests, for example for timber production. These may not be optimal for spiritual or aesthetic experiences, but can provide opportunities for physical recreation, such as running or skiing, and can also provide health benefits through income that improves livelihoods. Forests may also be established on previously non-forest land or re-established through afforestation or reforestation programmes, following previous clearance for agricultural land or urban expansion. Depending on the type of forest re-established, these can also serve a wide range of social and ecological purposes. Finally, urban or peri-urban forests can be part of a city's infrastructure and are sometimes specifically planted for human health and wellbeing. However, they can also serve as biodiversity hotspots (Nielsen et al., 2014; Almohamad et al., 2018). The multidimensionality of forest landscapes is met by the multidimensionality of individuals, communities, cultures, ethnicities, and geographical and climate contexts – all of which contribute to a complex pattern of interactions between humans and forests.

2.3 Ecocentrism, Traditional Ecological Knowledge, and the Reciprocal Relation Between Human and Forest Health

Applying an ecocentric perspective to knowledge generation and implementation may facilitate the recognition of the inherent interdependence between forest and human health and their non-hierarchical relationship (Figure 2.2). Contrary to an anthropocentric worldview, an ecocentric perspective, or *ecocentrism*, acknowledges the intrinsic value of 'non-human' nature and ecosystems (Batavia and Nelson, 2017). The 'wellbeing' of nature is thus as important as the health and wellbeing of people (Devall and Sessions, 1985). This means that every living organism has an intrinsic value, independent of its usefulness for human beings. The ecocentric worldview is integrated in the lifestyles, values and knowledge generation of many Indigenous peoples and local communities (IPLCs), which has resulted in sustainable use of natural resources and a mutuality in their relation to forests (Arquette et al., 2002).

Figure **2.2**

Anthropocentric versus ecocentric worldview

In the anthropocentric model, a human male is at the top of the hierarchy, followed by large mammals and all the way down to invertebrates, considered the lowest of species. The anthropocentric model is human-centred and states that only humans possess intrinsic values. The ecocentric model, on the other hand, acknowledges the intrinsic and equal value of every living organism and the human species is just one part of a non-hierarchical system (Source: Ehrnström-Fuentes, 2016).

Paradoxically, post-enlightenment Western science, which is largely based on *anthropocentrism*, may have lost sight of basic fundaments for long-term advancement of science, or more specifically its sustainable implementation. While the rigour of quantitative research methods (see Appendix 2) may be necessary to provide generalisable evidence and while the results from last century's scientific achievements have had tremendous impacts on health and longevity, a more holistic framework may be required to fully understand how we can continue to reduce poverty, improve wellbeing and increase life expectancy across the globe without the threat of a dying planet and rising *inequalities* (Whitmee et al., 2015). Despite the exceptional scientific advancements over time, we still need to develop and progress with innovative and complementary research methods to optimise solutions with both people and environment in mind. A first step may be to expand the meaning of "Standing on the shoulders of giants" (Newton, 1675) to consider also insights from, for example, *Traditional Ecological Knowledge (TEK)*, as part of the 'gigantic' contributions to scientific understanding about long-term relationships between people and the natural environment (Berkes et al., 2000). TEK is a knowledge system based on longitudinal data collected over generations from observations and feedback learning of various cultural and ceremonial expressions particularly among IPLCs. It has recently started to be applied in environmental health and climate change research (Pert et al., 2015; Maldonado et al., 2016). TEK as a valid and complementary knowledge system is also becoming an important component in global, regional and thematic assessments, for example in processes of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Tengö et al., 2017) and the Intergovernmental Panel on Climate Change (IPCC). In these assessments, the information and knowledge from TEK contribute significantly to understanding of ecosystem governance, deforestation control, carbon storage capacity, climate change and how to sustain resilient natural landscapes (Mistry and Berardi, 2016). The official IPLC response to the IPCC 2019 report (RRI, 2019) states that "Finally, the world's top scientists recognize what we have always known". Evidence suggests that forests that are legally owned or designated for use by Indigenous peoples are linked to, for example, less degradation (Blackman et al., 2017; Wehkamp et al., 2018), lower carbon emissions and higher carbon storage (Blackman and Veit, 2018), better biodiversity conservation (Garnett et al., 2018), more benefits for more people (Arce, 2019) and better social, environmental and economic outcomes overall (Dudley et al., 2018) – all compared to conventional practices that are based mainly on Western science (Kumar Dhir et al., 2020).

Addressing the root causes of health issues

An important result of the reciprocal thinking – that forest health and human health mutually influence each other – is that we move beyond the typical linear reasoning around risk factors and human health. Instead, through a systems approach, the fundamental causes threatening human health are addressed rather than the immediate risk. Such an approach recognises the intrinsic value of forests and the interdependence between forests and human health as being part of the same system. We must (re)learn how to interact in this system to keep it – including humans – intact and healthy. This re-learning could make use of TEK-based theories and practices. For example, while forests provide habitats for malaria vectors (most commonly the Anopheles mosquito), the drivers of malaria transmission are complex (Tucker Lima et al., 2017) and some research suggests that deforestation is actually related to an increased incidence of malaria disease (Guerra et al., 2006; Vittor et al., 2009). Thus, a solution to the malaria *epidemic* is not to remove the vector habitat (the forest and wetlands), but to invest in *sustainable forest management* and urbanisation processes that avoid loss of natural habitats for malaria vectors and unhealthy interactions between humans and vectors. Malaria prevalence and mortality are highest in low-income countries and apart from natural resource management and proper land cover planning, investments are naturally also needed in control and treatment programmes to combat the epidemic (Cohen et al., 2012).

Also, other examples of misconceptions related to 'harmful' consequences of nature exist, such as allergy-inducing pollen emissions from urban forests. First, allergy is a consequence of a dysregulation of the immune system and up to the end of the 19th century, allergy was an unknown phenomenon (Platts-Mills, 2015) but allergies have increased exponentially over the last decades (WAO, 2011). Industrialisation, urbanisation (with changed hygiene patterns), environmental changes and substantially reduced contact with nature and diverse microorganisms, have led to a change in the composition of our gut microbiome and impaired immune systems as a result (Haahtela et al., 2013), making us vulnerable to inflammatory conditions, including allergies. Another issue is that allergenic weeds with abundant pollen production thrive on land where natural vegetation has been disturbed by humans (Dahl et al., 2018) which, in combination with climate change and atmospheric pollution, induce prolonged pollen seasons (Ziello et al., 2012). In fact, allergic diseases are more prevalent in high-income countries (WAO, 2011) and are often caused by mould spores in homes, pet dander, dust and traffic or smoking related air pollution, more often than by pollen (Baldacci et al., 2015; Stewart and Robinson, 2022). This reinforces the importance of lifestyle changes and biodiversity protection as strategies to reduce the burden of allergenic illness.

Ecosystem services

Forests are essential providers of ecosystem services (ES). The concept of ES was popularised through the Millennium Ecosystem Assessment (MEA, 2005). In the original ES model, all services were considered to result in various constituents of human wellbeing, including health (MEA, 2005). The services are classified into four categories (Table 2.1): supporting, provisioning, regulating and cultural; all of which are dependent on biodiversity.

Table **2.1**

The four ES categories and examples

SUPPORTING	PROVISIONING	REGULATING	CULTURAL
Biomass production	Food and water	Climate regulation	Recreation
Nutrient and water cycling	Timber	Flood control	Aesthetic experiences
Soil formation	Wood fuel	Water purification	Physical and mental restoration
Habitat provision	Medicinal plants	Carbon storage	Education

Source: MEA, 2005

As described in the MEA framework, these services interact and relate to different aspects of human health and wellbeing. The relative impact on human health depends on, for example, socio-economic status and socio-demographic context. According to the MEA, the provision of ES results in freedom of choice and action and the opportunity to achieve one's life goals. Consequently, changes in ecosystems will have fundamental impacts on the prospects of thriving societies.

The nature-health connection was further emphasised in the most recent IPBES reports (IPBES, 2019) and the Common International Classification of Ecosystem Services (CICES) version 5.1. In CICES 5.1, ES are defined as the contributions that ecosystems make to human wellbeing. These services are considered final in the sense that they are the end-outputs from ecosystems that directly impact human health (Potschin and Haines-Young, 2011).

In this report, we refer to ES as they were originally outlined in the Millennium Ecosystem Assessment. This is consistent with the 2015 review by WHO/Convention on Biological Diversity (WHO, 2015). The ecosystem services framework is useful for realising and communicating the human health benefits of forests and their services. Nevertheless, the notion of 'services' has been criticised for being anthropocentric (Adams, 2017). In contrast, an ecocentric approach emphasises reciprocity in the system where humans are part of the ecosystem and ecosystem services go hand in hand with services to ecosystems in a healthy *socio-ecological system* (Comberti et al., 2015).

2.4 What is Health?

2.4.1 Definitions

Human health

The meaning of human health has changed over time and still varies across populations and individuals. From a strict biomedical point of view, health has been defined as functional organ sys-

Forests provide essential ecosystem services including provisioning (e.g. timber) and cultural (e.g. recreation) services
Photo © Nelson Grima

tems without signs of disease, injury, defect or physical pain (Engel, 1977). The World Health Organization (WHO), on the other hand, states that health should be defined "not merely as the absence of disease or infirmity", but as a resourceful state of "complete physical, mental and social wellbeing" (WHO, 1948). From this perspective, health is a multidimensional state with an interdependence between physical, psychological and social domains of wellbeing, where wellbeing is defined as "an individual's experience of their life as well as a comparison of life circumstances with social norms and values" (WHO, 2012a). More specifically, physical wellbeing indicates pursuit of healthy lifestyles, such as being physically active and eating healthily. It may also indicate not being hindered by physical limitations and experiences of bodily pain (Capio et al., 2014). Mental wellbeing relates to, for instance, subjective happiness, life satisfaction, experiences of pleasure, and positive psychological and emotional functioning (WHO, 2004). Social wellbeing refers to interactions between individuals and is determined by the quality of meaningful relationships with others. Having high levels of social wellbeing indicates feelings of authenticity, safety and personal value (Lee and Keyes, 1998). As of late, a fourth dimension of health has been introduced: spiritual health (Chirico, 2016) which is considered distinct to mental health in that it regards the spirit of a person rather than the psyche. It is closely connected to a person's sense of purpose and meaning in life, typically acknowledging that the world contains something beyond the powers of oneself and recognising a connection to the earth, the planet and the universe (Hawks et al., 1995; Dhar et al., 2013). It could also relate to eudaimonic wellbeing, which corresponds to resources and strengths and on life meaning, authenticity and purposefulness (Di Fabio and Palazzeschi, 2015).

A concept that is closely related to health is *quality of life* (QoL), defined by WHO as "an individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns" (WHO, 2012b).

Even before WHO coined its definition of health, the French physician George Canguilhem suggested the notion of health as the ability to adapt to one's environment, moving beyond the biomedical model (Canguilhem, 1943). Later definitions similarly suggest incorporating aspects of resourcefulness, adaptability and capacity to self-manage (WHO, 1986; Huber et al., 2011). Interestingly, this mirrors ecological definitions of healthy environments as resilient and capable of maintaining a stable system within a defined operating space (Rockström et al., 2009).

Recognising that health is not merely defined by absence of disease has implications for actors in the field, acknowledging that the health of individuals and populations is a common responsibility to be approached not just as a medical issue, but also from societal and environmental perspectives. The research agenda of WHO in 1997 for example, reflected the following 'emerging themes', among others: urbanisation; population; migration; environmental problems; and value systems (Mansourian, 1997).

Defining health is challenging and many definitions are open to interpretation. In the remainder of this report, we refer to health in accordance with the well-established WHO definition, while also recognising the importance of connected concepts such as spiritual health, QoL, adaptability and resilience.

Public health

Public health as a discipline or field of work has been defined as “the art and science of preventing disease, prolonging life, and promoting health through the organised efforts of society” (Acheson, 1988). This relates to the continuum of care that can be summarised as promotion, prevention, intervention and rehabilitation. ‘Health promotion’ refers to enabling individuals to maintain or improve their health, for example, by providing healthy environments for everyone independent of income, education or ethnicity. ‘Disease prevention’ can be described as efforts to reduce risk factors, such as air pollution on a population or smoking on an individual. ‘Intervention’ is what may typically be considered as health care, such as treatment to stabilise or cure a medical condition. ‘Rehabilitation’ refers to providing support and opportunities to an individual to recover from a disease or adapt to a new condition following illness or injury. Most of the research on nature and human health has operated on the levels of health promotion (e.g., providing green spaces for physical activity) and disease prevention (e.g., urban trees to prevent heat related morbidity), and to some extent on intervention (e.g., forest therapy) or even rehabilitation (e.g., rehabilitation after post-traumatic stress disorder, PTSD). A prominent example of using forests as a public health strategy, is the practice of Shinrin-yoku (‘Forest Bathing’) (Tsunetsugu et al., 2011). Shinrin-yoku originates from Japan and is based on the understanding that forest environments open humans’ senses and thereby bridge the gap between humans and the natural world. Studies have suggested a number of measurable health effects of Shinrin-yoku, including impact on stress hormones, blood pressure and immune function (Li, 2010; Tsunetsugu et al., 2011; Li and Bell, 2018).

Forest health

Forest health is mainly discussed in the forest sciences, but does not have a universally accepted definition. Forest health refers to the health of an entire forest system, including trees, plants, soil, wildlife and water, while tree health refers to the health of an individual tree. A certain amount of insect activity, disease, mortality and decay is normal and healthy within a forest system. Most definitions represent either an ecological or a utilitarian perspective emphasising human needs. From an ecological perspective, healthy forest ecosystems are defined as being able to maintain their organisation and autonomy over time while remaining resilient to stress (Costanza, 1992). In contrast, the utilitarian perspective sees a forest as healthy if managers’ and landowners’ objectives are met (Kolb et al., 1994). This definition may be adequate for single management objectives, but is inadequate when multifunctionality is pursued. Using a combination of both perspectives, forest health can be defined as a condition of forest ecosystems that sustains their complexity and resilience while simultaneously providing for human needs (O'Laughlin et al., 1994; Teale and Castello, 2011). The definition can, in principle, be applied also in assessing forest health (or its capacity) for delivering human health benefits through, for example, improved microclimates, carbon sequestration, absorbing pollutants or noise abatement. The capacities of different types of forests to deliver health benefits are further discussed in Chapter 4.

Today, forest health is threatened by pressures from human activities worldwide. The main driver of deforestation is the expansion of agricultural land for commodity production, including cattle ranching (Curtis et al., 2018; Feltran-Barbieri and Féres, 2021). Human activities also threaten forest ecosystem quality, as in the case of large-scale monoculture *plantation forestry*.

2.5 Multifactorial Determinants and Modifiers

The complexity of the interrelations between forest environments and human health cannot be overstated. Aside from the fact that human health and forests are concepts that elude simple definitions, there are a number of more or less interdependent contextual factors that determine or modify the character and degree of interrelation or impact. Although there is incomplete scientific evidence of how context may influence the relations, based on what we currently know, a number of contextual factors are considered in this report and outlined below.

2.5.1 National income level

The World Bank categorises economies into four income groups: low, lower-middle, upper-middle and high-income countries (World Bank website). In this report, we group economies into low-, middle- and high-income countries. Due to unequal distribution of resources and funding for research, most of the evidence on forest and human health interrelations is based on data from high- and, to some extent, middle-income countries (Gallegos-Riofrío et al., 2022). This hampers our understanding of how income and economy affect the relations; the health benefits from forests in low-income countries are likely different from those in high-income countries. Generally, low-income countries are more likely to obtain health benefits from forests through provisioning ecosystem services, such as supply of food and timber for livelihoods, while cultural ecosystem services, such as recreation and stress relief, may dominate the health benefits in high-income countries (MEA, 2005).

The Human Development Index (HDI) is a composite indicator of life expectancy, education and economics, currently used by the United Nations Development Programme (UNDP). A high level of HDI is reached when the lifespan, education levels and gross national income per capita are all high. A global comparative study shows that the level of *forest resources* of nations tends to be positively correlated with the HDI, suggesting that the forest resources of nations improve with progress in human development and wellbeing (Kauppi et al., 2018).

A detailed discussion about socio-economic factors as modifiers of the nature and health interrelation is provided in Chapter 3.

2.5.2 The urban-rural gradient

Very little research has been conducted that specifically compares health effects of urban versus non-urban forests or how people perceive or benefit from forests depending on whether they are urban or rural residents. One recent study suggested an urban-rural gradient whereby exposure to green spaces and forests increased further from an urban centre, while access remained the same (Jarvis et al., 2020a). This is highly context dependent though and we could assume that differences exist and that cultural ecosystem services may be relatively more significant in urban than in non-urban forests (Devisscher et al., 2019). On the other hand, less managed, remote areas, national parks and other non-urban forests carry immense values for people's needs for recreation and to escape from city stress (Bell, 2012; Li and Bell, 2018). Nevertheless, with a number of exceptions (Kovarik and Körner, 2005), the character of an urban or peri-urban forest is, in general, different from a large forest land, be it managed or 'biologically intact', which likely has consequences for the experiences and benefits people obtain from the environment (Konijnendijk, 2018). Further, health benefits also vary based on whether communities are urban, rural or forest-dependent (see further details in Chapter 4).

2.5.3 Climatic and geographical zones

Limited research has directly compared health impacts of forests across larger climatic and geographical zones, possibly reflecting the difficulty in selecting a health indicator that would apply for such a comparison. However, climate and geographic regions are naturally important to consider as modifiers of human health and forest associations with, for example, the experiences and health benefits of a Russian taiga being different from those of a tropical rainforest.

2.5.4 Landscape types and qualities, and ecological factors

Ecological indicators, such as faunal and floral species, habitats and *ecosystem functionality* all modify the relationship between human health and forests. In general, the relative impact on health likely depends on the type of outcome in question. For example, a serene forest may be more important for restoration and mental health (Annerstedt [van den Bosch] et al., 2012), while a forest's shading capacity may be the most important factor for heat-related morbidity or mortality (Graham et al., 2016; Ziter et al., 2019). There is still a large knowledge gap in our understanding of how different types of forests may influence health differently. Chapter 4 further outlines different qualities and characteristics that may modify the impact of forests on human health.

Forests and green spaces support human and animal health by providing fodder and shelter in Phobjikha, Bhutan
Photo © Dikshya Devkota

2.5.5 Socio-demographic factors

Age, gender, ethnicity and other individual or behavioural factors determine or modify the impact of any environment on a person's health. For gender differentiated health impacts of forests, results are generally inconsistent (Richardson and Mitchell, 2010; Sillman et al., 2022). Research on the modifying impact of ethnicity is relatively scarce, but studies on general greenness exposure suggest that there may be differences (Dadvand et al., 2014; Browning and Rigolon, 2018), although it is difficult to disentangle these from interconnected factors such as income. Gender, ethnicity and income are further discussed in Chapter 3.

The impact of forests on human health is important across the life course and Chapter 3 outlines the evidence for health impacts of forests by different age categories. In general, there is reason to believe that early life exposures to forests would have the highest impact since those modulate vulnerability to disease and resilience to stress later in life, in accordance with the Developmental Origins of Health and Disease (DOHaD) paradigm (Gluckman and Hanson, 2006a; 2006b).

2.5.6 Climate change

The precise scale and type of impact of climate change on future interrelations between forests and human health is difficult to predict. However, based on modelling of current and evolving events, we know that the impacts will be vast and devastating, particularly in *low- and middle-income countries* (IPCC, 2022). From a forest-health interaction perspective, we can expect increased negative health effects related to forest fires, altered host interactions and zoonotic diseases, impaired *food security*, and much more (Watts et al., 2018; IPCC, 2022).

In the 2020 Lancet Countdown on health and climate change, urban green space is included as one of the indicators for adaptation, planning and resilience for health (Watts et al., 2021). Equally, the carbon stock of large forest areas is substantial with a modifying impact on climate change (FAO, 2020). In general, implementation of the evidence provided in this report will be much determined by the inherent dynamics related to climate change and the consequences for forest environments across the globe. We should keep in mind that these consequences will be felt strongest in low-income parts of the world and this is where the lion's share of investments for maintaining healthy forests for healthy human lives should be directed. During the 27th Conference of Parties to the United Nations Convention on Climate Change (UNFCCC COP27) in Egypt (2022), this was recognised, not as support or aid, but rather as ethical payback from high-income countries, historically responsible for the problems caused by inadequate fossil fuel extraction, land use and forestry since pre-industrial times.

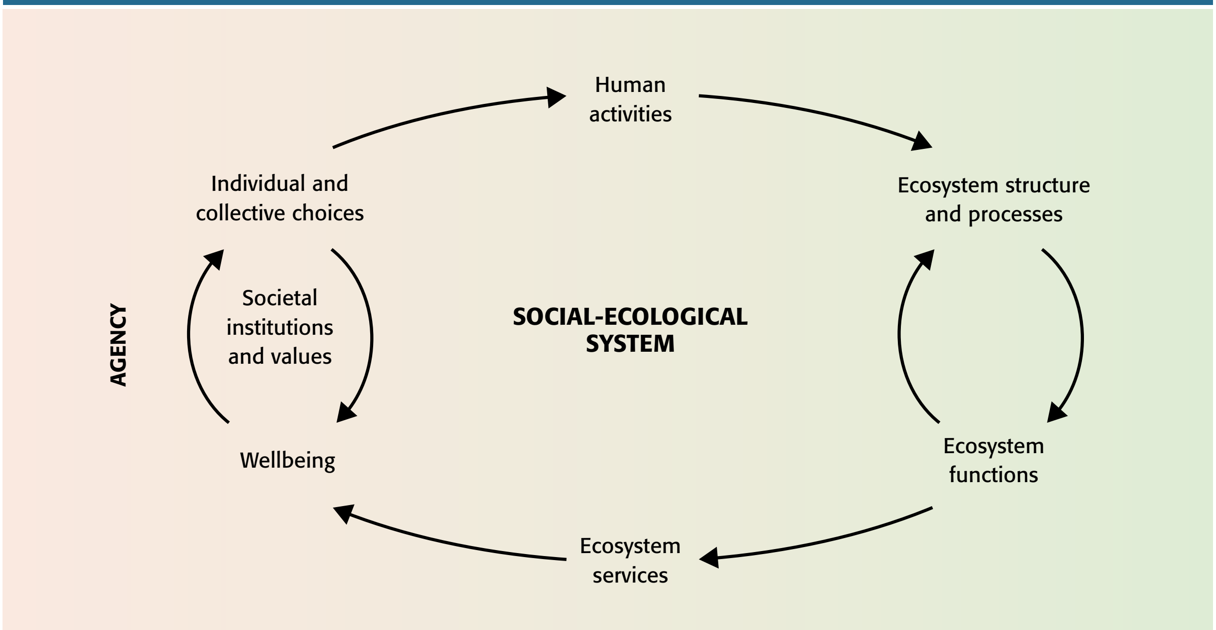
2.6 Human Health and The Environment - Central Frameworks and a Systems Approach

Interactions between humans and forests are studied across disciplines, including forestry, sociology, economics, ecology, biology, medicine, veterinary medicine, climate science, public health, among others. Incorporating knowledge from different fields, we take a pragmatic social-ecological systems approach in this report. Such an approach is based on the concept that social and ecological systems are interrelated and interdependent (Berkes and Folke, 1998; Ostrom, 2009).

Health and forest integrity can be defined as a coupled social-ecological system which needs governance systems structured as a network of different actors supporting human health, land-use planning and forest conservation (Figure 2.3). Recently, a social-ecological system health (SESH) framework has been proposed to explicitly link health and ecosystem management in order to prevent and cope with emerging health and environmental risks (de Garine-Wichatitsky et al., 2021). While this framework originally focused on agricultural transitions and biodiversity conservation, it could be adapted to other situations such as urban areas.

Figure **2.3**

Conceptual model of a social-ecological system



Source: Arctic Council, 2016

Studies of interlinked human and natural systems have been emerging as a growing field, promoting interdisciplinary dialogue, collaboration, and action in various areas and practices (Colding and Barthel, 2019). Pragmatically, applying a systems approach can contribute to finding unexpected solutions and lead to more sustainable solutions that consider and can manage synergies, trade-offs and feedback loops between multiple goals (Myers, 2017; Colding and Barthel, 2019).

In the context of a systems approach, we build upon three influential interconnecting concepts that are particularly relevant for assessing the forest – human health interaction: One Health, Eco-Health and Planetary Health, the latter being the main framework that is considered for the contents of this report. We describe these frameworks and concepts and give an overview of how their application in science, policy and practice can add value to understanding and acting upon the relation between forests and human health. Finally, we discuss how these concepts are interlinked through the perspective of resilience.

2.6.1 One Health

'One Health' is defined as "an integrated, unifying approach that aims to sustainably balance and optimise the health of people, animals and ecosystems" (OHHLEP, 2021).

One Health was first used in 2003–2004, as the connecting concept between human and animal health, and was associated with the emergence of severe acute respiratory disease (SARS), followed by the spread of the highly pathogenic avian influenza H5N1. Amidst complex patterns of global change and pandemics, growing evidence underlined the inextricable connectivity between humans, livestock, domestic animals and wildlife, necessitating integrated approaches to human and animal health and their respective social and environmental settings (Mackenzie and Jeggo, 2019).

A set of strategic goals known as the 'Manhattan Principles' recognise the threats that zoonotic diseases pose to ecosystem and biodiversity integrity, human health and economies, and the importance of collaborative and cross-disciplinary approaches to emerging and resurging disease response. Specifically, wildlife health was recognised as a key component of global disease prevention, surveillance, control and mitigation (Cook et al., 2004).

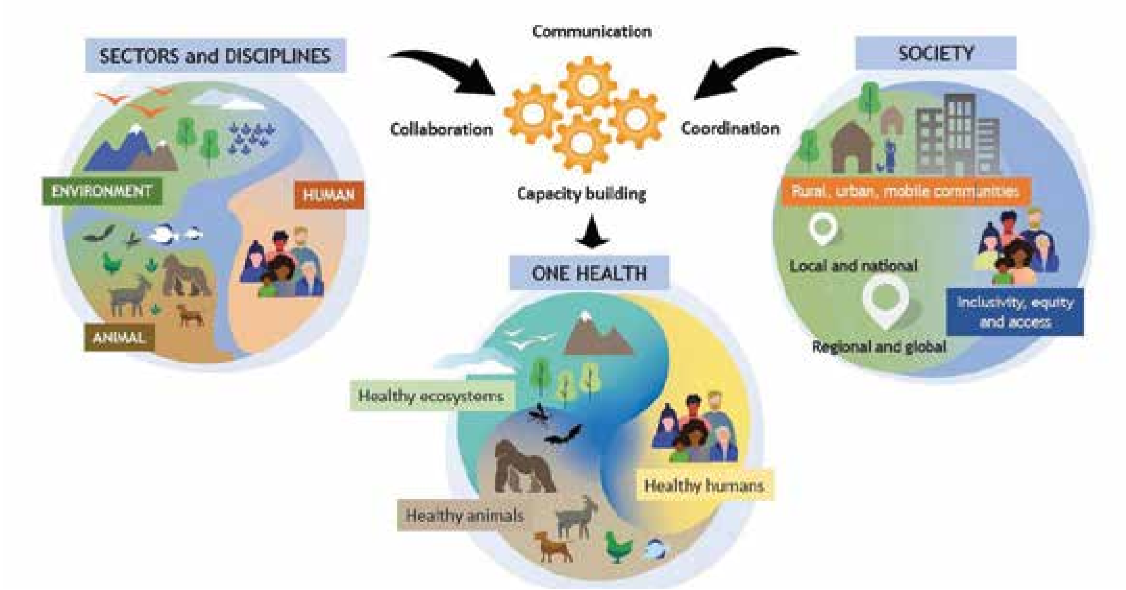
The concept emphasises the consequences, responses and actions at the ecosystem-animal-human interface, for emerging and *endemic zoonoses*. Responsible for a greater burden of disease in the low- and middle-income countries, these zoonoses cause major social implications in resource-poor settings and antimicrobial resistance (AMR), which can arise in humans, animals or the environment, and spread between countries (Mackenzie and Jeggo, 2019).

The concept of One Health further evolved and has been recently defined by the One Health High-Level Expert Panel (OHHLEP) – led by the Joint Quadripartite of the Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO) and the World Organization for Animal Health (WOAH), and the United Nations Environment Programme (UNEP) – as "An integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems" (OHHLEP, 2021) (Figure 2.4).

One Health thereby explicitly recognises the interdependence between the health of humans, wild and domesticated animals, and ecosystems. With roots in animal and human health science, it entails a coordinated, collaborative, multidisciplinary and cross-sectoral approach at national, regional and global levels to achieve socio-environmental health and wellbeing, and address potential or actual dangers such as zoonotic diseases and related potential pandemics (Mackenzie and Jeggo, 2019; OHHLEP, 2021).

Figure **2.4**

Schematic representation of the new definition of One Health endorsed by the One Health quadripartite with a holistic, integrative, and ecocentric vision of human, animal and ecosystem health



Source: WHO, 2021b

Forests and tropical forests in particular, yield a variety of products and ES that benefit humans in several ways. Shifting landscapes and environmental change, particularly felt in low- and middle-income contexts, are having significant consequences on ecosystem functioning and biodiversity protection, and on human and animal health and wellbeing.

Using a One Health lens, we can understand the relationship between forests and health through the following perspectives (a – c):

a) Biodiversity, habitat loss and health

Flourishing ecosystems lead to flourishing societies, and reducing environmental harms (both to ecosystems and to wild and domesticated animals) can mitigate harm to human health (IPCC, 2022). Undertaking practices of sustainable natural resource management across forests, agriculture and aquaculture, and harmonising conservation practices with livelihoods and health, can help to achieve a collective One Health (Bauch et al., 2015; Morand and Lajaunie, 2021).

Forest fragmentation and habitat loss, as a result of deforestation and increased agricultural production, can lead to increased interactions between pathogens, parasites, bacteria and wildlife in the biosphere, to humans, livestock and semi-domestic wildlife in the domestic landscape (Wilkinson et al., 2018). Deforestation can influence disease emergence by altering the feeding behaviour of reservoir hosts (Guégan et al., 2020). Habitat degradation can also alter the eating habits of certain wildlife species that use human products as food supplies, thereby increasing interactions at the human-domestic-animal interface, such as the introduction of the Nipah Virus (NiV) (Chua et al., 2002).

Increases in infection rates of vector-borne diseases are also associated with forest ecosystems and habitat loss (Morand and Lajaunie, 2021). For example, upland deforestation causes soil erosion and floods, which has resulted in epidemics of leptospirosis in individuals living downstream; as well as water-borne infections such as norovirus, campylobacter, cholera and giardia. Livestock health plays a crucial inter-connecting role between landscape health and human health, as livestock can act as intermediary pathogen hosts and enable spillover, impacting human and landscape immunity – the ecological conditions that maintain the immunity of wild species, thus preventing high rates of pathogen shedding in the environment (Brierley et al., 2016; Plowright et al., 2021; Reaser et al., 2022). Poorly regulated wildlife trade and associated pathogen spillover is also increasing human health threats.

b) Food security, food safety and anti-microbial resistance (AMR)

We can also understand the relationship between forests and human health, through the availability, accessibility and safety of food and food products. This also includes the safe handling of forest-sourced wild meat (Ndoye and Vantomme, 2017).

One of the biggest threats to food security and safety is AMR – a phenomenon whereby drug-resistant bacteria increase rates of infection, disease spread and mortality among humans and animals (Prestinaci et al., 2015). A notable prevalence of AMR also exists where wild animals are in close proximity to livestock and to humans, causing wider health concerns for an accelerated evolution of environmental bacteria resistance (Martinez et al., 2009; Radhouani et al., 2014). In addition, antimicrobial resistance has now been discovered deep within forest areas (Ramey, 2021). Low- and middle-income countries (LMICs) are significantly impacted by the effects of AMR, which threaten to destabilise food systems, livelihoods and healthcare systems (Murray et al., 2022).

c) Forest-based economies

One Health also allows us to understand the dynamic connections between forest foods and products (such as non-wood forest products (NWFPs) and medicines), and human health, livelihoods and economies. An estimated one billion people depend on forest-based foods and products (FAO and UNEP, 2020), directly increasing nutrition, gut health and immunity; and through their sale, increasing accessibility to other healthy foods and products (WHO, 2020). These include wild meats, fruits, nuts, mushrooms, vegetables, fish, insects, mushrooms and honey. Forest beekeeping and the trade of honey and beeswax provide crucial local and community income (Lowore, 2020), and may even provide incentives for stronger local *forest management* (Elzaki and Tian, 2020). Studies conducted in tropical forest areas found that forest products including food, fuel, fodder and construction materials, accounted for around 20% of household income and livelihood stability (Angelsen et al., 2014; Duchelle et al., 2014). The commercialisation of wild foods or forest foods such as animals, plants and fungi, is also often vital for accessing medical treatment at public health centres and hospitals, or traditional or ancestral medicine systems (Asprilla-Perea and Díaz-Puente, 2019).

2.6.2 EcoHealth

An 'EcoHealth' approach is defined as "committed to fostering the health of humans, animals, and ecosystems and to conducting research which recognizes the inextricable linkages between the health of all species and their environments" (EcoHealth Journal). EcoHealth has its roots in social-ecological systems thinking (Berkes and Folke, 1998; Ostrom, 2009) and emphasises the mutual interdependencies between people and nature. It has developed as a field of research, education and practice that adopts systems approaches to promote the health of people, animals and ecosystems in the context of social and ecological interactions (Lerner and Berg, 2017). To the social-ecological systems thinking, it adds a focus on and connection to human health; to human health, it adds a body of knowledge, approaches and solutions from studying complex systems dynamics. EcoHealth research draws on the natural sciences, health sciences, social sciences, the humanities and beyond, often working in collaboration with interested parties and community members to address issues at the interface of health, ecosystems and society.

In practice, an EcoHealth approach focuses on protecting and/or restoring high value ecosystems and improving human health through pathways of enhanced ecosystem management. For example, the EcoHealth Alliance project 'Forest Health Futures' in Liberia (EcoHealth website) applies a land-use planner framework to identify forested areas for conservation to maximise economic development, avoid loss of high carbon stocks and biodiversity, and minimise the risk for increased infectious disease burden.

2.6.3 Planetary Health

'Planetary Health' was launched by the Rockefeller-Lancet commission and is defined as "the achievement of the highest attainable standard of health, wellbeing, and *equity* worldwide through judicious attention to the human systems – political, economic, and social – that shape the future of humanity and the Earth's natural systems that define the safe environmental limits within which humanity can flourish" (Whitmee et al., 2015). In simple terms, Planetary Health is the health of human civilisation and the state of the natural systems on which it depends (Horton et al., 2014; Whitmee et al., 2015). The concept aims to respond to the fact that an increasing share of the global burden of disease is driven by the pace and scale of human disruption of Earth's natural systems (Whitmee et al., 2015).

An increasing evidence base shows that human activities are changing fundamental Earth system biophysical conditions at rates that are much higher than in the history of humankind (Rockström et al., 2009; Steffen et al., 2015). These biophysical changes are taking place across at least six dimensions: (1) disruption of the global climate system; (2) widespread pollution of air, water and soils; (3) rapid biodiversity loss; (4) reconfiguration of biogeochemical cycles, including those of carbon, nitrogen and phosphorus; (5) pervasive changes in land use and land cover; and (6) resource scarcity, including fresh water and arable land (Rockström et al., 2009; Steffen et al., 2015). All of these changes are interrelated and influence the impact of forests on human health (Figure 2.5).

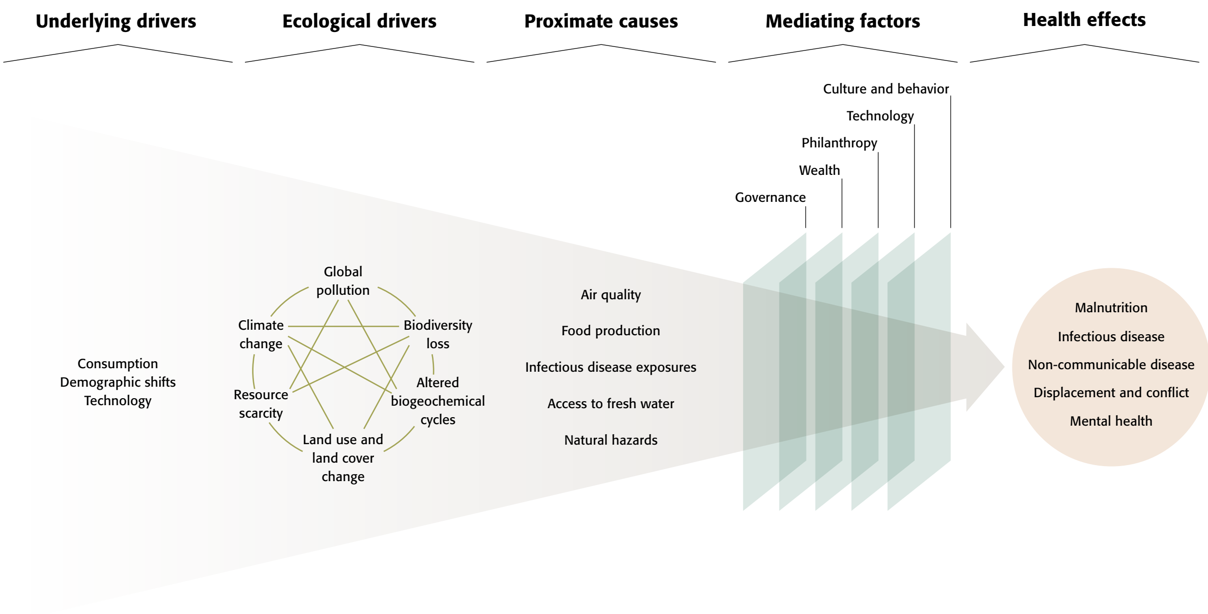
Each of these dimensions interacts with the others in complex ways, altering the quality of air, water, food and the habitability of the planet. Changing environmental conditions also alter exposures to infectious diseases and natural hazards such as heat waves, droughts, floods, fires and tropical storms. These changes to natural life support systems are negatively impacting human health in a variety of ways, including by affecting food availability and nutrition, increasing both infectious and noncommunicable diseases, increasing displacement and conflict and worsening mental health, and are expected to account for most of the global burden of disease in the coming century, disproportionately affecting today's most vulnerable, and future generations (Whitmee et al., 2015; James et al., 2018).

To protect human health, Planetary Health calls for collaboration across disciplinary and national boundaries, as well as across knowledge systems and the promotion of wellbeing economies. Planetary Health solutions involve characterising and quantifying the health effects associated with changes in a particular natural system, such as forests, and then working with communities, governments, businesses, nongovernmental and international organisations to improve management of that system so as to optimise health outcomes.

Taking a Planetary Health approach to the relationship between forests and human health stimulates investigation and action in at least four ways. First, a Planetary Health approach adds a dynamic nature to studying the relationship between forests and human health. It emphasises the importance of understanding the drivers of change, in particular the consequences of human activities, that might change the relationship between for-

Figure **2.5**

Illustration of the impacts of anthropogenic change on human health



Source: Myers, 2017

ests and human health. Second, Planetary Health acknowledges forest crises related to human activities and the impact thereof for human health, including climate change effects on forests and deforestation and fragmentation of forest habitats. For example, an increasing number of studies in the field of Planetary Health show that deforestation is leading to more infectious diseases in humans (Fawzi et al., 2020; Rodriguez-Morales et al., 2021). Third, Planetary Health emphasises a broader action and solutions space for human health including forest management and protection. For example, Myers (2017) notes that the notion of public health workers should not only apply to those in the conventional public health system but also to landscape managers, forest managers and others, emphasising the need for joint human health and environmental stewardship. Fourth, a Planetary Health approach encourages collaborative learning from different knowledge systems, including TEK (see Introduction), as these have been more consistent with stewardship of natural landscapes and ecosystems (Wabnitz et al., 2020).

Applying a Planetary Health approach to the relationship between forests and human health, thereby raises questions such as: How does deforestation influence infectious disease patterns, diet quality or mental health? How does this differ for rural, urban and forest-dependent communities, for low- versus high-income settings, for tropical versus temperate settings? What are opportunities to work with forest managers in addressing certain human health concerns? How do changes in the environment due to *agroforestry* influence human health? Several of these questions are discussed in the coming chapters.

2.6.4 Resilience

An important concept from social-ecological systems approaches is resilience which is defined in various ways, including by the IPCC as: “The ability of a social, ecological or social-ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change” (IPCC, 2007).

The essential quality of resilience is the capacity to withstand shocks and rebuild when necessary. The idea that resilience always means that things go back to the way they were after a shock or stress – like a spring – is only part of the story. Folke et al. (2010) call this ‘engineering resilience’. In the complex, inter-dependent social and ecological systems in which we live, resilience also includes the capacity for transformation when systems cross thresholds. This is ‘social-*ecological resilience*’ (Folke et al., 2010) and can be captured as a system’s capacity to manage change while continuing to develop. Such resilience approaches address ecosystems as a whole, rather than their component parts. This is a departure from conventional approaches that seek

Villagers resting under a tree on a hot summer day in Nepal
Photo © Sital Uprety

to maximise the yield of commercially important resources, such as fish or timber. Trees and fish do not exist in isolation however, they are enmeshed in ecosystems of breathtaking complexity. By focusing on one resource or outcome, forest managers may create unintended effects that disrupt and weaken the larger system with eventual impact on human health.

Resilience thinking has proved itself practical in holistically addressing local needs while offering an avenue to reach clear and specific actions, and has gained prominence with growing concerns on the impacts of climate change. For example, a climate resilience framework (CRF) was developed as a systems-based approach to building resilience to climate change. This framework has proven helpful particularly for local governments working with multi-stakeholders and cross-sectoral issues that arise when trying to address climate change, uncertainty and planning.

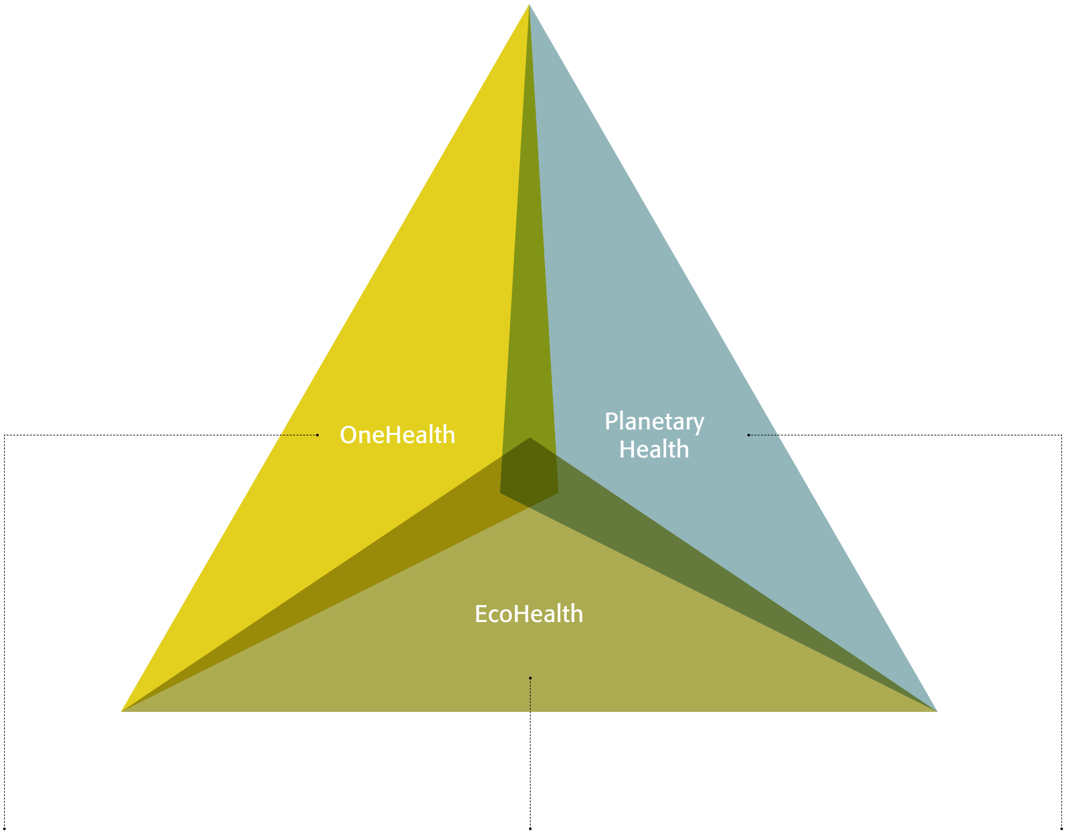
In this report, we build on resilience thinking as part of a pragmatic systems approach to better engage in complex contexts of forests-human health interactions. We thereby consider for example critical dynamics and vulnerabilities of forest-human health relationships (see Chapter 4 for further details), principles for building resilience in social-ecological systems (see Chapter 5 for further details) and potential shifts in practice for sustainable development (Reyers et al., 2013; Bennett and Reyers, 2022).

2.6.5 Implications of systems frameworks and concepts for assessing the forest-human health interactions

The various systems concepts and frameworks have evolved over time and, increasingly, more similarities than differences can be found between them (Lerner and Berg, 2017). In this report, we build upon these systems concepts to identify four main implications to better understand and engage with forests – human health interactions (Figure 2.6).

Figure **2.6**

Illustration of how this assessment builds upon the convergence of three systems approaches: One Health, Planetary Health and EcoHealth – each with roots in different backgrounds, but with increased convergence in the science-policy-practice space



OneHealth

Background roots in animal health – human health studies, centered around how the environment and environmental management impact zoonotic diseases Pandemics – including COVID-19, ebola, zika and others - have increased urgency to act upon this.

OneHealth science & practice have contributed to an increased evidence-base, awareness and policy space about the links between environmental management and zoonotic diseases.

EcoHealth

Background roots in biodiversity, ecosystem services and social-ecological systems studies.

The increased attention to, and impacts of, biodiversity loss contribute to further connect this field to human health and the urgency to act upon this.

EcoHealth science & practice have contributed to an increased evidence-base, awareness and policy space on the linkages between biodiversity and human health.

Planetary Health

Background roots in Earth system – human health studies, centered around how human-induced environmental change impacts human health.

Climate change impacts including extreme weather events, changing temperatures and droughts, have increased urgency to act upon this.

Planetary Health science & practice have contributed to an Increased evidence-base, awareness, and policy space about how climate change & environmental degradation affect human health.

This assessment builds upon the convergence between these three systems approaches and thereby underlines four related implications for understanding and acting upon forests-human health interactions:

- Multiple dimensions of health (beyond zoonotic diseases) are affected by and can benefit from forests-health management. This assessment thereby takes a holistic life span approach (Chapter 3).
- Forests-human health interactions are not static but dynamic social-ecological systems. It is therefore crucial to consider major drivers of change and how these impact forest-human health relationships. This also includes the recognition of forest crises and related implications on human health (Chapter 4).
- These systems approaches broaden the action and solution space for human health and for forest management & stewardship, emphasising a space for win-win-win actions and for anticipating & managing trade-offs (Chapter 5).
- Connecting the dots through these systems approaches for forests-human health interactions underscores the urgency to act and to invest in social-ecological resilience.

First, multiple dimensions of health (not only zoonotic diseases) are affected by and can benefit from improved forests-health management. Second, forests-human health interactions are not static but take place within dynamic social-ecological systems. It is therefore crucial to consider major drivers of change and how these impact forest-human health relationships. This also includes recognising forest crises and related implications on human health (Chapter 4) and anticipating and managing trade-offs (Chapters 4 and 5). The implication is that situations that are beneficial to the health and functioning of humans, forests and the economy can be created. Third, taking a systems approach broadens the action and solution space for human health and for forest management and stewardship, emphasising a space for win-win-win actions. Fourth, connecting the dots through these systems approaches for forests-human health interactions, underlines the urgency to act and to invest in social-ecological resilience (Chapters 5 and 6).

2.7 Framing the Health Impacts of Forests

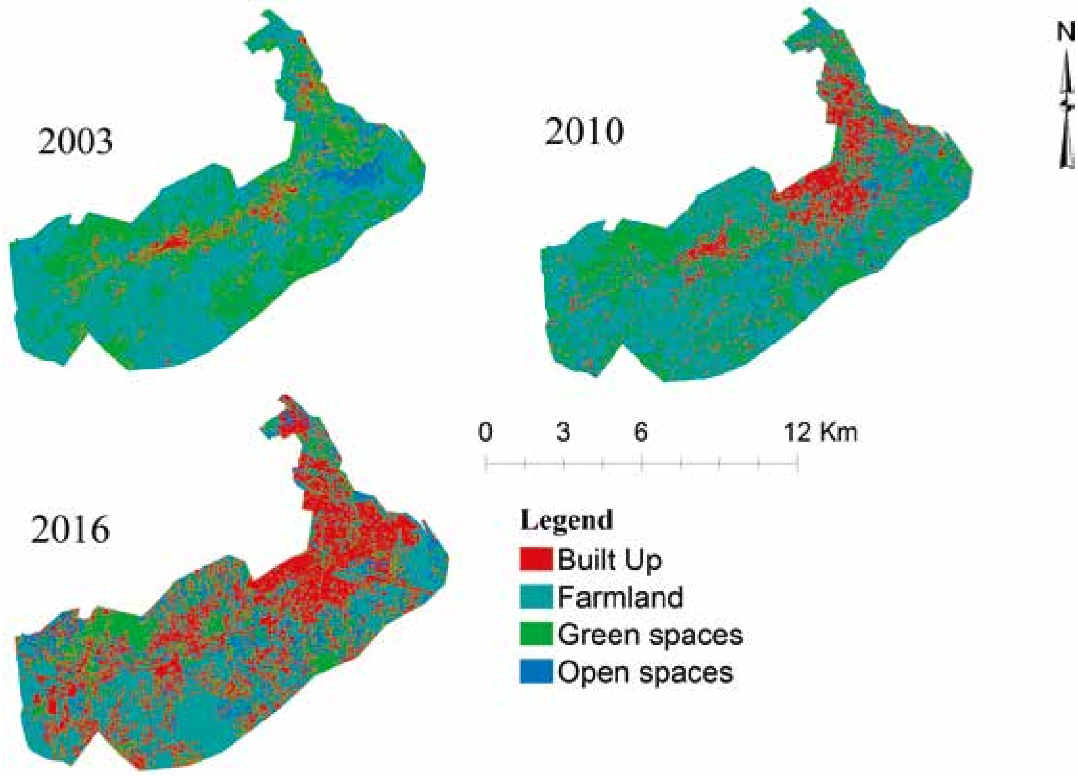
2.7.1 Disconnect between humans and forests

The opportunities for forest contact have been substantially reduced with urbanisation (Figure 2.7). Before industrialisation, daily and regular contact with nature was the norm. For millennia, humans evolved as hunter gatherers from the savannahs of Africa and migrated across the globe. But with adaptation to new and contrasting environments, humans developed new technologies attending to many necessities and desires including forms of housing, industry, food production, transport, sanitation, healthcare and entertainment. Innovation clustered geographically and this drew in more people, with wave after wave of migration from rural areas to urban centres driving rapid urbanisation. These processes have generated increasing distances between where people live and forests and other natural settings to which they might seek connection. Today, in urbanised societies, the vast majority of people spend their time indoors (Klepeis et al., 2001) without contact with or connection to the natural world. Of particular concern is children's increasing disconnect from nature, since it will influence their relationship with, and attitude towards, the environment for the rest of their lives, in addition to depriving them from the number of health benefits related to nature exposure in childhood (Louv, 2008).

This disconnect may have created or reinforced pre-existing anthropocentric notions of humanity as separate from the natural world. Some suggest that this underpins apathy to preventing environmental degradation (Louv, 2008; Whitburn et al., 2020). The spatial and cultural mismatch between humans and the 'more than human world' may be a driver of the declining importance of nature in contemporary dictionaries (Flood, 2015), fiction books, song lyrics and movie storylines in the English language (Kesebir and Kesebir, 2017), compounded by reverence for sports and music stars, TV and social media personalities (Aruguete et al., 2020). Some research indicates that children and adolescents spend more time indoors looking at

Figure **2.7**

Sebeta Town in Ethiopia. Land cover change from 2003 to 2016, illustrating a significant increase in built up land at the expense of green spaces



Source: Girma et al., 2019

screens than outdoors (Marshall et al., 2006; Larson et al., 2019). This deprivation of contact with nature and the ample human-made alternative demands for our attention may reduce a sense of connectedness with nature to such a degree that it becomes socialised and passed on inter-generationally, shifting the experiential baseline and generating a so-called 'environmental generational amnesia' (Kahn Jr et al., 2008). The net impact being new generations of humans living in a more dangerously unsustainable world without experience or knowledge of the rich diversity of life that once also called this planet home. This is further reinforced by an exaggerated risk perception where a growing sense of 'fear of nature' may occur (Ball and Ball-King, 2013, 2018). The result is generations that are unfamiliar with the natural environment and that consequently do not know how to interact with, or behave in, these settings.

Deforestation and lack of urban forests in cities reduce the availability and thereby opportunities for connection. There are also socio-economic aspects to this availability. For example, studies have reported that socio-economically disadvantaged populations tend to have lower levels of urban forest provision in many high-income countries (Feng and Astell-Burt, 2017; Markevych et al., 2017; Ferguson et al., 2018). An emerging literature indicates similar or more severe inequities in low- and middle-income countries (Rigolon et al., 2018). Nonetheless, there is appetite for using technologies to address the disconnect with nature via 'augmented reality', such as the Pokémon GO smartphone application that gamified being outdoors and encouraged people to visit nature (Adlakha et al., 2017; Marquet et al., 2018). To what extent such an approach contributes to addressing individuals' disconnect from nature or just merely attracts those with already strong senses of connection with natural environments is unclear.

2.7.2 Reconnection to nature

History and theory development

Environmental psychology

The nature and health discipline of environmental psychology emerged in the 1980s with the publication of the first experimental studies demonstrating the stress reducing and attention-promoting effects of viewing and walking through nature (Ulrich, 1979; 1984; Hartig et al., 1991). Until then, mainstream science had shown little interest in studying health benefits of nature. Belief in the 'healing powers of nature' was considered by many a kind of superstition that had become obsolete with the rise of modern medicine (Wagenaar, 2005). However, once the topic was opened to empirical investigation, the accumulating evidence sparked a new interest in the health-supportive functions of forests and other natural environments as a complement to regular therapy and treatment.

Research on the health effects of exposure to natural environments has for a long time been guided by two dominant theoretical perspectives: Attention Restoration Theory (ART) (Kaplan and Kaplan, 1989) and Stress Reduction Theory (SRT) (Ulrich et al., 1991). ART proposes that natural environments are rich in 'soft fascinations' which automatically draw our attention without requiring effort, thereby replenishing people's cognitive capacity and reducing their mental fatigue and increasing their focus and attention. SRT states that exposure to nature activates the parasympathetic nervous system as a 'vagal break on stress' and thereby facilitates psychophysiological stress recovery. Both theories refer to the innate connection of humans with nature developed through evolution as a possible ultimate explanation for the positive responses to nature. This evolutionary approach has been elaborated in more detail by the biophilia hypothesis (literally meaning 'love of life') which states that humans have an inherent preference to seek connections with other forms of life and with nature, and derive many benefits from making that connection (Wilson, 1984).

Theories and studies in environmental psychology have also suggested that exposure to natural environments and engaging in nature-based activities can increase pro-environmental attitudes and stimulate pro-environmental behaviour. This relation may, to some extent, be explained by automatic physiological reactions (Annerstedt van den Bosch and Depledge, 2015). But there is also strong evidence that the positive influence of nature exposure on pro-environmental behaviour is mediated by feelings of connectedness to nature, which make people more caring and respectful towards the environment (Martin et al., 2020; Whitburn et al., 2020).

Environmental epidemiology

Methodologically, around the turn of the 21st century, research on health benefits of nature took a new turn. Until then, research mostly consisted of experimental studies conducted by environmental psychologists. Epidemiologists, however, also became interested in studying the relationship between nature and health with their own methods (Takano et al., 2002; de Vries et al., 2003; Groenewegen et al., 2006). Using residentially geocoded information to connect data on green space in the living environment with public health data, *epidemiological* studies demonstrated strong positive relationships between the amount of green space and a wealth of health indicators, including morbidity and mortality rates (Twohig-Bennett and Jones, 2018). This line of research has gained much ground, with some studies suggesting even greater health benefits of green space for those living in deprived areas, thereby potentially reducing income-related inequalities in health (Mitchell and Popham, 2008; Dadvand et al., 2014; Wolch et al., 2014) although the findings are inconsistent, with other studies indicating a stronger association in wealthier areas (Crouse et al., 2017).

A key question for – experimental as well as epidemiological – research has evolved around the health impacts of different types of natural settings (Purcell et al., 2001). This knowledge would be central for urban planners to optimise health benefits within a constrained space. However, the matter is complicated since different types of nature likely influence different health outcomes and in different populations; thus, there is no one-size-fits-all. The results also vary in the literature with some studies finding no clear distinction in impact depending on nature type (van den Berg et al., 2014; Gidlow et al., 2016a; van den Berg, 2021), and others suggesting differences (Jarvis et al., 2020b; Jarvis et al., 2022). If anything, there seems to be a certain convergence towards the particularly beneficial impact of trees, in comparison to, for example, grass cover (Wolf et al., 2020).

Today, nature and health research has matured into a recognised, multidisciplinary field with its own unique theories and methods, and a substantive output of hundreds of peer-reviewed papers per year, including critical systematic reviews and meta-analyses (Mygind et al., 2019; Rojas-Rueda et al., 2019; Davis et al., 2021). One of the important contributions of this research which has provided evidence on the health and wellbeing benefits of nature, is that it has made people aware of the importance of connecting to nature. Importantly, this has resulted in policy and practice implementation and high-level recognition of the value of nature, seeing forests and green spaces highlighted in WHO public health policies (WHO, 2016) as well as in the Sustainable Development Goals (Devisscher et al., 2019) and as one of the indicators for adaptation, planning and resilience for human health in the latest Lancet Countdown on climate change and health (Watts et al., 2021).

Pathways and mechanisms

Following up on the theories and studies described in the previous section, significant research has been carried out to improve the understanding of why nature has an impact on health, exploring the potential pathways and mechanisms that underlie any association. This knowledge is essential to provide causal evidence and also to better describe which components and types of nature are beneficial for which health outcomes. It also helps research to rule out alternative explanations for associations, such as self-selection. By providing causal evidence, the arguments for urban green planning, biodiversity conservation and reforestation increase with clear planetary health benefits.

In the remainder of this section, different pathways that have been studied will be briefly introduced, with a focus on the link between nature and the mediating variable. Links between pathways and specific health outcomes are addressed in Chapter 3. A summarising model of how the pathways between nature exposure and health outcomes operate is provided in Figure 2.1.

From the early days of research on nature's impact on human health, a common way to describe the associations has been to refer to socio-behavioural pathways. These pathways are typically related to stress recovery, physical activity and social cohesion and some of them, but not all, may be considered as cultural ecosystem services. A relatively recent paper by Bratman et al. (2019) suggests a model where mental health, as identified through, for example, cognitive function and emotional wellbeing, is specifically acknowledged as an ecosystem service.

Stress recovery and attention restoration

A number of studies, from the nature and health discipline's early days, have demonstrated that nature may facilitate stress recovery as indicated both through physiological measurements and self-reports. The stress recovery may be a result of direct sensory stimulation from nature, such as exposure to fractal patterns, (Hägerhäll et al., 2008), smells (Matsumoto et al., 2014), sounds (Hunter et al., 2010), or stemming from opportunities for recreation and getting away from everyday demands.

Experimental studies tend to show beneficial (short-term) effects by just looking at natural scenes, compared to urban scenes, although the evidence seems stronger for self-reported stress measures than for physiological stress measures (Mygind et al., 2021; Bolouki, 2022). Kondo et al. (2018) arrived at similar conclusions based on studies in which participants were exposed to natural and built-up environments. As for epidemiological research, recent research has analysed allostatic load levels, which may be considered the physiological counterpart of chronic stress. Egorov et al. (2017) and Egorov et al. (2020) showed that, on average, people with a greener residential environment including a larger tree canopy cover, had a lower allostatic load level. Another indicator for chronic stress is the amount of the stress hormone cortisol in hair. Recent studies have found beneficial associations between the local amount of green space and hair cortisol levels (Levhar et al., 2021; Verheyen et al., 2021), although an earlier study did not find an association (Gidlow et al., 2016b). It is important to confirm the stress recovery impact in further high-quality studies because chronic stress is a major risk factor for many non-communicable diseases, as discussed in Chapter 3.

Physical activity

Like chronic stress, physical inactivity is a major risk factor for many diseases (see Chapter 3), and therefore, it is crucial to know if nature stimulates physical activity in a population. This could occur by simply providing a suitable environment (also, a cooler one during periods of heat) for running or using training equipment in a recreational forest or a park. A recent review concluded that physical activity is the most studied pathway between urban green spaces and health (Dzhambov et al., 2020) and it has even been suggested that the health benefits of physical activity are larger if they are conducted in a natural environment compared to an indoor setting (Thompson Coon et al., 2011; Wang et al., 2021). The findings are mixed however, with some studies indicating a positive association (de Vries et al., 2013; Konijnendijk et al., 2013), and others not (Maas et al., 2008; Triguero-Mas et al., 2015). Some studies support the role of physical activity as a mediator in the nature and health association (van den Berg et al., 2019) but the magnitude of this impact remains unclear. The inconsistency in evidence is likely due to several factors that interact and determine the impact, such as, for example, real accessibility (socio-culturally and physically) and quality and amenities

Reconnecting to nature is essential, especially for urban societies
Photo © Nelson Grima

of the area. In addition, study designs and methods for measuring exposure and outcome differ substantially between studies.

Social cohesion

Social cohesion can be understood as a sense of shared values, cooperation and interactions in a community. Natural environments can serve as democratic settings for social interactions between neighbours thereby creating social cohesion and a sense of community in both urban and rural areas (Elands et al., 2018). Social interactions in public spaces can provide relief from daily routines and offer opportunities to relate to people of various backgrounds (Dines et al., 2006). Several studies suggest a positive association between social capital and green spaces (Maas et al., 2009; Peters et al., 2010; Dadvand et al., 2016), but similarly to physical activity, research on the role of social cohesion as a mediator to health outcomes is not entirely consistent (Zhang et al., 2021). The mixed findings may be due to the difficulty in measuring social cohesion objectively and it is also likely that the quality and type of green space may be more important than the mere amount of green.

Place attachment

Place attachment, sometimes referred to as sense of place, represents an individual's emotional connection to a physical landscape (Lewicka, 2011). Natural elements and urban green spaces have been found to predict place attachment (Bonaiuto et al., 1999), although social factors are stronger determinants. Place attachment can, in turn, contribute to perceived restorativeness of a place (Liu et al., 2020) and thereby act as mediator to various health outcomes. A concept that is related to place attachment is solastalgia (Albrecht et al., 2007), which basically represents the distress produced by change of home environment, the place to which people are connected through, for example, place attachment. Solastalgia can occur as a result of displacement, notably because of natural disasters and climate change (Warsini et al., 2014; Ellis and Albrecht, 2017).

Old friends

A relatively recently introduced pathway that relates to nature's potential for direct health impact is through its capacity to influence humans' immune systems (Rook, 2013). This is sometimes referred to as the 'hygiene hypothesis', 'biodiversity hypothesis', or the 'old friends hypothesis' (Rook et al., 2014; Rook, 2018). Modern life, especially in high-income countries, is characterised by high hygiene levels and indoor living, which results in insufficient exposure to natural microorganisms and thereby an impaired development of our immune systems. This may be one of the explanations behind the exponential increase in, for example, allergies, asthma and inflammatory bowel syndrome (Hanski et al., 2012; Logan et al., 2016). According to recent studies, exposure to diverse microorganisms in nature can influence the human microbiome resulting in a more diverse composition of gut (Roslund et al., 2021) and skin (Lehtimäki et al., 2018) microbiota. This counteracts the dysbiosis associated with modern living, and thereby stimulates the development of a functioning immune system, (Roslund et al., 2020; Roslund et al., 2021), sometimes referred to as 'natural immunity' (von Hertzen et al., 2011).

Regulating ecosystem services

Heat: Urban trees and forests regulate the climate by reducing heat (TNC, 2016; van den Bosch and Ode Sang, 2017), particularly the *urban heat island* phenomenon (Oke, 1973). With global warming, this service will likely become of increasing importance to reduce heat-related morbidity and mortality (Watts et al., 2021). Green space can cool the environment through shading and evapotranspiration (Loughner et al., 2012; Qiu et al., 2013; Napoli et al., 2016). The shading mechanisms prevent heat storage in impervious surfaces and its later release. Large trees are, in this context, more important than grass or lower vegetation. The evapotranspiration effect refers to trees' water transportation which increases latent heat storage because some of the sun's energy will go to converting water from its liquid to its vapour form, rather than increasing air temperature. These effects can substantially reduce maximum summer daytime air temperatures at pedestrian level. Existing evidence suggests that urban greenspace can reduce the temperature by up to 3°C on average (i.e., not considering the impact on maximum temperature), depending on local context (Fryd et al., 2011). The spatial extent of the heat reducing effect also varies with context but, as a general rule, the maximum cooling distance amounts to approximately one park width from the park (or forest patch) (TNC, 2016). Research on the role of heat reduction as a mediator of health impacts supports this pathway (Graham et al., 2016).

The fruit and rhizomes of Hedychium spicatum*, a plant commonly found in Asia and Africa, is used for medicinal and religious purposes*

Photo © Arun Kumar

Altogether, the cooling impact of urban trees will likely have a substantial impact on thermal comfort and health in the future, especially in heat vulnerable populations such as children, the disabled and the elderly. This impact will be of particular importance in countries that are most impacted by climate change, often in low-income areas of the world with a large amount of the labour force working outdoors (Kjellstrom, 2009; 2015).

Air pollution: Ambient air pollution is currently the largest environmental health threat with more than seven million people dying prematurely each year due to its harmful impacts (Landrigan et al., 2018). A disproportionate burden is taken by low- and middle- income countries. Therefore, even small reductions of air pollution levels can have a large impact on a population level.

Urban green spaces can improve air quality by modifying the concentrations of gaseous and particle pollutants (Janhäll, 2015). Trees can impact gaseous pollutants through uptake by leaf stomata, absorption and adsorption to plant surfaces (Escobedo and Nowak, 2009). In the health literature, much attention has been given to particle pollutants (particulate matter, PM) because of the strong association with morbidity and mortality. Green spaces interact with PM by deposition, dispersion and modification.

Deposition refers to direct capturing of PM through, for example, absorption. In practice, the net impact of this mechanism is difficult to estimate because the value is also influenced by resuspension of PM due to wind, precipitation or defoliation. On a local scale (typically a distance of between 10 and 500 m), the effect can be substantial, with a removal capacity of up to 60% (Pugh et al., 2012; Steffens et al., 2012).

Dispersion is typically characterised by a physical or filtering green space barrier, which changes the velocity and trajectory of PM. In this case, it is clear that the positioning of the vegetation, relative to dominant air flows and emission sources, is important. In some cases, local PM concentrations may actually increase if the vegetation blocks air flows and keeps the polluted air trapped in, for example, street canyons (Gromke and Blocken, 2015).

Modification occurs when green spaces alter inherent properties of PM, which can accelerate deposition or even reduce the toxicity of the particles (Weyens et al., 2015). A large number of modelling and quasi-experimental studies have assessed green spaces' impact on air pollution and converging evidence suggests that there is a positive effect, although the magnitude is relatively small (Diener and Mudu, 2021). Nevertheless, given the scale of the problem, small effects can translate into large health impacts, especially if urban forest interventions are carefully planned with a focus on the most vulnerable populations in areas with high pollution levels.

Noise: Another way by which green space is assumed to protect health, is by reducing noise. Whereas the effect of vegetation on actual noise levels may be small, it can help to reduce the noise annoyance (Salmond et al., 2016). The same objective noise level may result in less noise annoyance if green space is present (Dzhambov et al., 2018; Mueller et al., 2020). This could be labelled a psycho-acoustic effect of the vegetation. Recent studies suggest an impact of trees also on objective noise levels (Zhao et al., 2021) as well as a mediating pathway role (Jarvis et al., 2021). Another way in which nature may help to reduce noise annoyance is by way of natural sounds – in particular birdsong (Van Renterghem, 2018) – masking manmade sounds (including traffic noise).

Disease transmission regulation: Only a small number of studies directly analyse the links between ecosystem services and the regulation of infectious disease transmission. The 'dilution effect', or the 'negative diversity–disease', has been proposed as an ecological mechanism of an ecosystem service of disease regulation. The dilution effect postulates that biodiversity losses may promote disease transmission (Keesing et al., 2006; 2010). Global land use changes, including *forest conversion*, may favour zoonotic reservoirs and the risks of zoonotic diseases (Gibb et al., 2020). Deforestation and biodiversity loss favour reservoir and/or vector populations, which affect disease transmission dynamics. For example, re-emergence of arthropod-borne leishmaniasis has been found to be associated with deforestation (Chaves et al., 2008). The ecological mechanism proposed is that forest fragmentation and biodiversity loss lead to the loss of ecological regulation of small mammals, which are main reservoirs of Leishmania species (Gottwalt, 2013). The fact that biodiversity prevents the emergence and spill-over of infectious diseases is currently of increasing concern as we become aware of the dire human health consequences of the COVID-19 pandemic (Kache et al., 2021). Moreover, global trade and climate change favour invasive species, which are new potential vectors or reservoirs in invaded localities increasing the risks of infectious diseases (Hulme, 2014).

A number of other regulating services are related to positive human health outcomes, although they have rarely been considered as mediators in the nature and health studies. Nevertheless, forests' capacity to reduce flooding and retain water contributes to lower risk of injuries and mortality related to flooding hazards (WHO, 2021a). Water purification is another service that reduces water contamination and related infectious diseases (Chiabai et al., 2018). This is further discussed in Chapters 4 and 5. The role of forests in disaster risk reduction and prevention has a large impact (Al Kautsar and Mulyono, 2021), not only on physical health, but also on mental health because of the distress and anxiety associated with extreme events (Sudmeier-Rieux et al., 2021).

Provisioning ecosystem services

Provisioning services are of high importance for food security, fresh water and fuel supply, and medicinal plants among others, especially in forest-dependent communities (Dhar et al., 2018). These are all essential components of healthy lives and even survival for large populations across the world.

Forest foods and tree products have been necessary components of rural diets for millennia. Food security is grounded in the diversity of biota, landscapes and production units, and forests and trees are critical for maintaining that diversity (Vira et al., 2015). Forests also provide high quality nutrients with impact on specific conditions related to undernourishment and micronutrient deficiency, such as osteoporosis, cardiovascular diseases, and many other non-communicable disorders (Afshin et al., 2019). A number of studies have found a positive association between having access to forests and various indicators of diet and nutrition (Rowland et al., 2017; Baudron et al., 2019) and a recent study from Tanzania was able to provide evidence for a causal relation between deforestation and decline in dietary quality (Hall et al., 2022).

In addition, more than one-third of the global population relies on fuel from forests for cooking and it is a vital source of energy for local economies. Medicinal plants from forests improve health not only in forest-dependent communities, but also form the basis of many pharmaceutical products produced globally. For example, wild forest resources include compounds that carry therapeutic properties, such as muscle relaxants, steroids and contraceptives (from wild yam). Quinine and artemisinin against malaria are also based on forest products, as are the anti-oxidant cancer drugs vinblastine, etoposide and taxol (Rao et al., 2004).

Making better use of TEK and combining it with western scientific knowledge could increase the role of forests in food security and nutrition (FAO, 2013). Indigenous people and local communities hold an immense knowledge base on the cultivation, harvesting and preparation of forest foods and other products. Another important aspect is to acknowledge women's often specialised knowledge of forests in terms of species diversity, uses for various purposes, and conservation and sustainable management practices, something that is currently typically underappreciated (FAO, 2013).

Altogether, we can conclude that the number and types of pathways between forests and human health are varied, multifaceted and highly interactive. There is overwhelming evidence supporting the notion that forests and natural environments are related to healthy behaviours and services that evidently lead to positive health outcomes (WHO, 2016; van den Bosch and Nieuwenhuijsen, 2017; van den Bosch and Ode Sang, 2017; Watts et al., 2021).

Trade-offs

Forest environments are not silver-bullet solutions to the extremely complex challenges the world is facing now and will be facing in the future. Human health is influenced by the local and global economy, war and conflicts, infrastructure and access to health care, education, lifestyles, and much more. Many of these factors are not, or only peripherally, related to forests. In many cases, trade-offs occur, for example when new infrastructure must be built on forest land to provide access to health care clinics or schools. This is often a more common problem in low-income countries where critical infrastructure expansion is still under development. For this reason, it is even more important to consider optimisation of investments, both from a human health and environmental perspective. One way of addressing this is through Environmental and Health Impact Assessments (EIA and HIA), which use systematic approaches and methodologies to estimate future consequences of proposed projects, activities, plans or policies. The aim is to identify and mitigate trade-offs and also find solutions to strengthen any investment or strategy for the benefit of both humans and the environment (Vohra et al., 2018). The focus areas for an EIA typically include flora and fauna; water, air and soil quality/quantity; noise; landscape and visual amenities; archaeology and heritage; and socio-economic environments (Morris and Therivel, 2001). An EIA usually only considers potentially adverse impacts of an activity. HIAs, on the other hand, tend to identify both positive and negative impacts on communities, and health and wellbeing. This is an important aspect for evaluating the positive effects of, for example, reforestation or urban green planning activities, while at the same time considering trade-offs. An HIA can include several focal areas, for example, food access, economic stability, recreation opportunities, air and water quality, and safety. A thorough discussion of trade-offs and synergies in the interactions between forests and human health is provided in Chapter 4.

2.8 Conclusion

This framing chapter has outlined how the interrelations between forests and human health can only be understood within the context of planetary health and related concepts. From this perspective, human health is understood as a multidimensional state that encompasses physical, mental, spiritual and social wellbeing, but also a capacity for adaptation and resilience, similar to a healthy forest environment from an ecological point of view. Disruptions to natural environments directly affect our own health.

To improve our understanding of these interrelated disruptions, we must also improve our understanding of the benefits that humans can obtain from healthy forests and how these benefits can be achieved in a context of reciprocity where ecosystem services are part of a circular system and can be returned through environmentally aware forest management methods and ecologically sound resource conservation (Comberti et al., 2015). This kind of knowledge requires transdisciplinary efforts, where not only different scientific disciplines collaborate, but also stakeholders, politicians, and practitioners as well as minorities, all genders, and Indigenous peoples, are involved throughout the knowledge generation process.

This chapter has also described how and why our disconnect with forest environments has occurred, why it prevails, and how the discipline around nature and health relations has developed from initial environmental psychology theories to research around pathways and mechanisms behind human health benefits from forests, some more evident than others. In doing so, we also address the current state of the art and how the evidence has been generated based on different study designs and measurements. These descriptions lay the foundations for how the knowledge presented in the rest of the Assessment can be interpreted and understood.

As reflected in this chapter, there is a deep injustice related to knowledge about interrelations between forests and human health. While many people in low- and middle-income countries depend on forest environments for their livelihoods, most of the research is conducted in high-income countries, with a predominant focus on urban forests. It is clear that we also need to fill the knowledge gaps that relate to how human health and forest interrelations are, and will be, impacted by the global increase in socio-economic inequalities and climate change.

In summary, human health does not exist without forest health. It is pivotal that this message be communicated to, and fully understood by, politicians, decision-makers, and everyone living on this planet because, despite the simplicity of the message, the way we treat our forests demonstrates that we are very far from having achieved this simple realisation and an outdated, anthropocentric worldview prevails.

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Appendix to Chapter 2
Research Design, Methods and Indicators

Introduction

The current evidence base on human health impacts of forests is developed from studies using different types of research designs, methods, tools and indicators. Here we provide an overview of methods typically used in traditional ecological knowledge (TEK) systems and give a brief overview of how Western, mainly quantitative, scientific knowledge has been generated, focusing on study designs and how aspects of exposure and outcome have been measured. It should be noted that a vast majority of studies on the direct impact of forests on human health have been conducted in urban environments, predominantly in Europe, North America and Australia (Gallegos-Riofrío et al., 2022).

The most considered modifiers are socio-demographic factors on an individual or neighbourhood level, such as socio-economic status and gender (although evidence is inconsistent with regard to gender-related differences). With few exceptions, modifiers and contexts related to national income level, urban-rural gradient, geographical zone and climate-change impact have not been included in the analyses. More recently, the quality of green space has increasingly been considered (Knobel et al., 2019; Jarvis et al., 2020), especially in urban settings, but evidence is scarce and inconsistent.

Traditional Ecological Knowledge (TEK)

In general, Western science is characterised as objective and systematic, while TEK is contrasted as being more subjective. However, it is important to consider that any knowledge or data are produced by socially situated actors and are value-laden (Weiss et al., 2013). TEK tends to be local and context-specific and is typically acquired longitudinally, orally or through demonstration, and made general through dialogue and a shared social memory. The data are filtered and analysed through the individual human brain, developing predictions of future events based on comparisons between what has happened in the past and what is happening now, within a constantly changing environment (Freeman, 1992). This interactive and longitudinal methodology that integrates a large number of variables qualitatively allows for a context-dependent knowledge and understanding of increasingly complex situations that are characterised by uncertainty, nonlinear dynamics and conflicting perspectives – all common elements in forest-health research. For this reason, real-life problems may be best addressed by considering TEK and Western science as complementary systems, with their distinct designs and methodologies. Because findings from TEK are rarely documented in scientific publications, due to the very nature of this approach – verbal rather than written – it is a challenge to provide a systematic list of TEK methods. This calls for locally conducted research and transdisciplinary approaches, where any stakeholder is included in the formulation of research questions, project design, and aims (Annerstedt, 2010). Data usually take the form of oral expressions or symbols, rather than written text or numbers.

Western science

Study design

In the Western science tradition, a hierarchy of study designs is typically considered when evaluating the quality of evidence generated from research. Briefly, this means moving from the lowest level of evidence obtained from case studies, through cross-sectional studies, case-control studies, cohort studies, to the highest level of evidence derived from *randomised controlled trials* (RCTs). Finally, systematic reviews can determine significance and effect sizes through meta-analyses of available RCTs. However, it should be noted that this evidence hierarchy has its origin from the practice of evidence-based medicine (EBMWG, 1992) used, for example, to guide clinicians to the most recommended treatment for a specified diagnosis. Moving towards more complex, interdisciplinary research questions, this hierarchy may not be an optimal way to assess the level of evidence (Concato, 2004). A complicating factor is also that RCTs are difficult to conduct on a complex and dynamic subject such as a forest.

From the Western science evidence hierarchy perspective, most nature and health studies would actually be considered as having a relatively high risk of bias and thereby the evidence would be assessed as limited. However, as resources for this area of research increase and refined methods and designs are developed, findings from observational studies have started to be confirmed in controlled trials (Lederbogen et al., 2011; Bratman et al., 2015). In addition, the sheer number of studies pointing in the same direction, supports the evidence of nature's positive impact on health. Most importantly, we may need to consider a more holistic approach to evidence generation, including complementary information and data in transdisciplinary projects and analyses.

Many of the observational studies on nature and health are of a cross-sectional design (see e.g., Boll et al., 2020; Fan et al., 2020). In these studies, exposure and outcome are measured at the same point in time, meaning that it is difficult to assess causality and there is a risk of self-selection bias, i.e., that those who are already of high income and good health are also those that live nearby green spaces. In a case-control study (see e.g., Demoury et al., 2017; O'Callaghan-Gordo et al., 2018; Helbich et al., 2020), cases (e.g., individuals getting diabetes) are compared with controls (e.g., individuals not getting diabetes) retrospectively and the respective exposure to green space is determined. This means that it is possible to identify whether exposure protects against disease (e.g., are those exposed to green space at lower risk of getting diabetes?).

The next level of evidence would be retrieved from longitudinal cohort designs. These studies follow a defined cohort over time, making it possible to determine a causal relationship in the sense that exposure precedes outcome (see e.g., Annerstedt [van den Bosch] et al., 2012; Dadvand et al., 2017; Astell-Burt and Feng, 2020). In natural experiments, researchers can take advantage of a change in the environment, as induced by, for example, deforestation and compare data on health outcome before and after, although randomisation in this case is impossible (see e.g., Donovan et al., 2015). The highest level of evidence, according to the Western science hierarchy model, can be obtained from an RCT, where most confounding bias can be eliminated through randomisation and the mechanism behind a causal relation can be identified. Fully powered RCTs in nature and health research are difficult to conduct in real settings, but a few examples exist (South et al., 2018; Sobko et al., 2020). For example, the study by Sobko et al. (2020) randomly assigned two groups of children to more or less biodiverse environments and found that the group that was exposed to biodiversity obtained a more diverse gut microbiome following the intervention compared to the control group.

Qualitative study designs are not aimed at establishing numerical evidence but strive to get an as rich and detailed in-depth understanding of a specific phenomenon or topic as possible, through a subjective approach. This can provide insights into, for instance, the meaning of nature for individuals and how people use, perceive and experience landscapes (Lygum et al., 2013; Bell et al., 2018). Another important aspect of qualitative research is how it can identify research questions and provide insights for how to interpret results from quantitative data analysis. It is also fundamental for being able to conduct mixed-methods studies, which often provide a holistic perspective of complex situations (Phoenix et al., 2013; Stigsdotter et al., 2017).

Measurement methods

Outcome assessments: Human physical, mental, social, and spiritual health and wellbeing

The measurement of human health and wellbeing has been approached in a variety of ways in the nature and health literature. The following paragraphs provide a summary of indicators and measurement methods.

Observational and physical data

Evidence from observational studies can be based on available data of risk factors, morbidity or mortality. These types of data can be from registers of the health system, including health insurance providers, from statistical offices, or from cohorts with specific research purposes. To measure risk factors, reported data on, for example, Body Mass Index (BMI), blood pressure, and birth weight, have been used. These relate to the identified pathways. Regarding diagnosed diseases, prevalence (how many people suffer from a disorder at a certain point or period in time) or incidence (the number of people being diagnosed with a disorder within a certain period) measures are typically used. Data on prescription of medicine have also been used as proxy measures for disease (Marselle et al., 2020). Existing data on all-cause or cause-specific mortality can be used, typically to assess reduction in premature mortality. Recent studies have included estimates of *Disability-Adjusted Life Years (DALYs)* to assess impact (Mueller et al., 2017). Physical activity can be measured by various smartphone applications and accelerometers, sometimes in combination with Global Positioning System (GPS) to track activity patterns.

Self-reported data

Impacts of forest on health can be measured through self-reported data using validated tools or scales of states of health and wellbeing or symptoms. These can be collected through surveys or questionnaires that are distributed to a population through mail, e-mail, phone calls or face-to-face. Research has indicated that there is an association between both self-reported measures and objectively measured health factors, including mortality (Idler and Benyamini, 1997; Krijger et al., 2014). A vast array of scales has been used: for example, the World Health Surveys (WHO online); EQ-5D (Yi et al., 2021); SF-36 Health Survey (Ware Jr and Gandek, 1998; van den Berg et al., 2019); and the General Health Questionnaire, GHQ-12 (van den Berg et al., 2010). Measures of quality of life (QoL) include, for example, the WHO Quality of Life scale (WHOQOL) (Hipp et al., 2016). The WHO-instruments for wellbeing focus on mental wellbeing (WHO-5), especially depression, whereas the WHOQOL have a much broader perspective, where being in good health is considered as a contribution to high QoL.

Scales that measure symptoms, pathways or risk factors can indicate, for example, perceived stress (e.g., the Perceived Stress Scale (Cohen, 1988); physical activity (e.g., International Physical activity Questionnaire, IPAQ (Loder and van Poppel, 2020)); social cohesion (e.g., Social Support List (Maas et al., 2009); or different mood states and happiness, (e.g., Profile of Mood States, POMS (Lin et al., 2019)). To measure nutrition status collection of indicators such as dietary diversity scores or consumption of certain nutritious food groups, for example fruits and vegetables, can be used (Hall et al., 2022).

Biomarkers and physiological data

Some cohorts have included sampling of biomarkers from, for example, blood, saliva, hair, skin or stool. Such sampling methods are often also used in experimental studies. The outcome measures that can be derived from biological samples include genetic material, for example telomere length (an early marker of ageing (Miri et al., 2020)), indicators of stress, such as cortisol (Ward Thompson et al., 2012) or allostatic load (a composite measure reflecting levels of chronic stress (Egorov et al., 2020)) and gut microbiome (related to immune system function (Roslund et al., 2021)). Experimental studies have also included non-invasive measurements of the autonomous nervous system to evaluate stress and stress recovery, for example blood pressure (Adhikari et al., 2021) and heart rate variability (Annerstedt [van den Bosch] et al., 2013). It is also possible to monitor impact of forest on brain function through various neuroimaging techniques, such as electroencephalography (EEG) (Olszewska-Guizzo et al., 2020), functional Magnetic Resonance Imaging (fMRI) (Tost et al., 2019; Chang et al., 2021), and neural blood flow (Bratman et al., 2015). A number of studies on Shinrin-yoku, specifically from Japan, have measured a broad set of biomarkers, for example, natural killer cells, anti-cancer proteins and adiponectin (regulating inflammation and metabolism) (Li et al., 2008; Li, 2010; Yi et al., 2022). The increased use of biomarkers and clinical measurements will contribute to an improved understanding of the biological fundaments for human health impacts of forests.

Qualitative data

To obtain information on people's subjective health experiences, perceptions and feelings related to forest environments, qualitative data through, for example, interviews or thematic writing are collected (Lee et al., 2019; Puhakka, 2021). These kinds of data can provide a deeper understanding of the meaning of forest environments to individuals and their personal wellbeing. Qualitative data have been used to measure, for instance, social cohesion and place attachment (Elliott et al., 2014).

Qualitative data is an important resource for understanding aesthetical and spiritual experiences in nature and how nature can be symbolised. It is also central for providing insights into childhood experiences of nature and how this can influence perceptions and pro-environmental behaviours across the life course. Several methods can be used for conducting qualitative research. Phenomenological studies examine people's lived experiences in nature through their own, personal descriptions. This provides insight into the meaning that experiences hold for the participants. Ethnographic research, on the other hand, looks more at data about cultural groups. This can be carried out, for example, with the researcher living with the group under study, such as a forest-dependent community, and becoming a part of their culture. By interviewing key informants or through observations, further knowledge can be obtained. As a final example of qualitative methods in nature and health research, case studies can be mentioned. These are in-depth examinations of a group in a specific situation, such as children's engagement in nature play, and may sometimes also include the collection of quantitative data. Case studies and other findings from qualitative research can be central for developing hypotheses or theories and lay the ground for further quantitative examinations.

Exposure assessment: Environmental indicators

Exposure to natural environments has various dimensions, each of which could be relevant to different mechanisms and health benefits. For example, while access to green spaces could be predominantly relevant to physical activity as a mechanism, residential surrounding green space could be more relevant for mitigation of harmful exposure, such as air pollution, noise and heat, which would be another mechanism towards health outcomes. Ecological indicators of, for example, below- or above-ground biodiversity are other components that may have particular impacts on humans' microbiome composition with subsequent health impacts (Rook, 2013). As such, the assessment of multifaceted exposure to natural environments is complex and methods are still evolving.

Urban forest and green space indicators

At a city level, several tools and indicators have been developed to assess different types and qualities of urban forests. These range from land use and land cover databases that can indicate, for example public versus private land or type of vegetation (e.g., deciduous or coniferous trees) (European Union, 2011; Williams et al., 2018), to qualitative indicators that consider people's experiences and perceptions of the natural environment (Grahn and Stigsdotter, 2010; Gidlow et al., 2012; Knobel et al., 2020).

To date, studies evaluating the health effects of urban natural environments have mainly relied on one or more of the following dimensions and assessments:

Surrounding natural environments

Indicators of surrounding natural environments estimate the amount of green space within buffer zones of various sizes (e.g., 100 m, 300 m, 500 m, 1000 m, etc.) around a point (or several points) of interest (e.g., home, workplace or school). To abstract these indicators, studies have relied on remote sensing-based indexes of green space or land cover/use maps. The *Normalised Difference Vegetation Index (NDVI)* (USGS, 2018) is one of the most widely used indices in the studies of the health effects of green space (Davis et al., 2021). Its values range between minus 1 and plus 1 with higher values indicating more photosynthetically active vegetation land cover. Other examples of remote sensing derived measures that have been increasingly applied because of the improved level of precision and specificity are Vegetation Continuous Fields (VCF) (Anabitarte et al., 2022) and unmixed pixel percentage data (Jarvis et al., 2021). In addition to these 2-dimentional (2D) indicators of greenspace, more recently studies have relied on 3D indicators of green space such as number and height of trees or size of their canopy and biomass around the point(s) of interest, mainly using Light Detection and Ranging (LiDAR) data (Zhao et al., 2021).

Physical access

Proximity to green spaces has been widely used as a surrogate of access to these spaces (Expert Group on the urban environment, 2001). This indicator could be assessed objectively or subjectively. The objective proximity to natural environment is mainly based on the Euclidean or network distance between the point(s) of interest (e.g., home, workplace or school) and the nearest natural space, usually identified with a land use/land cover map or by self-reports (e.g., by asking the participants whether there is a park within a 10-minute of walk from their homes). For example, WHO-Europe defines residential access to green spaces as living within 300 m from a green space with an area of one hectare or more (Annerstedt van den Bosch et al., 2016; WHO, 2016). Based on the characteristics of the indicator applied to identify natural environments, it is possible to also extract proximity indicators for different types of green spaces. The subjective proximity to natural spaces is an indicator of perceived access to these spaces.

Visual access from indoors

Indoor visual access to natural environments can be assessed subjectively or objectively. Questionnaires could be applied to obtain subjective information on the access (e.g., having a window with a natural view), intensity (e.g., the proportion of the window that is covered by the natural view) and frequency (e.g., the frequency of watching the natural view through the window) to natural environments. Other possibilities are using image processing techniques to quantify the nature view through the window in the photos taken from the window(s) of interest or relying on 3D maps of outdoor natural environment and modelling their view through the window(s).

Quality of natural environments

Quality characteristics of natural environments, such as safety, amenities, sport/play facilities, aesthetics and walkability could influence the use and corresponding health outcomes from these spaces (McCormack et al., 2010). Quality of green spaces can be assessed by interviews, individually or in focus groups, or systematic observation of these spaces by fieldworkers (or study participants) applying tools developed for this aim as listed in a recent systematic review (Knobel et al., 2019). Given the logistical constraints of conducting large-scale field surveys, there have been efforts to use remote sensing images (e.g., Google Earth Pro (Taylor et al., 2011)) to characterise quality of natural spaces, which have shown a strong correlation with the assessments made by field surveys. Biodiversity is a specific component of nature quality and is further discussed in the section on ecological indicators.

Streetscape

Recently, there has been an increasing interest in characterising the view in the streets surrounding the point(s) of interest (e.g., home, workplace, school) or commuting routes. These studies have been mainly relying on the Google Street View images to characterise, among others, different types of vegetations including trees that are visible in a given street, through use of image processing techniques (e.g., Nagata et al., 2020).

Use of natural environments

Data on the use of green spaces could be obtained subjectively through interviews, questionnaires and diaries. This data relates to the qualitative aspects of people's experiences of forest environments contributing to a deeper understanding of the meaning people attribute to spending time in nature. Validated scales and tracking devices can be applied to obtain objective and quantitative data on various aspects of nature use, including the type of activities and the type of natural environment visited. Tracking devices, such as GPS or smartphone applications, can be applied to obtain data on the time (and the level of physical activity) that the participants have spent in natural environments by overlaying the recorded time-stamped geolocations on land cover/use maps.

Non-urban indicators

Studies that have analysed health impacts of deforestation (and in rare cases, reforestation) have usually operated on an ecological study scale, using time-series analysis of unit-based exposures (e.g., loss of vegetation per km^2 as measured by remote sensing products) in relation to trends in a health outcome of interest, such as changes in infectious diseases, including vector-borne and zoonotic diseases (Morand and Lajaunie, 2021; Poirier et al., 2021; Pereira da Silva et al., 2022).

Biodiversity and ecological indicators

Biodiversity is the variability of living organisms, and it includes diversity within species, between species and of ecosystems (UN, 1992). Because biodiversity is the fundament of healthy forests and ecosystems, both in urban and rural settings, it is a crucial aspect to consider and properly measure in health and nature research. Without biodiversity none of the ecosystem services or other health benefits from forests can be derived. This recognition is pivotal at a time when biodiversity loss is accelerating at an unprecedented rate due to human activity (IPBES, 2019).

Apart from assessing people's wellbeing reactions to or perception of biodiversity (Dallimer et al., 2012; Cameron et al., 2020; Fisher et al., 2021), accurate indicators of biodiversity also have enormous importance for developing knowledge around how to identify 'hotspots' of potential drug sources in forests (Holzmeyer et al., 2020), which is urgent given the escalating emergence of multidrug-resistant bacteria. Biodiversity indicators are also important for a number of other reasons, such as to identify medicinal plants and prioritise conservation efforts (Cahyaningsih et al., 2021), to monitor distribution of disease vectors (e.g., *Aedes aegypti*) (Portilla Cabrera and Selvaraj, 2020), or distribution of allergenic species to quantify allergy risk across large areas (Rasmussen et al., 2017). Biodiversity indicators are important to assess the ecological regulation of reservoirs and vectors of infectious diseases and the quality of the ecosystem service of disease regulation.

A useful resource for studying biodiversity is the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/). This is an international network and data infrastructure that provides open access data about all types of life on Earth based on records of where and when various species occur. The information is derived from a variety of sources ranging from museum and institutional collections to geotagged smartphone photos by amateurs and eventually the data are compiled using the Darwin Core Standard (TDWG, 2017).

Another large-scale option for assessing biodiversity is remote sensing (RS) techniques. Based on the principles of image spectroscopy across the electromagnetic spectrum, RS can record biochemical, biophysical, physiognomic, morphological, structural, phenological and functional characteristics of vegetation diversity at all scales, from the molecular and individual plant levels to communities and the entire ecosystem (Lausch et al., 2020).

Indicators of biodiversity in nature and health research have focused on both above-ground (e.g., assessments of bird species) and below-ground (e.g., microbial composition of soil) diversity. There is a certain correlation between above- and below-ground biodiversity (Wardle et al., 2004). Most commonly, biodiversity is considered in terms of species richness, species diversity and community composition. Various methods for assessing these components exist, one common approach being through sequencing of genetic material (e.g., 16S ribosomal RNA, rRNA) and subsequent alignment against an rRNA database and classification based on opensource software for describing and comparing microbial communities.

The following sub-sections provide an outline of general assessments and links to nature and health research for species richness, species diversity and community composition.

Species richness

Species richness is defined as the number of species that occupy a particular area, habitat or a particular biological entity (i.e., species richness of parasites in a host) and can be expressed as the number of taxonomic entities in a list of recognised species. In health and nature research, species richness has been assessed on several levels. Species richness can be assessed through questionnaires, expert point count (Fisher et al., 2021), GBIF or through citizen science initiatives, using applications such as iNaturalista or eBirds (Den Broeder et al., 2018). One approach is to study a specific taxon, for example, birds. Birds are relatively commonly used as a proxy for biodiversity because they are highly visible (and would thus theoretically have an impact on human wellbeing) and are also indicators of ecosystem functions. Plant species richness is positively associated with diversity in soil microorganisms (Baruch et al., 2021), which would have implications for how we can assess microbial diversity and study health associations related to exposure to microbial components, such as bacteria, fungi and viruses. Species richness is one indicator of the dilution effect and disease regulation (Keesing et al., 2006; Magnusson et al., 2020).

Species diversity

Species diversity takes into account not only the number of species but also their relative abundances in a community (habitat, biological entity) (Kiester, 2013). Many indices have been developed for measuring species diversity (e.g., Simpson diversity index, Shannon–Wiener index), from microbial organisms to larger plants, trees and animals. The terms alpha, beta and gamma diversity were coined by Whittaker (1972) to describe and understand the species diversity in a landscape (gamma diversity) as the combined result of the species diversity at a local scale (alpha diversity) and the compositional heterogeneity of species among localities (beta diversity). While the alpha and gamma diversity describe the species diversity at small and large spatial scale, the beta diversity assesses the turnover of species within a small spatial scale resulting from highly differing ecological conditions. On a molecular level, species identification is assessed using the sequencing, or barcoding, of adequate molecular genes that are validated for a group of taxa. These kinds of methods have been used when assessing species richness among microorganisms with impact on human microbiota (Roslund et al., 2021).

Community composition

A community is defined as all forms of life that coexist and interact with each other in a particular habitat, i.e., a community of trees in a forested habitat, or a community of microbes in a gut of an animal. Studies on human health and nature have rarely specified what component of biodiversity is particularly important, therefore we lack information about the relative importance of community composition.

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Chapter 3

The Health and Wellbeing Effects of Forests, Trees and Green Space

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Abstract
This chapter provides an overview of the empirical evidence regarding the association between green space in general, and forests and trees in particular, and health outcomes. The evidence is organised by life stage, and within the three life stages – early life (Section 3.2.), adulthood (Section 3.3.) and the elderly (Section 3.4.) – by type of health outcome. At the end of each of these three sections, the strength of the evidence for the presence (or absence) of a beneficial or detrimental association for a particular health outcome, as assessed by the authors, is summarised. Section 3.6. is devoted to modifiers of the aforementioned associations, such as gender, ethnicity and socio-economic status. In the next section (3.7.), the evidence is placed in the context of global health challenges through elaborating on the potential of green space, and forests and trees in particular, in tackling major contributors to the global burden of disease. The final section concludes that the available evidence already strongly supports a wide range of beneficial associations including neurodevelopment in children, mental health and wellbeing, spiritual wellbeing and cardiometabolic health in adults, and mental health and wellbeing, cognitive ageing and longevity in the elderly. However, this evidence is predominantly based on studies on the health and wellbeing effects of green space, and the available evidence for such effects for forests and trees is still limited for most health outcomes. Moreover, these studies have been mainly conducted in high-income countries, with their generalisability to low- and middle-income countries not being self-evident. Furthermore, the causality of the observed associations is not always clear. Nevertheless, given that many of the involved health outcomes are among the major contributors of the global burden of disease, forests, trees and green spaces have a great potential for improving health and wellbeing of humans across all life stages in our rapidly urbanising world.

3.1 Introduction

An accumulating body of evidence has documented the potential of natural environments, including forests, trees and green spaces[3], to enhance mental and physical health and wellbeing. This chapter provides an overview of the available evidence, with a focus on forests and trees where possible, through all stages of life. To date, most studies of the health effects of natural environments have looked at nature or green space in general (sometimes termed 'greenness'), although most of these studies have included forests and trees as part of their assessment. Moreover, the pathways and mechanisms underlying the health effects of natural environments and green spaces in general, and forest and trees in particular, are likely to be similar to a large extent. Therefore, all available evidence on health and wellbeing effects of these different types of nature are included in this chapter. Regarding outcome measures, this chapter mostly covers studies that focused on direct indicators of mental and physical health and wellbeing, such as diseases, physiological indicators and quality of life. Studies on the mechanisms (i.e., 'pathways') underlying the health effects of natural environments, such as exposure to environmental hazards (e.g., air pollution, noise, and heat), physical activity, social contacts and stress, are not included in this chapter as they are discussed in Chapter 2. However, each sub-section starts with a brief overview of the relevant possible pathways leading from nature to that particular health outcome.

Following the stages of life, the chapter starts with evidence regarding pregnancy and birth outcomes, followed by that on the mental and physical health of children and their development. Subsequently, the evidence regarding the mental and physical health and wellbeing effects in adults is presented, and finally that in the elderly. The chapter then discusses factors that can modify these associations and effects. Section 3.7 then explores the potential of natural environments and especially forests and trees to tackle the main contributors to the global burden of disease. Finally, differences between low-, middle- and high-income countries are discussed.

3.2 Early Life – Perinatal Period, Childhood and Adolescence

3.2.1 Pregnancy

The beneficial effects of forests, trees and green spaces can be traced back to the foetal life. In this

3 All terms that are defined in the glossary of this report (Appendix 1) appear in italics the first time they are mentioned.

section, we will discuss two types of pregnancy outcomes: pregnancy complications of the mother and birth outcomes of newborns.

Healthy pregnancy

Evidence on the association of exposure to natural environments, including forests and trees, and pregnancy complications remains limited, with existing studies having mainly focused on gestational diabetes (high blood sugar that develops in women during pregnancy) and hypertensive disorders of pregnancy. The most commonly used green space metric in studies of the pregnancy outcomes is the Normalised Difference Vegetation Index (NDVI) in buffers around maternal residential addresses ranging in size from 50 m (Laurent et al., 2013) to 2,000 m (Sun et al., 2020). Some studies (Xiao et al., 2021) have used the enhanced vegetation index (EVI), which is less susceptible to atmospheric conditions than NDVI and may be better at accounting for vegetation structure (Huete et al., 2002). The next most common exposure metric is distance from maternal address to parks or other natural areas expressed continuously or dichotomised – less than 300 m from a natural area of at least 5,000 m^2, for example (Agay-Shay et al., 2014). A handful of studies used tree cover as an exposure metric. Tree-cover data were derived from street-tree inventories (Abelt and McLafferty, 2017), classified aerial imagery (Donovan et al., 2011; Yin, 2019), or Light Detection and Ranging (LiDAR – (Donovan et al.), 2019). Land-cover data – such as the US National Landcover Database (NLCD) – have also been used to create exposure metrics (Ebisu et al., 2016).

In a birth cohort study of more than 5,000 pregnant women from Guangdong province, China, Qu et al. (2020) studied the association between green space surrounding the residential address of pregnant women (assessed using NDVI, see Box 3.1) during pregnancy and gestational diabetes. They found that the risk for gestational diabetes decreased in residential areas with greater surrounding green space and that the beneficial associations were stronger among women with lower socio-economic status (Qu et al., 2020). Likewise, a cohort study of more than 6,000 mothers, performed in central China, reported that living in greener environments was associated with reduced maternal glucose levels as well as reduced risk of gestational diabetes and impaired glucose tolerance (Liao et al., 2019). However, other studies with comparably large samples of pregnant women in the USA did not detect significant associations between gestational diabetes and the extent of green spaces (e.g., beach parks, local parks and wildlife preserves [forests]) (Young et al., 2016) or proximity to recreational natural environments (including forests) (Choe et al., 2018).

In a retrospective cohort study among nearly 240,000 pregnant women in the USA, Runkle et al. (2022) investigated the associations between gestational hypertension and pre-eclampsia and exposure to green space, with the latter being estimated using three indicators: green space per county, green space per person, green space within a 10-minute walk. They found that higher levels of green space per person and green space within a 10-minute walk were associated with reduced risk of pre-eclampsia, a serious condition during pregnancy (formerly called toxemia) that causes high blood pressure in pregnant women, protein in their urine and swelling in their legs. Another cohort study of nearly 2,000 American pregnant women found that those with more tree canopy cover around their homes were less likely to develop gestational hypertension or pre-eclampsia (Tiako et al., 2021). Similarly, another population-based case-control study of 77,406 women in the USA, found that higher levels of residential green space (assessed using NDVI) were significantly associated with a lower risk of pre-eclampsia (Weber et al., 2021). However, in a US cohort study of over 60,000 pregnant women, Choe et al. (2018) assessed residential surrounding green space using NDVI and proximity to recreational facilities and found that these metrics were neither associated with gestational hypertension nor with pre-eclampsia (Choe et al., 2018). Similarly, two other studies, both conducted in the USA, did not find any significant association between exposure to green space and pre-eclampsia (Laurent et al., 2013; Young et al., 2016). To summarise, the available studies on the associations of exposure to natural environments and complications of pregnancy are still limited with heterogeneous (but no detrimental) findings, but tend to suggest a beneficial effect (Zhan et al., 2020).

Birth outcomes

Forests, trees and green space may affect the health of new-born infants through similar mechanisms that influence pregnancy outcomes of the mother: reduction of stress, mitigation of exposure to air pollution, noise and heat, and increased physical activity.

The two most commonly studied categories of birth outcomes are foetal growth and length of gestation. Birth weight (measured continuously or dichotomised as small for gestational age at birth or low birth weight [e.g., birth weight < 2500 g]), birth length, head circumference and in utero measures of abdominal circumference, head circumference and femur length have been applied as indicators of foetal growth in studies of the effects of natural environments and forests on pregnancy outcomes. Similarly, length of gestation has been measured continuously or dichotomised as pre-term (baby born before 37 weeks of pregnancy).

A recent meta-analysis of 29 studies of greenness and birth outcomes concluded that there was moderate evidence that babies born to mothers in greener neighbourhoods are less likely to be born underweight (Hu et al., 2021). Specifically, a 0.1-unit increase in NDVI was associated with an increase in birthweight of 8-15 grammes. Several studies also found that greenness surrounding maternal residential address was beneficially associated with other birth outcomes such as a lower risk of the baby being born small for gestational age (Casey et al., 2016; Villeneuve et al., 2022), a lower risk of pre-term birth (Hystad et al., 2014; Lee et al., 2021), and greater abdominal and head circumference (Lin et al., 2020). However, in general, across all studies the evidence for a relationship between green space and gestational age and pre-term birth is still mixed and no firm conclusions can be drawn.

Two studies have used forest or tree cover as an exposure metric, both in the USA. Donovan et al. (2011) found that higher tree cover within 50 m of the maternal address was associated with a reduced risk of a small gestational age at birth. Also in the USA, Abelt and McLafferty (2017) found that having more street trees within 250-500 m from the maternal address was associated with a reduced risk of pre-term birth.

In conclusion, multiple studies have supported a positive association between birth weight and the natural environment around a mother's home address. This relationship persists even after accounting for a mother's socio-economic status, race and exposure to air pollution. Although most studies focused on green space rather than trees specifically, several studies did find mothers who live in neighbourhoods with more trees are more likely to have healthy babies.

3.2.2 Childhood and adolescence

Studies on health benefits of contact with nature for children and adolescents have included a variety of health and developmental outcomes. In this section we distinguish between outcomes in five main developmental domains: (1) brain development and mental health; (2) cardiometabolic development; (3) respiratory and allergic outcomes; (4) infectious diseases; and (5) malnutrition.

Brain development and mental health

Contact with nature may affect brain development and mental health directly or through mediating pathways. Natural environments, for example, provide children with opportunities to bolster creativity, engagement and risk taking; empower a sense of self; and promote psychological restoration, which, in turn, could benefit brain development and mental health in children (Kahn and Kellert, 2002; Kellert, 2005). The influence of nature on brain development could also be mediated through nature's ability to promote social interactions (Dadvand et al., 2019), to increase physical activity (De la Fuente et al., 2021), to mitigate the exposure to harmful environmental hazards such as air pollution (Dadvand et al., 2015b) and noise (Schäffer et al., 2020) and by enriching microbial input (Rook, 2013).

Early studies were mainly small-scale experimental studies looking at the short-term 'therapeutic effects' of the brief contact with nature for children with neuro-developmental problems. Taylor and Kuo (2009), for example, observed in their study of 17 American children with attention deficit-hyperactivity disorder (ADHD) that a 20-minute walk in a park could significantly improve the attentional function. This is similar to their earlier findings that demonstrated a reduction in symptoms among children with ADHD after play in outdoor natural environments (which did not occur in built and indoor environments) (Taylor et al., 2001). More recently, an increasing number of large-scale epidemiological studies have emerged on the long-term effects of exposure to natural environments on brain development and mental health. In one of the first studies of this kind, Amoly et al. (2014) reported a reduced risk of behavioural and emotional problems and ADHD symptoms in a sample of over 2,500 primary schoolchildren in Spain, related to more time spent playing in natural environments and with higher residential surrounding green space. Following this research, a number of studies have suggested a lower risk of similar problems associated with cumulative exposure to natural environments among both children and adolescents (Davis et al., 2021). A recent longitudinal study from the UK, suggested that urban woodlands but not grasslands were associated with lower risk of emotional and behavioural problems for adolescents (Maes et al., 2021). A study in the Netherlands found an inverse association between the greenness of the residential environment (within

250 m) and the use of ADHD-related medication among 248,270 children between 5 and 12 years of age, especially in low-income neighbourhoods (de Vries and Verheij, 2022). A study in the USA also found an inverse association between exposure to natural environments and prevalence of autism spectrum disorders (ASD) (Wu and Jackson, 2017). A recent systematic review has concluded that while the available evidence on the effect of exposure to natural environments on behavioural development is still limited with regards to some behavioural aspects, it is suggestive of a beneficial association (Zare Sakhvidi et al., 2022).

An emerging body of evidence has also, relatively consistently, associated nature contact with improved cognitive development in children (de Keijzer et al., 2016). A longitudinal study conducted among Spanish school children, for example, demonstrated that a higher amount of green space in school premises was associated with enhanced development of working memory and attentional function over a period of one year (Dadvand et al., 2015a). Similarly, large cohort studies from Canada found associations between cumulative exposure to natural environments and early life development, including dimensions of social competence, emotional maturity, language development and communication skills (Jarvis et al., 2021; Jarvis et al., 2022). Other studies have, although inconsistently, associated natural environment exposure with increased intelligence as determined by intelligence quotient (IQ) tests (Reuben et al., 2019; Bijnens et al., 2020; Asta et al., 2021). Also, more green space on school premises has been associated with improved academic performance (Browning and Rigolon, 2019; Kuo et al., 2021). There is also preliminary evidence on the potential impact of exposure to natural environments on motor development (Kabisch et al., 2019).

Regarding general mental health and wellbeing, most studies suggest a beneficial impact of natural environments for children and adolescents (Ward et al., 2016; Andrusaityte et al., 2020). However, a few studies have suggested no (Söderström et al., 2013) or even inverse associations (Larson et al., 2018; Tillmann et al., 2018). The few studies that have analysed health-related quality of life (Kim et al., 2016) and social functioning (Flouri et al., 2014; Richardson et al., 2017) in young people have consistently found positive associations with exposure to natural environments. A recent systematic review (Stier-Jarmer et al., 2021) specifically looking at forest environments, reported that spending time in forests and forest-based activities could reduce depressive and anxiety symptoms, and negative emotions such as aggression and anger, and improve social skills, perceived quality of life and mental wellbeing.

All in all, the available evidence on the impact of contact with nature on brain development and mental health is still limited but accumulating and the findings generally converge to indicate a beneficial role of natural environments, including forests (Davis et al., 2021).

Cardiometabolic development

Natural environments may affect children's cardiometabolic development by reducing environmental hazardous exposures (e.g., air pollution and noise), increasing physical activity and reducing mental stress, which are all involved in the pathogenesis of cardiometabolic disorders. Many epidemiological studies have investigated the associations between green space and cardiometabolic risk factors.

In children, overweight and obesity, as a result of sedentary lifestyles, are linked to several factors that increase the risk for cardiovascular disease, such as hypertension, disturbed cholesterol and glucose levels, and systemic inflammation (McPhee et al., 2020). In a systematic review of 45 individual studies (41 studies were observational), Fyfe-Johnson (2021) concluded that the strength of evidence concerning nature and childhood overweight/obesity was 'moderate', and exposures were mostly assessed using residential green space in those individual studies.

Epidemiological studies have also examined green space exposure and blood pressure. In a national cross-sectional survey with over 60,000 Chinese children and adolescents, Luo et al. (2022) observed inverse associations between residential surrounding green space, measured by NDVI and soil adjusted vegetation index (SAVI), and both blood pressure levels and hypertension prevalence. Similar beneficial associations were also observed in a study of 10-year-old children living around the city of Munich, Germany (Markevych et al., 2014). These findings are in line with those of an Australian national cohort study (Putra et al., 2022) reporting that increases in perceived green space quality tracked from age 0 to age 12 years were associated with lower blood pressure in boys aged 11-12 years. However, no significant associations were observed between green spaces and blood pressure in studies in Iran (Abbasi et al., 2020), the Netherlands (Bloemsma et al., 2019) and four European countries combined (France, Greece, Spain and the UK) (Warembourg et al., 2021).

Other studies have focused on the potential effect of green space exposure on blood-based biomarkers, such as lipids (e.g., cholesterol) and sugar (i.e., glucose) levels. In a cross-sectional study of over 3,000 Portuguese children, Ribeiro et al. (2019) found that having a green space near (within 400-800 m) the children's school/home was associated with lower lipid levels. An Australian longitudinal cohort study reported children with consistently high availability of quality green space had lower lipid levels at ages 11-12 compared with peers who had low availability of quality green spaces (Putra et al., 2022). However, no significant association for greenspace and lipid levels was observed in two studies that were conducted with children from Germany (Markevych et al., 2016) and the Netherlands (Bloemsma et al., 2019). Dadvand et al. (2018) examined the associations with time spent in green spaces (parks, woods or other natural green spaces, private gardens or agricultural fields) with fasting blood glucose levels in a multicentric sample of more than 3,800 Iranian schoolchildren. They found that time spent in green spaces, especially in forests and other natural green spaces, was inversely associated with fasting glucose levels. However, another cohort study of 460 infants did not observe any significant association between exposure to green space and insulin resistance as a cause of high glucose levels (Jimenez et al., 2020).

Metabolic syndrome is a cluster of cardio-metabolic disorders, which is generally used as a comprehensive predictor of cardiovascular disease. Three studies calculated the metabolic syndrome index using adiposity metrics (e.g., waist circumference and percent body fat), blood lipids, blood glucose and blood pressures, and assessed green space using NDVI, percent of green space, and percent of park and recreation areas (Dengel et al., 2009; Gutiérrez-Zornoza et al., 2015; Bloemsma et al., 2019). However, only one of them observed a significant association between more green space and a lower metabolic syndrome score (Dengel et al., 2009).

All in all, the evidence for the potential effects of natural environments on children's cardio-metabolic health is still emerging and heterogeneous, with some suggestions for beneficial associations for a number of cardiometabolic risk factors.

Respiratory and allergic outcomes

Forests, trees and green spaces may affect respiratory and allergic health during childhood and adolescence in various ways, such as by promoting physical activity, reducing stress, improving the composition of the microbiome of children in very early life, and by improving air quality (Eisenman et al., 2019). Forests and trees can also be a major source of pollen, which could trigger allergic and respiratory symptoms in sensitised individuals.

Studies have examined whether living or going to school near green spaces (forests, parks, agricultural land) or areas of higher vegetation (often measured using the NDVI) is associated with less asthma and other allergic health outcomes in childhood. With respect to urban forests, one of the first studies reported that areas in New York City, USA, with more street trees within 1 km^2 had lower childhood asthma prevalence, but not fewer asthma hospitalisations (Lovasi et al., 2008). However, tree cover was not protective for childhood asthma in a follow-up analysis in New York City using individual-level data (Lovasi et al., 2013). Inconsistent results have continued to be observed for several asthma-related outcomes across different studies, as summarised in a systematic review published in 2022 (Mueller et al., 2022).

Studies suggest that forest type is likely relevant, as living near gorse (*Ulex europaeus*) or exotic conifers in New Zealand (Donovan et al., 2018), coniferous forests in Europe (Parmes et al., 2020), and 'allergic trees' in Germany (Markevych et al., 2020) was associated with a greater risk of childhood asthma and other allergic symptoms. It is also possible that vegetation diversity, as a marker of microbial diversity (Donovan et al., 2018), is more informative than only the presence, distance to, or quantity of surrounding vegetation. Overall, meta-analyses and systematic reviews summarising the effects of various green environment metrics (including forests) on asthma, allergic respiratory diseases and atopic sensitisation in childhood report that the evidence is highly heterogeneous and inconclusive (Lambert et al., 2017; Lambert et al., 2018; Hartley et al., 2020; Mueller et al., 2022).

Studies on lung function in childhood and adolescents are more limited and also show mixed findings. A longitudinal British analysis reported that children whose homes are in more vegetated places or in close proximity to green spaces have better lung function up to 24 years of age (Fuertes et al., 2020). However, other studies report no association, such as in children from several European countries (Agier et al., 2019) and in western Australia (Boeyen et al., 2017) in relation to vegetation levels around the home. In China, beneficial associations with vegetation levels appeared to be confounded by pollution (Yu et al., 2021) or restricted to lower-pollution settings (Zhou et al., 2021).

When considering the health effects of pollen released from vegetation sources (split between grass, trees, weeds and conifers), a systematic review and meta-analysis concluded that pollen exposure is an important trigger for childhood

Forests and green spaces provide areas for physical activity and wellbeing
Photo © Nelson Grima

asthma exacerbations requiring emergency department attendance (Erbas et al., 2018). This result was confirmed in a further systematic review and meta-analysis in which short-term (one day) pollen concentrations were positively associated with allergic and asthmatic symptoms in both children and adults (Kitinoja et al., 2020). This same review did not find evidence for associations with daily lung function levels, although only a limited number of studies were included in the analysis. However, an Australian study did find that exposure to high levels of pollen was associated with poorer lung function development into adolescence (Lambert et al., 2019).

In conclusion, forests and other aspects of the natural environment appear to affect respiratory health in various ways, including through beneficial pathways such as reducing pollution or influencing the development of the immune system, but they can also act as a source of pollen depending on the species which can exacerbate symptoms among those sensitised.

Infectious diseases

Research on infectious diseases in relation to nature and forest exposure has been of global interest though, often, of particular relevance in low- and middle-income countries (LMICs) and poor households. Forests may affect children's risk to contract an infectious disease mainly through the presence of reservoirs and vectors of infectious diseases such as wildlife and mosquitoes (Tucker Lima et al., 2017; Guégan et al., 2020). On the other hand, forests could also have a positive effect on the contraction of infectious diseases by enriching the microbiome of children and thereby improving their immune function, or by providing medicinal plants for the treatment of human infectious diseases.

While much of the available research in this domain includes adults, the findings are highly applicable to children since they are more vulnerable to infectious diseases. Children under 5 are particularly vulnerable to infectious diseases like malaria, pneumonia, diarrhoea, HIV and tuberculosis.

Regarding malaria as a serious health threat in LMICs, conditions such as vegetation cover, temperature, rainfall and humidity, provided by forests, are conducive to distribution and survival of malaria vectors (Kar et al., 2014). Losing forest cover also affects the transmission of the parasites that cause infectious diseases such as human malaria (Guerra et al., 2006; MacDonald and Mordecai, 2019), though the direction of the effect (positive/negative) might depend on type of environment created after the forest is cleared (suitability of habitat for the vector/species), the geographic location, etc. Some studies reported that deforestation increases malaria risk in Africa and the Americas while it diminishes it in Southeast Asia (Guerra et al., 2006; MacDonald and Mordecai, 2019). However, no association between deforestation and malaria prevalence was observed in a recent study by Bauhoff and Busch (2020) in 17 sub-Saharan countries. Differences across regions are therefore useful hypotheses for future research. Moreover, a study in Malawi found that when deforestation increases, access to clean drinking water decreases (Mapulanga and Naito, 2019) and this might mediate the occurrence/spread of infectious diseases. In line with this, studies conducted in several LMICs concluded that upstream tree cover affects water quality downstream and consequently the prevalence of diarrhoea (Herrera et al., 2017; Rasolofoson et al., 2020).

In addition to forest ecosystems as a whole, individual plants are also very relevant to infectious diseases. The use of medicinal plants for the treatment of human infectious diseases is well documented in the scientific literature, especially for well-known malarial, diarrhoeal, Zika virus (ZIKV) and respiratory infections (Holetz et al., 2002; Zuo et al., 2012; Chinsembu, 2015; Rehman et al., 2017; Debalke et al., 2018; Calzada and Bautista, 2020; Haddad et al., 2020; Vista et al., 2020; Owusu et al., 2021). However, only a few publications relate the findings to life stages. Many medicinal plants are being used in different parts of the world against different diseases and for the general wellbeing of children (Ndhlovu et al., 2021). For instance, Mukungu et al. (2016) reported on tree/shrub species with suggested high anti-plasmodial activity, such as *Albizia gummifera* (J.F.Gmel.), C.A.Sm., *Tithonia diversifolia* and *Harungana madagascariensis* Lam. ex Poir., used by communities in the treatment of malaria. However, though the benefit of these medicinal plants justifies efforts toward their sustained use throughout generations (Towns et al., 2014; Bruschi et al., 2019), some medicinal plants have strong toxicity in humans, and this can cause acute poisoning and complications such as hepatic or renal failure, and can be life-threatening in children as reported in some systematic reviews (Ghorani-Azam et al., 2018; Tajbakhsh et al., 2021). Some studies therefore recommend further research on toxicity and dosage to ensure the safety of medicinal plants (Gahamanyi et al., 2021).

In summary, the effect of forests on infectious diseases is mixed, depending on the type of human-forest interaction and the type of infectious disease and, if relevant, the behaviour of their reservoirs and vectors.

Malnutrition

Malnutrition is the condition that develops when the body is deprived of vitamins, minerals and other nutrients it needs to maintain healthy tissues and organ function. Undernutrition occurs when not enough essential nutrients are consumed or when they are excreted more rapidly than they can be replaced for example because of diarrhoea. Overnutrition occurs in people who eat too much, eat to reduce stress (emotional eating), eat the wrong things, do not exercise enough or take too many vitamins or other dietary replacements (John Hopkins Medicine website).

The Global Burden of Disease study on dietary risks (GRD, 2019) estimates that one in five deaths globally is associated with poor diet, and highlights that diet contributes to a wide range of chronic diseases in people around the world. Diets worldwide are far from being healthy and have not improved over the last decade (2021 Global Nutrition Report). Fruit and vegetable intake is still about 50% below the recommended healthy level of five servings per day (60% and 40% respectively), and legume and nut intakes are each more than two thirds below the recommended two servings per day (2021 Global Nutrition Report; EAT-Lancet, 2019). In contrast, red and processed meat intake is on the rise and almost five times the maximum recommended level of one serving per week, while the consumption of sugary drinks, which are not recommended in any amount, is also increasing (2021 Global Nutrition Report; EAT-Lancet, 2019). Lower-income countries continue to have the lowest intakes of key health-promoting foods such as fruits and vegetables and the highest levels of underweight, while higher-income countries have the highest intake of foods with high health and environmental impacts, including red meat, processed meat and dairy, and the highest levels of overweight and obesity.

Forests can contribute directly to children's diets through the harvest of wild meat[4], fish, wild fruits, wild vegetables, fungi and other forest-sourced foods (MEA, 2005; Baudron et al., 2019; Asprilla-Perea et al., 2020). There are both benefits and risks for human health identified with forest foods. On the one hand, a growing evidence base suggests that forest foods are of critical importance to the dietary diversity and food security of adults and children living in close proximity to forests – especially in communities with poor access to markets (Nasi et al., 2011; Vira et al., 2015; Rowland et al., 2017; Baudron et al., 2019). Forest foods play this critical role because: 1) they are often high in micronutrients (e.g., fruits) and quality protein (e.g., wild meat and fish); 2) the diversity of forest foods spans different seasons, and they are of particular importance in the lean season or during food crises, when agricultural and other food sources are scarcer (Vincenti et al. 2008; Rowland et al 2017; Hall 2021). In line with these findings,

4 Wild meat is also called bushmeat in some regions (particularly in Africa)

people living in or near areas with greater tree cover consume more diverse and nutritious diets (Johnson et al., 2013; Ickowitz et al., 2014; Galway et al., 2018; Rasolofoson et al., 2018; Baudron et al., 2019), while forest loss is associated negatively with dietary diversity and consumption of nutritious foods (Galway et al., 2018; Jendresen and Rasmussen, 2022).

In addition to the 'direct pathway' of forest foods contributing to people's dietary quality, two additional pathways are identified for how forests contribute to dietary diversity: the income pathway through which the sale of forest products contributes to improved food access on markets, and the agroecological pathway, through which forests support diverse crop and livestock production through an array of regulating ecosystem services (Baudron et al. 2019). Assessing seven tropical landscapes, Baudron et al. (2019) identify that these mechanisms can vary significantly from one site to another, and that the positive contributions of forests to rural diets cannot be generalised.

On the other hand, forest foods, particularly wild animal sourced foods, are considered potential vectors of rapidly spreading diseases worldwide (Asprilla-Perea et al., 2020; Zhou et al., 2022). The recent COVID-19 pandemic has been traced back to zoonotic transmission, with bats and pangolins identified as primary reservoirs for a wide variety of coronaviruses (IPBES, 2020). For many communities, wild meats are their only source of protein and may also hold cultural values (Vira et al., 2015; Roe et al., 2020). However, unsustainable markets for wildlife across several low-income settings referred to as the 'bushmeat crisis' (Robinson and Bennett, 2002) highlight the political economy and management challenges associated with wild meat. The illegal and unsustainable trade in wild meat – driven notably, by a growing population and changes in lifestyles – threatens livelihoods and wildlife alike. Deforestation and forest degradation also bring people and animals in closer proximity (IPBES, 2020).

3.2.3 Summary

Table 3.1 provides an overview of the strength of the evidence for associations of natural environments and forests with health and wellbeing in early life stages, based on the expert judgment of the authors. The evidence for all of the included health domains is generally positive, with the strongest and most consistent evidence for brain development and mental health in childhood. There is also strong evidence for positive contributions of forests to the prevention and reduction of childhood infectious diseases and malnutrition, especially in LMICs. However, in these domains there is also a (smaller) risk of some negative health impacts of forests. Evidence for health benefits (for both mother and child) in the perinatal period is strongly positive for foetal growth but somewhat mixed for gestational age at delivery and complications of pregnancy, which also applies to the evidence for cardiometabolic development and respiratory and allergic outcomes in childhood and adolescence.

Table **3.1**

Expert assessment (by authors) of the strength of the evidence for associations between forests, trees and other types of green space and different health outcomes in early life

EARLY LIFE: STRENGTH OF THE EVIDENCE **PERINATAL PERIOD**				
Pregnancy complications +/0	Birth weight +	Pre-term birth +/0		
CHILDHOOD AND ADOLESCENCE				
Neurodevelopment and mental health ++	Cardiometabolic development +/0	Respiratory/allergic outcomes +/-	Infectious diseases ++/-	Malnutrition ++/-

Note: Sign indicates type of association: + beneficial association, 0 no association, - detrimental (harmful) association. Number of same signs indicates strength of evidence for a particular type of association.

3.3. Adulthood

The vast majority of research on nature-health relationships, including those of forests, has involved adults. In this section, we distinguish between mental and physical health outcomes with a number of subsections for each category.

3.3.1 Mental health

Mental wellbeing and quality of life

This section focuses on general mental wellbeing and quality of life in adulthood as outcomes, including self-reported measures of overall mental health. Mood and stress pathways are particularly relevant when it comes to mental wellbeing. Several mood and mental disorders are about experiencing prolonged periods of negative moods or stress (chronic stress) (e.g., burnout (Marin et al., 2011)). Both social contacts and place attachment pathways are relevant for mental wellbeing (Holt-Lunstad et al., 2015). Physical activity has also been shown to affect mental wellbeing (Marquez et al., 2020). Physical health is considered a determinant of quality of life (see e.g., Suárez et al., 2018). In short, many of the pathways identified in chapter two may be relevant when it comes to mental wellbeing and quality of life, although the evidence on specific pathways is limited (Zhang et al., 2021a).

Several reviews have shown beneficial associations between the local availability of green space and mental wellbeing of adults (Houlden et al., 2018; Wendelboe-Nelson et al., 2019; Callaghan et al., 2021; Lackey et al., 2021; Li et al., 2021). Although there is less research on green spaces and (overall) quality of life, the available evidence points in the same direction (Houlden et al., 2018; Giannico et al., 2021), at least for the residential environment (Wu et al., 2022). When it comes to mental wellbeing, the usual assumption is that direct contact with green space is needed for such benefits to occur (Bratman et al., 2019) and that more contact is better, at least up to a certain extent. There is also some empirical support for this (see e.g., Coldwell and Evans (2018) and White et al. (2019); however, see also Garrett et al. (2021) who found associations between neighbourhood green spaces and better subjective wellbeing, but not via visits).

Before zooming in on forests, a distinction can be made between short-term effects of contact with nature and more long-term effects on mental wellbeing and quality of life. When it comes to short-term effects, mainly mood states, stress levels and cognitive function have been studied, and they in turn, have been identified as important pathways leading to long-term effects (see Chapter 2). Antonelli et al. (2021) looked at several reviews of field studies on the effects of spending time in forests, specifically in the form of 'forest bathing' or Shinrin-yoku, as it is known in Japan. They concluded that the programmed forest visits could promote psychophysical wellbeing, from heart rate variability and cortisol levels to self-reported mood improvements. Meyer-Schulz and Bürger-Arndt (2019) also looked at forest stays and arrived at similar conclusions. Another type of research is experience sampling, or ecological momentary assessments: upon receiving a message in daily life (e.g., on their smartphone) people are asked to report how they feel at that moment in time. Studies in the UK (MacKerron and Mourato, 2013) and the Netherlands (de Vries et al., 2021) show that people feel happier in forests than in built-up areas (but feel even happier in another type of natural environment, i.e., a natural coastline). More long-term, a Korean study showed that the frequency of visits to forests was positively associated with life satisfaction and that this frequency was higher if it took less time to reach the forest (Jang et al., 2019). A Finnish study reported that restorative experiences were the strongest in everyday favourite places located in outdoor exercise and activity areas, waterside environments and extensively managed urban woodlands. Restorative experiences in urban parks and in built urban indoor and outdoor places were significantly weaker by comparison (Korpela et al., 2010). A French study showed that the presence of forests within a 15-minute walk was positively associated with one's quality of life, and that association was stronger than with the presence of urban parks (Allard-Poesi et al., 2022). Jones (2021) looked at a large-scale natural experiment – the New York City (NYC) million trees programme – and found that already after the first years of the programme, life satisfaction in NYC increased, compared to neighbouring urban areas, but only when the trees were in leaf.

All in all, having easy access to forests and trees appears to be predominantly associated with higher mental wellbeing in adults. Coming into direct contact with these natural elements seems relevant for wellbeing benefits to materialise, although they may also be beneficial in ways that do not necessitate direct contact. Contact may also take place incidentally, outside the leisure domain of purposeful visits to forests, nature areas or parks.

Mental health disorders

In the previous section, we looked into research on mental wellbeing and (self-reported) overall mental health. Here, we focus specifically on the association between nature contact and prevalence of mental health disorders and illness. Following Bratman et al. (2019), mental health disorders, in accordance with definitions from the Diagnostic and Statistical Manual of Mental Disorders (American Psychiatric Association, 2013) or the International Classification of Diseases (WHO, 2017) are cognitive, affective and behavioural disorders such as depression, schizophrenia, anxiety and bipolar disorders. Potentially relevant pathways beneficially linking nature contact to mental disorders are the same as mentioned for mental wellbeing in the previous section, with the addition of immune function (or gut regulation) which has been linked to depression and other psychological disorders via the gut-brain axis (Rook, 2013).

There is mounting evidence that nature contact buffers against the onset of mental health disorders, in addition to decreasing symptomatology in some cases. In a (large-scale) cross-sectional study in Finland, Gonzales-Inca et al. (2022) found that higher NDVI within 100 m buffers of residential areas was associated with a decreased risk for doctor-diagnosed depression, after controlling for several individual-level characteristics. Another study in the UK found an association between NDVI greenness within 500 m buffers of residences and decreased risk for major depressive disorder, especially for lower socio-economic status and higher urbanicity areas (Sarkar et al., 2018). Using land use data, de Vries et al. (2016) found a relationship between green space (within 1 km of residence) and decreased rates of anxiety disorder (though not for mood disorders) in a nationally representative survey in the general Dutch population – replicating a similar finding by Maas et al. (2009). Using land cover data, Belgian researchers found that mood disorder medication sales for urban residents decreased 1-2% with a 10% increase in various types of nature – most significantly woodland – though this association did not hold for rural areas (Aerts et al., 2022). A similar association was observed in a Dutch study (Helbich et al., 2018b). In a study across 18 countries, White et al. (2021) found that visits to green spaces were associated with lower likelihood of using medication for depression.

Recent studies have explored the association between nearby green space and suicide. In the Netherlands, Helbich et al. (2018a) looked at the amount of green space at the municipal level and suicide mortality, with level of urbanicity being corrected for, to some extent (besides other covariates). They observed a lower suicide risk in greener municipalities. A similar association was observed in Taiwan, using counties as units of observation (Shen et al., 2022). A Japanese study, with municipalities as units of observation, paints a somewhat more nuanced picture. In densely populated cities, park density was inversely associated with suicide mortality, while in small- and medium-sized cities, it was park coverage (i.e., the proportion of the total park area to the municipal area), and only for women aged 40 and above. Finally, in rural areas it was not park coverage, but woodland coverage that was inversely associated with suicide mortality, but only for men aged 40 and above (Jiang et al., 2021b). However, a study conducted in Hong Kong looking at rent-only public housing community sites and the surrounding green space (in buffers with sizes up to 800 metres from the site) did not find any association (Jiang et al., 2021a).

With respect to nature in general, including urban green space, some evidence exists for the association between access and usage and the decreased prevalence of mental illness, though this evidence is mixed (Gascon et al., 2015). For example, some studies employing a *life-course approach* have found that early-life nature exposure may help prevent later incidence of mental health disorders, including schizophrenia, bipolar and mood disorders, and depression (Engemann et al., 2019; Li et al., 2021). Other evidence is less supportive of this temporal aspect of the relationship throughout the life course. A recent review of longitudinal observational studies reported that no statistically significant association was found for depression in six out of nine reviewed studies, while two showed a reduction of the risk and one showed a small increase in the risk with greater green space availability (Geneshka et al., 2021).

The evidence in support of a relationship of reduced incidence of mental health disorders with higher exposure to forests specifically is sparser. In recent research, Bolton et al. (2021) characterised land cover in 207 countries to examine the global change in forested areas from 2006 to 2016 at the country level. The authors found significant cross-sectional associations for the year 2016 (although not for changes in the amount of forest area): lower levels of forested areas were associated with higher levels of substance abuse and other mental health disorders for lower-middle-income countries, after adjusting for several confounders. The evidence on the association between nearby green space and medication shows that a higher urban street tree density is associated with a lower

The Bongeunsa temple and park offer a pleasant and peaceful retreat in the middle of Seoul's busy Gangnam district
Photo © Gerda Wolfrum

prescription of medication for depression (Taylor et al., 2015), especially for individuals with lower socio-economic status (Marselle et al., 2020; however, see Kardan et al. (2015) for a non-significant relationship).

In general, with regard to mental health disorders the evidence is somewhat heterogeneous. Most (published) studies thus far show a beneficial association between the amount of nearby green space and the prevalence of mental disorders, while some studies do not find such an association. However, detrimental associations are rarely observed. Finally, in addition to these associations, there is some evidence in support of decreased symptomatology from mental health disorders with nature contact. For example, individuals with depression may experience greater short-term affective benefits from nature interventions than nonclinical samples (Berman et al., 2012), and in research specific to forests, reviews have found support for the potential of Shinrin-yoku (forest bathing) to reduce depressive symptoms (Rosa et al., 2021; Stier-Jarmer et al., 2021; Yeon et al., 2021).

Spiritual wellbeing

Spiritual experiences in or with nature provide a sense and purpose to people's lives. These experiences occur whenever individuals feel a connection with the larger, natural world (Gardner, 1999), for example, through 'magical moments' during which they realise that all creatures great and small are intrinsically valuable (Talbot and Frost, 1989) or during moments of reminiscence, when they find comfort and support in feeling and remembering the connection with nature (Johansen and Thorsen Gonzalez, 2018). The pathways that lead to spiritual experiences are still largely unknown, but it can be postulated that reduced stress levels, increased attention and awareness, and a positive mood are important preconditions for experiencing nature as a source of spiritual wellbeing. In addition, feeling attached to a place, and absence of disturbing factors such as heat, bad air quality and noise might also be relevant.

Endorsement of spirituality has consistently been positively related to psychological health and wellbeing (Labbé and Fobes, 2010). Research on 'connectedness with nature' (Kamitsis and Francis, 2013) has shown a positive relationship with many outcomes, including psychological wellbeing, quality of life and pro-environmental behaviour (Cervinka et al., 2011; Nisbet et al., 2011; Capaldi et al., 2015). These positive effects of feeling emotionally and spiritually connected to nature have also been found to moderate the relationship between nature contact and wellbeing outcomes, with individuals who are more connected responding more positively to contact with the natural world (Martin et al., 2020). Another line of research has demonstrated positive impacts of sublime experiences with nature, as a mix of emotions – arousal, pleasure and vitality – together with feelings of awe (Bethelmy and Corraliza, 2019). Spirituality also emerges as a central theme in nature-based therapy. Based on interviews with experienced nature-based therapists, Naor and Mayseless (2020) conclude that "significant therapeutic effects are linked to spiritual experiences, including the experience of nature's immensity, which contributes to an expansive perspective; experiencing interconnectedness, which elicits a sense of belonging to the vast web of life; and the reflection of internal nature and truth by external nature as an accepting setting, which contributes to the discovery of an authentic self."

Within the spiritual domain, forests and trees are imbued with special meanings and values. In general, four types of spiritual values as they relate to forests can be distinguished (Clark, 2011): intrinsic sacredness (e.g., ceremonial forests in Thai villages as places for the souls of the dead to rest); sacredness associated with rituals or local traditions (e.g., the Celtic tradition to hang rags in trees near holy wells to ask for a cure); forests as a reflection of divine glory (e.g., Buddha's enlightenment under the Bodha tree); and forests as places to experience transcendence (e.g., individual experiences of forests of non-religious individuals as places for spiritual renewal and healing). These spiritual values of forests may be especially helpful in times of crises, to make people more resilient to negative impacts of pandemics and war (Tidball and Krasny, 2013). To summarise, there are many indications that natural environments, and forests in particular, could benefit different aspects of spiritual wellbeing.

3.3.2 Physical health

Communicable diseases

Infectious diseases

As already discussed in the section on children, ecosystem condition (including that of forests) might drive the change in the prevalence of infectious diseases. With regard to forests, vegetation cover, temperature and humidity might create conditions that are favourable to specific vector species (e.g., mosquitoes, ticks, flies) transmitting infectious disease (Kar et al., 2014; MacDonald and Mordecai, 2019; Guégan et al., 2020). As a consequence, loss of forest cover might create conditions unsuitable for certain vector species (e.g., *Anopheles dirus* in Thailand and *Anopheles fluviatilis* in India). However, it may also lead to conditions that enable development of new vectors (e.g., *Anopheles gambiae* and *Anopheles arabiensis* in the Sahara region) (Kar et al., 2014 and references therein). This highlights the need to understand site specific dynamic interactions between forest ecosystems and infectious diseases before adequate health relevant forest management can be carried out. Moreover, the regulatory service of forests, for watershed quality for instance, can be essential for reducing the prevalence of infectious diseases in communities living in the surroundings (also see Section 3.2.2).

On an individual plant level, ethnopharmacological studies have reported on plants being widely used against human infectious diseases across the world (Raal et al., 2013; Chinsembu, 2015; Ozkan et al., 2016). A recent study revealed that the well-known African Baobab (*Adansonia digitata*) has multiple medicinal benefits in the treatment of infectious diseases and the bark's extract has been found to be useful against malaria and fever (Asogwa et al., 2021). With regards to diarrhoea, there are reports on plant species used in traditional medicine in Mexico (Calzada and Bautista, 2020) and in Benin (Dougnon et al., 2021). Some plants are suggested for utilisation against respiratory infections in general (Rigat et al. (2013) in the Iberian Peninsula) or particular diseases such as tuberculosis (Madikizela et al. (2013) for examples in South Africa and Sharifi-Rad et al. (2020) for examples covering Africa, the South Pacific, America and Asia) and coronavirus diseases (Keyaerts et al., 2007; Adhikari et al., 2020; Mehmood et al., 2021). Many studies seeking to provide the scientific basis for the use of selected plants have also documented the biological activities of plant extracts on pathogens responsible for diseases (Zuo et al., 2012; Madikizela et al., 2013; Maggi et al., 2013; Rehman et al., 2017; Debalke et al., 2018; Owusu et al., 2021). However, it should be noted that some curative/preventive medicinal plants might have potentially serious side effects as reported in a systematic review by Alebie et al. (2017) and appropriate dosage needs to be identified for any medicinal plant.

In conclusion, the interaction with forests could be associated with infectious diseases, but the direction can be positive or negative depending on the context and dosage. Proper understanding of these complex relationships is needed to allow site-tailored forest management that optimises health benefits.

Chronic noncommunicable diseases (NCDs)

Cardiometabolic health

Physiological and lifestyle factors, including psychosocial stress and physical activity and environmental factors such as air pollution, noise and heat are closely linked with cardiometabolic health (also see Section 3.2.2). Forests, trees and green spaces in general have been shown to reduce stress, increase physical activity, strengthen immune function and mitigate exposure to air pollution, noise and heat, and thus could exert beneficial impacts on cardiometabolic health. Land use change through forest fires and deforestation may also impact cardiometabolic health through reduced place attachment.

The potential effect of natural environments on the cardiometabolic system is one of the most commonly studied topics in nature and health research. Several such studies have been performed worldwide, especially in western high-income countries and Asian countries like China. A recent systematic review by Liu and colleagues pooled epidemiological studies on green space (assessed by NDVI, percentage of green space, distance to the nearest green space, proximity to public parks, etc.) and cardiovascular disease (CVD) incidence/prevalence. The pooled evidence generally supports that exposure to areas with more vegetation was associated with reduced odds of CVD events (Liu, 2022).

Overweight and obesity are among the most important cardiometabolic risk factors. A systematic review by Luo et al. summarised studies on the association between green space exposure (assessed using various metrics including NDVI, distance to the nearest green space, proportion of green space and the number of parks) and overweight and obesity. They found that most of the included studies reported beneficial associations between green space exposure metrics and overweight/obesity prevalence and adiposity metrics such as body mass index (BMI) and waist circumference (Luo et al., 2020).

Hypertension is another important cardiometabolic risk factor. Zhao (2022) summarised studies on green space exposure and blood pressure and hypertension and found that the evidence supported beneficial associations between greater NDVI and proportion of green space (but not distance to nearest green space) and reduced blood pressure levels and lower odds of hypertension.

Diabetes is one of the major cardiometabolic conditions and a major contributor to the global burden of the disease. A total of 19 studies were included in the review by De la Fuente et al. (2021) and these studies consistently showed that living near green space, having higher residential green space levels, or having more parks near home, were associated with reduced risk of type 2 diabetes. Another study performed in northeastern China, which was not covered by the systematic review by De la Fuente et al. (2021), also reported that higher greenness levels were beneficially associated with glucose metabolism (Yang, 2019).

Several studies have also investigated the associations between green space exposure and blood lipids. A retrospective cohort study of about 250,000 Americans aged over 65 found that higher levels of residential NDVI were associated with lower blood lipid levels (Brown, 2016). Kim et al. (2016) found similar beneficial associations of higher density of nearby parks and green areas with lower blood lipid levels. In a cross-sectional study of Chinese adults, Yang (2019) found that living in neighbourhoods with higher green space was consistently associated with improved blood lipid profiles. However, another retrospective cohort study of 3,205 Australian adults did not find any significant association between public open green space and occurrence of abnormal blood lipid levels (Paquet, 2014).

As summarised in the review by Wolf et al. (2020), the impact of urban trees on cardiovascular health has also been explored adopting experimental designs. They found that forest bathing (Shinrin-yoku) could improve cardiovascular function and related health outcomes among healthy participants, including lower blood pressure, heart rate and sympathetic activity. In addition, forest bathing could also lower blood pressure and homocysteine (a biological marker of cardiovascular disease) levels among CVD patients (Wolf et al., 2020). Forest bathing and forest therapy are reported to be associated with positive cardiac health, specifically stress reduction, reduction of inflammation, better immune functions, blood pressure and cardiac rhythm regulation (Logan et al., 2018). Moreover, a potential link between forest loss and the double burden of malnutrition and its links to cardiometabolic diseases has been reported from sub-Saharan Africa (Zeba et al., 2012; Acharya et al., 2020). Forest fires, resultant heat and air pollution have complex negative consequences including on cardiometabolic health (Frumkin et al., 2017; Münzel et al., 2021). Land use change and deforestation in Indonesia and Malaysia for oil palm cultivation have been linked in complex ways to NCDs in general and potentially to cardiometabolic syndrome (Kadandale et al., 2019). With respect to forest proximate Indigenous communities, there is emerging evidence of the association between displacement or migration of forest-dependent communities from Southeast Asia and their rapid socio-economic change, and the deterioration of their cardiometabolic health (Phipps et al., 2015; Ashari et al., 2016).

In summary, studies show beneficial effects of green spaces on multiple aspects related to cardiometabolic health especially from high-income countries and to some extent from emerging economies like China. There is limited research on forest dwelling communities and their lifestyles on cardiometabolic health or the recent lifestyle transition in the context of out migration.

Respiratory and allergic conditions

Natural environments in general, and forests in particular, may affect respiratory health through different pathways including a reduction of stress, the promotion of physical activity, enriching microbiota, and mitigating exposure to air pollution on the one hand, and producing pollens on the other hand (also see subsection 3.2.2).

The most frequently studied adult respiratory outcomes in association with natural environments are chronic obstructive pulmonary disease (COPD) (Sarkar et al., 2019; Fan et al., 2020; Xiao et al., 2022), asthma (Alcock et al., 2017; Donovan et al., 2021) and allergic rhinitis (Kwon et al., 2019). The most commonly used exposure metric is the NDVI (Kwon et al., 2019; Sarkar et al., 2019; Fan et al., 2020; Donovan et al., 2021; Xiao et al., 2022), although some studies used plant-diversity metrics (Liddicoat et al., 2018; Donovan et al., 2021) or urban-landcover metrics that include forests (Alcock et al., 2017; Kim and Ahn, 2021).

Several studies have found that higher residential green space is associated with a reduced risk of suffering from COPD (Maas et al., 2009; Sarkar et al., 2019; Xiao et al., 2022). In China, Xiao et al. (2022) further found that higher residential green space was associated with improved lung function, although all associations were limited to women, people younger than 65 and non-smokers. In contrast, Fan et al. (2020) found that higher residential green space was associated with an increased risk of COPD among men in China. Local differences in plant species and air pollution may be important reasons for these inconsistent results, because air pollution can potentiate the allergic potential of plant pollen (Janssen et al., 2003). The inconsistent pattern between green space exposure and COPD is also seen in studies of short-term lung function, with improvements in lung function from walking in a park observed in both younger Austrians (Moshammer et al., 2019) and older British adults (Sinharay et al., 2018), whereas other studies have found associations with decreased lung function in Scandinavian adults (Nordeide Kuiper et al., 2021).

Several studies have found that exposure to green space is associated with reduced asthma risk (Maas et al., 2009; Alcock et al., 2017; Douglas et al., 2019; Kim and Ahn, 2021; Wu et al., 2021), whereas others have found that green space exposure is associated with increased asthma risk (Khan et al., 2010; Lai and Kontokosta, 2019; Donovan et al., 2021). Within these contradictory results, consistent patterns can be seen with regards to the critical role of the composition and structure of green space in the observed heterogeneities. Several studies have found that exposure to more diverse green space is associated with lower asthma risk (Donovan et al., 2021; Wu et al., 2021). In the USA, Kim et al. (2021) found that exposure to clusters of trees and small areas of private green space was associated with lower asthma risk, whereas there was no association with exposure to large areas of green space such as parks and golf courses. A handful of studies have found that exposure to green space is associated with a decreased risk of allergic rhinitis (Stas et al., 2021; Zhang et al., 2021b). Consistent with the asthma literature, the composition of the exposure matters. For example, Zhang et al. (2021a) found that exposure to more diverse greenness was associated with lower rates of self-reported allergic disease in China. However, exposure to more diverse plants with airborne pollen was associated with higher rates of allergic disease.

A small number of studies in the green space and adult respiratory health literature has specifically used trees or forests as an exposure metric. Alcock et al. (2017) found that urban areas in the UK with more tree cover had lower rates of asthma hospitalisation, although this relationship was only seen in areas with higher levels of air pollution. In contrast, Lai and Kontokosta (2019) found tree cover was associated with increased asthma risk in New York City. Finally, in Belgium, Stas et al. (2021) found that exposure to birch trees (*Betula* spp.) was associated with an increased risk of allergic rhinitis, whereas exposure to alder trees (*Alnus* spp.) was associated with a decreased risk.

In conclusion, although there is some evidence that exposure to the natural environment including forests may protect against respiratory and allergic diseases in adults, the overall evidence is contradictory. A systematic review published in 2022 concluded that the extant literature was suggestive of a potentially causal link between green space and respiratory health, with the evidence being stronger for mortality rather than morbidity (Mueller et al., 2022). The inconsistency of the literature may be because exposure to the natural environment is protective of respiratory and allergic outcomes such as asthma, atopy and allergic rhinoconjunctivitis, while it also exacerbates symptoms in susceptible individuals.

Cancers

Urbanisation, and the consequent reduction of contact with the natural environment, can increase exposure to anthropogenic contaminants and lead to changes in lifestyle and social behaviours that have been associated with cancer risk. Based on that, a number of environmental and socio-behavioural mechanisms could explain the potential association between natural environments and cancer incidence and/or prevalence. This association could be partly explained by the ability of natural environments to mitigate exposure to air pollution, which is an important cause of cancer (Loomis et al., 2013), and increase physical activity, which is a protective factor for cancer incidence and mortality (McTiernan et al., 2019). Similarly, the ability of natural environments to reduce stress, strengthen social contacts and improve immune function might constitute protective factors that may reduce cancer incidence and mortality.

There are still relatively few studies exploring the association between green space and cancer incidence and/or prevalence. A recent systematic review (Zare Sakhvidi et al., 2022) and a scoping review (Porcherie et al., 2021) have summarised the existing evidence on the topic.

Studies have mainly assessed green space availability based on measurement on surrounding greenness and land cover around home (Astell-Burt et al., 2014; Carles et al., 2017; Demoury et al., 2017; Datzmann et al., 2018; O'Callaghan-Gordo et al., 2018; Shao et al., 2019; Iyer et al., 2020; Harrigan, 2021; Zare Sakhvidi et al., 2021). Additionally, some of these studies have also included measurements of green space accessibility (Carles et al., 2017; Zare Sakhvidi et al., 2022).

Most of the evidence of the association between green space and cancer comes from studies on skin, prostate and breast cancer. There are three major studies available on skin cancer. Residential surrounding green space was associated with lower risk of non-melanoma skin cancer in a study conducted in Germany (Datzmann et al., 2018), but with increased risk of melanoma skin cancer in a study in France (Zare Sakhvidi et al., 2021) and with increased prevalence of skin cancer overall (melanoma and non-melanoma) in another study in Australia (Astell-Burt et al., 2014). From four studies on prostate cancer, three studies conducted in Canada, Germany and the USA found reduced risk of prostate cancer associated with the increase in residential surrounding green space (Datzmann et al., 2018; Demoury et al., 2017; Iyer et al., 2020). However, one study carried out in France suggested the opposite results (Zare Sakhvidi et al., 2021). There are also four major studies on breast cancer, of which two conducted in France and Germany reported that residential surrounding greenness was a protective factor (Datzmann et al., 2018; Zare Sakhvidi et al., 2021), one carried out in Canada reported no association (Harrigan, 2021) and one based on participants from Spain reported that surrounding greenness was a risk factor (O'Callaghan-Gordo et al., 2018). However, this last study showed different results when land use was taken into account: urban green areas were associated with reduced risk of breast cancer, whereas agricultural areas were associated with increased risk. These findings could at least partially explain the heterogeneity of results observed in studies on green spaces and cancer that only take into account the amount of surrounding green space without considering the type of green space or the activities conducted in such areas. There are a few other studies on the association between green space and other cancer sites including lung cancer, colorectal cancer, brain cancer, mouth and throat and all-sites cancers (Carles et al., 2017; Datzmann et al., 2018; Shao et al., 2019; Zare Sakhvidi et al., 2021). The evidence from these studies is mainly mixed and inconclusive. One early ecological study looked specifically at forest coverage and mortality due to different types of cancer. Using Japanese prefectures as units of observation, Li et al. (2008) observed inverse associations between the percentage of forest cover and the standardised mortality rate for several types of cancer.

In conclusion, the available evidence on the association between green space and cancer is still evolving. However, it suggests a beneficial association for some of the cancers, particularly hormone-dependent cancers such as breast cancer. To our knowledge, only one study to date has explored specifically the association between exposure to forests and/or trees and cancer.

3.2.3 Summary

Table 3.2 provides an overview of the strength of the evidence for associations between forests, trees and green spaces on the one hand, and health and wellbeing in the adult life stage on the other, based on the expert judgement of the authors. The evidence for most of the included health domains is generally positive, with the strongest and most consistent evidence for mental and spiritual wellbeing and quality of life, and cardiometabolic health. Although somewhat more mixed, there is also mostly positive evidence for the contribution of natural environment and forests to the prevention and reduction of (symptoms of) mental disorders. In the other domains, including infectious diseases, respiratory and allergic outcomes, and cancers, the evidence is more mixed, with positive as well as negative impacts being reported.

Table **3.2**

Expert assessment (by authors) of the strength of the evidence for forests, trees and other types of green space being associated with different health outcomes among adults

ADULTHOOD: STRENGTH OF THE EVIDENCE			
MENTAL HEALTH			
Mental wellbeing and quality of life ++	Mental disorders +/0	Spiritual wellbeing ++	
PHYSICAL HEALTH			
Infectious diseases +/-	Cardiometabolic health ++	Respiratory/allergic outcomes +/-	Cancers +/-

Note: Sign indicates type of association: + beneficial association, 0 no association, - detrimental (harmful) association. Number of same signs indicates strength of evidence for a particular type of association.

3.4 The Elderly

In this third stage of life, we distinguish between studies focusing on healthy ageing, mental health and longevity.

3.4.1 Healthy ageing

Cognitive decline and dementia

Natural environments may affect cognitive decline and dementia through alleviating risk factors such as physical inactivity, loneliness, depression, obesity, cardiovascular diseases and air pollution, and by buffering negative impacts of major life events such as hospitalisation and institutionalisation (Livingston et al., 2020).

A systematic review of 13 studies available up to 2016 on the link between exposure to green space and cognitive functioning indicates low quality evidence (e.g., cross-sectional self-reported data) (de Keijzer et al., 2016). In particular, the four studies with elderly people showed inconsistent results regarding the association between green space and cognitive functioning. Since 2016, at least 30 studies including analyses of longitudinal data have been published. These include Australian cohort studies that have isolated tree canopy from other types of green space (e.g., grass and shrub), indicating reduced risks of subjective memory complaints (Astell-Burt and Feng, 2020b) and dementia risk over 11 years (Astell-Burt et al., 2020). These findings on the potential benefits of urban tree canopy cover are complemented by cohort studies assessing associations with NDVI-based measure of residential green space, reporting lower 10-year risks of cognitive decline in the UK (de Keijzer et al., 2018) and dementia over a 13-year period in Canada (Paul et al., 2020). However, such protective effects of green space are not always observed for all people (Jin et al., 2021).

Current research is assessing different types of dementia, such as a USA-based cohort study (Slawsky et al., 2022) reporting a lower risk of all-cause dementia with more NDVI-based green space, but not with dementia sub-types such as Alzheimer's disease (AD). Studies are also examining associations between nature and brain measurements. For example, Falcón et al. (2021) observed an association between residential surrounding green space and specific brain areas known to be affected in AD, indicating a lower vulnerability in a large sample of cognitively unimpaired individuals at risk for AD. This result aligns with that reported by Crous-Bou et al. (2020), wherein more exposure to green space was associated with greater thickness in brain regions known to be affected by AD, thus indicating a beneficial effect on vulnerability in brain areas involved in AD. A recent experimental study in South Korea reported that repeated forest therapy sessions could mitigate the physical, psychological, and cognitive risk factors of dementia among at-risk elderly (Lim et al., 2021). Another recent trial on dementia patients in four French nursing homes reported that visits to gardens improved cognitive function and ability to carry out daily activities independently (Bourdon and Belmin, 2021).

To summarise, the evidence on the beneficial impacts of natural environments, including forest, on decelerating cognitive ageing and reducing the risk of dementia, is accumulating and indicative for such an impact.

Physical functioning and frailty

Physical functioning is defined as the ability to perform daily activities unassisted (Covinsky, 2006). A poor physical functioning is associated, among others, with a higher risk of age-related frailty (Rodríguez-Gómez et al., 2021). Frailty is a multidimensional syndrome, including a number of physical, cognitive, psychological and social problems (Levers et al., 2006), which has been associated with a higher risk of disability, hospitalisation and mortality and lower quality of life in later life (Kojima, 2017; Chu et al., 2021). Pathways through which natural environments, including forests, could influence physical functioning and frailty are mostly similar to those for cognitive decline, as described in the preceding section.

Physical functioning and its decline in older adults have been extensively investigated, also in relation to lifestyle factors (e.g., van Assen et al., 2022). Regarding contact with green space, Vogt et al. (2015) found in a sample of older German adults that certain features of a residential environment, including proximity to green space, were not associated with self-rated physical constitution, disability and health-related quality of life. However, the authors attributed this finding to the fact that the city under consideration, i.e., Augsburg, has many green spaces, thus making it difficult to isolate its effect on citizens. A later longitudinal study that investigated the effect of exposure to natural environments (i.e., green and blue spaces) on physical functioning among nearly 6,000 middle-aged and older healthy adults in the UK found that higher residential surrounding green space was associated with a slower 10-year decline in walking speed, an indicator of lower body physical functioning (de Keijzer et al., 2019). They also observed indications for a similar association for grip strength, an indicator of upper body physical functioning. In another study in China, more residential green space was found to be associated with lower odds of developing disabilities related to basic and instrumental activities of daily living in the elderly (Zhu et al., 2019). Consistent with this, another longitudinal study found a negative association between the amount of residential green space and the likelihood of frailty among over 16,000 Chinese older adults (Zhu et al., 2020).

A recent study reported an association between residential surrounding green space and bone mineral density (BMD) change and incident fracture in a sample of Hong Kong Chinese older adults (Lin et al., 2021). BMD loss is correlated with osteoporosis, both of which are among common indicators of physical frailty in the elderly. This study found that residential surrounding green space was associated with slower 14-year increase in lumbar spine BMD. Mixed findings were instead found in whole body BMD, which showed to be associated with greenness measured in a 300 m buffer, but not a 500 m buffer. However, green space was also found to be associated with a higher risk of fracture incidence in the same sample. The authors posit that it is highly likely that the association between higher green space level and bone health is mediated by physical activity. Another possible mediator could be through mitigation of exposure to air pollution (Weuve et al., 2016), which is supported by recent findings reporting associations between exposure to long-term air pollution and risk of osteoporosis-related fracture in the elderly (Heo et al., 2022). However, air pollution was not significantly associated with decline in physical functioning in other studies (e.g., de Keijzer et al., 2019).

Summarising, although the available evidence on the association between exposure to natural environments, including forests, and physical functioning and frailty is still limited with some inconsistencies in their findings, it is suggestive of a beneficial relationship.

3.4.2 Mental health

With regard to mental health, psychological pathways (i.e., stress reduction, mood improvement) are of key importance although physical activity may also be a relevant pathway (Kadariya et al., 2019). Specifically for the elderly, the social contacts pathway is deemed relevant for their mental health and wellbeing, since social isolation

Forests and green spaces are essential for physical and mental wellbeing
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is a more common risk factor for this age group (Choi and Matz-Costa, 2018; Urzua et al., 2019; Domènech-Abella et al., 2021).

In their review, Kabisch et al. (2017) reported on the effects of (mainly urban) green space on elderly people (and children). They conclude that, although a universal protective health effect of urban green space has not been established due to the relatively limited available studies, the trend is positive. A study by Ode Sang et al. (2016) in Sweden reported that higher perceived naturalness in the neighbourhood was associated with more activities and higher self-reported wellbeing. Similar results were found in Japan by Soga et al. (2017) with regard to urban allotment gardens. Moreover, in China, Zhou et al. (2020) found that neighbourhood green space was positively associated with older adults' mental wellbeing via social interactions. A field study in Finland on urban parks and woodlands found that both had restorative effects, but nature (versus city) orientedness and noise sensitivity modified the effects (Ojala et al., 2019). For example, in the high nature-oriented group, the highest restorative effects (observed based on psychological measures only) were found in urban woodlands. Other studies report on the importance of physical activities. In a cross-sectional study in Germany, 272 adults aged 65 answered questions regarding health-related quality of life, physical activity and exposure to urban green spaces (Petersen et al., 2018). The analysis showed significant positive associations between weekly duration of exposure to urban green space and health-related quality of life. Similarly, a study conducted in six European countries showed the importance of urban green spaces for the quality of life of seniors residing in care facilities, as well as for the staff and visitors (Artmanna et al., 2017).

A review by Oh et al. (2017) in China and Korea focused on articles analysing the effect of different forest therapy interventions on physical and psychological health outcomes. Two of the three studies with elderly participants measured psychological responses with the profile and mood state questionnaire which is used to measure current affect (Mao et al., 2012; Jia et al., 2016). They reported that the forest therapy intervention group had significantly lower scores in the negative subscales (tension-anxiety, depression, anger-hostility, fatigue and confusion) and increased vigour. A similar study in Korea compared different health outcomes of a forest therapy group versus a control group of elderly hypertensive patients and found a significant decrease in cortisol level and improvement in quality of life measures (Sung et al., 2012).

Some work supports a beneficial association between availability of and/or proximity to nature and risk for mental disorders in elderly populations, especially depression. A USA-based study found that the elderly living in greener neighbourhoods had a reduced risk of depression (Brown et al., 2018). The reduction was larger in low-income neighbourhoods. A study among older women (mean age 70) in the USA Nurses' Health Study who lived in the highest quintile of green space (using average NDVI) within 250 m buffers had a reduced risk for the onset of depression over 10 years of the study period (Banay et al., 2019). In China, the middle-aged and elderly living in a city district with a green space coverage above 38% had lower odds of having depressive symptoms than those living in districts with a coverage below 38% (Zhou et al., 2022). Specifically with regard to forests and trees, Nishigaki et al. (2020) assessed depression rates (using the Geriatric Depression Score) in 126,878 adults 65 and over, and found that greater amounts of trees within district areas were associated with lower odds for depression.

With respect to symptomatology, Wu et al. (2015) found that the amount of neighbourhood green space was inversely associated with sub-threshold levels of depression and anxiety symptoms among a sample of elderly adults (age 74 and over) in the UK. Other work from the USA found that depressive symptoms were inversely related to tree canopy coverage (especially for buffer sizes between 0-250 m and 250 m-500 m) around 9,186 nursing homes (Browning et al., 2019). A Korean study on the effect of a 10-week urban forest therapy programme for low-income elderly living alone showed that the elderly had fewer depressive symptoms after the programme and also fewer than a control group (Lee and Son, 2018; also see Lim et al. (2021) for a similar Korean study, with a similar result). We are not aware of any other studies looking specifically at forests and trees in relation to mental health disorders and symptomatology among the elderly.

In short, it can be concluded that there is suggestive evidence that urban green spaces contribute positively to mental wellbeing and quality of life for the elderly, resulting in a lower prevalence of mental disorders and sub-clinical levels of related symptoms. This pertains especially to depression, which appears to be the most frequently researched disorder in connection to green space. The few studies looking specifically at the effect of forests on wellbeing of elderly people indicate positive impacts on both wellbeing and quality of life.

3.4.3 Longevity and mortality

Exposure to natural environments, including forests, has been associated with reduced risk of mortality and improved life expectancy. These effects would seem to be the ultimate result of all relevant pathways.

A systematic review and meta-analysis of longitudinal epidemiological studies found that increments in green space surrounding the residential address – especially in a buffer of 500 m – were significantly associated with reducing all-cause mortality (Rojas-Rueda et al., 2019). This review included 13 studies with more than 8 million individuals across seven countries: Australia; Canada; China; Italy; Spain; Switzerland; and the USA. Although the review could not conclude which mechanisms underlay the reduction in mortality, many biological, lifestyle, and environmental mechanisms and pathways (e.g., physical activity, stress, microbiome, air quality and heat) could mediate the association between green space exposure and mortality. Moreover, exposure to green space has been associated with longer telomere length (Martens and Nawrot, 2018; Miri et al., 2020). Shortened telomere length is an indicator of cellular ageing, therefore a positive association between exposure to nature and telomere length could indicate a deceleration of cellular ageing.

The evidence between exposure to nature and mortality is robust enough to allow modelling the future impacts of urban greening strategies on mortality. A number of studies have been able to quantify the mortality impacts of future greening strategies (Mueller et al., 2018; Kondo et al., 2020). In such a study in Philadelphia, USA, researchers assessed the health impacts of 2025 tree canopy goals (Kondo et al., 2020). In this study, the most ambitious tree canopy goal (achieving 30% of the city land covered by tree canopy) was estimated to prevent 403 premature annual deaths among the adult population. This study also quantified the health-related economic benefits, estimating that the increase in the tree canopy to cover 30% of the city land will result in health economic benefits of USD 3.8 billion annually.

To summarise, the available evidence is indicative for the capability of natural environments to reduce mortality, decelerate cellular ageing and promote longevity.

3.4.4 Summary

Table 3.3 below gives an overview of the strength of the evidence for associations of natural environments and forests with health and wellbeing in later stages of life, based on the expert judgment of the authors. The evidence for the four included health domains is generally positive, with strong and consistent evidence for three out of four domains: cognitive decline and dementia; mental health and wellbeing; and longevity and mortality. The evidence for an impact of contact with nature and forests on physical functioning and frailty is somewhat more mixed, mostly because the physical activity pathway underlying these benefits may also lead to accidents and bone fractures.

Table **3.3**

Expert assessment (by authors) of the strength of the evidence for forests, trees and other types of green space being associated with different health outcomes among the elderly

ELDERLY: STRENGTH OF THE EVIDENCE			
Cognitive decline and dementia	Physical functioning and frailty	Mental health and wellbeing	Longevity and mortality
++	+/0	++	++

Note: Sign indicates type of association: + beneficial association, 0 no association, - detrimental (harmful) association. Number of same signs indicates strength of evidence for a particular type of association.
Source: MEA, 2005

3.5 Other Health and Wellbeing Effects

3.5.1 Sleep quality and duration

Studies on the potential of forests, trees and green spaces to support population-wide improvements in sleep are emerging. Stress relief, physical and social activities, and protection from chronic noise, excess heat and air pollution are all plausible and likely intertwined mechanisms (Astell-Burt and Feng, 2020), though evidence is still in its infancy. A systematic review on green space exposure and sleep (Shin et al., 2020) identified 13 studies up to 31 December 2018, including seven epidemiological studies with a cross-sectional design (Astell-Burt et al., 2013; Singh and Kenney, 2013; Bodin et al., 2015; Chum et al., 2015; Grigsby-Toussaint et al., 2015; Triguero-Mas et al., 2017; Johnson et al., 2018), one case report (Rappe and Kivelä, 2005), three uncontrolled pre/post trials (Lee and Kim, 2008; Morita et al., 2011; López-Pousa et al., 2015) and two randomised controlled trials (Gladwell et al., 2016; Dolling et al., 2017). Findings indicating that contact with green space may support healthier sleep durations and/or quality were reported in all five of the trials (Dolling et al., 2017; Gladwell et al., 2016; Lee and Kim, 2008; López-Pousa et al., 2015; Morita et al., 2011) and in six of the seven epidemiological studies (Astell-Burt et al., 2013; Bodin et al., 2015; Grigsby-Toussaint et al., 2015; Johnson et al., 2018; Singh and Kenney, 2013; Triguero-Mas et al., 2017).

Since the aforementioned review, six cross-sectional studies (Feng et al., 2020; Xie et al., 2020; Yang et al., 2020; Li et al., 2021; Williams et al., 2021; Zhong et al., 2021) and three longitudinal studies (Astell-Burt and Feng, 2020a; Mayne et al., 2021; Putra et al., 2022) have been published. Six focussed on adults and three on children and adolescents. Results from six out of eight of these more recent studies indicate that contact with green space may support sleep-related outcomes (Astell-Burt and Feng, 2020a; Li et al., 2021; Mayne et al., 2021; Xie et al., 2020; Yang et al., 2020; Zhong et al., 2021). Two longitudinal studies found evidence of benefits from nearby tree canopy (Astell-Burt and Feng, 2020a; Mayne et al., 2021). In a study of adolescents, Mayne et al. (2021) report that an increase in neighbourhood tree canopy was associated with earlier sleep onset and earlier sleep offset. In a study of adults, Astell-Burt and Feng (2020) reported 13% reduced odds of insufficient sleep (<6 hours) among participants with >30% tree canopy within a 1.6km buffer in contrast with peers with <10% tree canopy, while there were no associations for other types of green space (e.g., open grasslands).

3.5.2 Other physical health benefits

In addition to the aforementioned health outcomes, exposure to nature has been associated with reduced risk of other morbidities. For example, a study by Maas et al. (2009) based on data from over 345,000 participants in the Netherlands reported that a higher percentage of green spaces in buffers of 1 km and 3 km around the residential address of participants was associated with lower risks of medical visits for musculoskeletal problems (e.g., severe neck, back and shoulder complaints), neurological problems (e.g., migraine/severe headaches and vertigo), gastrointestinal infections and acute urinary tract infections. Other studies have also suggested a protective association between exposure to natural environments and refractive errors of eyes such as myopia and astigmatism among children (Dadvand et al., 2017; Huang et al., 2021).

3.5.3 Potential adverse health effects

Natural environment could also be a source of a number of adverse health effects. For example, the pesticides applied to maintain green spaces could expose individuals who use these spaces or live in their vicinity to these chemicals. Exposure to pesticides, in turn, has been associated with a wide range of health effects including cancers as well as adverse conditions in reproductive, nervous, immune and endocrine systems (Blair et al., 2015). Moreover, users of natural environments, particularly children, could experience accidental injuries such as drowning or falls when they are in these environments. However, such injuries occurring in natural environments account for a very small proportion of accidental injuries at the population level (WHO regional Office for Europe, 2016).

3.6 Modifiers of Forest Potentials to Improve Health

The health and wellbeing effects of green spaces and forest can vary across the strata of socio-economic status, sex/gender, ethnicity and degree of urbanicity. These potential moderators are discussed in this section. Typology and quality characteristics of natural environments may also affect the amount and type of interaction between people and these environments, and hence could influence their potential to exert health benefits. For example, in their systematic review Nguyen et al. (2021) concluded that trees are more effective than grass in exerting benefits for mental wellbeing, allergic respiratory conditions and cardiovascular conditions. An in-depth discussion of the relevance of the typology and quality characteristics of the natural environment to human health can be found in Chapter 4 of this report.

3.6.1 Socio-economic status

Evidence is growing about the differential health effects of exposure to outdoor nature by socioeconomic status (SES). A review of 122 analyses across 85 articles found moderate evidence that those with lower-SES show more beneficial associations across seven physical health outcomes from outdoor nature exposure than higher-SES populations (Rigolon et al., 2021). These differential benefits were more prominent in analyses of public parks than generalised measures of nature/vegetative cover. Differential benefits were also more prevalent in European studies than in North American studies. Lower SES populations benefitted more from outdoor nature among several of the reviewed studies in LMICs, including China (i.e., Huang et al., 2020) and Brazil (Rossi et al., 2019). Studies on mental and socio-emotional health outcomes also suggest stronger beneficial effects of nature exposure for those in lower SES strata (McEachan et al., 2016; van den Berg et al., 2016; Triguero-Mas et al., 2017; Pearce et al., 2018; McCrorie et al., 2021; Browning et al., 2022a).

Beyond evidence on SES as an effect modifier on the health benefits of outdoor nature, some studies have explored interactions between SES and other potential modifiers such as urbanicity or gentrification (Maas et al., 2006; Mitchell and Popham, 2007; Cole et al., 2019; Zayas-Costa et al., 2021). For example, Cole et al. (2019) focused on adults' self-perceived general health in New York, USA, and found only those living in gentrified neighbourhoods with higher education or income levels benefitted from green space. A review of 15 studies on gentrification following urban greening found long-time, marginalised residents felt excluded from and used, new green spaces less than newcomers (Jelks et al., 2021).

Lower SES populations may benefit more from nature than privileged groups for multiple reasons. Populations with limited financial resources could be more dependent on their neighbourhoods because of lower rates of vehicle ownership than more privileged populations (de Vries et al., 2003; Maas et al., 2008; McEachan et al., 2016; Rigolon et al., 2021). Limited resources could also increase reliance on freely available health-promoting facilities such as green spaces rather than cost-prohibitive services (de Vries et al., 2003; Triguero-Mas et al., 2017). Additionally, people with lower SES are vulnerable to poor health outcomes resulting from environmental and social stressors across the lifespan, resulting in suppressed baselines and having more to gain from outdoor nature regarding improvements in health (Braveman et al., 2010; Ursache and Noble, 2015; Robinette et al., 2017; Rigolon et al., 2021). A notable exception to lower-SES populations benefitting more from nature than their privileged counterparts are residents of neighbourhoods witnessing green gentrification (Rigolon and Collins, 2022). In these cases, studies in both higher income countries and lower income countries show only higher-SES populations may benefit from exposure due to changes in senses of

Shorea roxburghii, *a plant mostly found in Asia, is commonly used for medicinal purposes*
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community and belonging, perceived safety, physical activity levels and financial pressures, among other factors (Cole et al., 2019; Jelks et al., 2021).

There is little evidence on differential impacts of forests specifically on health by SES. One notable exception is a study of sedentary behaviour, obesity, asthma and allergic rhinoconjunctivitis amongst Spanish children (Dadvand et al., 2014a). The authors found stronger beneficial associations between residential proximity to forests and lower sedentary behaviour (screen time) for children of parents with higher education levels. Another relevant exception is an exploration of associations between street tree density and species richness with antidepressant prescriptions amongst German adults; in this study, lower prescriptions were associated with street tree density and species richness only amongst respondents with low SES (Marselle et al., 2020).

Collectively, the available evidence, along with reasons to expect that outdoor nature benefits low SES residents more than other populations, supports the likelihood of forests and trees having 'equigenic effects', i.e., narrowing socio-economic inequalities in health (Mitchell et al., 2015). Individuals in the greatest need may receive the greatest health benefits from living in or visiting areas with abundant canopy cover.

3.6.2 Gender

Women and men may perceive and experience nature differently. In some cultures, women tend to express greater safety concerns in urban parks and densely vegetated areas, such as forests, than men (Sreetheran and van den Bosch, 2014). This could result in less optimal use of these spaces for health and wellbeing benefits among women. At the same time, women tend to be more connected to nature and supportive of the idea that contact with nature can be beneficial for health, as evidenced by a large survey among a representative sample of Dutch residents (van den Berg, 2012). However, direct evidence for differences between men and women in the nature-health relationship is mixed and inconclusive. In discussing the available evidence, we considered gender as a binary construct, because all studies that are available treat gender as such. However, we acknowledge that the research falls short in recognising that many individuals identify as non-binary, bigender, agender or other (Springer et al., 2012).

Systematic reviews of self-rated health (Bolte et al., 2019), physical health (Sillman et al., 2022) and cardiovascular health (Núñez et al., 2022) have examined how gender impacts the health benefits of green space but provide little guidance on differential benefits of trees/forests. Bolte et al. (2019) identified seven studies on self-rated health and green space, natural land cover, or perceived green space amount/quality. Four studies showed no difference between men and women while the remainder showed associations for one group or the other. A more extensive review by Sillman et al. (2022) identified 81 analyses of gender differences across 62 articles on associations between cardiovascular disease, cancer, diabetes, general physical health, non-malignant respiratory disease, mortality and obesity-related outcomes with different types of green space measures. Some of these measures (e.g., green land cover) included forested land, but this was not distinguished as a separate category. Results of this review were again mixed and inconclusive, with 42% of the analyses reporting stronger associations for women, 35% showing no differences between women and men, and 23% showing stronger associations for men. Protective associations for women were most prominent in obesity-related and mortality outcomes, when green space was measured very close to home, and for green land cover estimates that included forests. In no case did men show more prominent protective associations among specific health outcomes or types of nature. Núñez et al. (2022) found women tended to benefit more than men from exposure to nature when measured with NDVI values but not when using other exposure assessments across the 22 reviewed studies. Another recent study among Chinese adults that was not included in the review found some evidence that street view green space was negatively associated with hypertension among women but not men (Wang et al., 2022). No gender differences were found for the relationship between total vegetative cover using overhead estimates (i.e., NDVI). These results suggest the location and type of vegetation – including trees – defines when gender differences are present in associations between nature and human health.

Taken together, research points to a small but potentially significant role of gender in how people relate to nature and forests and the health benefits they derive from interacting with forests, trees and green spaces. Contrary to the finding that women tend to feel more unsafe in parks and forests, and thus might avoid visiting these spaces for health purposes, the benefits seem to be slightly more in favour of women. This might be related to women's stronger connection to nature and how this inspires them to engage in nature-based activities such as gardening, taking walks in (safe) natural areas, and other activities that allow them to reap the health benefits of nature.

3.6.3 Ethnicity and culture

The evidence on ethnicity and culture as effect modifiers in relationships between nature and health is scarce and contradictory. Defining such group identities remains complex and challenging. For a start, culture and ethnicity are distinct; a shared system of symbols (i.e., language) and values can define cultural groups whereas social boundaries restricting 'in' and 'out' group members can define ethnic groups (Ordóñez-Barona, 2017; Kaufman and Hajat, 2021). However, in American contexts, such divisions are historically dominated by ethnoracial differentiations (i.e., Hispanic, Black and Asian), whereas in many European countries, divisions are often made between locally- versus foreign-born individuals (Gentin, 2011). In LMICs, broad and multifaceted definitions have been used alongside population sizes to identify potential minorities. Here we use 'ethnicity' to describe how groups of minority and majority populations beyond their SES might derive benefits differently from nature and forests (Victora et al., 2020).

McEachan et al. (2016) found no role of ethnicity as an effect modifier in associations between residential green space exposure and depressive symptoms among pregnant women in a UK birth cohort. In contrast, another study of the same cohort reported positive associations between surrounding green space and birth weight for White British but not for Pakistani newborns (Dadvand et al., 2014b). However, in the review by Rigolon et al. (2021), the collective findings of 25 articles showed no notable differences between White and other racial/ethnic groups across seven physical health outcomes. Another review of the use and perceptions of urban natural environments by ethnic minorities found that passive, social activities, larger group sizes and manicured landscapes with fewer trees tended to be most preferred (Ordóñez-Barona et al., 2017).

Individual characteristics such as ethnicity and race are frequently used as surrogates of the experiences of racism and social discrimination. Certain ethnic or racial population groups such as minorities and immigrants may not enjoy the same economic, political and health status as more privileged groups (Mohai et al., 2009; Chen and Miller, 2013). Green space quality, programming and safe access are often lower among non-Whites, even where there is equal green space proximity. Such patterns could perpetuate lower exposure to these health-promoting amenities (Frumkin et al., 2017). New or improved green spaces may also be intimidating and fear-inducing for some minority and immigrant groups because of memories or narratives of discrimination, violence, lynching and crime (Rigolon and Németh, 2018; Anguelovski et al., 2020). Some authors have suggested that minority and immigrant groups may also lack the confidence to visit green spaces; for example, some populations fear getting lost in urban green spaces (Cronin-de-Chavez et al., 2019). Inadequate understanding of the needs (e.g., route finding), languages, identities and preferred uses of green spaces of different racial and ethnic groups may result in inequitable health benefits of these spaces. Inclusive participation in the design and maintenance of green spaces may help overcome ethnoracial disparities in the health benefits of forests, trees and green spaces (Anguelovski et al., 2020).

3.6.4 Urbanicity and rurality

The health-promoting benefits of forests, trees and green spaces can span the urban-rural continuum. Whether these benefits are more prominent in cities, suburbs or countrysides is poorly understood. Forests are heralded for their array of ecosystem services (Roeland et al., 2019) including cultural services related to human health, economic development and tourism (Nesbitt et al., 2017). These services may be particularly valuable in urban contexts where environmental stressors are concentrated, including air pollution, heat and noise (Boehmer et al., 2013). Trees thus provide health benefits by filtering air pollution, mitigating the urban heat island effect and diffusing traffic noise (Markevych et al., 2017). Trees and forests can also support physical activity, social interaction and sleep quality, while restoring attention and aiding in stress recovery (Nilsson et al., 2010).

Dozens of studies have been conducted on the health benefits of trees and forests in exclusively urban settings without rural comparisons (Wolf et al., 2020). In turn, dozens of other studies have determined the therapeutic benefits of forests in larger tracts of forested land without examining their urban counterparts (Yau and Loke, 2020; Cheng et al., 2021). Scant research has attempted to answer the question of how trees may impact health differently across the urban-rural spectrum. Some insight is available from a review on how urbanicity impacts relationships between physical health and green space (in all its forms), which found stronger protective effects for urban than less urban areas (Browning et al., 2022b). Across 57 analyses in 37 reviewed articles, around 50% showed no differences, 40% showed higher benefits for more urban areas and 10% showed higher benefits for less urban areas. Prior narrative summaries support such findings (Kabisch et al., 2017; Markevych et al., 2017; Fong et al., 2018). These differential effects were present across both higher-income and low-to-middle-income countries, such as China (Huang et al., 2021).

Conflicting evidence on where forests and trees matter most persists in many nationwide studies. Annual healthcare expenditures (an outcome of healthcare utilisation, presumably linked to poor health status) among older adults was lower in American counties with more forest coverage. Contrary to the reviewed literature above, these associations were strongest in rural counties (Becker et al., 2019). Meanwhile, the same authors found opioid-related mortality was positively associated with tree canopy cover in American counties. Sensitivity analyses uncovered that these effects persisted only in rural counties and in fringe areas around major cities (Becker et al., 2022). Carrus et al. (2020) revealed rural Italian residents exhibited higher connectedness to nature scores (CNS) than urban residents. CNS scores were in turn positively correlated with the perceived importance of forests for sports, relaxation, illness prevention, social cohesion and community identity, suggesting urbanicity might differentially affect perceptions of forest health benefits.

3.7 Global Health Challenges

3.7.1 The potential of forests to tackle major global health challenges

Over the past decades, economic development together with advances in healthcare and food security have resulted in changes in population growth trajectories and composition (e.g., ageing populations) and in patterns (e.g., increased life expectancy) and causes of mortality which, together, are considered as the 'epidemiological transition' (McKeown, 2009). The pace of this transition has been different across different countries, mainly depending on the developmental level of each country, with high-income countries being generally more advanced in this transition. A consequence of the epidemiological transition has been a shift from communicable diseases (CDs) to chronic noncommunicable diseases (NCDs) as major contributors to the global burden of disease (GBD). As presented in Table 3.4, while in 1990 (the year for which the first GBD was systematically estimated) CDs dominated the top 25 contributors to the GBD (calculated as Disability-Adjusted Life Years or DALYs), this list was mainly dominated by NCDs in 2019 (GBD 2019 Diseases and Injuries Collaborators, 2020). Natural environments, including forests, have a potential role in preventing many of the NCDs and some of the CDs in this list. More specifically, the available evidence is suggestive for a protective association of contact with natural environments and ischaemic heart disease, stroke, lower respiratory infections, diarrhoeal diseases, diabetes, lower back pain, depressive disorders, headache disorders, musculoskeletal disease, self-harm and anxiety disorders. Moreover, in the case of a number of mental health conditions such as anxiety and depressive disorders, natural environments could also provide therapeutic effects. For malaria and some other vector-based infectious diseases, however, poor management and unsustainable use of forests can increase the risk of transmission and the burden associated with disease (Kar et al., 2014; Ranjha and Sharma, 2021).

Table **3.4**

Top 25 causes of global burden of disease in terms of disability-adjusted life years (DALYs) in 1990 and 2019

Leading causes of DALYs (1990)	Leading causes of DALYs (2019)
1. Neonatal disorders	1. Neonatal disorders
2. Lower respiratory infections	2. Ischaemic heart disease
3. Diarrhoeal diseases	3. Stroke
4. Ischaemic heart disease	4. Lower respiratory infections
5. Stroke	5. Diarrhoeal diseases
6. Congenital birth defects	6. COPD
7. Tuberculosis	7. Road injuries
8. Road injuries	8. Diabetes
9. Measles	9. Lower back pain
10. Malaria	10. Congenital birth defects
11. COPD	11. HIV/AIDS
12. Protein-energy malnutrition	12. Tuberculosis
13. Lower back pain	13. Depressive disorders
14. Self-harm	14. Malaria
15. Cirrhosis	15. Headache disorders
16. Meningitis	16. Cirrhosis
17. Drowning	17. Lung cancer
18. Headache disorders	18. Chronic kidney disease
19. Depressive disorders	19. Other musculoskeletal disease
20. Diabetes	20. Age-related hearing loss
21. Lung cancer	21. Falls
22. Falls	22. Self-harm
23. Dietary iron deficiency	23. Gynaecological diseases
24. Interpersonal violence	24. Anxiety disorders
25. Whooping cough	25. Dietary iron deficiency

Source: Adopted from GBD 2019 Diseases and Injuries Collaborators, 2020

The potential of forests and natural environment to tackle global health challenges also includes their ability to moderate some of the leading risk factors contributing to the GBD. Based on the available evidence, forests and trees outside forests as key components of urban and rural ecosystems could contribute to the mitigation of most of the 10 leading risk factors for global DALYs (Table 3.5), including hypertension, high fasting plasma glucose (i.e., hyperglycaemia), low birth weight, high body-mass index (i.e., overweight and obesity), short gestation (i.e., pre-term birth), ambient air pollution and high cholesterol level (GBD 2019 Risk Factors Collaborators, 2020). In addition to reducing the risk of major disease and mitigating the major risk factors contributing to the GBD, natural environments, including forests, could also reduce the GBD through the co-benefits that they provide including enhancing the mitigation, adaptation and resilience to ongoing climate change, which in turn has direct and indirect health and wellbeing effects.

Table **3.5**

Top 10 risk factors for the global burden of disease in terms of disability-adjusted life years (DALYs) in 1990 and 2019

Leading causes of DALYs (1990)	Leading causes of DALYs (2019)
1. Child wasting	1. High systolic blood pressure
2. Low birth weight	2. Smoking
3. Short gestation	3. High fasting plasma glucose
4. Household air pollution	4. Low birth weight
5. Smoking	5. High body-mass index
6. Unsafe water	6. Short gestation
7. High systolic blood pressure	7. Ambient particulate matter
8. Child underweight	8. High LDL* cholesterol
9. Unsafe sanitation	9. Alcohol use
10. Lack of handwashing	10. Household air pollution

Source: Adopted from GBD 2019 Risk Factors Collaborators, 2020
**LDL: low-density lipoproteins.*

3.7.2 Differences between high-, middle- and low-income countries

Forests and other natural environments may have varied effects on human health in diverse regions across low-, middle- and high-income countries due to (i) the different stages of the epidemiological transition of these countries, and (ii) some differences in the nature of interactions with, and reliance on, forests and forest products, especially for spiritual and cultural services and traditional medicines. While high-income countries mainly face the challenge of NCDs, middle-income countries exhibit a mix of communicable and non-communicable diseases burden with a higher proportion of NCDs. Low-income countries continue to have a disproportionately higher burden of communicable diseases while NCDs are also rising rapidly. Low- and middle-income countries (LMICs) also face a higher burden of nutritional deficiencies, pollution and related morbidities in general, which makes them potentially more sensitive to forest loss or degradation (FAO et al., 2021). Moreover, LMICs are in greater danger of forest loss and degradation because of local and foreign economic interests, corruption and poor enforcement capacity (Robinson et al., 2010). Nutritional deficiency and vector-based infectious diseases continue to be a challenge in many LMICs. Consequently, many studies from LMICs have focused on how forests can contribute to reducing malnutrition and related health challenges such as vector-based infectious diseases (Vira et al., 2015; Fungo et al., 2016; Rowland et al., 2017; Rasolofoson et al., 2018; Vinceti et al., 2018). Rasolofoson et al. (2018) indicate that forest exposure can improve dietary diversity by up to 25% thus preventing micronutrient deficiency (vitamin A and iron) in LMICs. Similarly, there is a stronger focus on non-wood forest products and their direct and indirect health benefits in LMICs, including contributions to nutrition and dietary diversity, (Ahenkan and Boon, 2011; Boulom et al., 2020), direct treatment of communicable and non-communicable ailments (Ahenkan and Boon 2011) and spiritual health based on biocultural cosmologies, and associations with forests and forest products (e.g., Caluwe et al., 2009; Cocks et al., 2012).

Aesthetics, spirituality, sense of place and educational experiences enhance the recreational effects of green spaces
Photo © Alexander Buck

Consequently, there appear to be differences in the way research priorities on forests and human health are established in these contexts. A major difference in terms of research evidence is that much of the data on the direct impact of natural environments on health, is from high-income countries and typically urban contexts. Available evidence on the effects of natural environments on health in LMICs is limited but growing (Labib et al., 2020; Shuvo et al., 2020). Such evidence may be constrained by other priorities related to development planning, limitations of resources and research capacities. In Dhaka, Bangladesh, Labib et al. (2020) report that there is an inadequate supply of, poor access to, and low attractiveness of, green spaces in the city. Likewise, Hong et al. (2021) based on a study from Cali, Colombia, report that a challenging health disparity within LMICs is better access to green spaces for wealthier as compared to lower income populations. Another systematic review of 46 studies by Rigolon et al. (2018) found inequities in quantity and proximity to urban green spaces based on socio-economic status and race-ethnicity across Asian, African and Latin American cities. Globally, estimates indicate that only 13% of urban residents live in neighbourhoods with higher than 20% forest cover to experience its mental health benefits (McDonald et al., 2018) with urban development generally reinforcing privatisation and exclusion (Byrne and Wolch, 2009). A review of 22 studies from LMICs illustrates the challenge of generalising findings from 125 LMICs due to methodological constraints of available evidence (Shuvo et al., 2020). Most studies use subjective and cross-sectional designs, lacking robust, objective and longitudinal data.

In summary, the majority of available studies on the health effects of natural environments have been conducted in high-income countries while their findings are not necessarily generalisable to LMICs, given the differences in cultures, climates and types of interactions with these environments, in particular with forests.

3.8 Conclusions

This chapter provided an overview of the best available evidence regarding the association between green spaces in general, and forests and trees in particular, and human health and wellbeing across all life stages. For most health outcomes, the observed associations were predominantly beneficial and in a smaller number of cases were mixed. Evidence of beneficial associations was stronger for some outcomes, such as mental health and wellbeing or longevity, than for others (e.g., cancers) due to fewer studies having been conducted on the latter. For some health outcomes, the evidence is more mixed, with both positive and detrimental associations being observed. This was especially the case for allergic and respiratory conditions, such as asthma, and for infectious diseases such as malaria. Relatively little research has been done specifically on forests and trees versus green space more broadly. Regarding the focus on adults, there is a case to be made that for many health outcomes the underlying processes and mechanisms are likely to be the same for children and the elderly, with similar outcomes. This is especially the case when more basic physical and physiological processes are involved (e.g., air pollution and heat stress reduction). Thus, results for adults may to some extent be generalisable to other life stages (and vice versa). Regarding the focus on residential surrounding green space, here we want to point at the importance of the proximity, the exposure and the amount of direct contact with the green space. Results on nearby green space are unlikely to be generalisable to green space that is located further away, or that is only rarely approached.

In this chapter we focused on empirical research often looking at spatial differences in the local availability of and/or access to green spaces, forests and trees or at changes herein over time, and how these are associated with human health and wellbeing. Effects of large-scale biodiversity loss over decades, or large-scale changes in ecosystems due to climate change, were not included. Given a wider and longer time perspective, the presence and state of nature elsewhere may have local health consequences. Chapter 4 in this report focuses more specifically on forests and their characteristics.

Besides fewer studies being conducted in LMICs thus far, the focus of studies on forests and health differs to some extent between LMICs and high-income countries, largely due to differences in main health problems (e.g., CDs versus NCDs and undernutrition versus malnutrition or overnutrition) and contextual differences in the use of green space and forests. With regard to generalisability of findings from studies conducted in high-income countries to a LMIC context, to some extent also here underlying processes and mechanisms may in principle also apply in LMICs, but may be less prominent or relevant due to different starting situations and baseline values. Also, generalisability is more likely for basic physical and physiological processes than for 'higher order' culturally-defined processes.

Most of the studies conducted thus far had a cross-sectional design, which has limited the ability to draw firm conclusions regarding the causality of the observed associations. Besides longitudinal studies, intervention studies, looking at the impact of substantial changes in the local natural environment could help, although their generalisability is often also limited (Woolcock, 2022). Furthermore, knowledge on underlying processes and mechanisms may also help to determine the causality of observed associations between nature and human health and wellbeing. Although several plausible mechanisms have been identified, research on which process contributes how much to the association, thereby establishing its causality, is still scarce. To some extent, the most relevant processes are likely to differ by health outcome. Knowledge on processes is also likely to give indications of which type of green space, with which characteristics is likely to facilitate the process, and thereby yield the best positive health outcome. The importance of the type of vegetation is still very much an open question, which calls for future investigation. Moreover, research is warranted into unintended side effects, such as gentrification, that diminish the health returns of green space interventions.

In summary, the body of evidence on the health and wellbeing effects of green spaces in general, and forests and trees in particular, is accumulating. The available evidence already strongly supports a wide range of beneficial associations including neurodevelopment in children, mental health and wellbeing, spiritual wellbeing, and cardiometabolic health in adults and mental health and wellbeing, cognitive ageing, and longevity in the elderly. Moreover, the current evidence is suggestive for such a beneficial association for pregnancy outcomes and complications, cardiometabolic health in children and mental disorders in adults. These associations could vary across the strata of gender, ethnicity, culture, socio-economic status, urbanicity, and types and quality of green spaces and forests. Given that many of the aforementioned outcomes are among the major contributors of the global burden of disease, forests, trees and green spaces have a great potential for improving health and wellbeing of humans across all life stages in our rapidly urbanising world. This potential adds to the co-benefits that these spaces could exert through their other ecosystem services.

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4

Chapter 4

Forests for Human Health – Understanding the Contexts, Characteristics, Links to Other Benefits and Drivers of Change

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Abstract
This chapter presents the key relations between people and communities in different local and global contexts and different types of forests, trees and green spaces. The focus is on the interactions between forests and urban, rural and forest-dependent communities. Health outcomes related to forests, both at the individual and community level, can considerably differ between different types of forest contexts and communities, along a gradient of human landscape transformation that includes urban, rural, and forest-dependent settings. The chapter also discusses synergies and trade-offs between health outcomes of forests on the one hand, and other ecosystem services on the other. Synergies exist, for example, between regulation or cultural services (such as outdoor recreation or biodiversity targets, and health and wellbeing benefits of forests). However, there can also be important trade-offs leading to negative changes in health outcomes, such as those related to closing off forests to local communities or visitors for specific purposes or to changing forest type and structure for biomass production. Where synergies need to be enhanced and trade-offs limited, it is also important to understand direct and indirect threats, as well as drivers causing forest loss and degradation, as these impact the availability and capacity of forests to meet human health demands. Direct threats relate to, for example, economic threats such as agriculture and energy production and biophysical threats such as climate change and fires. Indirect threats such as cultural ones related to technology and increased consumption, need to be addressed as well, while governance and political drivers also have to be understood.

4.1 Introduction

The direct and indirect links between forest[5] ecosystems and human health and wellbeing are increasingly being understood. Health outcomes are provided by urban, peri-urban, rural and peripheral forests that may be preserved or managed in various ways to meet local and more distant needs. Forests are exposed to increasingly unfavourable environmental and climatic changes worldwide, as well as to anthropogenic pressures that affect both the capacity of forest ecosystems to sustain their complexity and resilience, and their capacity to provide for material and immaterial human needs. Although decision-makers at different levels acknowledge the role that forests play in contributing to the sustainable development goals (SDGs), the importance of forests for achieving health and wellbeing goals (SDG 3) are not yet sufficiently understood (Katila et al., 2019).

This chapter first explores the key relations that people and communities have with different types of forests and specific forest characteristics, as well as the human health impacts of forests in different local and global contexts. We focus on the interactions between forests and urban, rural and forest-dependent communities (see also Beatty et al., 2022). Whereas Chapter 3 focused on the impacts of forests on human health, this chapter explores the forest characteristics that contribute to health outcomes.

Forests globally develop under a variety of environmental and socio-economic conditions leading to very diverse forest ecosystem characteristics. This chapter includes a wider view of human-forest interactions in a global context, understanding that mechanisms and channels to deliver and perceive health and wellbeing benefits may vary significantly depending on where one is in the world. The chapter also discusses synergies and trade-offs between the health outcomes of forests and a range of other benefits and ecosystem services that are not yet comprehensively understood. In particular, the links between health benefits and various cultural, provisioning and regulating ecosystem services, as well as with biodiversity, are explored.

The final section of this chapter looks at key drivers that affect the loss and degradation of forests and forests' abilities to deliver human health outcomes. It discusses and describes the key land and forest use threats impacting human health including political, cultural and economic drivers impacting on forest management and transformation.

5 All terms that are defined in the glossary of this report (Appendix 1) appear in italics the first time they are mentioned.

4.2 Health Impacts of Forests in Different Contexts

4.2.1 Forest-health relations in urban, rural and forest-dependent contexts

Whilst all forests deliver a common suite of essential ecosystem services, they vary signifcantly in the diversity of species that they host and the relative magnitude of the different ecosystem services provided. In this section, the forest-human health relationships for three broad contexts will be explored along a gradient of human landscape transformation, namely from high transformation typical of urban contexts, intermediate in rural contexts and relatively low transformation for many (albeit not all) forest-dependent or proximate contexts (Figure 4.1). For each of these three contexts we broadly consider the forest and user attributes relevant to the nature and strength of the human health outcomes.

Urban Forests

Forest attributes

Urban forests may comprise only a few species and strata or be extremely species- and structurally-rich. Irrespective, the urban context often means that most, albeit not all, forests are subject to greater degrees of management and higher use pressures than those in protected areas or remote rural locations with limited human impact.

Increasingly, cities are seeking to secure or establish more urban forests as nature-based solutions to mitigate climate change and to improve microclimates, air quality and stormwater infiltration. Recent studies have shown that urban forests managed for recreational purposes can be structurally close to natural forests and may provide habitat features, such as dead wood, that are scarce in intensively managed forest landscapes (e.g., Korhonen et al., 2021). In addition to green urbanisation, the conservation of forests and agroforestry systems in peri-urban landscapes is strategic to achieving more sustainable cities. Peri-urban green areas regulate temperature, improve air quality, offer recreational space and, critically, promote landscape connectivity (Von Thaden et al., 2021).

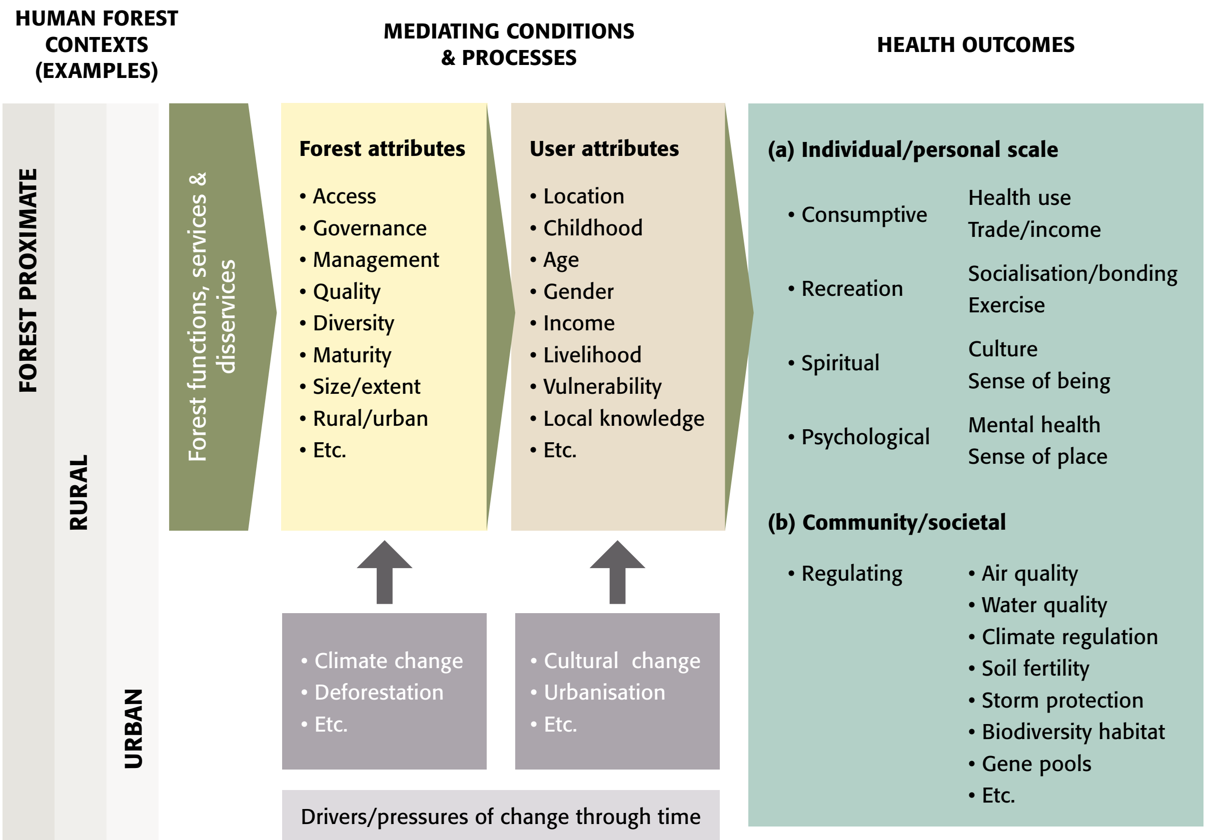
In an urban context, management goals may include recreational use or shade provision, and are measured using different metrics such as canopy cover, species richness, area of green space, to mention a few (Ordonez et al., 2019), although in resource poor settings there is generally little or no monitoring against goals (Chishalshale et al., 2015). Urban forests may be managed to enhance biodiversity, landscape values and forest vitality. They may also be managed to create and maintain attractive outdoor recreation environments and to improve urban areas, for example influencing microclimates and water infiltration (Tyrväinen et al., 2005). Other urban forests may receive relatively little active management, either by design or due to resource constraints. In contexts where use and management of rural forests for wood production is intensive, urban forests may act as biodiversity hotspots for some groups of species (Ives et al., 2016; Korhonen et al., 2021). Management goals and approaches also vary according to contextual factors such as tenure, governance, stewardship and available skills and resources.

In urban areas the growth conditions for forests and trees are often challenging. Most urban and peri-urban forests are subject to some degree to negative influences associated with the urban context leading to a decrease in forest or single tree vitality. These threats include heavy metal pollution, reduced populations of pollinators or dispersers, urban heat island effects as well as opening of the subcanopy for human access. In rapidly urbanising contexts, the danger of land transformation leading to forest loss or forest fragmentation can be more pronounced both in high- and low- income countries.

Studies have demonstrated that mental, social and physical health, and economic and ecological sustainability, correlate with the amount of green space in an urban neighbourhood. The flow of health benefits from urban forests is likely to be unevenly distributed within cities due to the uneven distribution of forest area, tree cover, species richness and even forest quality. The wealth status of households also influences the distribution and quality of, and access to, green space and forest, and consequently the benefits that they provide (Nero, 2017; Wüstemann et al., 2017; Riglon et al., 2018; Nesbitt et al., 2019; Venter et al., 2022). As green space benefits are reflected in property prices, high-income households are more likely to live in a green environment than low-income families, unless city planning takes these inequalities into account by providing adequate amounts of good quality green areas for all income classes (Tyrväinen et al., 2005; Escobedo et al., 2015). In wealthier countries efforts have been made to expand green space, and make its access more equitable (Loures et al., 2007; Marušáková and Sallmannshofer, 2019). In low- and middle-income countries, calls have been made for urban planners to better understand the diversity of ways

Figure 4.1

Interdependencies of forest-human health relationships in three human-forest contexts



residents interact with natural areas, which includes recognising that people view themselves as part of, not separate from, nature (Cocks et al., 2016; Cocks et al., 2020).

Furthermore, with the increasing frequency of severe heat, drought, flooding and storms, urban areas designed with adequate green space play critically important roles in mitigating negative environmental impacts and supporting human health (Russo and Cirella, 2018). Cities such as Copenhagen, use 'green fingers', that reach out from the city to the suburbs, allowing for broad access to green spaces (Brüel, 2012). In Singapore, urban planners are working to ensure that 80% of Singapore's residents live within 400 metres of a green space (Tng and Tan, 2012) and in China, an ambitious afforestation plan resulted in over 50 million trees being planted in Beijing and a 10% increase in overall forest cover (Yao et al., 2019).

User attributes

Urban forests cater to the needs of a diverse group of urban dwellers in terms of ages, genders, education, *local knowledge*, cultures, length of residency in urban settings and relationships with forests (Janowsky and Bekker, 2003; Shackleton and Blair, 2013; Aasetre et al., 2016). Most groups use urban forests for cultural ecosystem services, mainly for diverse recreation activities (such as exercise, relaxation, picnicking, family occasions, nature watching, etc.), although in some contexts there may be a high dependence on provisioning benefits (such as wild foods, traditional medicines, fuelwood) (McLain et al., 2013; Shackleton et al., 2017). Extent or frequency of use of public urban forests is mediated by relative ease of access, either physically or financially, as well as the quality of the green areas. Within private spaces, urban citizens may themselves maintain a diversity of elements associated with green spaces, ranging from a few plants in containers to structurally- and species-rich gardens (Loram et al., 2008; Bigirimana et al., 2012; Heezik et al., 2013).

Previous studies suggest that lower socio-economic status groups are more dependent on public green areas and therefore, may benefit more from them than high-income class residents (Ward Thompson et al., 2016; Triguero-Mas et al., 2017; Rigolon et al., 2021). In spite of efforts to offer equitable access to urban forests for different user groups, access is lower among minorities and poorer communities leading to lower exposure to these health-promoting environments (Rigolon et al., 2021). Women and men experience urban nature spaces differently as women often appreciate green areas more but also express greater safety concerns than men (e.g., Sreetheran and van den Bosch, 2014) that call for specific management actions such as maintaining good visibility and good lighting conditions in forests. There is also some evidence that women use nature more frequently than men, and seem to better appreciate the availability of, and possibility to connect with, nature (e.g. van den Berg, 2012; Neuvonen et al., 2022).

Urban forest attributes that contribute to health outcomes

There is a growing focus on understanding the ways in which specific elements of biodiversity itself matters for human health (Marselle et al., 2021b). The benefits of nature views, immersion and experiences, including of urban forests and trees on a range of mental health and wellbeing conditions and indicators – such as reduced anxiety, depression, fatigue, stress and tension resulting in improved mood and sense of restoration, wellbeing and happiness – may relate to specific forest attributes (Shanahan et al., 2015; Honold et al., 2016; Pataki et al., 2021). For example, there is some evidence of positive relationships between health outcomes and tree number (e.g., Townsend et al., 2016), tree cover (e.g., Egorov et al., 2017), and evergreen, as opposed to broadleaf, species (Gonçalves et al., 2021). A study in an urban setting in Italy found that self-rated wellbeing was greater in more biodiverse sites than less biodiverse ones (Carrus et al., 2015). Research in a low-income country context (in South Africa) found a positive relationship between tree species richness in school grounds and the pupils' rating of their ability to concentrate whilst at school (Shackleton et al., 2018).

Other important features of urban forests that impacts on health include their size (Lin et al., 2015) and connectivity, orientation and nature of the surrounding urban matrix (Lindén et al., 2016). All of these have an impact on the cooling effect of urban forests. Allied to this is the reduction in ill-effects from ultraviolet (UV) light radiation, with denser canopies having a greater effect in reducing UV radiation (Heisler et al., 2003).

Rural Forests

Forest attributes

Forests that rural communities benefit from, can be of different types, including savannah, dry forest, humid forest, mangrove, etc., depending on their geographical location and nature of transformation (e.g., agroforests). Different ownership and governance types will determine management objectives and practices, and access by rural communities. Management will also impact the structural and species diversity of the stand. Communities may enjoy the benefits from a single tree (e.g., when plant parts are used for medicinal purposes) or from many hectares of forests, when the health benefits are derived from the whole forest ecosystem as is the case for example, with recreational or spiritual uses of forests.

An important consideration influencing the health (and other) benefits from forests in rural landscapes is the extent of transformation and intensity of landscape management. In general, whilst there are many reasonably intact forests in rural locations, there are also many manifestations of managed trees in fields, agroforests and as boundary or perimeter markers between fields or parcels of land. Frequently, trees in such contexts have been planted or retained because of particular services that they provide to landowners and users. Some agroforests host numerous species and are structurally rich, although rarely as rich as intact forests (Scales and Marsden, 2008), providing multiple nutritional, medicinal, cultural and regulating services. Many agroforestry designs and practices are deeply embedded in local cultures and ecological knowledge and have ancient roots, such as the Satoyama forests in Japan (Katoh et al., 2009; Nishi et al., 2022), the home-gardens in Kerala, India (Mohan et al., 2007; George and Christopher, 2020), or the cultural parklands of West Africa (Assogbadjo et al., 2012).

User attributes

Rural forests cater mostly to the needs of rural households that extract a wide variety of products (wood and non-wood forest products) from nearby forests for their health, food, energy and other aspects of rural welfare (Mahapatra et al., 2005), as well as maintaining trees in fields and homesteads. In many rural settings, especially in low- and middle-income countries, use of wild and cultivated plant species underpins the health of all family members irrespective of gender and life cycle stage, including babies, children, mothers and adults (de Souza Silva et al., 2014; Torres-Avilez et al., 2016; Randrianarivony et al., 2017; Shaheen et al., 2017; Ahmed et al., 2018). Use of edible insects and their by-products for nutritional, health and livelihood benefits has been reported across different regions (Gahukar, 2020).

Rural households' reliance on forests and forest products is substantial because of their less diversified income (Wei et al., 2016; Sheppard et al., 2020) which makes them more vulnerable than urban households. Forest use is also influenced by remoteness from markets, government services, and other urban amenities, with correspondingly lower income and employment opportunities and with higher levels of poverty, and social and political marginalisation (Sunderlin et al., 2005; Belcher et al., 2015). Research also shows that, even within a group of rural households, local wealth conditions determine the demand for, and perceived importance of, forest ecosystem services (Ahammad et al., 2019). The role of rural women in the forests and health nexus as primary collectors and users of forest produce, and the need for integrating conservation and human health objectives have also been highlighted (Wan et al., 2011). The use of forests and forest products is positively linked to the *traditional knowledge* and cultural traditions that communities possess and this has a significant impact on forest conservation and sustainability. Indeed, the loss of local and indigenous knowledge (notably on the benefits and uses of forest products) is likely to reduce the motivation to manage these resources sustainably, thereby leading on the one hand, to a reduction in effective conservation of biodiversity, particularly in community-based conservation efforts, (Aswani et al., 2018; Fernández-Llamazares et al., 2021), and on the other hand, to negative impacts on health outcomes.

Rural forests may also be visited and used by urban people for recreation and tourism, providing income to rural enterprises both in low- and high-income countries while bringing direct wellbeing outcomes to urban visitors. In northern Europe, outdoor recreation surveys show that 76% to 91% of the adult population visit forests (both urban and rural) each year (Edwards et al., 2013). Regular visits to forests are shown to maintain and support human wellbeing (Tyrväinen et al., 2019). Furthermore, nature-based tourism is an important business sector, for example, in central and northern Europe and in the Americas. It has high potential globally in forest-rich countries where natural features of forests and forested landscapes have been well maintained (e.g., Tyrväinen et al., 2017a). Nature-based tourism firms are typically located in rural regions and provide a complement to more traditional resource uses such as farming and forestry, contributing to diversifying rural livelihoods and maintaining rural populations (Fredman et al., 2021). In addition to rural and urban forests, peri-urban forests, an 'intermediate' category, have also been shown to provide key ecosystem services (Livesley et al., 2016).

Rural forest attributes that contribute to health outcomes

Forests and trees that provide a source of food and medicine are both highly important in rural contexts. For instance, Tata et al. (2019) reported that plant foods from the forest may make important contributions to iron intake and reduce the risk of anaemia in women. A study undertaken in 35 countries found that forest cover is associated with reduced anaemia, stunting and diarrhoeal diseases in children, particularly for the poorest (Fisher et al., 2019; Beatty et al., 2022).

Dependence on medicinal plants may be very high in rural contexts. In India, for the years 2014-2015 for instance, of the total national demand for medicinal plants of 512,000 metric tonnes (MT), an estimated 167,500 MT was consumed by rural households, 90% of which was sourced from the wild (Goraya and Ved, 2017).

In rural settings, the location of forest cover may also determine the regulating services it can provide to rural households. For instance, forests in upper watersheds regulate water quality downstream with direct effects on health. Indeed, higher upstream tree cover was found to be associated with lower probability of diarrhoeal disease downstream (Herrera et al., 2017). Rural communities are more likely to be dependent on such regulating services for improved health outcomes than are urban populations, as healthcare facilities are often more readily available for the latter. Certain types of trees also regulate to a greater extent soil fertility (Hong et al., 2018; Bayala et al., 2019; Dierks et al., 2021) which is relevant to populations in rural contexts for agro-pastoral production which can represent a substantial part of rural livelihoods.

Forest-Dependent Communities

In this report we address forest-dependent communities separately from rural communities. According to Newton et al. (2016), the term 'forest-dependent people' is widely used to describe human populations that gain some form of benefits from forests. These authors call for users of the term 'forest-dependent people' to define their population of interest with reference to the context and purpose of their forest- and people-related objectives. In this section, we refer to forest-dependent communities or people as communities who 'rely more' (pronounced dependence) on forests than rural communities. This includes people living within or very close to the forest ('forest peoples') and, who are heavily dependent on forests, primarily for subsistence, for their livelihoods.

Forest attributes

The forest-dependent context is typically characterised by human interactions with forests and trees in a variety of settings, ranging from large expanses of forests, through to trees in fields and homesteads. In some cases, forests might be in their natural state. However, many expansive patches of forest are increasingly experiencing various local and external pressures that affect their extent, quality and the services they provide. Because forests in these contexts are larger and often less transformed than most urban or rural forests, they can be structurally and compositionally more diverse for the climatic region in which they are located, but this is locally variable. While in many cases forests for both forest-dependent and rural communities might be similar, their cultural uses differentiate them.

User attributes

Forest-dependent communities derive a substantial proportion of their livelihood needs from the forests in which they live or reside. This 'dependence' means reliance on forests in a manner that is either difficult or impossible to replace, for a portion of environmental services, subsistence needs, safety net and gap filler functions, and opportunities for poverty elimination (Sunderlin et al., 2005). It also fulfils the literal sense of 'dependence', that their condition would worsen if they no longer had access to the forest outputs that form an integral part of their livelihood systems (Somorin, 2010). They exist around the world but are mostly found in low-income countries. Their needs may be directly consumptive or for income, as well as for culture and identity (Scherr et al., 2003; Newton et al., 2016). For instance, approximately 1.6 billion people globally are estimated to be dependent on forests or *non-timber forest products* (NTFPs) for their livelihoods (FAO, 2001).

Numerous factors influence the extent of reliance on forests and consequently associated health impacts, including biocultural diversity, tradition, gender, socio-economic status, age, family size, indigeneity, longevity in a region and proximity to forest (Laird et al., 2011; Aung et al., 2014; Shanley et al., 2015; Nguyen et al., 2019). For example, in Viet Nam, Nguyen et al. (2019) found that NTFP use increased with household size and age of household heads, and decreased with education level and land area, and that Indigenous people in the area consumed a larger number and diversity of NTFPs than immigrants to the region. A study in the mountainous areas of Cameroon also found that, while both migrant and Indigenous households rely on forest as a complement to farm income, Indigenous forest-dependent households do this to a far greater extent and derive roughly four times the income from wild and native species compared to migrants (Laird et al., 2007; Laird et al., 2011).

Attributes of forests that contribute to health outcomes among forest-dependent communities

Forests are a source of many important medicinal plants, which are the foundation of primary healthcare for the majority of people in many low- and middle-income countries (WHO, 2002), especially in forest-dependent communities due to their lifestyles (Rahman et al., 2022).

Forest-dependent communities recognise many individual species as well as sites within the forest as having cultural or spiritual significance. Specific species are required for particular traditions or rituals and non-adherence or observance of taboos and rituals typically results in 'misfortune' and hence negative mental wellbeing (Posey, 1999; Cocks et al., 2012). The same negative effects may result from degradation of the forest or loss of certain species.

4.2.2 Forest attributes and characteristics in delivering health benefits

A vast diversity of factors affect the health and wellbeing outcomes of forests, including accessibility, size and density, diversity, forest type, age, species composition and biodiversity (Tyrväinen et al., 2007). The wide range of forest ecosystem services that support human health directly and indirectly, their relative importance for human health and the key pathways for delivery can vary substantially in different global (and local) contexts.

Accessibility

In high-income and urbanised areas, access to forests is often linked to proximity and usability of forests for recreational purposes. Access in different countries and regions is regulated by different policies and practices varying from free access to all undeveloped land such as in Nordic and Baltic countries, to restricted access to forests, as is the case in the United States (Pröbstl et al., 2008). In rural and peripheral areas, forest access may be largely linked to ownership that also regulates use of various forest products (e.g., timber, NWFPs, forest foods etc.).

Urban users often appreciate recreational infrastructure such as trails and signposts or other on-site facilities, as well as maps and other information about the forest. Planned forest access and use also help to prevent negative ecological effects from use or conflicts between user groups (Bell et al., 2008).

Although in theory people may have access to many forests, often a range of barriers may prevent them from visiting or using these spaces (Weldon et al., 2007). These include, for example, lack of suitable public transport, poorly maintained and signposted footpaths making it difficult for people to find their way, and the perception of risks or safety.

Size and density

The larger the size of the forested area the more beneficial it is on wellbeing and cognitive performance. Research demonstrates that generally larger green spaces, either parks or urban woodlands, have stronger positive impacts on these measures than small parks (e.g., Tyrväinen et al., 2014b; Akpinar, 2016). In Philadelphia, an increase in urban tree canopy to 30% was found to prevent 403 premature deaths annually while the implementation of Barcelona's Superblock programme – which converts streets to green walking areas – could prevent 667 premature deaths annually (Kondo et al., 2020; Mueller et al., 2020). Schäffer et al. (2020) conclude in their study in Switzerland that more vegetation is associated with lower sensitivity to noise from road and rail traffic.

The size of the urban park/forest has a considerable impact on cooling and buffering of the urban heat island effect. Whilst the general effects might be an average of only 1–3°C difference, the benefits are starkly evident during heatwaves when the risks of heat stress and stroke are severely heightened. The distance to which any cooling effect is felt is proportional to the size of the urban forest patch (Lin et al., 2015) and several other factors such as connectivity, orientation and nature of the surrounding urban matrix (Lindén et al., 2016).

Allied to this is the reduction in ill-effects in UV radiation, probably most marked in the tropics, but there is little research from those regions. Denser canopies have a greater effect in reducing UV radiation (Heisler et al., 2003).

Diversity

A number of recent studies have stressed the importance of a highly ecologically diverse environment for the optimal functioning of the human immune system. One of the most prominent theories related to this is the biodiversity hypothesis stating that "contact with natural environments enriches the human microbiome, promotes immune balance and protects from allergy and inflammatory disorders" (Haahtela, 2019). Previous studies report that a more diverse environment is correlated with a rich human microbiome (Hanski et al., 2012), and lower risk of allergies (Haahtela et al., 2013).

Perceived environmental qualities, such as the attractiveness of the landscape, natural soundscapes, species richness and cultural features have been positively associated with increased use of forests for physical activity (Björk et al., 2008). Moreover, soundscapes and auditive characteristics of forests, together with visual aspects, influence the health promoting ability of forests. Natural sounds have limited potential to mask disturbing sounds, however, birdsong, for example, is perceived as relaxing in itself and acts as an indicator of intact, nearby nature (Ratcliffe et al., 2013; Renterghem, 2019).

Types of forests

There is limited evidence based on field experiments or other studies examining how different types of forests or green spaces support mental health, although some studies are available (see Tyrväinen et al., 2014b; Ojala et al., 2019) and even less field studies have compared the wellbeing effects of different forests (see Martens et al., 2011; Sonntag-Öström et al., 2014; Takayama et al., 2017). Nevertheless, the variation in the effects on psychological wellbeing and restorativeness between different forest types (e.g., pine forest versus mixed forest, large urban parks versus extensively managed urban woodland) has been supported by some studies (Sonntag-Öström et al., 2014; Tyrväinen et al., 2014a). Care must be taken when comparing the study results, as the understanding of the level of naturalness may vary significantly in different contexts.

Age

Age of forests is also a factor affecting the perceived or real health benefits of forests. A recent study in Finland showed that older forests have stronger restorative effects compared with younger forests (Simkin et al., 2020). In the above-mentioned study, the three older forests were natural spruce stands managed for recreation, wood production or biodiversity conservation. Edwards et al. (2010) found that mature forests contribute to the wellbeing of visitors as long as they show a certain degree of openness. This is consistent with the recently

Timber from the surrounding forests ready to be transported away in Para, Brazil
Photo © Nelson Grima

planned network of old growth forests for human health in Spain, the recreational effects occurring in nature reserves and the idea of wilderness therapy (Menton-Enderlin and Schraml, 2017). The demand for a wide view and large crowns is usually satisfied in older forest stands without dense undergrowth.

Species

Tree species vary in their absorptive capacity for air pollutants (e.g., Nowak et al., 2014), with coniferous species rating higher than broad-leafed species (Zhang et al., 2017). A more specific feature of forests with effect on the immune function is the role of phytoncides. These are volatile organic compounds that have been studied most extensively in Asian and Mediterranean forests and, that have been found to positively influence the activity and percentage of natural killer cells (Li et al., 2009; Albert Bach et al., 2021). The concentration of phytoncides in the forest air depends on tree species and differs largely between countries and regions of the world. The false cypress, for example is found to emit a comparably high concentration of phytoncides.

Biodiversity

Biodiversity includes a myriad of pollinators that are vital to global agriculture, fruit trees, forests and all food systems (CBD and WHO, 2015). It is the basis of adaptation and resilience in all species, which is critical in light of climate change. Biodiversity is also the source of a wide diversity of medicinal plants and fungi, hundreds of nutrient-dense forest and traditional smallholder foods and, linked with cultural diversity, is the foundation of our unique relationships with place, and spiritual and mental health (Posey, 1999; Cocks et al., 2016). For example, forest-derived medicines are prominent in Indigenous health care systems. Many of the drugs upon which Western medicine depends are derived from forest plants and were discovered as part of the traditional health systems of forest peoples (Fabricant and Farnsworth, 2001).

Research has demonstrated some positive relations between biodiversity and human health, but the research evidence is still somewhat limited. An influential report by the Harvard Medical School highlighted the overall importance of biodiversity to human health (Chivian, 2002), mentioning for example, the importance of medicinal plant provision, ecosystem disturbance and the potential spread of human infectious diseases and food production. In a joint report, the Convention on Biological Diversity (CBD) and the World Health Organization (WHO) also stressed the important inter-linkages between biodiversity, ecosystem stability and epidemic infectious diseases such as the Ebola virus; and the connection between biodiversity, nutritional diversity and health (CBD and WHO, 2015).

At a forest site level, there can also be important synergies between biodiversity and human health. The presence of a diverse vegetation and of wildlife can enhance the recreational experience and serve as an attraction. In their review, Aerts et al. (2018) found evidence for positive associations between species diversity and wellbeing (psychological and physical) and between ecosystem diversity and immune system regulation. Marselle et al. (2021a) also mentions these positive associations, outlining different pathways that link biodiversity to health. As an example of individual studies that looked into this, Hedblom et al. (2014) concluded that the presence of (diverse) birdsong influences young people's appreciation of urban landscapes. Curtin's (2009) ethnographic study of wildlife tourism shows the health benefits of wildlife encounters, inspiring positive feelings of connection with other beings, awe and contemplation.

Furthermore, several studies demonstrate that forest attributes and characteristics, for example, habitat diversity and the biodiversity, multi-structure and multi-functionality of forests influence the abundance and value creation of NTFPs. A study in the Brazilian Amazon showed that recreational ecosystem services are helping to complement the benefits from NTFP extraction, and thus maintain biodiverse forests (Ribeiro et al., 2018). A study in the northern periphery of the Boumba-Bek National Park in Southeast Cameroon, demonstrated that habitat fragmentation driven by human activities such as industrial logging and shifting cultivation, destroys the forest ecosystem and has a strong influence on the sustainability of the major NTFPs in the locality (Ngansop et al., 2019). On the other hand, a study in Burkina Faso found that the local oil tree occurrence showed significant differences between land cover types and sites, but the oil tree seemed fairly resilient to human pressure and tended to recolonise disturbed lands (Lankoandé et al., 2017).

In spite of substantial knowledge gaps, it is clear that forest loss and degradation, and associated biodiversity loss, can be a major threat to human health, for example because of proliferation of zoonotic diseases (with COVID-19 as a recent example), loss of food sources and reduced ecosystem stability. Smith (2022) calls for close integration of biosecurity concerns into conservation policies, which requires greater acknowledgment of the unique challenges for human communities.

4.2.3 Forest management and health outcomes

Forest management targets are often dominated by timber production and intensive management may decrease forests' qualities for health and wellbeing. Poor management and logging practices can undermine biodiversity and environmental services upon which human health depends. The health impacts of different forest management activities such as thinning may vary, although there are few studies in different settings and cultural contexts. Chiang et al. (2017) found that a dense forest is better suited for attention restoration effects while Martens et al. (2011) reported on more positive impacts of tended forest compared to a wild forest with denser vegetation. Similarly, increased stand density and shrubs influenced negatively the perception of the psychological benefits from forest visits (Tomao et al., 2018; Kim et al., 2021).

As studies on health effects related to the different management regimes are limited, useful information can be obtained from forest landscape preference studies that have explored which types of forest environment people appreciate and prefer to visit. These studies conclude that people appreciate mature forests with good visibility, some undergrowth and a green field layer with no signs of soil preparation (Stoltz et al., 2016; Tyrväinen et al., 2017b). A forest after clear-felling is the least preferred environment (e.g., Gundersen and Frivold, 2008; Kearney and Bradley, 2011). The relatively low tolerance by recreational forest users of unmanaged understories, or dead or decaying wood, can also be the result of decreased feelings of safety, visibility and walkability of forests (Tyrväinen et al., 2003; Gundersen et al., 2017). Forests that are thought to be in their natural state, or that look natural and bear no visible trace of human activity, are usually preferred as long as there is little dead wood.

Some forest management activities are often needed to improve visibility, walkability and bring light to forest scenery as well as to reduce the amount of dead wood. Once visitors understand the value of dead wood for nature conservation, they are better able to appreciate it and it can even improve their nature experience (Bröderbauer, 2015).

It is challenging to manage highly-used forests to ensure safety, at least along paths, whilst making them look well-tended but still close-to-nature (Bell et al., 2008). Preference studies suggest that often light silvicultural management of forests increases their recreational value and also their health benefits. Amenity values may, however, often be understated in forest management, even in urban and peri-urban forests where use intensities are the highest. Moreover, rural forests deliver significant wellbeing effects through nature-based tourism or provision of NTFPs.

In rural areas logging can provide many benefits to people, including construction materials, shelter, fuelwood, and household items of critical importance around the world. In Europe, for example, the goals and motivations of forest owners to manage their forests vary substantially, depending on forest size, their connection to their property, preferences regarding economic, environmental and social values, and their flexibility to respond to market trends (Weiss et al., 2019). In some countries, such as those of central Europe, forests are often managed for multiple purposes, including the provision of environmental services, including erosion control and water management, together with landscape and recreational values, while in southern Europe an important management goal is forest fire prevention (Weiss et al., 2021). Natural, or well-managed, forests mitigate risks from flooding, storms, drought, extreme temperatures, landslides and wildfires (Beatty et al., 2022).

4.2.4 Disservices of Forests for Human Health

The ecosystem disservice concept has been introduced recently reflecting negative effects of ecosystems on human wellbeing or health (Shackleton et al., 2016). Although criticised (Schaubroeck, 2017), the concept of ecosystem disservices is useful to highlight the trade-off between an ecosystem service and one component of human health (Dunn, 2010), for example the pollination service and the allergic reaction to pollen. An ecosystem disservice for health can be the climate regulation service of afforested and reforested areas that may also enhance disease outbreaks. A global study has found an association between conversion mostly to monoculture plantations of commodities such as oil palm, and the increase of both zoonotic and vector-borne diseases (Morand and Lajaunie, 2021).

Biodiversity can also conflict with the health benefits of forests. Some studies have indicated that high diversity (understood as dense forests) can negatively impact wellbeing (e.g., Kim et al., 2021). For example, pests and pathogens that inhabit forests represent the ecosystem health disservices related to biodiversity. Aerts et al. (2018) found high species diversity to be associated with both reduced and increased vector-borne disease risk. Tick-borne diseases such as Lyme's disease and tick-borne encephalitis (Tomalak et al., 2010), but also mosquito-borne diseases such as dengue fever, are increasingly seen as a barrier to forest recreation across the world (e.g., van Gestel et al., 2021). The rise in numbers of these diseases is partly linked to climate change and partly to disturbance of forest ecosystems that boost the multiplication of some species. Other forest-associated diseases include malaria, Chagas disease, African trypanosomiasis (sleeping sickness), leishmaniasis and lymphatic filariasis (FAO, 2020). Some outbreaks of infectious diseases are assumed to be linked to biodiversity loss (Smith et al., 2014) which is related to forest loss and degradation. Moro et al. (2009) discuss the potential risks of nature recreation pertaining to especially snake bites. Limited understanding of citizens regarding the importance of biodiversity may decrease acceptability of management actions that enhance biodiversity.

4.3 Valuation of Health Benefits of Forests

The previous sections have linked forests in different contexts, as well as a range of forest attributes and characteristics, to health outcomes. Valuation is another important aspect of understanding and promoting the health benefits of forests. While market values exist in certain areas for some NTFPs that contribute to health, such as wild meat, plants or medicines, many other health-specific ecosystem services of forests have no tradeable market, such as water purification, disease regulation and various cultural benefits. Cultural services such as traditional importance to native groups, cognitive development, and spiritual enrichment are less common in the literature than, for example, provisioning or regulating services (Mandle et al., 2020). Due to this, these ecosystem services have often been excluded from cost-benefit calculations, for example, around conservation, which can lead to underestimation of forests' values.

In recent years, more studies have attempted to estimate these values through stated and revealed preference methods which can be costly and time consuming. Some valuation methods have been found to be better suited to certain ecosystem services than others (Ferraro et al., 2012; Taye et al., 2021). Water regulation and provisioning are often considered outside of the NTFP category and relatively few valuation studies have focused solely on these services (Lele, 2009; Ojea et al., 2012). Air improvement and carbon sequestration have seen an increase in the valuation literature in recent years due to public discussions of carbon emissions' implications for climate change and human health. In one study on the contiguous USA, health benefits from removed air pollution by trees and forests were valued at around USD 6.8 billion in 2010, while another study on Canadian national parks found that they sequester 4.43 gigatonnes of carbon with an annual value of approximately USD 107-116 billion (Kulshreshtha et al., 2000; Nowak et al., 2014).

Disease regulation, another less frequently mentioned ecosystem service, is typically discussed within the context of land use change and water purification for forests (Pattanayak and Wendland, 2007; Pattanayak and Yasuoka, 2008). One study in Indonesia estimated that there would be approximately 2,600 less cases of diarrhoea a year due to ecosystem services from Ruteng Park in Indonesia, for a total cost decrease of USD 5,900 (in 1985 terms) (Lerman et al., 1985; Pattanayak and Wendland, 2007).

Several studies examine the value of trail use and recognise the physical health benefits of green spaces, yet significantly less studies have explicitly examined the valuation of health and well-being benefits (Wolf et al., 2015; Wolf and Robbins, 2015; Moseley et al., 2018). Two recent studies that controlled for socio-economic factors found that health care spending is lower for people living in greener spaces. A study in northern California found health spending to be USD 374 lower in the greenest versus least green areas, while another study in the USA found spending was USD 632 less in areas for each 0.1 Normalised Difference Vegetation Index (NDVI) increase (Becker and Browning, 2021; Eeden et al., 2022).

Forest recreation values have been studied both in Europe and the USA. Studies valuing the recreational use of forests, for example, in Finland, include both revealed preference (travel cost

The recreational values and physcial health benefits of forests are increasingly recognised, particularly in high income countries
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and property value methods) and stated preference (contingent valuation and choice experiment methods). Studies have focused on the valuation of urban recreational areas (Ovaskainen et al., 2012), national parks or national hiking areas (Huhtala and Pouta, 2009), and recreational benefits at a national level (Lankia et al., 2015). Research has also been carried out on valuing forest attributes such as scenery and species richness in municipal recreation sites (Horne et al., 2005) and measuring tourists' willingness to pay for improved landscape and biodiversity characteristics in nature-based tourism areas through *payments for ecosystem services (PES)* (Tyrväinen et al., 2014a).

In general, economic valuations of public health interventions can aid decision-making on the efficient allocation of resources aimed at improving public health in the face of fixed budgets.

4.4 Synergies and Trade-Offs Between Health and Other Forest Ecosystem Services

4.4.1 Synergies and trade-offs between forest health benefits and cultural ecosystem services

Many health benefits of forests relate to forest recreation and tourism. Urban forests provide opportunities for everyday recreation, physical activity, mental restoration and social meeting places. Rural forests can be important destinations for both day recreation and for tourism. Forests also provide other cultural ecosystem services including spirituality, aesthetic and educational services (MEA, 2005; Figure 4.2.).

In many cases, health and cultural services go together. Aesthetics, spirituality, sense of place and educational experiences can all be related to, and promote, forest recreation and tourism, and enhance the recreational experience of forests. Although synergies between health outcomes and cultural ecosystem services provided by forests and trees are common, there can also be trade-offs that need to be understood and managed (e.g., Dobbs et al., 2014). It may also be that the demand for the range of cultural services is not adequately known and therefore, not included as a key forest management target (Tyrväinen et al., 2017a; Cheng et al., 2021). As these services are often regional- and individual-specific as well as influenced by local human – ecosystem relationships, demand surveys and other social science tools are needed to ensure that these services are incorporated into planning and management objectives (Riechers et al., 2016; Hegetschweiler et al., 2017). In some European countries, NTFPs such as herbs and medicinal plants have important cultural and socio-economic meanings (e.g., Guarrera and Savo, 2016; Sisak et al., 2016). Forests and other wooded lands are of outstanding importance for a range of non-wood and cultural ecosystem services, but use regulations are common features in many countries thereby limiting access (Tyrväinen et al., 2017a). The prevalence of self-treatment with medicinal plants in rural populations can also be influenced by other attributes, including traditional knowledge, cultural traditions and education (Thorsen and Pouliot, 2016; Aswani et al., 2018).

A first area of (potential) trade-offs is within the recreational use of forests, as different types of forest recreation conflict with and even exclude one another. This can result in some people obtaining health benefits through recreational activities associated with forests, trees and green spaces, at the expense of other users. Confer et al. (2005) offer an overview and typology of outdoor recreation conflicts. They mention that conflicts often arise between local populations (with their own recreational or other landscape uses) and visitors. Often conflicts emerge between more active forms of recreation that have a high 'footprint' (e.g., mountain biking, or motorised activities that create noise and nuisances) with recreation that is more centred on for example, nature experience (e.g., hiking, wildlife viewing). In their European report, Bell et al. (2007) found that conflicts between different types of forest recreation are most likely to occur in more densely populated areas with limited forest areas (e.g., in urban areas, but also in densely populated countries).

Problems within forest recreation and tourism also relate to groups being (or feeling) excluded from forests. This can relate to lack of availability or proximity of forests, lack of access, exclusion and fear for example in relation to other user groups, but also lack of knowledge, adequate skills and awareness (e.g., Sreetheran and Konijnendijk van den Bosch, 2014). Byrne (2012) studied the case of an urban national park in the Los Angeles, USA, area. Many urban dwellers of Latin American heritage refrained from recreation in the park because of the "predominantly White clientele of parks; (..) a lack of Spanish-language signs, fears of persecution; and direct experiences of discrimination". White et al. (2013) highlight that relations between Indigenous communities and ecotourism are very complex. Although these communities can benefit from ecotourism, there are also risks of exclusion.

Some forms of health benefits (e.g., related to mental health) will benefit more from silent and serene environments, as well as opportunities for solitude or activities performed in small groups.

These include, for example, hiking, bird watching and other activities in which finding peace and nature experiences are valued (Haukeland et al., 2021). The experience of the serene can be closely linked to spirituality, as for example reflected in the Japanese 'Shinrin-yoku' (forest bathing) concept (Hansen and Jones, 2020). More active and noisy forms of recreation (e.g., motorised sports or activities in larger groups) can negatively affect spiritual experiences, which results in trade-offs between users seeking recreational and health benefits, and those seeking more spiritual and health benefits.

Spiritual values, sense of place and religious values of forests can also be connected to forest groves. These can have high cultural values for local communities, including rural and forest-dependent ones. In some cases, these groves are closed off for other people, implying that their recreational and health benefits are not fully realised. On the other hand, opening up these groves for wider use can threaten the benefits to the local community. Sacred natural sites are primarily protected by communities for their spiritual or cultural value, but may be additionally valued and used for other social, economic and ecological reasons, resulting in different forms and intensities of social conflict and unfavourable human impact on sacred sites (Rutte, 2011; Cogging and Chen, 2022).

The recreational and touristic use of forests, which can be pathways towards better health, can have a negative impact on biodiversity, for example through disturbance of wildlife, trampling of vegetation and the like (e.g., Marzano and Dandy, 2012). Although urban and peri-urban forests served as a critical infrastructure for adaptation and stress relief during the COVID-19 pandemic, in many instances the overcrowding of most popular sites surpassed in their social carrying capacity and may have had negative impacts on ecological values (Geng et al., 2021; Neuvonen et al., 2022). The lessons learnt from the COVID-19 pandemic suggest that areas that provide multiple ecosystem services for people are at the same time of ecological importance. These multifunctional sites enable simultaneous biodiversity conservation and wellbeing outcomes (Andersson et al., 2014; Fagerholm et al., 2021).

Where biodiversity conservation is prioritised, for example by means of establishing protected areas such as nature reserves, this can lead to the (partial) closing off of forest areas to recreation and tourism, but also to other health-promoting forest uses (e.g., gathering of food and medicinal plants, spiritual use; Thomas and Reed, 2019). Where the demand for recreational opportunities is the highest, for example in urban areas, this can lead to a major loss in terms of health benefits, especially as available forests and green spaces are often more limited.

4.4.2 Synergies and trade-offs between health benefits and provisioning services

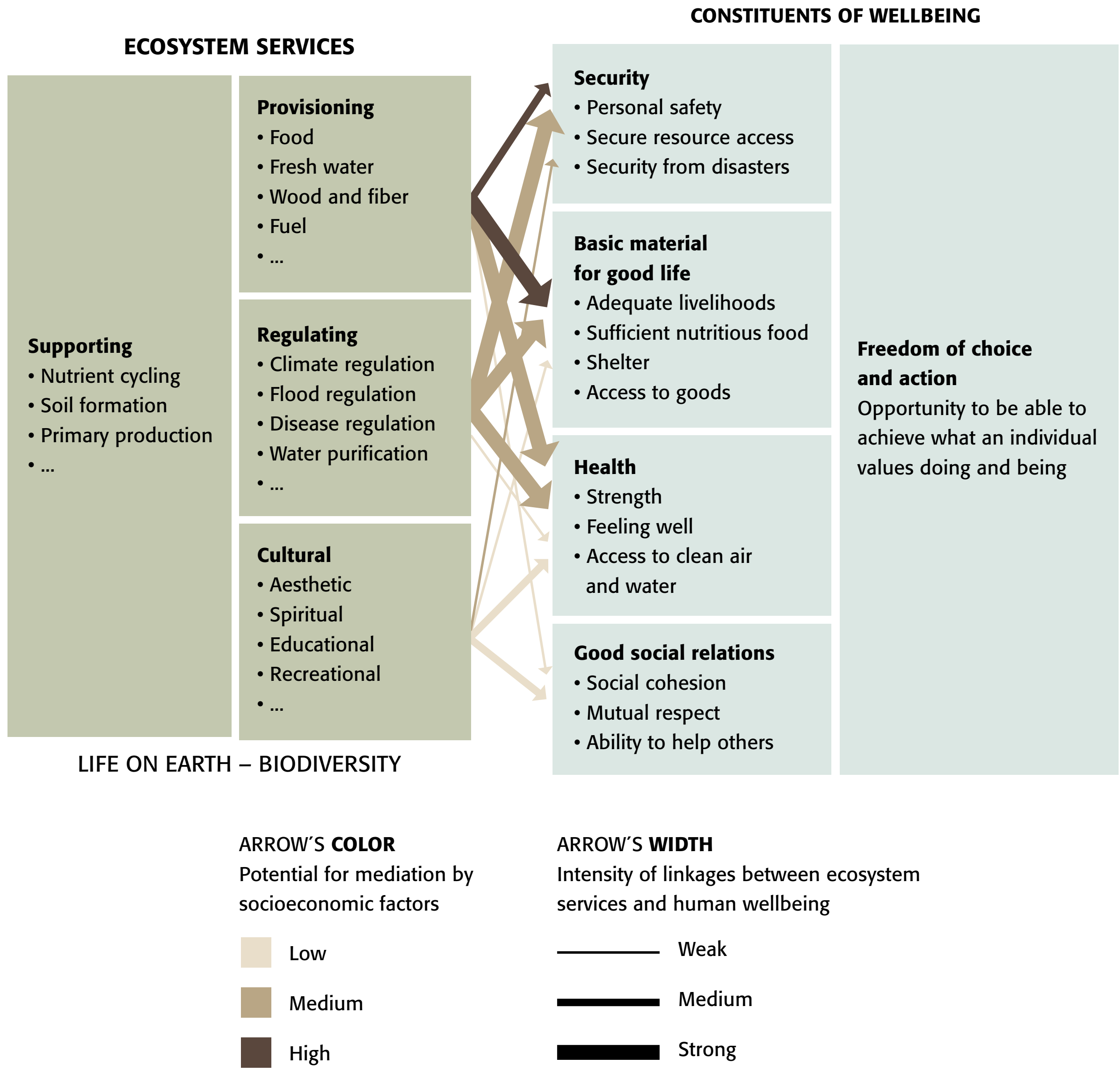
Provisioning services are the tangible resources or goods that people obtain from ecosystems. These services can be grouped into five types: food; fodder; timber and fibre (for construction and energy); chemical and medicinal products; and fresh water (MEA, 2005). Biodiverse forests provide a vast range of plants and animals with nutritional and medicinal values. They are of local importance and also commercialised on national and international markets. In Europe, NTFPs such as game, mushrooms or berries provide values – beyond supplying food – that are related to recreation benefits, sense of place, culture, education and traditional knowledge. A large variety of game (38 species), mushrooms (27 species) and vascular plants (81 species) is collected and consumed in member states of the European Union (EU). Overall, more than 100 million EU citizens consume wild food (Schulp et al., 2014). Wild foods, particularly wild game and other forest products, are also commonly consumed in North America (Chamberlain et al., 2018). Use regulations and limited access are, however, common features in many countries (Schulp et al., 2014).

The provisioning services of biomass and timber production can have positive health impacts (e.g., contributing to livelihoods) but also negative impacts when forests become less attractive for recreation or are closed off to local communities. In particular, intensive wood (biomass) production and forest management (e.g., clear cuts, shortened rotation cycles and large management units) negatively influence the recreational quality of forests (and the associated health-related impacts of nature visitation) and the business opportunities of nature-based tourism companies.

Peri-urban areas can also be a source of nutritious wild and semi-domesticated forest products including fruits, fungi, nuts and game (Russo and Escobedo, 2022). Due to their proximity to urban markets, peri-urban areas offer market opportunities and can catalyse smallholders to experiment with innovative management strategies, increasing the density of nutritious fruits and valuable forest goods, offering critical sources of income to smallholders, while facilitating the transmission of traditional knowledge linked with culturally valued forest goods (Brondízio et al., 2021).

Figure **4.2**

Ecosystem services and links to human wellbeing



Source: MEA, 2005

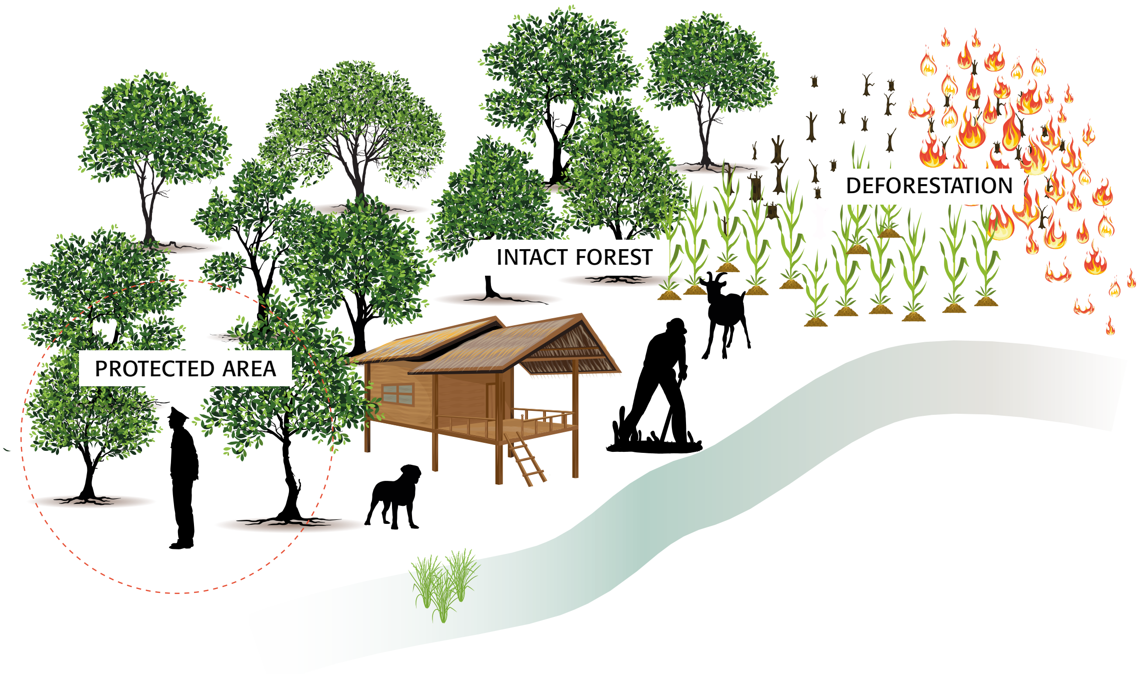
4.4.3 Synergies and trade-offs between health benefits and regulating ecosystem services

Disease regulation appears in the classification of ecosystem services as a regulating ecosystem service (MEA, 2005). Conflicting results emerge from studies on disease regulation (Cardinale et al., 2012), which can be explained by the few studies focusing on human diseases compared to studies on other regulating services such as climate. The protective role of biodiversity against infectious diseases has been put into question (Lafferty and Wood, 2013) by the fact that the diversity of human pathogens is linked to the species diversity of birds and mammals, and that species-rich and forested countries host high diversities of human pathogens (Dunn et al., 2010). On the other hand, the role of biodiversity in protecting from diseases via the 'dilution effect' has been acknowledged. The dilution effect, or the 'negative diversity-disease', postulates that biodiversity losses may promote disease transmission (Keesing et al., 2006). A recent meta-analysis (Magnusson et al., 2020) gives support to the dilution effect by showing a significant negative diversity–disease relationship across spatial scales from global to small sites.

Analyses done at country level show that the number of outbreaks of infectious diseases, taking into account the diversity of known diseases, appears to be linked with biodiversity loss (Smith et al., 2014; Morand, 2020). For example, deforestation in Cambodia was found to be associated with an increased incidence of diarrhoea, fever and acute respiratory infection in children, while protected area coverage was associated with decreased incidences of these diseases (Pienkowski et al., 2017). Suggested mechanisms underlying the association between forest destruction and childhood diseases include reduced ability of degraded forests to regulate microbial contamination of surface and ground waters, leading to increases in diarrhoeal diseases, and smoke from biomass burning (which accompanies deforestation) exacerbating respiratory illnesses.

Figure **4.3**

Examples of potential links between protected areas, forest cover, deforestation and health



PROTECTED AREA	INTACT FOREST	DEFORESTATION
+) Safeguarding hydrological services that regulate microbial load, reduce flooding, and increase groundwater recharge, suppressing diarrhoea risk +) Restriction of human-wildlife contact, reducing risk of zoonotic disease transmission +) Amelioration of air pollution, restriction of access to domestic biomass fuel, and management of fire occurrence, reducing risk of acute respiratory infection +) Formalisation of sustainable access to natural resources within multiuse protected areas, which could stabilize access to forest products important for health	+) Diverse host communities mitigate disease risk in individual species (the dilution effect) +) Provision of products, such as food and medicine, important for health +) Provision of social and cultural functions, such as recreation, that support mental, social, and physiological health +) Predator populations might suppress vector abundance, regulating disease risk	+) Income from extractive activities, new employment opportunities, and agriculture, which can improve diets, and access to health care, and buffer against environmental risks +) Increase in dietary quality from agriculture in some cases +) Can be associated with the expansion of other industrial activities, which might reduce some disease risks

- Restriction of access to forest products from strict protected areas, such as food and medicine, important for health
- Crop raiding by wild animals could potentially reduce agricultural yields, exacerbating malnutrition, and increasing disease risk
- Zoonosis from high populations of wild animals transgressing park boundaries
- Increased exposure to zoonotic diseases among protected area staff and visitors+)

- Supporting forest-dependent hosts and vectors, harbouring emerging infectious diseases, or maintaining disease reservoirs
- Zoonoses from human wildlife contact during forest product harvesting and processing
- Forests can be associated with socioeconomic contexts, such as restricted access to health care and economic opportunities that perpetuate poverty – a strong predictor of health outcomes

- Smoke from fires containing fire particulate matter increases the risk of acute respiratory infection
- Loss of dietary diversity and quality of forest foods, impairing the immune system and increasing disease vulnerability
- Increased run-off, increasing microbial load and diarrhoea risk from surface water
- New biophysical conditions suitable for some vector and disease species
- Changing human behaviour, such as guarding crops at night, increasing disease exposure
- Might be associated with the expansion of other industrial activities posing novel health risks
- Habitat encroachment and stressed host populations might increase emerging infectious diseases risk

Source: Pienkowski et al., 2017

Defaunation is the global or local extinction of animal populations from ecological communities that can negatively affect ecosystem services (e.g., soil functioning, pollination, pest control, water quality) (Dirzo et al., 2014). The resulting 'empty forest' (Redford, 1992; Benitez-Lopez et al., 2019) may enhance the loss of disease-regulating services. Defaunation contributes to the loss of ecological regulation of small mammals, which are the main reservoirs of several zoonotic diseases (Johnson et al., 2020). Gibb et al. (2020) demonstrate how global land use changes, including forest conversion, may favour zoonotic reservoirs and the risks of zoonotic diseases.

Forests fulfil other regulatory ecosystem services that are strongly related to health, such as providing or protecting sources of clean drinking water (e.g., Dudley and Stolton, 2003). Many of the world's cities derive their drinking water from forests and other protected areas, and in some cases, cities have even owned and managed more remote forests to ensure a safe supply of drinking water, as in the case of the Vienna water source protection forests (Dudley and Stolton, 2003; Richards et al., 2012). Drinking water protection and provision thus should be an important consideration in land use planning, and it can perhaps inspire the wider consideration of health benefits of forests. Although clean water is essential to health, the closing off of reservoir and watershed forests can limit other health benefits obtained through for example, forest recreation or the livelihood uses by forest-dependent populations.

Carbon sequestration and air filtration represent important ecosystem services that may lead to synergies and trade-offs with health outcomes. Increasing forest and forest canopy cover can be beneficial for carbon storage, air pollution reduction and human health (e.g., Lave and Seskin (2011) and Nowak et al. (2014) specifically for urban (forest) contexts). However, focusing on for example, specific tree species that optimise carbon storage and/or air pollution reduction could potentially result in negative impacts on other aspects of human health (e.g., monocultures with lower recreational values (Filyushkina et al., 2017) or selection of trees that produce more pollen (Sousa-Silva et al., 2021).

4.5 Threats and Drivers Causing Deforestation, Tree Cover Loss and Forest Degradation, with Implications For Human Health

4.5.1 Rate and extent of deforestation, tree cover loss and forest degradation

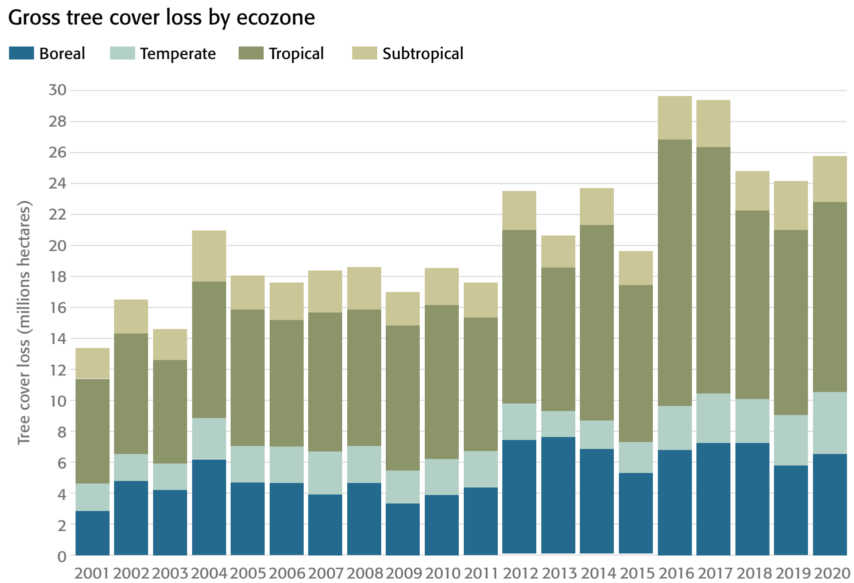
More than 40% of the earth's forest has been lost, with 10 million hectares of forest lost each year between 2015 and 2020, and much of what remains being significantly degraded (Lovejoy and Nobre, 2019; FAO, 2020). Loss of forests can be temporary or permanent and, in this context two main terms are used: tree cover loss and deforestation (see Box 4.1.). Permanent forest cover loss can be caused by commodity agriculture and urbanisation, while temporary loss can be caused by intensive logging, shifting cultivation and fire. Deforestation refers to human-caused permanent land use change from natural forest to another land use (Curtis et al., 2018; WRI, 2022a). It is estimated that one-third (1/3) of forest loss since 2000 is permanent deforestation, and two-thirds (2/3) is temporary tree cover loss (WRI, 2022a). Section 1.3 in this report summarises recent information on permanent deforestation.

Temperate and boreal forests have lost 158 Mha of gross tree cover since 2000, with 95% mainly due to potentially temporary drivers like forestry and wildfire, primarily in Canada, Russia and the USA (WRI, 2022a) (Figure 4.4.). In this case, forests will often recover naturally or the sites are reforested by planting which is required by forest legislation, for example, in Finland, Sweden and in most EU countries. Tropical forests, led by Brazil and Indonesia, account for 204 Mha – half of global tree cover loss - since 2000, but 96% of deforestation, with the rate almost doubling in the last 20 years (WRI, 2022a) (Figure 4.4.).

Biodiversity loss, which accompanies forest loss, is often paired with climate change as a global tragedy impacting our planet. Despite the CBD entering into force in 1993, subsequent decades have seen little increase in awareness of the importance of biodiversity for human health, forests and our environment. Like climate, however, in recent years the pace and extent of change has made it difficult to ignore the environmental, economic and health implications of biodiversity loss. The report by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) published in 2019 highlighted some stark trends: around 1 million animal and plant species are now threatened with extinction, many within decades; average abundance of native terrestrial species dropped by at least 20% since 1900; and more than 40% of amphibian, 33% of reef forming corals, and a third of all marine mammals are threatened (IPBES, 2019).

Figure **4.4**

Annual rates of global tree cover loss have risen since 2000



Source: WRI, 2022

The loss and degradation of forest are due to a range of direct and indirect threats, which are reviewed in this section along with the human health impacts and trade-offs. Economic drivers include massive expansion of commodity and shifting agriculture; illegal and unsustainable logging; energy expansion in oil and gas, biofuels and biomass; destructive and poorly planned infrastructure; and urban sprawl (Figure 4.5.). Biophysical drivers include climate change, fire and invasive species. Indirect threats to forests include cultural and political drivers like urbanisation, technology, consumption, loss of biocultural diversity and governance. Figure 4.5. highlights the significant regional variation in the drivers of deforestation and tree loss.

Box **4.1**

Defining and measuring deforestation and forest loss

According to the definition used by FAO's Global Forest Resources Assessment (FRA), deforestation is "the conversion of forest to other land use independently of whether human-induced or not" (FAO, 2020). That is, deforestation is essentially referring to a change in land use, not in tree cover. Defining deforestation thus implies a definition of forest, which, in the FRA, combines physical criteria (minimum thresholds of 10% canopy cover, 0.5 ha in area and 5 m in height) and a notion of the predominant land use, excluding tree-covered areas where the predominant use is agriculture or urban; hence, the definition excludes plantations of agricultural tree crops (such as oil-palm plantations and orchards) as well as urban parks but includes various types of planted forests (including rubber plantations) (FAO, 2022). Furthermore, the data used in the FRA are provided by countries and there may be significant divergences in interpretations and methodologies applied.

Many technical and scientific studies do not use FAO's definition but rather equate forest loss with tree-cover loss without taking land-use criteria into account. These datasets use remote-sensing-based methodologies. They consider both all tree cover (including tree-covered areas not meeting FAO's forest definition) and instances of non-permanent tree-cover loss (e.g., the clear-felling of a natural or planted forest that will later regrow, and the temporary consequences of a forest fire) as loss of forest. When interpreting figures on forest loss in different studies, therefore, users should be aware of the impacts of the definitions and tools used.

4.5.2 Direct threats to forests and human health

Economic drivers

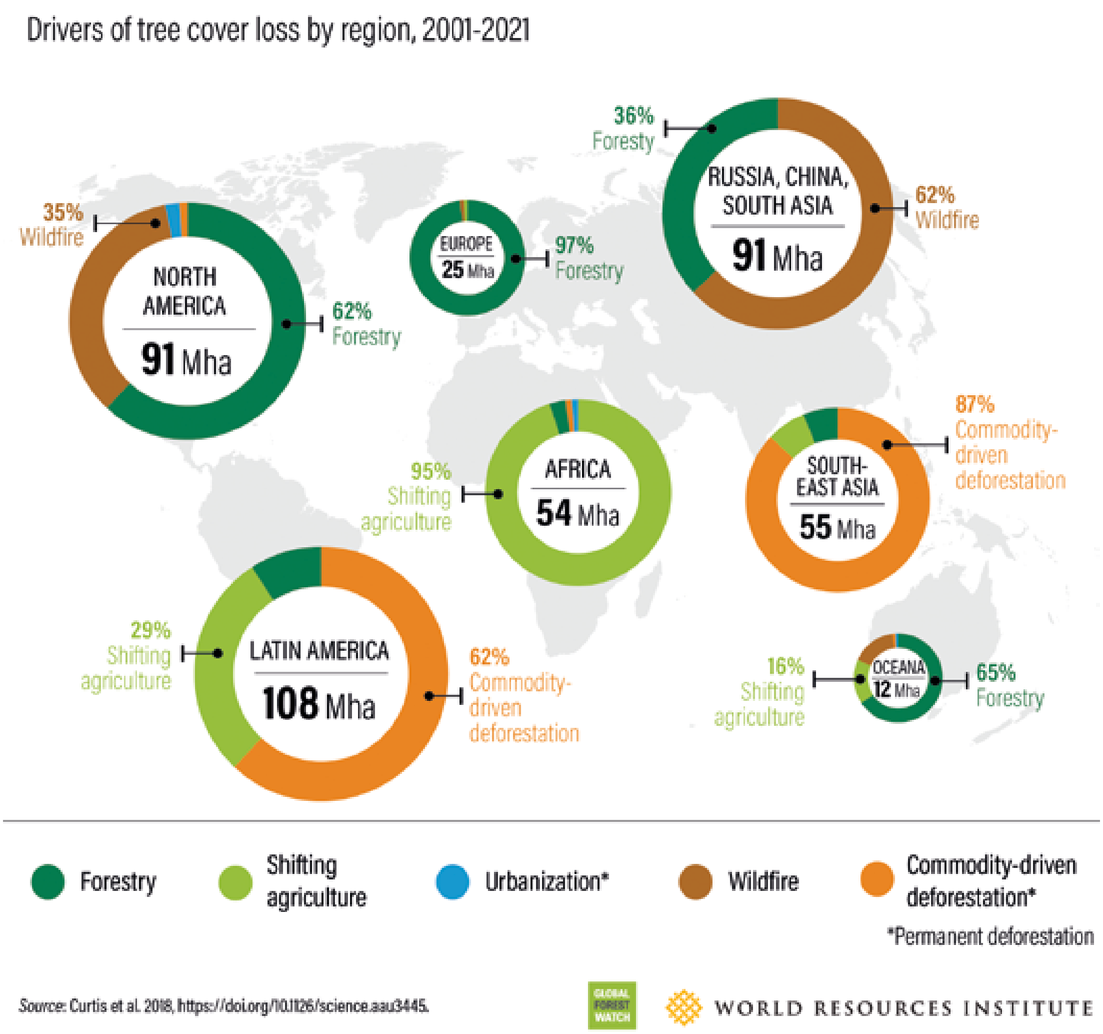
The most significant economic drivers of forest loss and degradation include large-scale commodity and shifting agriculture, illegal and unsustainable logging, energy expansion, infrastructure development and urban sprawl (Figure 4.5). Curtis et al. (2018) identified the primary drivers of tree cover loss from 2001-2015 as 26% from forestry; 27% from permanent land use change for commodity production; 24% from shifting agriculture; and 23% from wildfire.

Agriculture

Large-scale commodity agriculture, including cattle ranching, is the most significant contributor to deforestation and to greenhouse gas emissions. Food crop production has increased 300% since 1970 (IPBES, 2019) and around 47% since 2001, with 63% of this rise taking place in tropical regions, which now represent around half of all global output (WEF, 2021). Since 2002, more than 60 million hectares of primary forest have been lost in the tropics, with more than 80% of this in areas in which agriculture is the dominant driver, and the cause of half to three- quarters of total deforestation (WRI, 2022b). Cattle pastures occupy 36% of all areas deforested for agriculture from 2001-2015, followed by oil palm, soy, cocoa, plantation rubber, coffee and plantation wood fibre – which together account for 57% of all tree cover loss associated with agriculture between 2001 and 2015 (WRI, 2022b). Commodity-driven permanent conversion of forests from 2001-2020

Figure **4.5**

Drivers of forest and tree cover loss by region (2001-20)



Source: WRI, 2022a

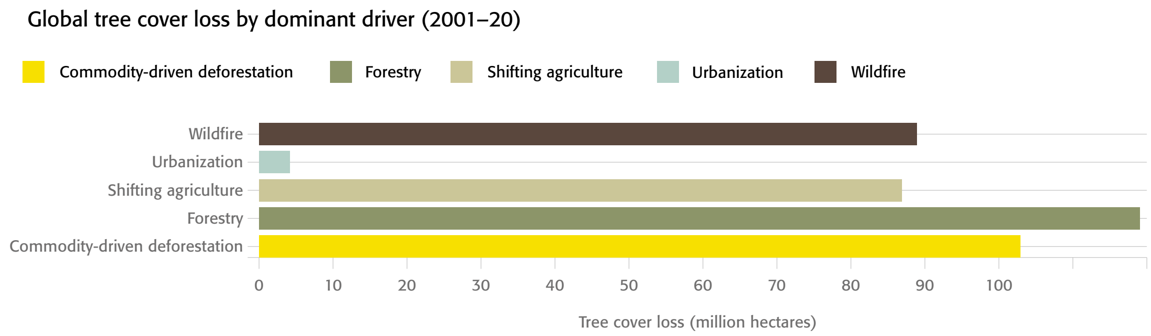
is associated with 103 Mha of tree cover loss. Shifting agriculture, which includes many different smallholder agriculture systems around the world in which forests are cleared for agriculture, but then temporarily abandoned to allow trees to regrow and soil fertility to return, is associated with 87 Mha of tree cover loss during the same period (WRI, 2022a).

The global food system was found to be responsible for at least 16 billion tonnes of greenhouse gas emissions in 2018, a third of total global anthropogenic emissions, with net forest conversion being the single largest emission source estimated on agricultural land in the period 1990-2018 (Crippa et al., 2021; Tubiello et al., 2021). As a result, at the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Glasgow in 2021, world leaders issued a declaration on forests and land use that called for halting and reversing forest loss and degradation by 2030, including “implement and, if necessary, redesign agricultural policies and programmes to incentivise sustainable agriculture, promote food security and benefit the environment” (UNFCCC, 2021).

Intensive agriculture degrades wildlife habitat, soils and biodiversity, including pollinators upon which 75% of global food crop types depend (IPBES, 2019), and impacts on surface temperatures, rainfall patterns and energy fluxes to a far greater extent than rural smallholder agriculture, which retains greater vegetation cover (Maeda et al., 2021). Large-scale commodity agriculture also wastefully uses scarce water resources, pollutes and mines for nutrients, while undermining the biodiversity and pollinators upon which natural systems and proximate smallholder agriculture

Figure **4.6**

Forestry, commodity-driven deforestation, wildfire, and shifting agriculture are the leading causes of tree cover loss



Source: WRI, 2022a

depend. Intensive agriculture can lead to reduced crop yields and food insecurity, loss of agrobiodiversity, and can lock small farmers into hunger, malnutrition and poverty (Leakey et al., 2021). It can undermine nutrition by producing cheap, processed low quality foods that lead to poor health outcomes and obesity (CBD and WHO, 2015), eroding local cuisines, nutrition, and leading to economic dependence (Ladio and Lozada, 2004; Dounias and Aumeeruddy-Thomas, 2018). These systems also present socio-economic challenges, including underpaid workers, sometimes exposed to chemical inputs which cause significant health impacts (CBD and WHO, 2015).

Forestry

Logging can coexist with healthy forests if done sustainably and at long enough rotations, but 10-15% of global timber supplies are provided illegally, and in some regions, this is as high as 50% (Kleinschmit et al., 2016; IPBES, 2019). Since 1970, raw timber production has increased 45%, and from 2000-2013 intact forests were reduced 7% (IPBES, 2019). Forestry accounted for 119 Mha of tree cover loss between 2001 and 2020. However, most of this loss can be considered temporary, as long as natural forests are allowed to regenerate or trees are planted, although this depends upon the nature of logging, length of rotations and condition of the forest (WRI, 2022a).

Forests are among the most significant climate change mitigation strategies proposed in global policy today (Lewis et al., 2019; Moomaw et al., 2019; UNFCCC, 2021). Research in the last decade has identified natural, old-growth forests as significant carbon sinks (Anderson, 2019), and found that the rate of carbon capture and storage increases with the age and size of trees (Luyssaert et al., 2008; Stephenson et al., 2014). Accumulation of carbon in forest soils also increases with time, and levels can be very high (Morriën et al., 2017). Plantations established on logged land cannot fully replace the loss of biodiversity, environmental services and carbon sink values of forests, and those in biodiverse tropical regions are disproportionately planted with non-native species (Axelsson and Grady, 2022), including 98% of South American plantations (Jong et al., 2021).

In addition, in many tropical and subtropical countries, large-scale logging, particularly where it is carried out illegally, can threaten sources of important NTFPs for subsistence; local and global trade; and local sources of fuelwood and timber (Laird, 1999; Angelsen et al., 2014; Aung et al., 2014). Important NTFPs include a wide range of nutritious foods, as well as medicinal plants which make up the primary health care of the majority of the world's population (WHO, 2002; Shanley and Luz, 2003; Cunningham et al., 2008; Laird et al., 2011; Shanley et al., 2015). An estimated 2.77 billion rural people use NTFPs in the low- and middle-income countries and 0.79 billion users in the high-income countries, with a global total in rural and urban areas of 5.8 billion NTFP users (Shackleton and Vos, 2021). Forest plants, microorganisms, insects and genetic resources also provide important starting points or foundations for natural product pharmaceuticals, with almost a quarter of all new drugs from 1981-2019 derived from nature, and another 20% mimicking nature (Chivian, 2002; CBD and WHO, 2015; Newman and Cragg, 2020). Logging and forest degradation and fragmentation associated with agriculture, also create a launch pad for novel human viruses, improving and altering the biology of disease vector's habitats (Dobson et al., 2021; Beatty et al., 2022).

Energy

Energy expansion impacts forests and human health on several fronts. Global subsidies for fossil fuels of USD 345 billion result in USD 5 trillion in overall costs, including nature deterioration externalities, with coal accounting for 52% of post-tax subsidies, petroleum for 33% and natural gas for around 10% (IPBES, 2019). Pollution and the by-products from fossil fuel combustion cause a wide range of health problems, including respiratory disorders, asthma and heart attacks, and are considered the world's most significant threats to children's health, and major contributors to environmental injustice (Perera, 2017). Biofuels and biomass, once viewed as alternatives to fossil fuels, are now understood to create significant environmental, social and health challenges of their own, and contribute less than anticipated to combatting climate change (Stephenson et al., 2014). Both rely on raw material and biomass which can be agricultural feedstocks produced on land that was previously forest (WRI, 2022b), or wood from natural or planted forests, and 'woody debris' that removes important nutrients from forests. Additionally, arable land is often planted with crops and plantations for biofuel and biomass energy and can result in land conflicts with Indigenous peoples and local communities (IPLCs) and other local groups. At the same time, forests – left intact – contain more carbon than exploitable fossil fuels, and absorb a quarter of the carbon generated by humans (Dunne, 2018).

Urbanisation

Urbanisation, and associated infrastructure, can result in encroachment and fragmentation of forests; loss of green corridors and relatively small reservoirs of biodiversity and wildlife in peri-urban areas; loss of genetic pools for restoration of forests; reduction in carbon sink capacity and pollution control; depletion of groundwater and water management capacity; and loss of biodiversity, wildlife, and other environmental services provided by forests (Beatty et al., 2022). Urban areas have grown more than 100% since 1992 (IPBES, 2019) and account for 3 Mha of forest loss between 2001 and 2020, with the majority in temperate forest (WRI, 2022a). Uncontrolled urban sprawl can remove scarce forest areas which provide recreation, forest bathing and tourism benefits for physical and mental health (Marušáková and Sallmannshofer, 2019), and may reduce the private amenity benefits of owning forests and living in the countryside. Redevelopment of urban areas can involve removal of trees, particularly when tree protection ordinances do not exist or are weak. Planting of monocultures of street trees throughout cities can also expose the entire city's canopy to pests and diseases.

Uncontrolled urbanisation coupled with forest fragmentation is leading to degradation of ecosystem and human health, with infectious disease on the rise. Recent estimates reveal that globally, only 13% of urbanites live close enough to nature to experience its mental health benefits (McDonald et al., 2018).

In response to forest fragmentation, urban sprawl, and the numerous environmental hazards impacting the wellbeing and livelihoods of city dwellers worldwide, there is a growing trend to design compact cities, with high density, mixed-use patterns, leaving green space, planting trees and improving resilience (Pataki et al., 2021).

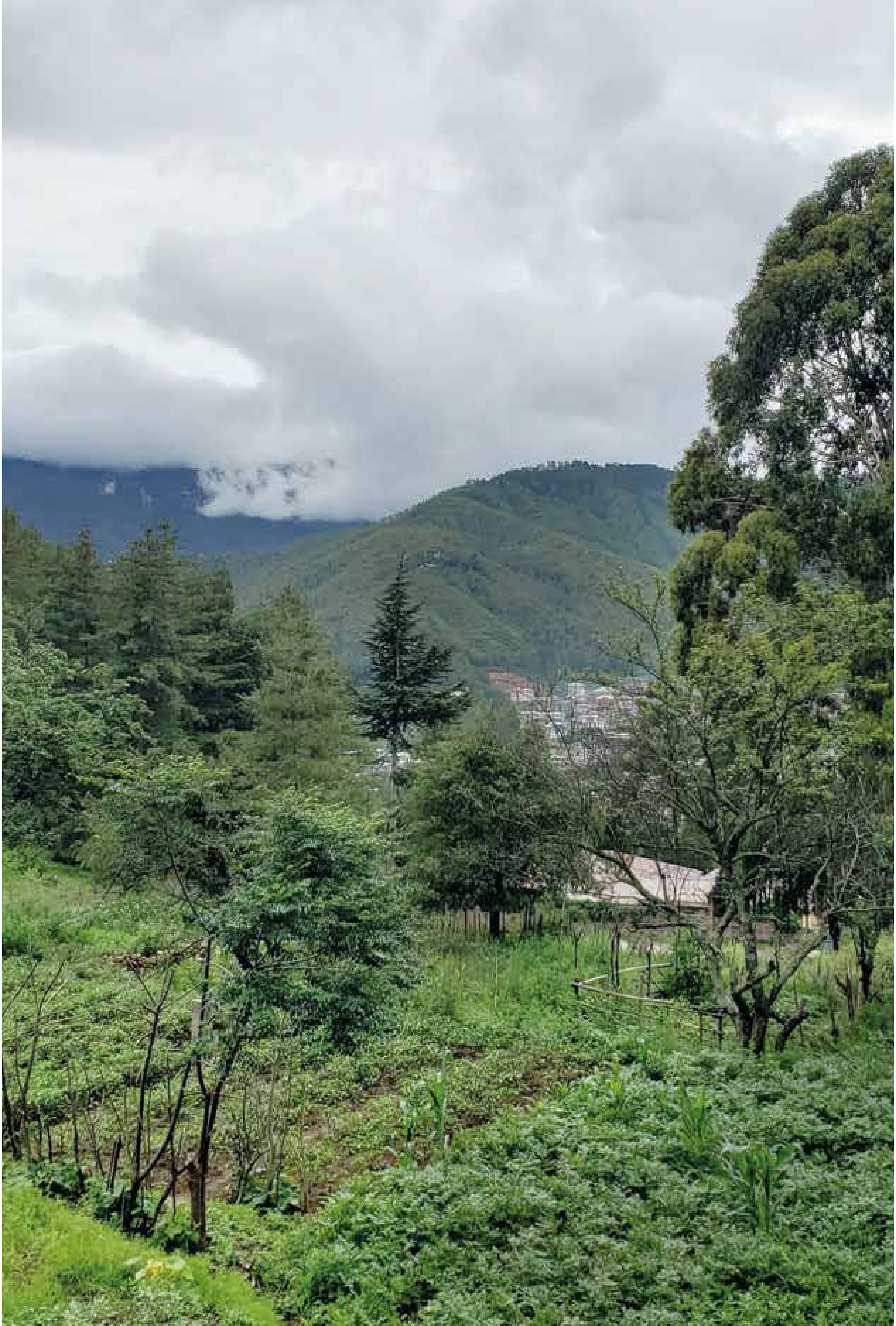
Biophysical drivers

The following sub-sections review some of the interlinked biophysical drivers with direct impacts on forests, and their impact on human health, including climate change, fire and invasive species.

Climate change

Climate change is referred to as the "existential crisis of our time" and is interwoven with all other drivers of deforestation. It negatively impacts forests in a myriad of ways, with impacts on human health, such as: reducing species diversity (including species with medicinal, food and other qualities for local and global communities; Applequist et al., 2020); facilitating the spread of tree pests and diseases (Linnakoski et al., 2019); increasing drought and flooding (Beatty et al., 2022); and creating conditions for wildfires and the spread of diseases (Dobson et al., 2021). The World Economic Forum (WEF) found that climate change has already adversely impacted food security, and that tropical and subtropical regions are likely to be the most vulnerable to crop yield declines (WEF, 2021).

The socio-economic impacts of these changes disproportionately affect the poor and marginalised around the world. For example, flooding impacts poorer countries more than wealthy ones, and within wealthy countries the poorest communities bear the brunt of climate induced flooding or other extreme climate events (Gourevitch et al., 2022). Climate change multiplies existing risks to human health and generates conflict, water scar-



Forested landscape and green spaces are essential elements of residential areas in Thimphu, Bhutan
Photo © Dikshya Devkota

city, land degradation and fires. From 1996 to 2015, an estimated 1.3 million people died as a direct result of so-called natural hazards like flooding, hurricanes, drought, wildfires, landslides and extreme temperatures, and these are increasing due to climate change. Forest cover can help provide protection from these hazards, including buffering and absorbing floodwater, stabilising soils and reducing ambient temperatures (CRED and UNISDR, 2016).

Medicinal plants, which provide primary healthcare to 70% of the world's population (WHO, 2002) and are threatened by overharvesting and habitat destruction, are also negatively impacted by climate change, including changes in temperature and precipitation, disruptions in commensal relationships, increased pests and pathogens, and impacts on species' productivity and quality (potency and chemical composition). In addition, concerns have also been raised about climate change-induced alterations in the nutritional quality of food crops (Applequist et al., 2020).

Fire

Fire as a by-product of climate change, as well as a tool for forest clearance, has significant impacts on human health. Wildfires accounted for 89 Mha of tree cover loss between 2001 and 2020 (WRI, 2022a). Climate change, which produces drier and warmer conditions, and forest degradation and fragmentation, has led to more fires globally, over larger areas and burning at higher temperatures as a result of the hotter and drier conditions produced by climate change (WRI, 2022b). Fires lead to loss of human life, and the associated smoke creates significant and prolonged illness. For example, in the Brazilian Amazon, fire was the primary method used to clear 15% of the forest between 1976 and 2010, and researchers have estimated an average of 2,906 premature deaths annually due to deforestation fires (Reddington et al., 2015; Beatty et al., 2022). Fires also affect human health by leading to the loss of important environmental services including clean air and water, and carbon sequestration.

Invasive species

Invasive species are a by-product of the massive increase in global trade, as well as climate change which allows species to spread to areas previously deemed inhospitable. They can elbow out important food, medicinal and other forest species, and profoundly change forest composition and succession, which in turn undermines the provision of important environmental services critical for human health (Trumbore et al., 2015). For example, invasive plants degrade and undermine forest health and natural regeneration processes by overwhelming native species, aggressively absorbing water and nutrients, light and space (Trumbore et al., 2015). Invasive insect vectors of disease can also directly impact human health (Juliano and Lounibos, 2005).

4.5.3 Governance and political drivers

Approximately 75% of global forests are controlled by governments, with higher percentages in many countries (Barr et al., 2014; Sunderlin et al., 2021). Governance and political power significantly impact forests and associated human health benefits. Ineffective, poorly designed laws and policies contribute to forest loss and degradation, and in many countries corruption, weak law enforcement and patronage politics undermine forest governance (Laird et al., 2010; Barr et al., 2014; Sunderlin, 2021).

Land rights represent some of the greatest challenges to forests around the world, with property rights historically contested by the state, private-sector and IPLCs (Barr et al., 2014). The land rights of many IPLCs in highly forested countries remain unrecognised under statutory law, including around 8.8% in Asia, 7.4% Latin America, and 49.9% in Africa (Rights and Resources Initiative, 2020). When land *tenure* and resource rights are secure, forests and the food and medicinal species within them are more likely to be sustainably managed, communities can access wild nutritious plants from a range of habitats, including forests and fallow, and food security, nutrition, wellbeing and human health are enhanced (Cunningham et al., 2008; Laird et al., 2010).

In some countries, governments might subsidise or create perverse incentives in related sectors that lead to forest loss, while in other sectors they might work to conserve forests. Governance and political issues associated with forests and human health are explored in greater detail in Chapter 5.

4.6 Conclusions

This chapter has shown that the health outcomes related to forests, trees and green spaces, both at the individual and community level, can considerably differ between different types of forest contexts and communities (i.e., rural, urban, forest-dependent). It is important to have insight in this complexity of forest-human health relations, also in terms of response options as presented in Chapter 5. Moreover, response options related to planning, design, and management for instance, need to be based on an understanding of the attributes and characteristics of forests that affect their health impacts. These relate, notably, to structure, species composition and development phase of the forest.

Synergies exist between the health outcomes of forests and many of the ecosystem services provided. Often there are synergies between regulation and biodiversity targets and health and wellbeing benefits of forests. However, there can also be important trade-offs, for example related to closing off forests to local communities or visitors for specific purposes or to changing forest type and structure for biomass production and carbon storage.

In the future, it will be important to maintain and strengthen those human-forest interactions and practices that locally support human health and wellbeing the best and integrate these practices, if possible, with other locally or regionally important forest ecosystem services to find adequate support and justification for the necessary land-use and forest management changes.

When developing governance, planning, management, and other solutions, these synergies and especially also trade-offs need to be considered and reconciled in forest management. It is also important to consider different forest users and user groups, from local communities to visitors from further afield, and from urban to rural and forest-dependent communities. Use of the forest for health reasons by one user group can also hamper other uses by other groups, as seen in the case of spiritual forests and recreational versus livelihood uses of forests.

Finally, it is also essential to understand the many threats and drivers of deforestation, tree cover loss and forest degradation, as these will impact the availability and capacity of forests to meet human health demands. Part of the response option for promoting positive forest-human health relationships while minimising those relationships that can threaten health, will be directly linked to these threats and drivers.

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5

Chapter 5

Response Options:
Access, Spatial Dimensions, Design, Communications and Economics

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Abstract
This chapter gives an overview of five categories of response options available to secure health benefits of forests, trees and green spaces: the management of access; spatial dimensions; design, communications and education; and governance and economics. Across these areas, some common solutions emerge, although response options differ between settings and regions of the world. In general, there is a need to explicitly include and acknowledge human health as an important value (or ecosystem service) in the development of visions, plans and other strategic policy documents pertaining to forests. Initiatives aimed at improving access to health benefits of forests and reducing inequity need to consider a wide range of interconnected factors including property rights and natural, physical, human, social and financial capitals. The spatial dimensions of providing health-promoting forests revolve essentially around the current location of forests in different settings as well as finding optimal spatial configurations. Key factors are proximity and accessibility, visibility and developing well-connected networks of forests and other green spaces. From a design perspective health needs to become a guiding principle in master plans and more detailed designs for forest areas, focusing on enhanced safety, accessibility and usability and promotion of positive experiences. Communication and education have to shift their focus from informing people about the evidence for health benefits to building understanding of why forests are beneficial for health and wellbeing, using for example informal learning through hands-on experiences. Governance related to health benefits of forests requires a change in the forest conservation and land-use discourse, as well as new alliances between governments, markets and civil society actors, mobilisation of resources and changes in governance rules of the game. Economic and other assessment methods and payments for ecosystem service schemes need to include health outcomes.

5.1 Introduction

This report has so far presented the current theories and evidence on the multiple relations between forests, trees and green spaces[6], and human health outcomes. It has also discussed some of the relations between different types of forests and forest characteristics on the one hand, and specific health benefits or risks on the other. Moreover, synergies and trade-offs between the health impacts of forests and other ecosystem services (and disservices) have been highlighted, as well as many key drivers that can either strengthen forest-health relations or serve as barriers to these. Based on this analysis, and as a foundation for future policies and interventions, this chapter presents five response options towards optimising the positive impacts of forests on human health, while also managing potential negative impacts. These response options are categorised under the themes of: 1. management of access; 2. spatial dimensions; 3. design; 4. communications and education; and 5. governance and economics.

The relevance of the response options differs between different regions of the world. In many countries, property rights for example, will affect the forests-health relationship. To ensure a wide applicability, each response option is illustrated with examples and evidence from a variety of regions and countries.

Each response option is first briefly introduced, followed by a discussion of relevant factors that may shape the relation between forests and health, and some key associated issues that need to be addressed to enhance this relationship. These insights are then used to highlight response options and solutions for forest managers, policymakers and other stakeholders.

5.2 Response Options Related to the Management of Forest Access: Property Rights and Capitals

5.2.1 Introduction

An important precondition for individuals to reap the health benefits from forests is that they have access to those forests. With access being defined as the "ability to derive benefits from things" (Ribot and Peluso, 2003). The ability to derive health benefits from forests is to a large extent ensured by public ownership of forested areas in many countries, and by these forests being ac-

6 All terms that are defined in the glossary of this report (Appendix 1) appear in italics the first time they are mentioned.

cessible for recreational and other health-related activities (e.g., wild foods). In many low-income countries, largely due to historical legacies, access of local communities and other forest-dependent groups is often limited by unclear or conflicting property rights. In addition, natural, physical, human, social and financial capitals can either constrain or enable people to benefit from forests (Peluso and Ribot, 2020).

This section introduces property rights and capitals as key factors that shape people's access to forest health benefits, along with a discussion of the issue of inequity in access to forest health benefits and the pathways that may lead to inequity. The section focuses mostly on low-income countries where access, and other property rights, are a major issue.

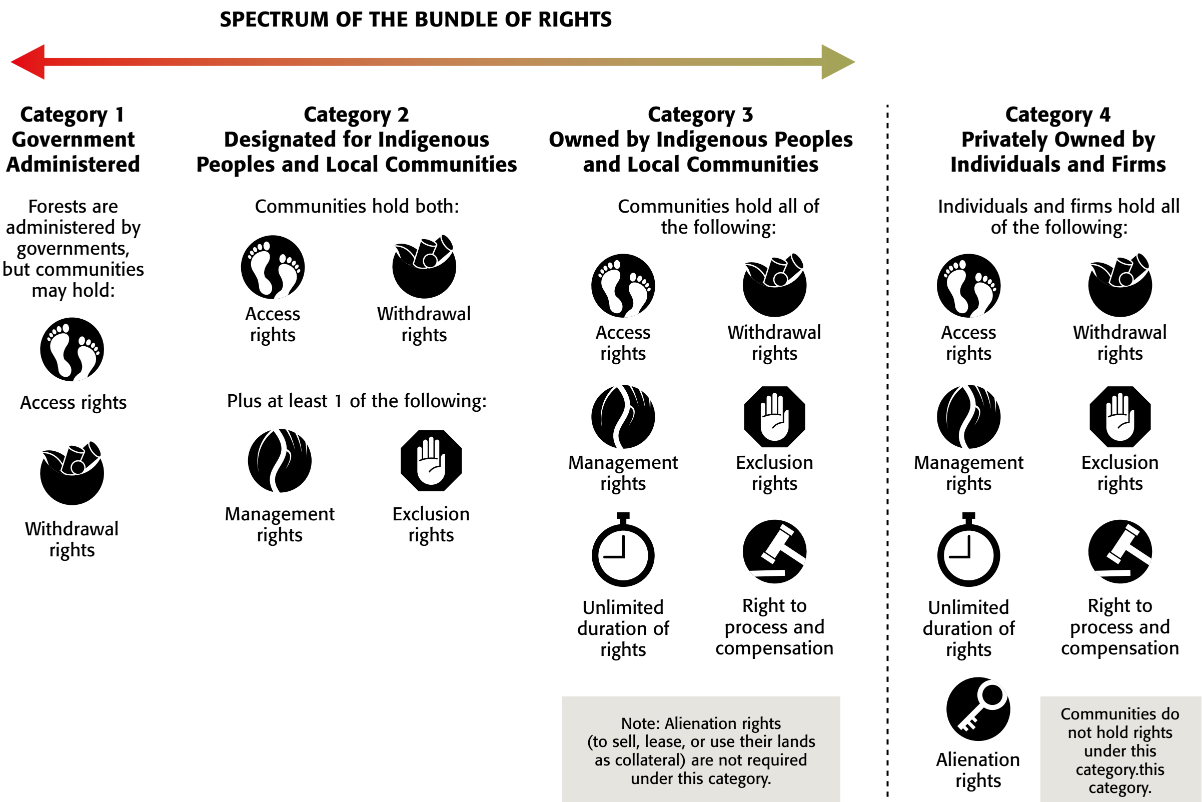
5.2.2 Factors relevant to access to forest health benefits

Property rights

Rights are claims to benefits that are acknowledged and supported by society through law, custom or convention (White and Martin, 2002). In the context of forests, property rights are important means for local communities to gain access to health-related forest products, such as forest foods, medicinal plants, as well as timber and non-timber products that are sources of income that people can then use for health care. Moreover, securing the property rights of local communities to forest resources matters for ethical reasons, as these communities have often customarily owned these resources for many generations and their wellbeing and way of life depend on access to them (Mollett and Kepe, 2018). In general, four categories of forest tenure can be distinguished (Rights and Resources Initiative, 2018): (1) government administered; (2) designated for Indigenous peoples and local communities (IPLCs); (3) owned by IPLCs; and (4) privately owned by individuals and firms. As illustrated in Figure 5.1, these four categories classify forest tenure according to the rightsholder and can be plotted against the specific property rights (or legal entitlements) recognised by national-level laws and regulations.

Figure **5.1**

Spectrum of the bundle of rights



Source: Rights and Resources Initiative, 2018

Community ownership: Legal and customary

Legal ownership provides IPLCs with the highest level of control and therefore, the best ability to derive health benefits from forests, i.e., they can mediate or exclude others to forest resources. Local forest owners also have rights to due process and compensation in case of conflicts. Yet, an analysis across 58 countries showed that, as of 2017, local communities were legally recognised as owning only 12.2% of global forest area, with an additional 2.2% having legally designated rights. By comparison, governments have legally-enshrined administrative authority over more than two-thirds of global forest area (Rights and Resources Initiative, 2018, see Figure 5.2).

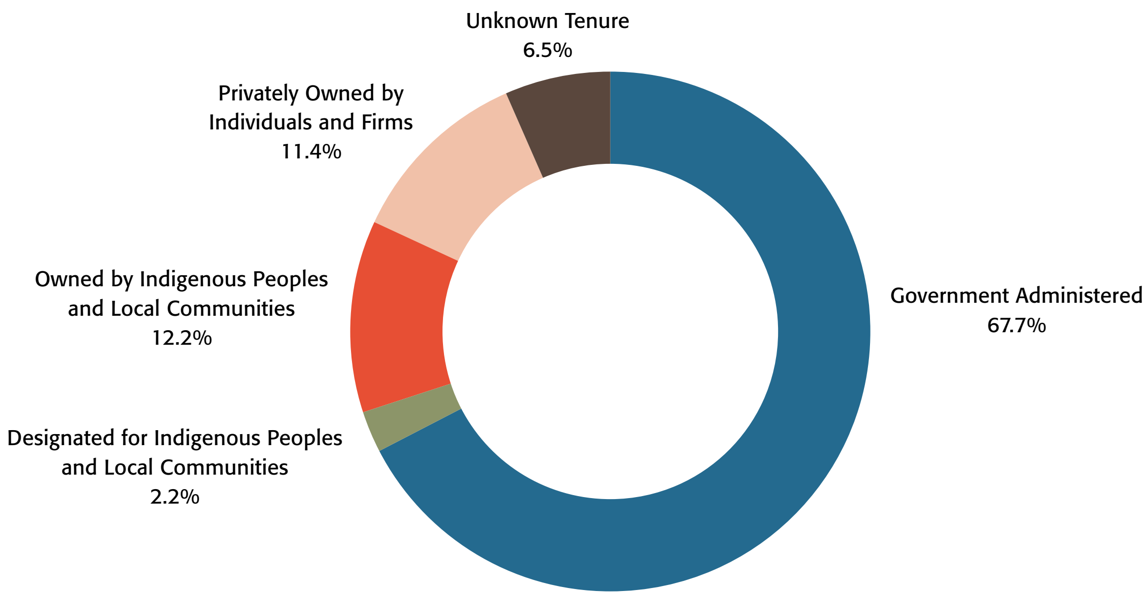
Where local communities do not have legal ownership of forests, national laws often recognise the customary ownership of local communities without requiring formal registration of customarily owned lands. In countries with such laws (e.g., Kenya, Mali, Mozambique) the percentage of community ownership is higher than the official data. However, overlap between legal and customary ownership can result in access ambiguity that, in turn, may lead to conflicts. Moreover, whenever local communities have no legal ownership, their legal rights and their access to forest resources, including those associated with health benefits, remain insecure as the government, which legally owns the forests, is the ultimate access mediator, adjudicator and power holder.

Private ownership

As shown in Figure 5.2, in the 58 countries reviewed, an estimated 11.4% of forestlands are owned by private individuals or firms. These private forest owners are often smallholder farmers whose vulnerability and dependence on forest resources may be like that of local communities. However, there is no global data on the proportion of private forestlands owned by smallholders compared to firms, corporations or families with large holdings. The lack of data reflects inadequate attention to laws that are needed to secure the ability of smallholders to access benefits, including health benefits, from forest resources.

Figure **5.2**

Global status of statutory forest tenure in 58 countries as of 2017 by percent



Source: Rights and Resources Initiative, 2018

Conservation areas

Of particular interest is the continuing expansion of protected areas for biodiversity conservation that are often administered by governments. About 18% of the world's forests are currently within the boundaries of legally established protected areas (FAO and UNEP, 2020). While the majority of protected areas established during recent decades allow multiple uses of forest resources (International Union for Conservation of Nature (IUCN) categories V – VI), access to resources within many of these protected areas is still contested by local communities (Sunderland and Vasquez, 2020). Furthermore, there are still many protected areas where access to forest resources is more strictly regulated (IUCN categories I – IV). Target 3 of the Global Biodiversity Framework (GBF) adopted during the 15th Conference of the Parties (COP) to the Convention on Biological Diversity (CBD) in 2022 approved a target to protect at least 30% of terrestrial areas through protected areas and other effective area-based conservation measures (OECMs).

Extensive versus limited rights

In general, more extensive rights (rights to exclude others or to sell or lease) are more likely to improve outcomes than more limited rights (use rights of physical access to forests and withdrawal of forest products) (Miller et al., 2021). For example, individuals of households in communities in Bhutan who participated in community forest management (and thus had management rights) significantly increased their calorie intake, as a protection against the health risk of malnutrition (Rahut et al., 2015). In Namibia, people living in communal conservancies – areas under customary property rights in which rights to benefit from natural resources are devolved to local communities – have significantly higher ownership of bed nets (for malaria prevention) than people in non-conservancy comparison areas. This is attributed to the fact that the community structure provided by conservancies makes it easier for authorities to distribute such nets (Riehl et al., 2015). Communities around the Loita forest in Kenya, which is managed under traditional property rights in which local communities are the owners of forests and have the right to exclude others, perceived that the control of access to forest resources granted to the communities improved their health status (Mbuvi et al., 2015b). Even having limited property rights can already provide benefits compared to having no rights, as indicated by a study with households from 34 low-income countries (Naidoo et al., 2019). Living in multiple-use protected areas with limited rights to withdraw forest products (IUCN categories V – VI) promoted child growth (greater height-for-age and weight-for-age) compared to living in non-protected areas.

However, a few studies indicate greater health benefits of having limited rights compared to more extensive rights. In Tanzania, for example, local communities perceive improvement with regard to access to forest medicinal plants, and hence health, where there are more limited rights, but not where there are more extensive rights (Vyamana, 2009). Another study in Tanzania detected significant positive associations between community forest management rights and child nutritional status (height-for-age, weight-for-age), where rights grant more limited control of access to the forest communities. No significant association was detected where the management rights allow for more extensive control of access (Pailler et al., 2015). Such inconsistent findings might be explained by the fact that, though property rights are important, they represent only one means by which to gain access. Other contextual factors act in parallel or interact with property rights to determine access. Below, several of those contextual factors relating to natural, physical, human, social and financial capital are discussed.

Capitals

Natural capital

Natural capital comprises the natural resources people depend on for their livelihoods. The state of forest resources affect people's ability to access the health benefits that they provide. The amount of forest and their configuration across landscapes have been significantly associated with diet quality, a key determinant of nutritional status in Ethiopia, Malawi, Nigeria, Tanzania and Uganda (Rasmussen et al., 2020). A study found that in Indian villages, women used to walk 1–2 km every day to gather sufficient firewood for cooking, but where forests were degraded, they needed to walk 8-10 km for the same activity (Wan et al., 2011). Such an increase in the time and energy needed by women to collect firewood, reduces the time and energy that they have available as primary caregivers for food preparation, more careful child feeding behaviours, income generation and health care, which can impact the health of household members (Johnson et al., 2013). As another example, when forests in upstream areas of watersheds are degraded, the quality of downstream water can be affected (Cunha et al., 2016).

Physical capital
Physical capital includes infrastructure that people need or tools and equipment that they use to make a living. Roads, for example, open access for alternative food and health services that can reduce communities' dependence on forest resources (Myers et al., 2013). Living near roads can also support forest-dependent people in converting forest benefits to nutritional benefits (Rasolofoson et al., 2018), although roads can also increase access to forests for other (competing) users.

The role of physical capital in enhancing access to the health benefits of forests can also be illustrated by the multiple-barrier approach to clean drinking water provision. From source watersheds to water distribution, multiple consecutive barriers to pollutants and contaminants are needed to ensure safe drinking water (Ernst et al., 2004). By filtering raw water, forested watersheds can act as early barriers and reduce the cost of clean water. Nevertheless, additional infrastructure is necessary at point-of-use or source (e.g., point-of-use chlorination, water treatment plant) to enhance the benefits of water filtration by forested watersheds in providing clean drinking water and preventing waterborne disease (Cunha et al., 2016).

Multiple examples where physical capital improved the health outcomes of forests can be seen around the world. For example, local communities in the Maya Biosphere Reserve of Guatemala who started buying their own logging and processing equipment saw an increase in net household revenues and social cohesion as important health influencing factors (Nittler and Tschinkel, 2005). In the Democratic Republic of the Congo, gun ownership allowed richer people to enjoy the health benefits of bushmeat consumption (De Merode et al., 2004). In the Gunung Palung National Park in Indonesia, a programme that established a health clinic and offered discounts to communities based on reduction of *illegal logging* activity saw an increase in clinic usage (Jones et al., 2020).

Human capital
Key components of human capital include skills, education and knowledge. In Cameroon, development of skills needed for indigenous tree domestication and agroforestry increased consumption of nutritious fruits and use of medicinal plants, which in turn, resulted in a reduction in the frequency of sickness and hospitalisation (Tchoundjeu et al., 2010). Level of education can strengthen the effects of forests on diet quality as more educated people may be more diet-conscious and, thus, more likely able to translate forest benefits into nutritious diet. A conservation project that involved education on family planning increased contraceptive use among women in a national park in Madagascar (Korhonen-Kurki et al., 2004). Nutrition knowledge for women is of high significance given that decisions regarding household food use and practices are mostly made by women (Vira et al., 2015). Knowledge on the use of medicinal herbs is another human capital that is essential for traditional medicine practice and is common in forest dependent communities (Mbuvi et al., 2015a).

Social capital
Social capital generally refers to the network of social relationships that people have, including relationships with either more powerful people or with others like themselves, or membership of groups or organisations. Privileged relationships with authoritative individuals or institutions that design, implement or enforce forest use rules can strongly influence who benefits from forest resources (Ribot and Peluso, 2003). In Madagascar, for example, there are reported cases in which community elites, thanks to better skills and education (human capital), developed relationships with state authorities and implementing organisations (Pollini and Lassoie, 2011). Such relationships led to rules favouring these community elites, allowing them to capture forest benefits and other resources. Group membership can also affect the distribution of benefits from forest resources. For example, in Ethiopia, members of forest user groups – who were allowed to graze livestock and harvest timber – enjoyed increased livestock assets and income, while non-members lost access to forest products and grazing – leading to income shocks (Ameha et al., 2014). In turn, these income shocks can have repercussions on household health care.

Exchange relations that provide access to markets are another type of social capital. The collection and sale of forest products can provide support especially for those who lack the means to engage in other livelihood activities (women and the most disadvantaged members of a community) (Vinceti et al., 2013). Cash income can be used for health care. Forest-based programmes involving improvement of market access, such as forest certification, have shown positive or neutral effects on socio-economic outcomes (Burivalova et al., 2019). Specifically, in Indonesia, forest certification reduced firewood dependence, air pollution, respiratory infections and malnutrition while having no effect on the number of healthcare facilities (Miteva et al., 2015). Creation of producer business groups that link smallholder farmers of indigenous fruits to wholesale buyers have also been reported to result in increases in farmers' incomes in Kenya and Uganda (Jamnadass et al., 2011).

Financial capital

Financial capital includes cash income and remittances, credit, savings in kind and cash. The status and power afforded by financial capital can be used to acquire other means of access. For instance, financial capital can be used to purchase tenure rights, pay for rents or access fees, tools or equipment (physical capital) for resource extraction, acquire education and knowledge (human capital) and invest in relationships with or buy the influence of people with authority (social capital). In the Democratic Republic of the Congo, for example, poorer households made proportionately less use of wild meat and fish because they could not afford the high-capital tools (e.g., guns and nets) necessary to exploit these resources (De Merode et al., 2004). In a community-managed forest in Uganda, wealthy households saw significant gain in income from forests because they were able to extract and commercialise illegally harvested timber by offering bribes to forest officials responsible for monitoring and enforcement of rules (Jagger, 2008). In a study in the Sundarbans, greater availability of financial capital was correlated with higher capacity to harvest crab and fuelwood from the mangroves (Kibria et al., 2018).

5.2.3 Inequity in access to forest health benefits

Dependence on the benefits of forests, including dependence on health benefits, differs across different groups of people and communities. More vulnerable people and communities often have greater dependence on these benefits than less vulnerable ones. Vulnerable people and communities have limited resources that enable them to access health services provided through infrastructure and market, and therefore turn to forest resources for the provision of these services (Myers et al., 2013; Fisher et al., 2019). However, vulnerable people and communities also often have limited means (rights and capitals) to benefit from forest resources (Miller et al., 2021). Therefore, benefits from forest resources, are inequitably distributed with studies reporting more benefits for wealthier, better educated or male-headed households (e.g., De Merode et al., 2004; Pailler et al., 2015; Rahut et al., 2015; Rasolofoson et al., 2018; Nerfa et al., 2020)

The inequitable distribution of forest health benefits operates through three major and interlinked pathways. First, without adequate property rights and capitals, vulnerable people will not be able to directly benefit from forest products of direct relevance to human health (e.g., nutritious forest food, medicinal plants). For example, some forest products cannot be extracted without the use of tools, and without knowledge of nutritional or medical virtues of forest products, nutritious and medicinal forest products will be left unused. Second, other forest products (e.g., timber, fodder) and ecosystem services need to be transformed or enhanced by capitals to yield health benefits. For example, timber needs markets to generate income that can be used for health care; pollination needs agriculture assets to be transformed into nutritious food products. Vulnerable people who do not possess the capitals to achieve such transformation will not be able to derive health benefits from these forest products and ecosystem services. Third, wealthier, better educated and male community members tend to be more likely to participate in forest management and conservation activities that promote health, such as the promotion of contraceptive methods or the distribution of bed nets. Such participation reinforces their rights and capitals while leaving the vulnerable destitute.

5.2.4 Solutions

Efforts of governments and other authorities to improve access of local communities to forest benefits are often framed in terms of socio-economic benefits. However, as described in this section, having access is also of crucial importance to the ability to derive health benefits from forests, and as such deserves more attention. Policies, regulations, legislation and interventions aimed at improving access to health benefits of forests need to consider a wide range of interconnected factors including property rights and natural, physical, human, social and financial capitals. When communities have more extensive control over their forest resources, they are empowered and incentivised to engage in collective action leading to more equitable health and health-related outcomes. Such collective action does not only deliver equitable outcomes, but also strengthens capitals, which, in turn feeds back into sustaining acquired health outcomes.

Governments and authorities may also directly strengthen local communities' physical, human, social and financial capitals (for example through educational programmes or through forest certification) particularly for vulnerable community members, to ensure that they are able to benefit equally from forest health resources. However,

Forests provide settings for camping in nature as well as firewood for cooking
Photo © Nelson Grima

care is needed because these capitals can also lead to unsustainable use of forest resources and thus imperil natural capital. An accountability mechanism, which links local forest user groups and external organisations (e.g., Korhonen-Kurki et al., 2004; Miteva et al., 2015; Jones et al., 2020; Miller et al., 2021), can be another way to promote equitable and sustainable outcomes (Persha and Andersson, 2014).

5.3 Response Options Related to the Management of Spatial Dimensions of Forests

5.3.1 Introduction

The spatial dimensions of providing health-promoting forests revolve essentially around two questions: where are forests located today in relation to urban, rural or forest-dependent human communities? What is the optimal spatial configuration of forests in terms of human health benefits? When it comes to the location of forests, most people now live in settings where forests are often not readily available, unless cities and towns have good urban forest infrastructures. However, even in rural areas the availability of forests can be limited, for example due to clearing for agricultural uses or resource extraction. Issues that arise with a further distancing from forests include a disconnection from nature (Farcy et al., 2018) and poor mental health (Bolton et al., 2021).

The spatial configuration of forests (i.e., the size and arrangement of forest patches across a landscape) affects ecological functions and human access to forest resources (Rasmussen et al., 2020). Forest fragmentation, for example, increases the proportion of forest coming into contact with the edge ('edge effect'), which in turn can result in increases in tree mortality; changes in plant and animal composition, diversity, seed dispersal, predation; and altered microclimate (Broadbent et al., 2008). All of these changes impact the availability of forest products and services important to human health. However, forest fragmentation also makes it easier for people to access forest resources that were deep in the forest interior before fragmentation (Peres, 2001).

This section first introduces some key spatial dimensions related to the location and spatial configuration of forests, followed by a discussion of challenges and opportunities for spatial management aimed at optimising health benefits of forests. The section closes with an overview of solutions.

5.3.2 Factors relevant to spatial dimensions of forest health benefits

Proximity and accessibility

Proximity of forests is an important indicator of spatial availability. When forests are nearby, they are more likely to be used for recreational and other activities that promote health and well-being. In urban and peri-urban areas, for example, research has shown the importance of proximity and ease of access (Hörnsten and Fredman, 2000; US Forest Service, 2019). More generally for urban green spaces, the World Health Organization (2017) calls for a maximum of 300 metres from one's home to the nearest green space. Many studies, as discussed in the previous chapters, have shown that having forests and other green spaces nearby can be related to better physical and mental health.

While proximity is mostly favourable to health, in some cases forests nearby can also result in more negative health impacts, for example in the case of vector-borne diseases, dangers from wild animals, forest fires and their resulting smoke and haze, and the like. Sometimes the term 'ecosystem disservices' (see Chapter 4) is used in this context (Dobbs et al., 2014). Having forests too close can evoke feelings of fear and danger (Skår, 2010; Konijnendijk, 2018); fears which can result from a wide range of causes, including fear of other people, of getting lost, of wild animals or a more general anxiety related to nature (Dobbs et al., 2014). Sanjay Ghandi National Park which is surrounded by the megapolis of Mumbai in India hosts a resident population of leopards that sometimes roam the city's streets and pose dangers to pets and humans (Surve et al., 2022).

Recent years have seen increasing focus on the issue of 'urban forest equity' and the fact that urban forest canopy cover is often unevenly distributed across a city (Shiraishi, 2022). It is also common for higher urban forest cover to be found in the more affluent parts of a city, while areas with lower socio-economic status and more vulnerable populations are not well catered for. Forest equity can also be considered more generally, including a fair and equal distribution of forests and forest benefits in rural areas, and access to forests for forest-dependent communities (Larson et al., 2008).

Both in urban and rural areas, forest proximity in combination with accessibility play an important role for example, in recreation and tourism. People may be willing to travel greater distances to specific forests that are of high recreational, natural or cultural value, but they will also make an evaluation of the costs (e.g., travel time) and benefits involved. Urban dwellers may be willing to travel several kilometres to an urban or peri-urban forest if there are no 'forest experiences' available nearby, or when they want to avoid overcrowding or conflicts with other recreational users (Bakhtiari et al., 2014).

Visibility

Visibility of, and visual access to, forests is another important spatial dimension. Just seeing trees and other vegetation has been found to promote mental and other types of health benefits (Wolf et al., 2020). Both visual and physical access to forests are also important for specific user groups, such as school children. Offering forest experiences to children during their school time can generate improved learning and health benefits. The so-called 'Forest Schools' that have been established across Europe and elsewhere are an example of a response to this finding (O'Brien, 2009).

Connectivity

Connectivity can enhance the functionality of forests and green infrastructure. Many cities across the world have focused on developing green infrastructure networks (Lafortezza et al., 2013). Barcelona, Spain, is one example of a city with an ambitious green infrastructure and biodiversity plan that also has strong links to public health (Ajuntament de Barcelona, 2022). Urban forest fragmentation in contrast can be linked to loss of human health benefits, for example, due to a decrease in ecosystem functioning and patch sizes (Tsai, 2014; Haaland and Konijnendijk van den Bosch, 2015) resulting in loss of biodiversity as well as a reduction of ecosystem service provision (Mitchell et al., 2015).

Multifunctional landscape mosaics characterised by patches of forests or trees intermixed with small-scale agricultural production systems have the potential to provide nutrient-rich foods and support diverse diets for women, young children and families, especially those living in rural communities (Sunderland and Vasquez, 2020). A study covering rural households in Ethiopia, Malawi, Nigeria, Tanzania and Uganda shows that the amount and spatial configuration (number or size of forest patches) of forests across landscapes are positively associated with more diverse diet (Rasmussen et al., 2020). This association can be explained by multiple pathways. Pollination is an important ecosystem service for the production of fruits and vegetables (Eilers et al., 2011; Garibaldi et al., 2022). However, pollinators, such as birds, bats, butterflies, moths, flies, beetles, wasps, small mammals and bees have a limited foraging range

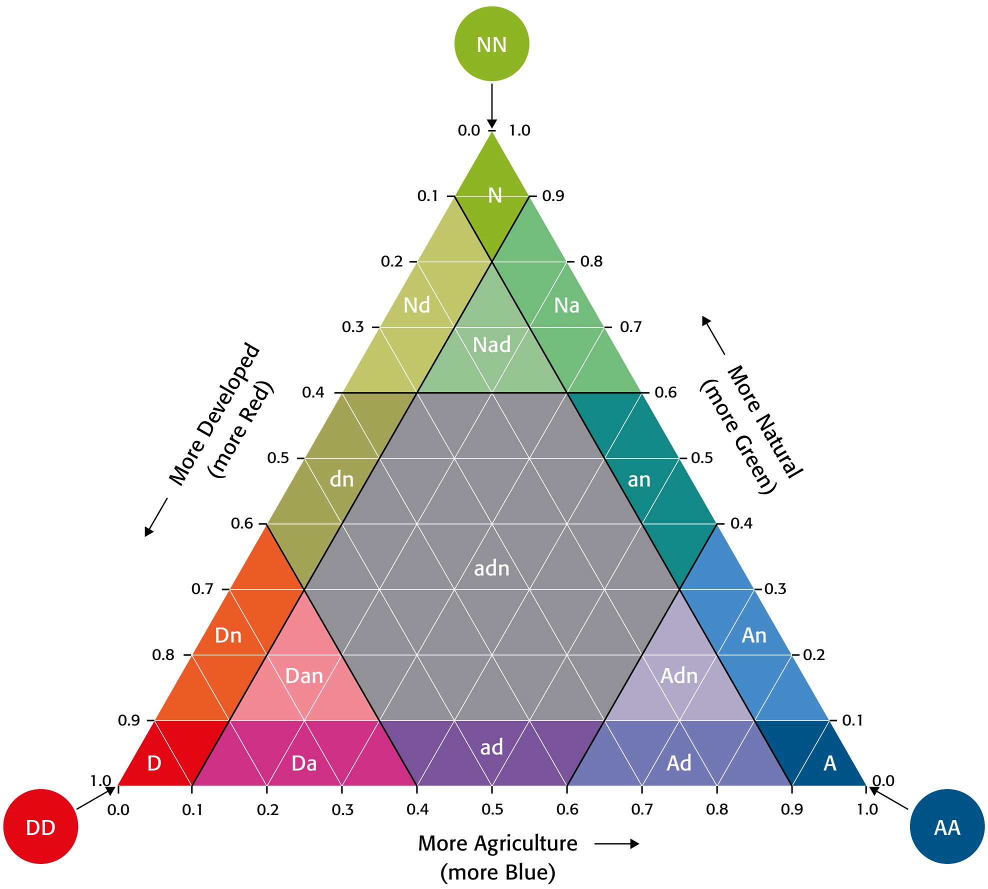
(Kennedy et al., 2013). Multiple forest patches offer pollinators habitats scattered across a landscape enabling them to reach a large total crop area within their foraging distance. Wild foods in forest patches are also more accessible than those in large blocks of forests (Hickey et al., 2016), where access may be more limited, not only because of their size, but also because they are more likely to be protected for conservation (Ickowitz et al., 2019).

Strategic spatial arrangements

The strategic location of forests in upstream areas of watersheds may increase the effectiveness of water treatment and thereby reduce diarrhoeal disease prevalence in downstream areas (Herrera et al., 2017; Rasolofoson et al., 2021). Forests may also be strategically placed to provide a buffer between livestock and water bodies. Also, forests can help to keep pathogens (e.g., Cryptosporidium) in livestock waste from reaching water sources, mitigating the effect of livestock and human waste on water quality (Brauman et al., 2007; Pattanayak and Wendland, 2007). The strategic spatial arrangement of forests is particularly relevant for vulnerable communities in low-income countries that cannot afford expensive water treatment technology. Similarly, programmes have been developed to reduce fire risk especially close to where people live, by leaving buffers, selecting less flammable tree species and managing undergrowth (Calkin et al., 2014).

Figure **5.3**

The Landscape Mosaic showing 19 mosaic classes and their proportions to the three land cover types - Agriculture (A), Natural (N) and Developed (D)



Adapted from a living document in the free online EU GuidosToolbox Source: European Commission, 2021

5.3.3 Managing spatial aspects

Enhancing the proximity, availability, visibility, connectivity and strategic spatial arrangement of forests (and trees) is a key issue for policy- and decision-making, as a neglect of these spatial aspects can reduce potential health gains. If policymakers and other decision-makers fail to address these aspects, interests of different population groups can clash; for example, when natural and rural forest areas are made available for recreation and tourism mainly for urban dwellers, with negative side effects for rural dwellers.

To manage spatial aspects requires firstly analysing where forests are located in relation to human populations using geospatial tools. Moreover, specific forest types need to be placed in relation to different population groups (see also Chapter 4). Next, the specific health benefits for the different groups have to be determined, balanced with other forest ecosystem services and with each other. When clear gaps are determined, a next step is to see whether new forests can be created, which can be challenging because of competition with other land uses. In urban areas this can be particularly challenging due to lack of available space, the high competition for land and high land prices. Connectivity is also important, as less fragmented and more connected forests in different settings can provide more health and other benefits due to better ecosystem functionality.

Management challenges and opportunities are thus central to the spatial dimensions of forests for human health. Although overall global figures indicate a net forest loss (FAO, 2020), there are signs of a reversing trend at least regionally or locally. Climate change, public health and biodiversity policies and actions have resulted in larger-scale afforestation and reforestation programmes in many countries. A megacity like Beijing, for example, has planted 50 million additional trees during recent years, and is in the process of adding another 50 million, with public health as an important consideration (Yao et al., 2019). Prior to afforestation, a detailed spatial mapping was carried out to determine where new forests were most needed and feasible. Many cities have launched efforts to expand their urban tree cover, although a key challenge lies in the proper protection of existing forests and tree canopy cover, for example on private properties (Ordóñez-Barona et al., 2021).

5.3.4 Solutions

From a spatial perspective, it will be important to include the health outcomes of forests in both forest and overall land-use planning. Currently this is rarely the case, especially in high-income countries where there has been more focus on providing recreational forests close to urban centres. Standards such as the Woodland Access Standard prepared by the Woodland Trust (2010) in the UK, and the WHO standard for access to urban green space (WHO, 2017) are examples of spatial planning guidance. The distributional aspects are also important, ensuring forest equity and the equal provision of health benefits of forests to all segments of the population. American Forest's Tree Equity Score is a good example of an assessment tool that addresses this issue (American Forests, 2022). The example of Beijing's afforestation strategy illustrates how spatial analysis can help determine which areas should be prioritised for afforestation, notably, from a health perspective.

A key task for spatial planning will be the development of well-connected networks of forests and other green spaces. A green infrastructure planning approach has been applied across cities worldwide that has proven successful in enhancing connections between forests and other green spaces, promoting better ecosystem functionality and easier movement for people and other species (Lafortezza et al., 2013).

During their history, many cities across the globe have developed forest greenbelts, primarily with protection and recreation benefits in mind (Konijnendijk, 2018). China's Forest City programme rewards cities based on a detailed set of criteria and indicators related to the provision of forests and trees (Pei et al., 2019).

At the same time, potential negative impacts of forests on health need to be recognised, minimised, and managed. These negative impacts, sometimes called disservices (Dobbs et al., 2014) can have a spatial dimension, with nearby forests potentially bringing diseases, wildfires and resulting smoke, roaming wild animals, and a wide range of risks and fears, most of which are connected to specific segments of the human population living close to forests and unable to move to a safer place for economic or other reasons. Spatial analysis can assist with determining where the highest risks are in relation to where people live, and find ways of buffering and managing these risks. Nevertheless, in most cases the health and other benefits of forests will surpass the potential risks and disservices.

5.4 Response Options Related to The Design of Forests, Trees and Green Spaces

5.4.1 Introduction

There is increasing demand for forest design principles and guidelines that promote the health and wellbeing of visitors, locals and other user groups. This applies specifically to recreational forests and woodlands in urban areas that provide health services to large numbers of urban dwellers. In this context, positive health functions of forests need to be balanced with potential negative aspects of forest experiences such as the fear of getting lost, feeling unsafe, physical barriers, conflicts between different groups of users, and diverse usage patterns among genders and age groups.

A key challenge for landscape architects and designers is to support forest managers in achieving an optimal balance between meeting basic needs (for safety, comfort, accessibility and usability) and more advanced needs for enjoyment and challenge. This design principle is also known as balance between "prospect and refuge" (Appleton, 1975; Gatersleben and Andrews, 2013) or between "understanding and exploration" (Kaplan and Kaplan, 1989). It is allegedly rooted in the evolution of the human species in natural environments with concomitant survival-promoting needs for safe shelter with a good overview of threats and dangers, and needs for exploration of the environment to find food, water, relief and other essentials (Wilson, 1984).

This section first discusses design aspects of forests that support and promote safety, usability, comfort and challenge, as key pathways to promoting health and wellbeing, followed by an overview of culture and crisis as moderators to consider in designing forests for different target audiences. The section closes with an overview of solutions on how to enhance health benefits of forests through forest design. This section mostly focuses on more intensively managed and designed urban forests and recreational area in different parts of the world.

5.4.2 Design aspects relevant to forest health benefits

In recent years, the discipline of landscape architecture has seen a transition from formal approaches that rely on expert knowledge and formal design principles and patterns, to a more evidence-based approach that is informed by scholarly work (Fagan, 2017). This evidence-based approach has yielded many relevant aspects to be considered when designing forests in order to optimise users' health and wellbeing (Doimo et al., 2020; Grilli and Sacchelli, 2020). Studies have highlighted, among other things, the importance of accessibility (De Meo et al., 2015); type of forests (e.g., mixed, deciduous, coniferous) (Liu et al., 2021); tree species composition, canopy openness, stand structure (Ebenberger and Arnberger, 2019); facilities (Zhao et al., 2020); and perceptual indicators and visual quality (Li et al., 2020).

Several schemes for organising these health-promoting design aspects have been developed. Of these, the Perceived Sensory Dimensions (PSD) scheme is one of the best-known and most used (Stigsdotter et al., 2017; see Table 5.1). The scheme comprises eight sensory dimensions that may contribute to restoration from stress: social; prospect; rich in species; serene; culture; space; nature; and refuge. For each of the dimensions, several key natural qualities and features are specified. As illustrated in Box 5.1 describing the design of a mangrove forest park in Malaysia, the PSD scheme is particularly useful as a tool for designing restorative spaces (or 'rooms') within forest areas.

For the purpose of this report, a more broadly applicable scheme is used that organises the various health-related design indicators found in the literature in terms of their contribution to users' needs for safety, usability, positive experience and challenge. These indicators can be divided into objective indicators (e.g., tree diversity) and perceived indicators (e.g., naturalness). The latter are often less spatially explicit and leave more room for interpretation by architects and designers. A review of the recent literature assists with identifying a set of structural and functional indicators according to the following criteria (Harshaw et al., 2007):

- Relevant to health and wellbeing
- Credible
- Measurable
- Cost-effective
- Connected to [urban] forestry

Design aspects of forests that promote safety

Design guidelines for promoting safety relate to wayfinding, signing, amenities, trails, the density, maturity and diversity of the forest, tree form and the quality of views.

Clear wayfinding and adequate signing respond to the fear that visitors have of getting lost if they were to venture more into the forest interior

Table **5.1**

Number (Nr.), names and short descriptions of the eight perceived sensory dimensions (PSD) - a tool for designing restorative spaces in forests

Nr.	PSD name	Key nature qualities and features
1	Social	Possibility to: • watch shows/films • attend exhibitions • visit restaurants
2	Prospect	• Lawns and well-cut grass • Vistas over the surroundings • Sports facilities
3	Rich in species	• Several animal species • Native fauna and flora • Many native plants to study
4	Serene	• Silent and calm • No bicycles • Few people
5	Culture	• Decorated with water features, statues • Various exotic, ornamental and kitchen plants
6	Space	• Spacious • Areas without paths/roads • Presence of lots of trees
7	Nature	• Nature-like • Wild and untouched • Free growing lawns
8	Refuge	• Many bushes • Animals in feeding/petting pens • Play areas such as sandpits

Source: Adapted from Stigsdotter et al., 2017

(Sonti et al., 2020). Proper parking amenities, sufficient numbers of rubbish bins, and presence of security guards and rangers may give users a sense of familiarity and increase perceived safety.

Providing multiple trails of different lengths can increase perceived possibilities to escape potential threat encounters. In addition, trails should be well-maintained and have adequate lighting for physical activity after dark (Ballantyne and Pickering, 2015). Preferences for paved versus unpaved paths may differ widely across different cultures and regions (Hochmalová et al., 2022) and with the age and other characteristics of visitors (Arnberger et al., 2010).

Open and visually accessible forests are perceived as less dangerous and evoke less fear than dense environments with no clear lines of vision and many hiding places (Gatersleben and Andrews, 2013). Mature trees, natural plantings and native species promote feelings of safety by creating a sense of place and refuge and, in urban areas, reinforcing neighbourhood identity (Liu et al., 2021). Mixing various types of trees and plants such as deciduous and evergreens, rough and fine textures, and dense and thin branches, offers an open view and visual diversity that reduce perceived situational threats (Chiang et al., 2014).

Surrounding forests and green spaces enhance the spiritual health benefits of Kinkakuji temple in Kyoto, Japan
Photo © Sital Uprety

With tree tops representing safe places for our ancestors, forest users today still tend to judge a tree by its climbability (Townsend and Barton, 2018). Climbable trees are an implicit sign of safety in modern human minds, and forest managers should be careful in removing lower branches which represent a key visual cue for climbability.

As a more indirect indicator, the attractiveness of views along the forest road (as measured by forest diversity) has been reported to reduce the speed of vehicles, lowering the frequency of road accidents and fatalities (Janeczko et al., 2016b).

Design aspects of forests that promote accessibility and usability

Design guidelines for improving physical access relate to the number, length and maintenance of the trails, the use of suitable materials for the surface, and the principle of universal design.

Providing multiple trails of different lengths can offer users different options for their activities. Trails can be in the form of boardwalks (e.g., concrete and paved) that reduce soil erosion due to excessive trail usage and the risk of the trail widening. They may also be designed as small informal bare earth trails that bypass large trees, with minimum disturbance to existing forest structure and canopy cover. Another option to consider is treetop walkways which have the potential to enhance the forest infrastructure, offer a different perspective and experience, and introduce an attractive element in the forest (Ke et al., 2021).

By implementing the idea of universal design, the aim is to make forests accessible for all users, including those with a physical disability. An analysis of 20 projects and studies in Britain revealed that disabled respondents emphasised the need for detailed information about access and facilities, preferably supported with photographs, so that they could choose appropriate woodlands and plan their visit (Morris et al., 2011). A survey among people in wheelchairs from three European countries on their preferences for forest trail features showed that they preferred asphalt surfaces, concrete surfaces or surfaces made of paving stones. Wooden surfaces were least appreciated (Janeczko et al., 2016a). In general, paving materials from wood should be avoided as they are slippery when wet. In the Netherlands, nature organisations are experimenting with supplying balance bikes for adults with walking difficulties to enable them to visit the forest.

Design aspects of forests that promote positive experiences

Design guidelines for promoting positive and pleasurable experiences relate to visual access, naturalness, size, visual variety, elevations, water elements, sound and lightscape, and number of users.

An evaluation of forest trails in the Royal National Park in Australia showed that visual access improved forest experiences by decreasing situational concerns about getting lost or fears of wildlife (Chiang et al., 2014). This study also showed that visual access can be achieved by having vegetation on one side of the trail planted in layers, and the other side having either large trees or no vegetation to maintain visual transparency. Other design characteristics that contribute to visual access include the forest's topography and the illumination cast by the foliage (Füger et al., 2021). Look-out towers enable users to get an overview of the whole area above the treetops, as well as providing a point of interest and rest (Hansen-Møller and Oustrup, 2004).

Mixed forests with irregular structure are generally perceived as more natural and attractive than mono-specific forests and have been reported to contribute to the restorative experiences of users (De Meo et al., 2015). Landscape elements such as large trees, buttress roots in coniferous forest settings and small-scale landscape elements such as flowering plants, may contribute to naturalness and visitor satisfaction (Zhang et al., 2020).

Creating an undulating terrain with gentle hills and variation of elevation in trails can increase visual variety while offering visual openness and partial concealment (Chiang et al., 2014). A change in elevation can offer different experiences in designs through the use of existing undulating terrain (Skłodowski et al., 2013).

Water elements are also generally much appreciated (Skłodowski et al., 2013). In particular, open views of streams along forest trails are an important factor that influences visitors' satisfaction with the trail (Cervinka et al., 2020; Zhang et al., 2020). However, users of different types of forests may differ in their preferences concerning water elements. Lowland forest users prefer forest sites near waterscapes or water edges (e.g., sea or water reservoir), while mountain forest users prefer forest sites that are open and easy to access (e.g., forest openings, trails, forest roads) due to the danger of steep slopes and inaccessible terrain (Gołos, 2013).

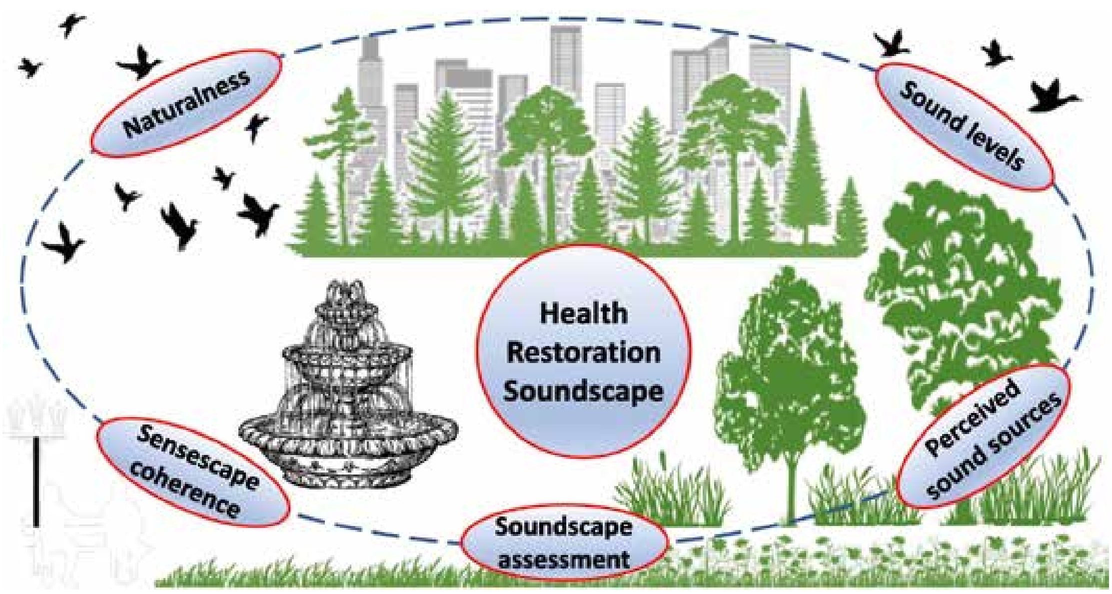
The soundscape of the forest, including both natural sounds and background noise, provides positive and relaxing forest experiences (Fang et al., 2021; Ratcliffe, 2021; Hong et al., 2022). In urban areas, the Health Restoration Soundscapes Criteria (HeReS-C) model (see Figure 5.4) provides a practical tool for evaluating and improving the soundscape of forested areas in terms of five conditions: naturalness; sound levels; perceived sound sources; soundscape assessment; and sensescape coherence (Kogan et al., 2021).

The lightscape may also influence visitors' experiences. Forest areas with good natural lighting conditions may support visitors' visual interest in the nearby and more distant surroundings during forest walks (Gao et al., 2021). Focusing the presence of artificial light towards greenery versus parking lots and roads may enhance the perceived restorative potential of urban night time in forest environments (Nikunen and Korpela, 2009).

The number of users and forest carrying capacity have also been mentioned in relation to creating positive experiences in the forest environment, with lower numbers of users being preferred, while at the same time preserving the forest's intrinsic values (De Meo et al., 2015).

Figure **5.4**

Summary of Health Restoration Soundscapes Criteria (HeReS-C)



Source: Kogan et al., 2021

Design aspects of forests that promote challenge

Design guidelines for promoting challenge relate to 'allowing the forest to be wild and unpredictable' thereby 'allowing the users to challenge themselves mentally and physically' This design aspect may especially apply to children, who are often restrained in their opportunities to discover the more challenging side of the woods (Louv, 2008).

Participants of wilderness programmes that challenge them to go beyond their own mental and physical boundaries, often report improvements in psychological wellbeing (Kaplan and Talbot, 1983). These beneficial effects can be linked to the experience of forests' immensity, which contributes to a sense of feeling connected to a "greater power"; the experience of interconnectedness, which elicits a sense of belonging to all other living things on earth; and the reflection of internal nature and truth by external nature as an accepting setting, which contributes to the discovery of an authentic self (Naor and Mayseless, 2020).

The available literature provides few design guidelines for promoting challenge – perhaps the best guideline is not to overdo measures for safety and usability, as discussed in the previous paragraphs. One concrete guideline, deriving from research on visual preferences, is to introduce an element of mystery, as indicated by winding paths and rivers, and hilly mountains (Kaplan and Kaplan, 1989). This may seduce users to further explore the environment. In a similar way, the presence of climbable trees, hills, water bodies, muddy grounds and other obstacles can seduce both adults and children to go outside their comfort zone to challenge themselves (Heft, 1988).

5.4.3 Moderators

Health impacts of forest design can differ according to moderating variables such as gender, personality, culture, age, income, education, personal situation and type of usage, as well as perceptions and needs linked to these variables. For example, individuals with a low need for sensation tend to be more oriented towards safety than high-sensation seekers (Van den Berg and Ter Heijne, 2005). Involvement of users in the design process, by means of user-oriented design and participatory approaches, provides a way to gain insight into these individual differences. Below, we highlight culture and crisis as two important moderating factors.

Culture

Designers of forests and green space need to take into account the preferences of different users to avoid potential conflicts between visitors with different needs. Within all cultures, some individuals are more oriented to safety, and others more towards seeking challenge. Some cultures, notably in Asia, are more oriented towards group activities, while most western countries are more individualistic (Zhai et al., 2018). Therefore, forest designs should allocate areas to accommodate both group activities, such as lawns and barbecue areas, and more solitary experiences. The size of the areas should be carefully thought out as overcrowding in forest visits may induce conflict, noise and ambient disturbance, and obstruction of views.

Crisis

During the COVID-19 pandemic, many people turned to nature for solace and healing experiences. Several studies have reported on these experiences (Pichlerová et al., 2021; Weinbrenner et al., 2021). One study describes how urban forests in Bogor, Indonesia, were improved to meet visitors' needs (Paramitadevi et al., 2021). An online survey provided insights to improve forest experiences during the crisis, including aspects related to whether the visited site evoked feelings of comfort and/or tranquillity, the availability of facilities such as seats and toilets, and the presence of edges that help structure the area provided by trees, bushes and fences. Forest managers and planners could add more restrooms, resting facilities, ramps to facilitate wheelchair/disabled access, composting areas, rain and stormwater harvesting, special environmental events, solar lighting and 'smart' seating that include solar-powered charging opportunities for mobile devices.

5.4.4 Solutions

From a design perspective, it is important to explicitly include health as a guiding design principle in master plans and more detailed designs for forest areas. Currently, when it comes to meeting users' needs, most designs and master plans for green spaces are focused solely on recreational and aesthetic values. However, while these values provide important pathways to deriving health benefits from forests and trees, a more health-specific focus is required for optimal use of the health potential of forests. A common misconception is that the promotion of aesthetic values will automatically translate into health benefits but health values depend to a large extent on accessibility and usability. As such, these aspects should be prioritised in the design.

A key challenge for health-promoting design of forests is to create universal designs that meet the

Box **5.1**

Designing a Mangrove Forest for Health in Malaysia

Mangrove Point is a newly designed park located within a mangrove forest along the Klang River in Malaysia which opened to visitors in early 2022. The 28 ha park is the first of its kind in Malaysia, designed based on the concept of 'biophilia' which incorporates nature into the built environment to create healthy, restorative and connective spaces.

The idea of turning the mangrove area into a health-promoting park was inspired by similar initiatives in Scandinavian countries, such as the health forest Octovia in Denmark. However, its location in a vulnerable mangrove ecosystem with a delicate balance between land and water is unique and posed many challenges for landscape architects. Most importantly, the architects needed to ensure the mangrove provided recreational benefits while also protecting sensitive areas along the river.

Using the Perceived Sensory Dimensions (PSD) approach (see Table 5.1), the architects created several restorative places in different areas in the existing mangrove to help park users unwind. Following the principle of universal design, physical and sensory barriers were avoided to ensure that everyone, regardless of age, gender or disability could use the space. To further promote usability and accessibility, the forest layout was designed to be easily understandable for new users through locatable entrances and exits. The design included walkways with appropriate signage, clear connections and destinations. Opportunities for diverse activities were included to stimulate active use by different users.

For safety purposes, dense vegetation, walls or other features were avoided along primary routes to maintain a feeling of openness, clear visibility and avoid entrapment areas. Pathways were designed to allow night movement along well-lit routes. The design also ensured that the edges of the park were open enough to allow views in and out of the site.

To support positive experiences, a combination of different materials, vegetation and various path layouts was applied, and planting schemes using textures, colours and shapes were employed. Appealing scenery with interesting views during different times of the day and the year were created throughout the site.

needs of all users. This entails the provision of adequate infrastructure that accommodates all user needs, regardless of their disability or handicap. It also entails balancing the different psychological needs for safety and challenge of individuals and user groups. Multidisciplinary project teams with experts from landscape architecture, psychology and geography, can provide well-informed and consensual guidelines on how to adequately address these issues.

The COVID-19 pandemic has highlighted the importance of visits to the forest for maintaining good mental and physical health. Many lessons were learned regarding design strategies that accommodate these health functions of forests in times of crisis, ranging from the provision of more toilets to the availability of protocols for ensuring health and safety. It is important that forest managers as well as researchers share their insights with landscape architects and designers to make forests more robust and equipped to welcoming large influxes of visitors in future times of crisis.

5.5 Response Options Related to Communications and Education

5.5.1 Introduction

Communications and education can play a significant role in conserving and optimising the health benefits of forests. To date, however, the human health benefits of forests have largely been ineffective or absent from communications regarding forests and/or health (Doimo et al., 2020). Despite mounting evidence that forests offer a distinct, powerful solution and/or treatment to innumerable ecological, sociological, medical and psychological problems, in practice and policy, all too often, forests continue to be treated as a short-term commodity and are razed and/or degraded (Karjalainen et al., 2010). At this critical juncture in history, limited public understanding of the health benefits of forests can result in missing vital opportunities for improving human health, and for conserving multifunctional forests.

The role of communications and education is culturally dependent. In the case of forests and health the focus of communications and education will depend upon the extent and nature of, and access to, local forests, as well as the common ailments, health care options, lifestyles and concerns of local people. Equitable access to forests and to information regarding the benefits offered by forests is necessary in light of the profound contribution of forests to human health.

This section discusses aspects of communications and education relevant to optimising health benefits of forests. It draws on concepts and approaches from various relevant fields including health promotion, communication science and environmental education (e.g., Monroe et al., 2008). The distinctions between urban and rural communities, and age group (children, adults, the elderly) are key moderators to consider in developing communication and education strategies for different target audiences. Besides the general public, forest managers are also discussed as a distinct target group for communications and education. The section closes with an overview of solutions on how to enhance health benefits of forests through spatial management.

5.5.2 Aspects of communications and education relevant for health benefits of forests

Communications

For millennia, Indigenous cultures have recognised and relied upon the healing power of forests. Many long-held beliefs about the 'healing powers of nature' are now being confirmed through research and shared with the public through information campaigns, Internet resources, and reports issued by governments and other institutions.

To convey persuasive communication messages, authorities and other actors can choose between statistical approaches (that rely on quantitative scientific evidence) and narrative approaches (that tell a personal story of a real person sharing his or her experiences). Research suggests that statistical approaches are more effective in changing beliefs and opinions while narrative approaches are more effective in stimulating intentions to change behaviour (Zebregs et al., 2015).

Especially in low-income countries, culturally responsive approaches that account for interpersonal, sociocultural and socio-economic realities are essential for effective communications (Kaholokula et al., 2018). The effectiveness of these approaches can be enhanced by using narratives and visuals (Hinyard and Kreuter, 2007; Bergeron et al., 2019; see also Box 5.2).

Thus far, communications in the forest-health domain has mostly relied on informing (adult) audiences about the scientific evidence, using a statistical approach. However, to inspire action, it seems essential to build a deeper and informed understanding of why and how forests support human health and wellbeing, using a more narrative approach. Such a compelling, inclusive approach which includes youth and marginalised populations, can reduce health care costs and diminish access disparities.

Disciplines like behavioural psychology, social learning and public health have generated methods that bring scientific understanding to the public; these methods, field-tested over decades, can provide important insights and guidance for forestry initiatives seeking to bridge knowledge and action (Shackleton et al., 2009; Garzón-Galvis et al., 2019). Participatory research, in which scientific evidence is combined with lived experiences of local stakeholders provides an alternative to 'blind science', and may provide results that are useful for practitioners, policymakers and local communities (Bannister, 2018). Participatory approaches strive to take an equitable approach to research and communication, balancing and interweaving local, Indigenous and Western scientific ways of knowing and viewing the world (Shanley and Lopez-Binnqüist, 2009; Wright et al., 2019).

Over the past several decades, a new model of 'citizen science' has emerged which enlists the public in collecting data across a wide range of habitats over long-term time frames, from microbiomes to galaxies (Bonney et al., 2009). The model is effective not only in advancing scientific knowledge, but also in helping participants gain hands-on experience with biodiversity. Positive results indicate that citizen science will continue to be employed as a cost effective, inclusive, research methodology, with the added benefit of connecting people with nature.

Education

Current approaches to environmental education strongly rely on facilitating hands-on experiences with nature (Stern et al., 2014). These approaches, which are mostly targeted at young children and people from urban backgrounds, are primarily aimed at strengthening the connection with nature through embodied experiences that use all senses. Teaching practical skills is another key element of environmental education, for example, learning how to make a fire, climb a tree, or knowing how to orient oneself using the moon or sun as guidance (Bergeron et al., 2019). Hands-on experiences and practical skills help students

Box **5.2**

The importance of visuals

Visuals help viewers to better retain messages than if they are in written form. About a decade ago, British film-maker David Bond became concerned about his children spending too much time indoors. He decided that it was time to reconnect children with nature, and initiated 'Project Wild Thing'. He directed a film in which he, as a father, attempts, mostly with little success, to get his own daughter and son off the couch and into the outdoors. The film, which is available for free on YouTube, is entertaining, and has reached a large audience. Project Wild Thing also released a popular short animation in which the health benefits of nature are explained in less than 90 seconds.

Today, Project Wild Thing has evolved into The Wild Network, a coalition of organisations eager to encourage children and parents to get into the great outdoors.

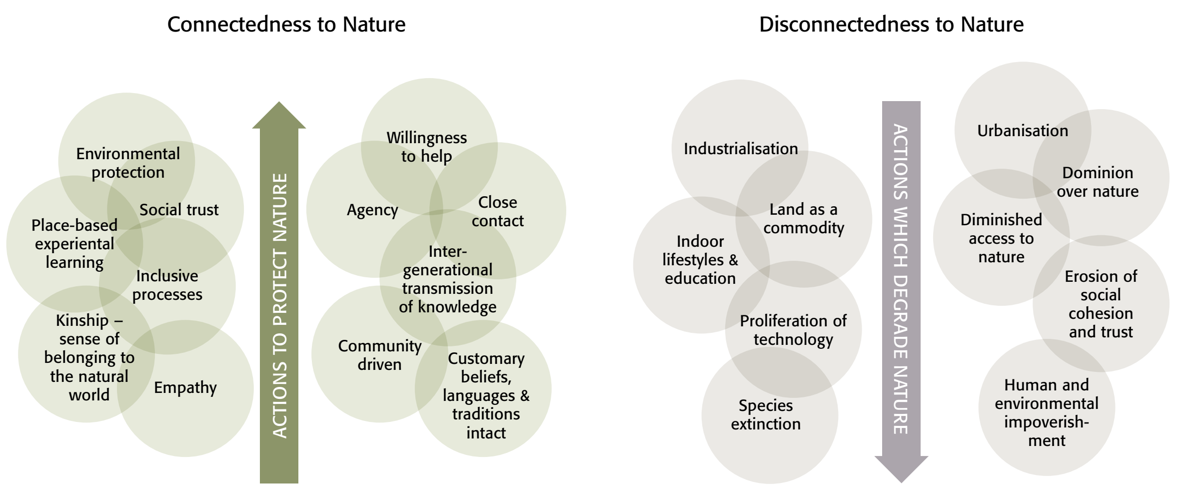
build self-esteem and take away psychological barriers, exaggerated fears or even avoidance of forests, and more generally, help to overcome impediments to the use of forests for mental and physical health and wellbeing (Mirrahimi et al., 2011). Although outdoor experiences are known to benefit children's psychological and intellectual development, a global review of educational themes in schools finds a lack of hands-on activities related to biodiversity and climate. Notably, a review of national education documents from 46 countries found that 45% made little-to-no reference to environmental themes (UNESCO, 2021).

Children living both in hunter gatherer villages and city centres spend the bulk of their days indoors at school, losing the biocultural knowledge of surrounding wild foods, medicines, fish and wildlife (Dounias and Aumeeruddy-Thomas, 2017). One telling outcome of modern education is that many youths graduate without the ability to identify a single tree. Scholars have described the current chasm between people and nature as the 'extinction of experience' (Pyle, 1979; Miller, 2005). Outdoor education (which may involve both formal education in schoolyards, and informal education in areas outside the school) provides a much-needed alternative to formal indoor education, especially for children with special needs such as attention deficit-hyperactivity disorder (ADHD) who find it difficult to sit still and concentrate (Van den Berg and Van den Berg, 2011). Many local and Indigenous groups have long called for systemic changes in public educational systems to respect the traditions, knowledge, languages, values, history and identities of their cultures. As a transdisciplinary approach to solving complex problems, local, indigenous education holds the profound potential to address the array of forest, health and sustainability challenges facing the planet (Cajete, 2012; Fernandez-Llamazares et al., 2022).

There is growing recognition of forests or woodlands as interconnected systems, with their own means of communicating among trees and other elements, through biochemical compounds spread via the air and the roots (Wohlleben, 2016). Indigenous people have long recognised this interconnectedness of forests and the reciprocal relationship with human health and wellbeing (Arnold et al., 2021). Making students aware of forests as interconnected systems is an important element in both formal and nonformal education about the health benefits of forests. However, educators need to consider different cultural backgrounds and entry levels of students when it comes to their openness to a more holistic, spiritual approach.

Figure **5.5**

Actions promoting connectedness to and disconnectedness from nature



Source: IPBES, 2022

In general, nature education, aims to (re)connect children and adults to nature, as an important pathway to deriving the health benefits of nature. Figure 5.5 illustrates the actions, related to protection and degradation of nature, involved in the processes of becoming connected to or disconnected from nature (IPBES, 2022). An ongoing trend creating a chasm between people and nature, is the proliferation of technology. However social media can also change public perception, and raise awareness of environmental issues, with subsequent policy impact (Mavrodieva et al., 2019).

5.5.3 Shifting the focus: Forest managers as a target group for communications and education

Historically and presently, most national forest management systems have developed with a focus on timber extraction with a short-term economic lens and narrow spectrum of uses. In light of research findings demonstrating the critical role of forests in supporting human health, mitigating climate change and curbing species extinction, it is urgent to tailor communications to forest managers and policymakers about the need to manage forests for multiple goals, including health. Interestingly, this policy reform is currently taking place mostly in more low-income parts of the world, but in some medium- and high-income countries as well. In countries such as Argentina, Brazil, India, Mexico, the Philippines and South Korea, forestry ministries and training programmes are being restructured to encompass a wide-ranging view of the human health benefits which forests offer, as well as officially recognising the advantages of community and indigenous forest management systems. For example, in Brazil, official forest management training includes identification and understanding of the nutritional and medicinal values of non-timber forest products to urban and rural populations during forest inventories and harvesting (Neri-Numa et al., 2018). In the Philippines, forestry officials have updated policies in support of traditional resource management systems. The Mexican government based sustainable management regulations of chicle on local stewardship practices and embedded this within national legislation (Shanley et al., 2002). And in some regions, Indigenous knowledge regarding the use of fire as a valuable tool rather than a threat, is now recognised and used as an intentional and legitimate instrument to maintain forest resources (Trauernicht et al., 2015).

Parallel to policy reform in forestry management, innovations are also occurring in forestry education. At the Tropical Research Centre (CITRO) at the University of Veracruz in Xalapa, Mexico, traditional farmers have transformed a five-acre forest on campus into a research area collaboratively managed with Indigenous peoples, where students learn forestry techniques from rural farmers. The Ministry of Education in the Philippines has revised elementary and secondary education whereby traditional ecological knowledge, values and skills are integrated into the school curricula and bilingual teaching materials. Time spent in forests with elders learning forest traditions, is now officially acknowledged as being in school, thereby introducing responsibility and knowledge about forest management during an early life stage (Quierrez and De Beer, 2014). In Argentina, a United Nations Environment Programme (UNEP) project is bridging scales and sectors, resulting in strengthening national and provincial regulations to support sustainable management and use of high conservation value forests at the landscape scale. This is being accomplished through education, participatory workshops, forest enrichment, and new financial mechanisms to support trade in medicinal and food plants as a source of genuine employment, health and nutrition while empowering local smallholders, mainly women (Sharry et al., 2022).

Multi-institutional collaborative research through the European Forest Institute (EFI), is highlighting the bio-economies of standing forests and communicating to policymakers and the public the profound value of cultural landscapes to urban and rural lifestyles and human health (Malkamäki et al., 2022). In the USA, the Nature Rx programme encourages medical prescriptions on spending time in nature for health purposes. Such programmes are not actually new, but a re-emergence of the therapeutic use of nature that existed in the late 19th and early 20th centuries (Crnic and Kondo, 2019). University campuses from Asia to the Americas are also beginning to promote time spent in nature and forests as an essential antidote to the stress of college life (Rakow and Eells, 2019).

5.5.4 Solutions

From a communications perspective, it is important to shift the focus of messages from informing people about the evidence for health benefits of forests to building understanding of why forests are beneficial for health and wellbeing. While mere exposure to forest environments can already set into motion a wealth of beneficial effects including lower stress levels and enhanced resilience, such direct effects are hard to understand intuitively, and cannot be explained by secondary causes, such as exercise or fresh air (Marselle, 2019). Relevant explanations that are not yet broadly known may include immune function support deriving from contact with a biodiverse environment (Rook et al., 2017) or fractal patterns in nature as an easy-to-process input for the human visual/perceptual system that is grounded in human evolutionary history (van den Berg et al., 2016).

From an educational perspective, informal learning through hands-on experiences and teaching practical skills are essential tools for reconnecting people with nature as a basic requirement for overcoming fears and reaping the health benefits of forests. Trends in both educational research and practice encourage outdoor and environmental education in which learning is based on a combination of experiences in forests, community and culture, centring on stories, ecologies, languages, histories and politics embedded in place (Orr, 2004; Cajete, 2012). However, forest-based education remains the exception, as it is often unavailable, costly and/or inaccessible. Therefore, formal recognition and implementation by national educational systems of forest-based learning, cross-generational knowledge transmission and a wider range of outdoor, experiential approaches, would allow greater engagement of school children with forests, leading not only to personal health gains, but long-term connections with nature, place and improved local stewardship.

As the impacts of climate change intensify, a global movement with significant representation from young people has emerged which provides a contemporary model of effective communication and education (Bowman and Pickard, 2021). While this movement has garnered substantial attention from policymakers, the public and youth, forests, are sometimes missing from the messaging. This oversight reflects a persistent lack of comprehension as to the vital role that forests play in human and planetary health. Moving forward, increased time in forests, and intersectoral cooperation is needed to help the public and policymakers appreciate the synergistic effects of forests on climate resiliency, biodiversity protection and human health.

5.6 Response Options Related to Governance and Economics

5.6.1 Introduction

Human health benefits of forests often do not feature strongly, nor explicitly in governance and economics. Instead, other ecosystem services of forests, such as climate change mitigation and adaptation and biomass production, have often been prioritised. If human health benefits are addressed, it is mostly implicitly. At the global level, for example, in the UN Strategic Plan for Forests 2030, Strategic Goal 2 calls for enhancing forest-based economic, social and environmental benefits, including the livelihoods of forest-dependent people (United Nations, 2019). However, the goal mentions food security and clean drinking water but not human health specifically.

The section starts with an introduction to dimensions of governance arrangements relevant to health benefits of forests, followed by a discussion of economic issues and innovations. Possible solutions presented are based on case studies of successful inclusion of health benefits in forest governance and economics.

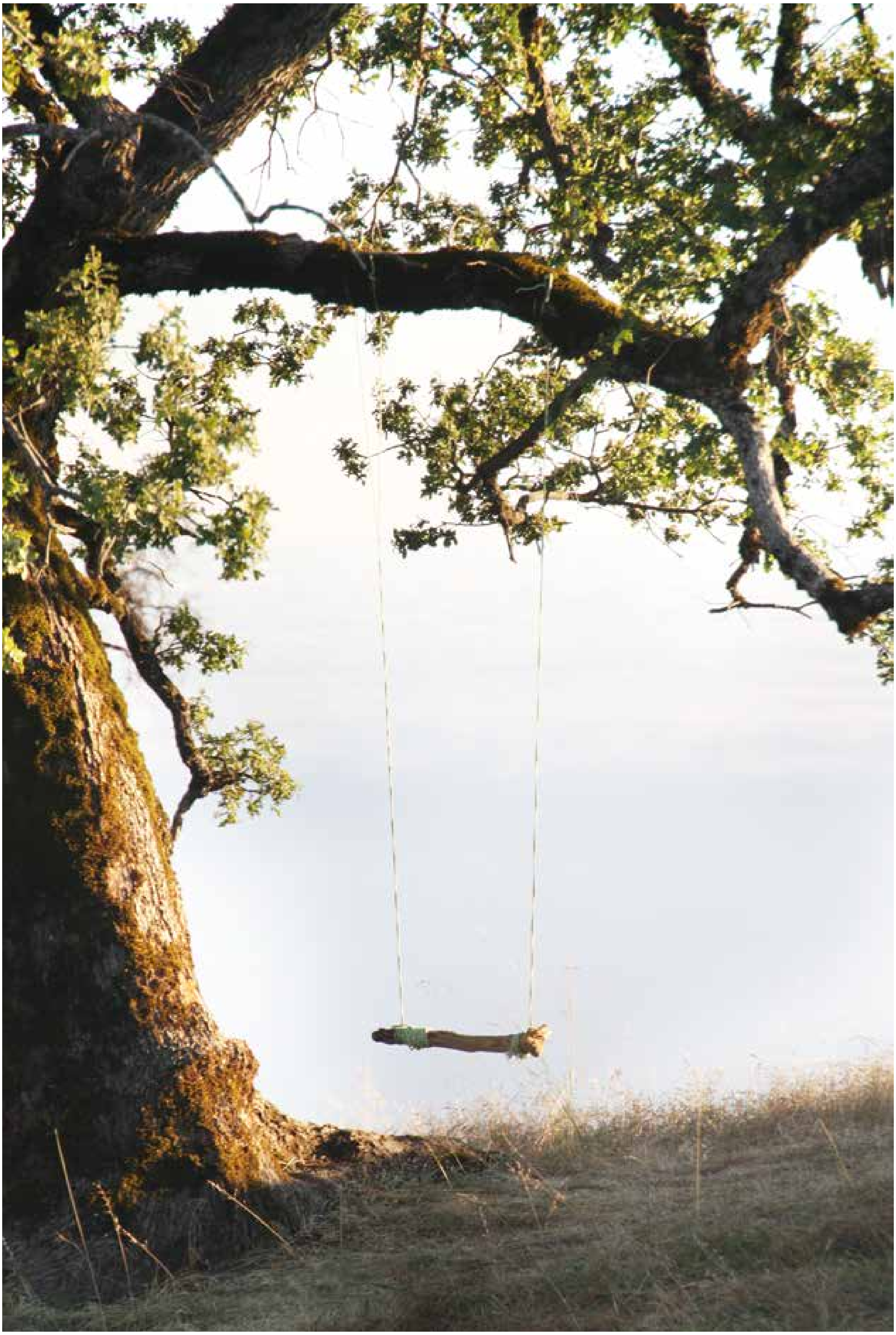
5.6.2 Aspects of governance relevant for health benefits of forests

Governance arrangements involve the dimensions of discourses (i.e., the key narratives under discussion), actors and the alliances they can form, resources (including power) that are mobilised by actors in decision-making, and the rules of the game in terms of the ways in which decision-making is structured (Arnouts et al., 2012). Forest and wider landscape governance are complex, as they involve a wide range of discourses, actors, resources and rules of the game, often at the intersection between forestry and other sectors.

Discourses
With regard to discourses, policies and programmes at different scales highlight the essential contributions of forests, but the links to health are often more indirect or implicit. Forest policies that fully recognise and include health considerations can help with avoiding or minimising potential conflicts and trade-offs, as well as assist with prioritising forests in land-use planning lobal. Globally, the recent Worldwide Fund for Nature (WWF) report on the vital role of forests for human health for all types of communities is a good example of a new discourse that includes the functions of forests for human health (Beatty et al., 2022). In the UK, forest policies specifically highlight human health benefits (Department for Environment Food and Rural Affairs (DEFRA), 2021). Other countries, like China, have also started highlighting the human health benefits of forests, especially in an urban context (Pei et al., 2019). At the local level, one of the key objectives of Melbourne's Urban Forest Strategy is to promote human health and wellbeing. A priority of the strategy is to design urban forests for health and wellbeing, enhancing cooling effects and encouraging the recreational use of public green spaces (City of Melbourne, 2014).

Actors and alliances
The need for more collaboration and coordination between different governance actors is another key issue. Although forest governance has started to include a wider range of actors, there is still a lack of involvement of key actors such as the medical field as well as Indigenous and/or forest-dependent populations. Perhaps the most promising governance approaches along these lines have been developed in urban areas, where the health benefits of urban forests are often prioritised. Here we also see new partnerships and policy alliances emerge that slowly start engaging with the medical field. Examples of this are the green prescription programmes, such as PaRx in Canada (PaRx, 2022) which represent alliances between the medical sector, green space sector and policymakers (James et al., 2019; Kondo et al., 2020). In these programmes, physicians are encouraged to prescribe spending (active) time in nature for different ailments. Similar thoughts are integrated into the regional Natural Health Service programme in the UK (Natural Health Service, 2022) which connects to forestry actors that have started prioritising the health benefits of forests. Increasingly, global policies and programmes are starting to consider urban forests and other green spaces, climate adaptation, public health and biodiversity conservation (WHO, 2016; UNECE, 2021).

Resources
A wide range of government resources needs to be mobilised for the optimisation of forest health benefits, from mainly raising awareness about the health benefits of forests to dedicated policy plans and funding streams, legislations and regulations, and management plans and strategies. When it comes to raising awareness, government agencies



A strong connection to nature enhances human wellbeing
Photo © Nelson Grima

are key actors, but not-for-profit organisations can also play an important role, as demonstrated by the example of The Nature Conservancy (TNC) in the USA (The Nature Conservancy, 2022). As part of its strategic goals for 2030, TNC has included 'Our Nature's Health is our Health' and issued a series of research reviews and policy briefs to inform decision-making at national, regional and local levels (e.g., House et al., 2016). Another example is the Flemish 'Dokter Bos' (Doctor Forest) programme targeted at healthcare institutions and other stakeholders (Bos+, 2022). A key aspect of resources is that of power and power relations, as these determine which discourses are prioritised, who has a say and who takes the decisions. As such, power issues need to be explicitly addressed, also when it comes to including the knowledge and interests of IPLCs.

Rules of the game

A final relevant dimension of governance relates to the rules of the game, i.e., the ways in which decision-making is structured and organised. Currently, forest policies, as well as health and other policies, are often organised sectorally, whereas cross-sectoral approaches may be more appropriate. This implies bringing in actors from other sectors in decision-making, also to foster the new alliances and actor constellations mentioned above. The example of other key forest contributions, such as water, can provide inspiration, where some cross-sectoral governance approaches using regulatory and information instruments have been set up (see Baulenas and Sotirov, 2020, for an example of EU member states). Beatty et al. (2022), in their recent report on the importance of forests to human health, call for systems and collaborative approaches. The authors note that 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. They call for cross-sectoral governance and management approaches, for example, involving agriculture and public health. Urban forest governance in the USA is a true partnership endeavour between the federal, state and local governments, but also not-for-profit organisations such as American Forests. An example of this is the Tree Equity Score tool (American Forests, 2022), which assesses cities for their (non-) equitable provision of access to urban forests, including access to their important health benefits. The involvement of not-for-profit organisations like the ParkRx partnership programme between the forest sector on the one hand, and the medical sector on the other, are other good examples of this effort. As the health of local communities is concerned, mechanisms need to be in place to involve these communities and their interests in governance processes. This also relates to the tenth sustainable development goal (SDG 10) on reduced inequalities within and among countries and greater environmental justice (Basnett et al., 2019) and the recent call for 'tree equity'.

5.6.3 Economic issues and innovations

Governments often overlook the value of their natural resources, typically due to many of these resources not having clear market prices. In many low- and middle-income countries, governments sell or even gift forest land to companies looking to exploit it (Cisneros et al., 2021). The government may receive a one-time payment or some sort of stream of rents from the companies, but the amount often neglects accounting for an assortment of services the forest provides to the wider community. In many areas of the world, deforestation and land use change have been associated with increased disease risks due to loss of services provided by healthy forests such as air and water purification, which may in turn lead to additional health expenses for governments through lost workdays, incurred treatment costs and death (Pattanayak and Wendland, 2007; Pattanayak et al., 2009; Bauch et al., 2015). Additionally, by allowing a company to deforest, governments fail to take into account the extent to which residents rely on the forest for their livelihoods (Miller et al., 2020). Accounting for these neglected values may help to consider forests' real costs and benefits, prompting governments to prioritise forest conservation rather than selling forest land.

A solution to counteract the drivers of deforestation that has grown in popularity in recent years is establishing Payments for Ecosystem Services (PES) schemes. The concept of PES emerged in the early 1990s aiming to integrate the economic value of ecosystem services into market prices. This concept is based on the idea that those in charge of managing landscapes that provide ecosystem services should be compensated by those who benefit from these services (Pagiola and Platais, 2002; Van Hecken et al., 2015). Although compensating stewards of ecosystems for their beneficial land management practices already existed for a long time in different forms, the concept of PES provided the necessary structure to optimise and replicate this idea (Wunder et al., 2008). The initial definitions of PES proved to be limited, and often did not reflect the reality on the ground (Muradian et al., 2013). Consequently, authors have kept revisiting the conceptualisation of PES to provide more suitable definitions based on lessons learnt (Wunder, 2015). Despite the concept of PES being criticised by some authors for putting a price on nature (McCauley, 2006; Peterson et al., 2010; Midler et al., 2015) and for limitations on implementation and outcomes (Schröter et al., 2014), the fact is that PES schemes are a tool widely used by governments, NGOs and private enterprises, which nowadays not only addresses ecosystem degradation, but also aims to improve the socio-economic context of the actors involved (Hayes et al., 2019).

Some PES schemes aim to address the observed lack of balance between high-income (and sometimes middle-income countries) willing to pay for forest conservation, and the many forests with high conservation values and high levels of ecosystem services that tend to be in low-income countries, where residents are often incentivised to cut down forests for agriculture or to harvest from them at unsustainable rates (Milder et al., 2010). PES schemes have the potential to bridge this gap and make both parties better off. However, the established markets are often unclear, and corruption can lead to payments being captured by elites before they reach the local level. Direct and transparent channels are needed between these groups of countries to reach the full conservation potential of PES. Further streamlining of payment channels from governments or private enterprises – both within countries and across countries – to individuals could aid in PES schemes being adopted more widely. Here it is important to also consider individual forest owners and forest managers, as they are often insufficiently rewarded for the health (and other) benefits provided by their forests.

5.6.4 Solutions

Tackling governance issues related to health benefits of forests requires a change in the forest conservation and land-use discourse, as well as collaboration and new alliances between governments, markets and civil society actors, mobilisation of resources, and changes in governance rules of the game. Opportunities exist, for example, linking the health aspects of forests to the discourses that highlight the important role of forests in climate change action, biodiversity conservation, *poverty alleviation* and securing livelihoods. This will require better linking SDG 3 with other SDGs when it comes to forests, strengthening health objectives in global, national, and local forest policies and programmes, as well as bringing forest aspects into public health policies and programmes.

Cross-sectorally, little has been done so far to promote approaches specifically for the health benefits of forests, unlike in other areas such as biodiversity and water. Recent initiatives of the American government that mobilise urban forests to protect vulnerable communities (and workers) from heat can be mentioned (The White House, 2021). This work is supported and implemented by various agencies, including, but not limited to, the US Forest Service, which issued a report on climate adaptation actions for urban forests and human health, explicitly linking several key areas of policy (Janowiak et al., 2021). The report synthesises adaptation actions to address climate change in urban forest management while also promoting human health and wellbeing through nature-based solutions.

From an economics perspective, the lack of consideration of forest health benefits is not unlike that of many other (especially cultural) forest ecosystem services. Currently very few economic assessment methods are in place that include health impacts of forests and trees, apart from some initial attempts to monetise the value of forests and trees in urban contexts. It is important to include health benefits in ecosystem service valuation, as these can be substantial, for urban, rural and forest-dependent communities alike. From a market perspective, PES schemes are one mechanism to address the health benefits of forests, but only a few examples are available, often at a more local level. To date, the focus of PES schemes and subsidies has been mostly on other benefits of forests, such as carbon storage, water protection and biodiversity conservation. PES needs to ensure that forest owners and managers, from public actors to local communities, benefit financially. Box 5.3 provides an example from Italy, based on the phenomenon of ‘forest bathing’ or ‘forest therapy’, which was developed in Japan and other Asian countries where it has become common practice (Hansen et al., 2017; Li, 2018).

For markets to develop, it is important for the green economy around health benefits of forests and trees to mature, based on market outlooks, opportunities, local entrepreneurship and improved knowledge of these benefits. This could be done through the emergence of green entrepreneurs at the interface between forests and healthcare, but also in relation to activities such as forest recreation and tourism. The European Green4Care project has looked into ‘green care’ and prepared a series of European market outlooks for this activity, including forest-based care and urban green care (Green4Care, 2021). Moreover, markets need to be fair and inclusive of the interests of local communities, especially those in low- and middle-income countries.

In summary, good governance and market inclusion of the health benefits of forests, both positive and negative, require full integration of these benefits in all relevant strategies, policies, assessments and markets. Moreover, dedicated initiatives

Box **5.3**

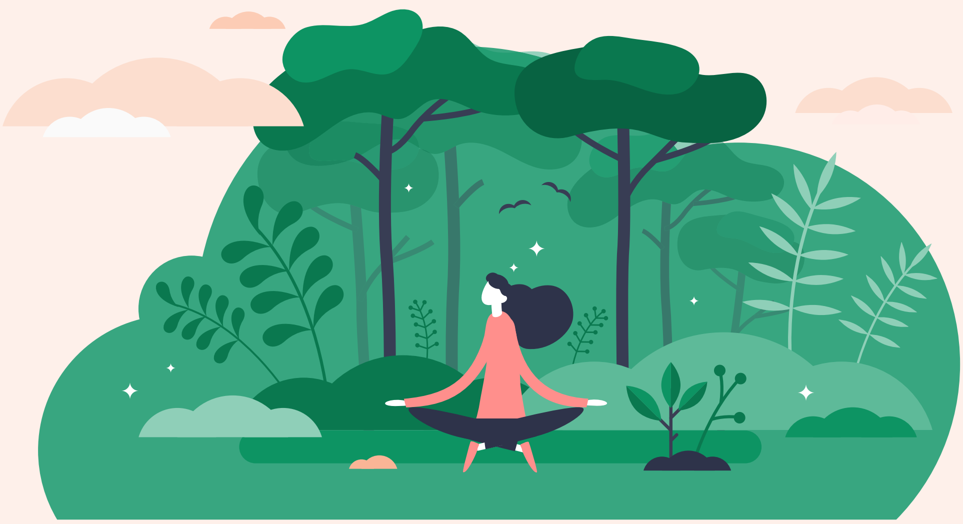
Forest therapy in northern Italy

In 2014, the Terapia Forestale in Friuli Venezia Giulia project was established in the Natisone Valleys of northeastern Italy with financing from the regional government. This forest therapy project aimed to establish a base to attract sustainable health tourism, following the notion that the abundance of nature in the region would have a wide range of psychophysical benefits, in particular regarding anxiety and respiratory issues (Droli et al., 2021). This notion was guided by the outcomes of previous studies and clinical trials stating the health benefits of spending periods of time as short as a week in similar conditions (Saretta et al., 2007)

As part of the project, the association Malin-Mill was created to manage and coordinate the development of activities such as forest bathing, to train local residents to become forest therapy guides, and to investigate the potential of the region for the purpose of health tourism (Malin-Mill, 2022). The association also aims to promote further academic research in the region, such as a study conducted in a path called Cascata di Kot, a short walking route through a broadleaved forest culminating in a waterfall that proved to lower the anxiety levels of its users (Droli et al., 2018).

Public funding of this project is combined with private funding, not only through the in-situ expenditures of tourists, but also through initiatives created by Malin-Mill. One of these initiatives is called Adotta un Sentiero (Adopt a Path), and focuses on channelling donations from the general public into directly maintaining existing historical paths and managing the forests in which these paths are located.

The initial success of the project attracted the attention of further public and private organisations and academic centres (e.g., local governments, universities, health providers), which in turn allowed for further investment and the expansion of the project to the forests of neighbouring municipalities. This expansion included the presentation in 2020 of a full programme of activities named Servizi Ecosistemici per la salute umana (ecosystem services for human health) to be implemented in the region for the period 2021-2023.



are needed that focus on health aspects, inspired by some of the examples provided in this section. Governance, economic assessments and markets need to be inclusive and address the interests and stakes of local communities.

5.7 Conclusions

This chapter has given an overview of the response options available for putting into action the evidence for health benefits of forests, as described in the previous chapters. Five areas for action are distinguished: the management of access; spatial dimensions; design; communications and education; and governance and economics. Across these areas, some common solutions emerge. Perhaps the most crucial of these is the need to explicitly include and acknowledge human health as an important value (or ecosystem service) in the development of visions, plans and other strategic policy documents pertaining to forests. As noted in the section on design, benefits of forests for human wellbeing are still mostly considered in terms of recreation and aesthetic values. However, as this report makes clear, health constitutes a distinct value that cannot be fully optimised by promoting recreational and aesthetic values. To realise the health benefits of forests, national forest management programmes need to undergo transformation from a single lens focus on timber, to a broader focus on the urgent priorities of planetary and human health. This requires updating forestry programmes to include the nutritional, cultural, ecosystem service values and human health benefits offered by forests.

Once health benefits of forests are recognised in strategic plans, the next question becomes: what can be done to (better) realise them? This chapter makes clear that many evidence-based as well as practice-based options are available. However, as noted in the section on governance, putting these options into practice requires a system change in the world of forestry, with more openness to collaboration and new alliances between governments, markets, and civil society actors, mobilisation of resources, and changes in governance rules of the game. Although this represents a major challenge, even small initiatives, like making an animation movie about health benefits of nature (Box 5.2.) can have big impacts and set into motion a train of positive actions. Successful local examples, like the creation of a health-based mangrove park in Malaysia (Box 5.1.) and the forest therapy project in Italy (Box 5.3.) can also inspire similar initiatives in other regions and countries.

While taking the steps towards a new, more health-focused approach to forests, three important and recurrent lessons from this chapter need to be taken into account. First, response options towards optimising the positive impacts of forests on human health should consider and adequately address, possible negative health impacts (e.g., proximity increases the ability to derive health benefits, but at the same time also makes people more vulnerable to risks such as forest fires). Second, it is important to distinguish between different types of populations, and more specifically urban, rural and forest-dependent communities, as these will have different needs and requirements vis-à-vis the forest. Finally, there may be trade-offs between options aimed at managing the health of forests, and options aimed at managing forests for the health of people, that need to be taken into consideration.

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6

Chapter 6

Key Messages and Conclusions

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6.1 Overview

In this chapter, we summarise key findings that have emerged from the GFEP assessment on forests[7] and health and discuss their implications for decision-makers. We identify critical gaps in knowledge that require further research and conclude by reflecting on the future of forest-human health relations in light of contemporary challenges and opportunities, as well as a changing global burden of disease.

This GFEP assessment has highlighted the importance of forests, trees and green spaces for human health in settings and communities across the globe. Urbanisation and a disconnect from nature have contributed to the health challenges faced by society today, such as malnutrition and stress-related morbidity. The global burden of disease has shifted: non-communicable diseases, including mental health problems, are on the rise, while the same can be said for zoonotic diseases as illustrated by the recent COVID-19 pandemic (The Lancet, 2019). In many cases, health challenges are directly or indirectly related to disturbed relations between people and forests, or nature more generally. Logging, forest degradation and fragmentation associated with large-scale agriculture create a launch pad for novel human viruses, improving and altering the habitats of disease vectors (Dobson et al., 2020; Beatty et al., 2022; Chapter 4).

The expert panel has taken a broad view of forest-health relations, defining health in a comprehensive way, and looking at forests, trees outside forests and other green spaces (see Chapter 2). The importance of a more integrative perspective of human health and the health of ecosystems and other beings was stressed in Chapter 2, with the use of novel frameworks such as the One Health perspective.

Forests affect our physical, mental, social and spiritual health in multiple ways, through a range of direct and indirect pathways, as shown in Chapters 2 and 3. Research has identified proven health outcomes of forests for all human life stages, starting from the prenatal stage. A systematic review and meta-analysis of longitudinal epidemiological studies found a strong correlation between increments in green space surrounding homes and reduced all-cause mortality (Rojas-Rueda et al., 2019).

By far, most of the health outcomes are positive, but there are also some negative health outcomes that need to be considered and mitigated. Negative impacts, such as those related to zoonotic diseases, are generally the result of disturbed relationships between forests and people, and a lack of good forest governance and management. The COVID-19 pandemic is a clear illustration of this disturbed relationship (IPBES, 2020; Beatty et al., 2022).

Research to date on the links between forests and health has focused predominantly on high-income countries and urban communities, while much less is known about forest-health relations in low-income countries. In urban areas, proximity and exposure to forests, trees and green spaces in general have been found to be essential for enhancing positive health outcomes. For rural and forest-dependent communities, the pathways by which forests affect health will be different than for urban communities given that their livelihoods are more directly dependent on forests (see Chapter 4). Moreover, forest-dependent communities are more directly affected by forest loss and degradation. Evidence to date has been stronger for some outcomes (e.g., mental health) than for others (e.g., cancer prevention), although that is most likely due to a lack of studies.

Health outcomes of forests are also dependent on the types of forests and forest characteristics. Chapter 4 offered a more in-depth analysis of the role of different forest attributes, also further elaborating on differences between forest-health relations in urban, rural and forest-dependent communities. It showed, for example, that almost a quarter of all new drugs from 1981 to 2019 derived from nature, and another 20% of new drugs were mimicking nature (Chivian, 2002; CBD and WHO, 2015; Newman and Cragg, 2020). This chapter also highlighted the importance of forests in low-income countries and the dependency of many vulnerable communities on forests, also as 'safety nets' during times of crises (FAO, 2020). As forests across the globe are increasingly threatened by urbanisation, climate change, biodiversity loss and other negative trends (FAO, 2022), this role has come under greater pressure. Chapter 4 also discussed a range of synergies and trade-offs between health outcomes and various ecosystem services provided by forests, demonstrating that in many cases health and other services go hand in hand. However, there can also be trade-offs between services and priorities, for example, between recreational uses of forests and tourism, that need to be carefully managed.

This report also offered a series of response options for strengthening the positive health outcomes of forests and trees, while mitigating the

7 All terms that are defined in the glossary of this report (Appendix 1) appear in italics the first time they are mentioned.

negative ones. Chapter 5 in particular discussed ways in which governance, spatial planning, management of access to forests, design, and communications and education can be directed towards improving forest-health relations. This comes at a time when these relations are still insufficiently addressed by decision-makers, in forestry and land use but also in the healthcare sector.

6.2 Key Messages and Implications for Decision-Makers

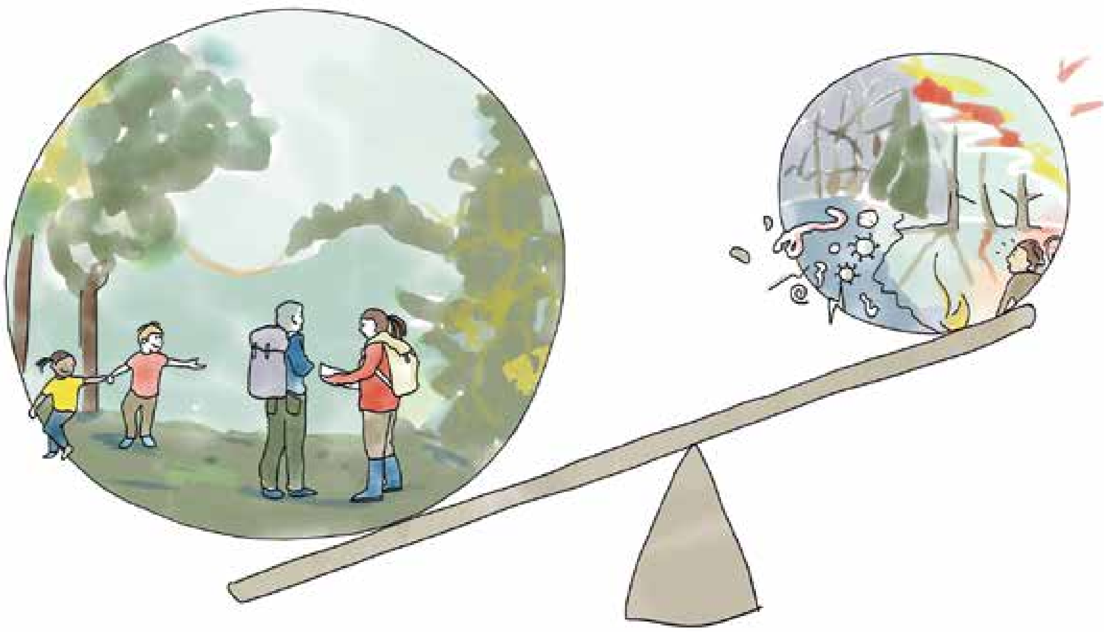
Several key messages that have implications for decision-makers at different scales can be derived from this report (see Table 6.1 for an overview).

KEY MESSAGE 1
Forests, trees and green spaces impact human health across all life stages

A growing body of evidence points to the (mostly positive) impacts of forests, trees and green spaces on human health (Chapter 3). This concerns all life stages, starting from the prenatal stage to the elderly. For example, exposure to green space has been associated with longer telomere length which is associated with slower cellular ageing (Martens and Nawrot, 2018; Miri et al., 2020).

Forests and trees affect our physical, mental, social and spiritual health through the various sub-systems of the human body (e.g., nervous, immune, cardiovascular and digestive systems). They also enhance social interactions and social health, and provide important spiritual benefits. Although all life stages are affected, the significant impacts on children deserve to be highlighted, not least because of repercussions in later life. Medicinal plants from forests and other ecosystems are also an important component of health impacts as they provide primary healthcare to 70% of the world's population (Chapter 4).

Decision-makers from different sectors and at different scales, and specifically those concerned with forests and human health, need to have access to the current knowledge on forest-health outcomes, so that they can integrate this essential role of forests, trees and green spaces in their strategies and policies. Although some initiatives have been taken recently, also at the global level (for example, CBD and WHO, 2015; FAO, 2020; WHO, 2020; FAO, 2022), much more remains to be done.



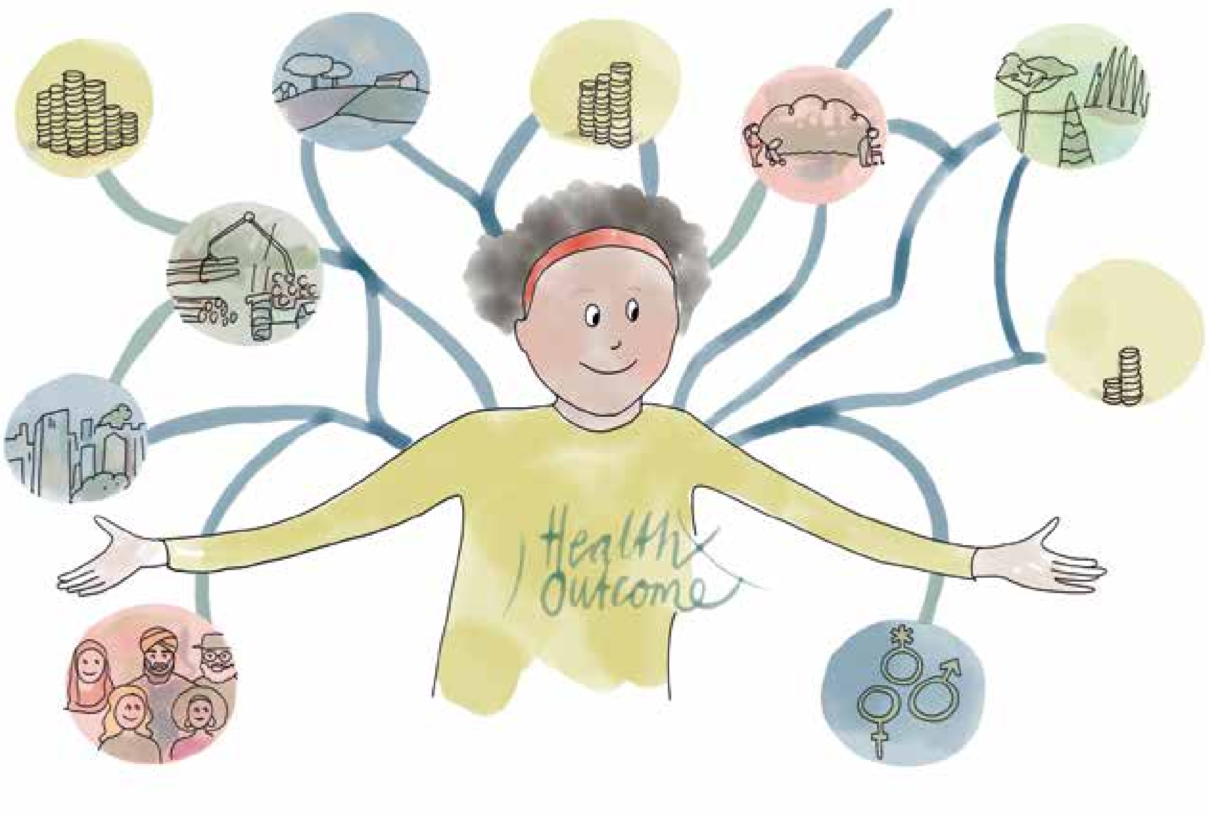
KEY MESSAGE 2
Positive health outcomes of forests, trees and green spaces significantly outweigh negative ones

The evidence collected in this report demonstrates the multiple types of positive benefits that forests, trees and green spaces have on health outcomes. These positive effects range from mental wellbeing, to reduced cardiovascular events and an overall reduction in mortality.

Yet, this report also shows that sometimes forests and trees can have negative effects on human health, for example, through zoonotic diseases, reduced air quality because of forest fires and allergies. Evidence suggests that these negative impacts result in most cases from factors such as the disturbed forest-people relationship, poor forest conservation and management or wrong tree species choices in areas where people live (see also WHO, 2011; CBD and WHO, 2015).

It is clear however, that positive health outcomes from forest interactions far outweigh negative ones, with overall positive effects in terms of reduced mortality and morbidity, improved birth outcomes, and enhanced affect resulting in wellbeing and happiness. Furthermore, where there are negative health outcomes, the underlying causes (e.g., tenure conflict) often generate multiple adverse outcomes on people, well beyond health.

Decision-makers in both the forest and health domains need to understand the extent of the positive outcomes and ensure that they are secured and enhanced through their effective integration into policies and strategies. At the same time, negative impacts need to be managed and minimised, for example through policies and management that conserve healthy forests and promote healthy forest-people relationships. Vulnerable populations are more significantly affected and need to be carefully considered in forest and health policies and management.



KEY MESSAGE 3
The health outcomes of forests are the result of several pathways that are dependent on context and individual lifestyles

Forests and trees affect health through multiple pathways such as physical activity or the relief of stress. All population groups are dependent on forests for human health to some extent but the intensity, the priority pathways and primary health outcomes depend on the context and individual lifestyles. This report has shown that context matters, and that health outcomes of forests and trees are different between low-, medium- and high-income countries, as well as between urban, rural and forest-dependent communities. Differences also occur depending on life stage, cultural background, gender, as well as many other factors. Policies and initiatives to promote positive health outcomes of forests and trees should recognise these differences. Priorities and focus will differ, reflecting the diversity of roles, types of forests, pathways, and so forth.

By better understanding the different pathways, decision-makers can promote opportunities for more vulnerable populations to benefit from forests and trees, and better tailor responses to different population groups – such as increasing green spaces in disadvantaged neighbourhoods.

Key message 4
Forest-health relations offer solutions to global crises

The role that forests play in health outcomes may provide solutions for tackling global crises, notably pandemics and climate change. In times of crises, forests and trees provide important safety nets for vulnerable populations, but climate change, urbanisation, land-use change and biodiversity loss all endanger this important role.

Global health crises, such as the recent COVID-19 pandemic, can have devastating and far-ranging impacts on human societies. The links between forest-health relations and climate change are many and cannot be understated (WHO, 2020; 2022b). In cities, for example, green spaces and trees contribute to cooling the effect of infrastructure, which is especially important as we anticipate more frequent heat waves (Masoudi et al., 2019). Forests across the world are impacted by climate change, resulting in a negative spiral that includes an increase in forest fires and forest degradation, which in turn fuel the climate crisis. Biodiversity loss is another global crisis that can have adverse impacts on human health, for example by affecting food security and more generally on opportunities to be in contact with nature.

In the face of accelerating global trends and challenges, with climate change leading the way, there is an urgency for decision-makers to act. Forests are already an important component of climate change and biodiversity policies at the global and other scales, but there is still a lack of awareness and consideration of complex and important forest-human health relations. Inclusion of the forest-human health link in relevant policies is especially urgent as forests are also directly affected by global change and trends.

Key message 5
Integrative and cross-sectoral approaches need to be adopted to improve the forest-health link

A number of approaches that consider the human-nature relationship in a more inclusive fashion have been recently developed. They include the One Health, Planetary Health and EcoHealth frameworks, all of which stress the need to link human health to the health of other beings, of ecosystems and of the planet as a whole. Such approaches hold the promise of improving the understanding of the human-forest link and its impact on human health.

Policies associated with health and forests, as in other sectors, have often been siloed, failing to properly integrate across disciplines and policy areas. Although consideration of health outcomes has recently emerged in forest policy, wider consideration of the multiple impacts of forests, trees, green spaces and other natural elements, on people has often been lacking.

Forest-health interactions, as highlighted in this report, offer an opportunity to broaden the solution space – in policy, practice and stewardship – both for forest and health management. As healthcare across the world is changing and shifting its focus to more holistic approaches that focus not only on curing but also on preventing ill health, linking health and environment, universal health coverage, and building resilience in human populations (WHO, 2016; 2022a), forests and trees need to be given due consideration in new strategies. Equally, forest policies, conservation and management have to recognise their essential impacts on human health and consider this role as one of the key aspects of forest and tree management.

Wider adoption of One Health, Planetary Health and EcoHealth frameworks by both health and forestry decision-makers can lead to better consideration of forest and health relationships, and the design of more integrative solutions. These frameworks can also help with gaining more in-depth understanding of complex forest-health relationships, for example by guiding new research. More cross-sectoral policies and initiatives can build on past efforts to link human health, biodiversity (with forests and trees as important elements) and climate change (WHO, 2011; CBD and WHO, 2015; FAO, 2020). For forestry, as well as other disciplines and sectors that manage trees and green spaces, better consideration of health impacts can result in increased preservation and multi-targeted management of forests, trees and green spaces.

Table **6.1**

Summary table of key messages on forest-health outcomes and implications for decision-makers

Key message	Implications for decision-makers	Chapter reference
1. Forests, trees and green spaces impact human health across all life stages By bringing together the evidence and considering both direct and indirect pathways, it is clear that forests affect human health in multiple ways, through various sub-systems of the human body (e.g., nervous, immune, cardiovascular and digestive systems) and across all life stages.	Decision-makers should recognise the multiple roles of forests and trees in promoting human health across life stages, and they should integrate this role into forest, land use and health policies and management.	Chapters 3, 4
2. Positive health outcomes of forests, trees and green spaces significantly outweigh negative ones Positive health outcomes far outweigh negative health outcomes of forest interactions, with overall positive effects on reducing mortality and morbidity, improving birth outcomes and overall wellbeing and happiness.	Decision-makers should promote and enhance the positive health outcomes of forests and trees, while minimising and managing potential negative impacts especially on vulnerable populations.	Chapter 3
3. The health outcomes of forests are the result of several pathways that are dependent on context and individual lifestyles The intensity, the priority pathways and primary health outcomes of forests depend on context and individual lifestyles, but all population groups and communities are dependent on forests for their health to some extent.	When taking action and developing policies, decision-makers should take into account that forest-health relations will depend on contexts, lifestyles and socio-demographics.	Chapters 2, 3, 4

4. Forest-health relations need to be considered when dealing with global crises The acceleration of negative global trends and challenges, including climate change and pandemics, alters and intensifies the importance of forest-human health relations, and requires urgent action.	Decision-makers should acknowledge the critical role of forest-health relations in tackling global challenges and crises. They also need to be aware that this role is in turn impacted by challenges such as climate change.	Chapters 1, 2, 4
5. Integrative and cross-sectoral approaches need to be adopted to improve the forest-health link Integrative and cross-sectoral approaches that apply One Health / Planetary Health / EcoHealth perspectives can lead to better consideration of the forest-health relationship. Forest-health interactions offer an opportunity to broaden the solution space – in policy, practice and stewardship – both for forest and health management.	Decision-makers in forest, health and related domains should adopt more integrative perspectives for addressing forest-human health relations. By linking forest and human health policies and strategies, new and innovative solutions can be identified.	Chapters 2, 4, 5

6.3 Research Priorities and Knowledge Gaps

Although more is known today about a wide range of forest-human health outcomes, there are also many knowledge gaps. The evidence base on specific health impacts is growing, but remains fragmented. For example, there is more evidence for green spaces (in cities in particular, such as urban parks) than for forests per se. This GFEP assessment revealed a number of priority research needs. Table 6.2 provides an overview of the most pressing research priorities and associated questions, grouped under five overall themes.

Research priority 1
Developing rigorous methods and studies

Many of the direct and indirect pathways that link forests to human health outcomes need more investigation. Moreover, causality rather than correlations needs to be confirmed (see Appendix 2). Finding innovative and viable solutions to enhance the positive health outcomes of forests will also require knowing the impact of different forest types and characteristics, in different contexts. To do this, more robust research designs are needed as well as different types of research designs given the complexity of forest-health relations. For example, in light of the rise of reforestation and afforestation projects, it would be valuable to have more experimental studies including so-called natural experiments where the health impacts of new afforestation or greening projects can be studied.

Research priority 2
Studying different populations and contexts

Not all populations, life stages and forest contexts have been equally well studied when it comes to forest-health outcomes. There are major gaps for specific health outcomes as well as pathways. We still know very little, for example, about spiritual health benefits of forests and trees. Urban contexts have so far been much better studied than rural and forest-dependent ones, and the evidence base is much stronger for most health outcomes in high- rather than low-income countries. Particular groups, such as Indigenous communities and vulnerable groups, should be given more attention in future research. Studies are needed that explore individual versus community-level health outcomes.

Research priority 3
Strengthening the valuation, assessment and sharing of health benefits (and costs)

Sound valuation and assessment methods of forest-health outcomes are an essential part of decision-making. Assessment methods should include health impact assessments of forests, trees and greening projects. Valuations and assessments will also provide an important background for the equitable sharing of health benefits (and costs) and need to consider full costs and benefits, expressed in monetary or other terms.

Research priority 4
Broadening the scope

Applying more holistic One Health, Planetary Health or similar frameworks should also guide research, so that studies of human health can be linked to research on species and ecosystem health. A more integrative perspective will contribute to studying the crucial climate-forest-health nexus – an area where research has still been limited. Understudied topics, such as the role of medicinal plants and aspects of spiritual health, need to be added to research agendas. Also of importance is understanding the linkages between forest and landscape management and zoonotic diseases.

Research priority 5
Strengthening the science-policy interface

Research and new evidence underscore effective policymaking related to both forests and health, providing the evidence base to steer guidelines and norms. The science-policy interface needs strengthening, based on a more holistic view of forest-health outcomes. Not only do we need to know "what works" in terms of positive health outcomes, but also what does not work (and can potentially generate negative impacts). The relationship between health outcomes and other forest impacts needs to be studied, notably in terms of synergies and trade-offs. Importantly, research can help identify barriers as well as possible facilitators of response options (e.g., policy priorities, funding, institutions, land use, legislation, amongst others) that enhance positive health outcomes and mitigate negative ones.

Table 6.2

Research priorities and key questions related to forest-health outcomes

Research priority	Some key questions
Developing methods and studies	• How can we design studies to learn more about different direct and indirect pathways (and their suitability for health promoting activities), including determining pathway causality (e.g., what is the causal relationship between disease and exposure) and dealing with residual confounding factors? • What are the respective contributions of different forest types and forest characteristics to different health outcomes? • How can the health outcomes of different measures and interventions be properly assessed? • How can more tangible exposure measures be included in research? • How can natural experiments be used in research, for example actual cases of greening or green loss? • How can longitudinal studies, cross-scale studies and intervention studies be designed in different contexts? • Which design methods would best identify critical thresholds in forest-health relationships?
Studying different populations and contexts	• What are the differences in outcomes and pathways between high-, medium- and low-income countries? • What is the relative, context-dependent importance of different pathways? • How do forest-health outcomes affect Indigenous communities? • How can research better inform inclusiveness of vulnerable groups? • How do different worldviews and relationships with nature affect health outcomes, for example in relation to mental and spiritual health? • How do individual and community benefits compare?
Strengthening valuation, assessment and sharing of health benefits (and costs)	• What types of health impact assessments and economic valuations of health benefits and costs can be carried out to support decision-making? • How can the results of valuation studies be best included in forest and health decision-making?

	• What are the synergies and trade-offs between forest-health outcomes, but also between health outcomes and other impacts of forests? • How can access and benefit sharing be promoted to enhance health equity?
❥ Broadening the scope	• How can One Health and other integrative frameworks, guide research, for example, to link ecosystem and species health to human health (e.g., in relation to biodiversity, forest health, the role of micro-organisms)? • What is needed to promote joint research programmes across the climate, forest and health disciplines? • How can research on spiritual health in relation to forests improve broader knowledge and decision-making on health? • How do different landscape management types affect outbreaks of zoonotic diseases? • What can be done to develop a more comprehensive knowledge base on medicinal plants, both at the regional and global level?
❥ Strengthening the science-policy interface	• How can research better inform the development of guidelines and norms, and more evidence-based planning and management in forests and health? • How can we deal with the mismatch between demand and supply of positive health outcomes of forests in different contexts? • How do we generate more knowledge on what does not work in terms of forest-health relations? • How can research inform the carrying capacity of different forests in terms of health outcomes? • What are the barriers and facilitators (e.g., related to policy priorities, funding, institutions, land use, legal aspects) to options that aim to enhance positive health outcomes and mitigate negative ones?

6.4 Transformations towards Integrative Policies and Initiatives for Forest-Health Outcomes

In a world that is one third covered in forests – where forests and trees play a critical role in the maintenance of planetary life-support systems such as pollination services, carbon and nutrient cycling, food production and medicinal plants - forests and human health are inextricably linked. As a result, much more should be done to promote positive health impacts of forests and trees, while mitigating negative ones. In order to do this in a meaningful, impactful and equitable manner, the combined efforts of the forestry, land use and healthcare sectors are needed. Holistic frameworks such as the One Health, Planetary Health and EcoHealth perspectives can all guide these efforts and ensure that the essential links between human health, the health of other beings, forest ecosystem health, as well as that of the planet as a whole, are recognised.

As new strategies are rolled out to foster healthy forest-people relations it is important to apply cross-sectoral and transdisciplinary approaches. Health professionals should just as much be part of forest-health initiatives as foresters and other natural resource professionals. Forest-health outcomes need to be much better integrated into health, forest and land use policies and programmes. Specific attention should be given to the climate-forest-health nexus, as climate change, forest health and human health are closely intertwined.

Opportunities exist to make better connections with other global and policy initiatives that focus on health and forests. The latter includes the work within the Convention on Biological Diversity (CBD), where links between biodiversity and human health have been specifically highlighted and addressed (CBD, 2022). The two-way link between the forest-health relationship and the Sustainable Development Goals (SDGs) is fundamental and bringing it to the fore can help to accelerate implementation of both agendas.

As the world is facing numerous planetary challenges, this report provides decision-makers with a sound knowledge base of available scientific evidence on forest-health linkages, as well as identifying priorities to foster transformation towards more integrative policies and initiatives. Forests, trees and green spaces are essential to our health and wellbeing and much can be gained from developing stronger and more positive relations between people and forests, while also enhancing the health of ecosystems and the many other species with which we share this planet.

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Appendix I
Glossary

Adaptation (in relation to climate change impacts)

In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2022).

Afforestation

Establishment of forest through planting and/or deliberate seeding on land that, until then, was not classified as forest (FAO, 2010). According to the definition used by the UNFCCC, afforestation can take place on land that has not been covered by forest for at least 50 years.

Agroforestry

A collective name for land use systems and practices in which woody perennials are deliberately integrated with crops and/or animals on the same land management unit. The integration can be either in a spatial mixture or in a temporal sequence (World Agroforestry Centre, 2017). There are normally both ecological and economic interactions between woody and non-woody components in agroforestry (Leakey, 1996; Leakey and Simons, 1998).

Anthropocentrism (also 'anthropocentric')

Valuing nature because of material or physical benefits it can provide for humans (Thompson and Barton, 1994)

Biodiversity (= Biological diversity)

The variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems (CBD, 1992).

Climate change

A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use.

Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition and climate variability attributable to natural causes (IPCC, 2022).

Disability-Adjusted Life Years (DALYs)

The World Health Organization (WHO) defines DALYs for a health condition or disease as "the sum of the years of life lost to due to premature mortality (YLLs) and the years lived with a disability (YLDs) due to prevalent cases of that disease or health condition in a population" (WHO online).

Deforestation The conversion of forest to another land use, or the long-term reduction of the tree canopy cover below the minimum 10% threshold (FAO, 2010).

Explanatory notes:

- Deforestation implies the long-term or permanent loss of forest cover and implies transformation into another land use. Such a loss can only be caused and maintained by a continued human-induced or natural perturbation.
- Deforestation includes areas of forest converted to agriculture, pasture, water reservoirs, and urban areas.
- The term specifically excludes areas where the trees have been removed as a result of harvesting or logging, and where the forest is expected to regenerate naturally or with the aid of silvicultural measures.
- Deforestation also includes areas where, for example, the impact of disturbance, overutilisation, or changing environmental conditions affects the forest to an extent that it cannot sustain a tree cover above the 10% threshold (FAO, 2001).

Degradation See 'Forest degradation' and 'Land degradation'.

Ecocentrism Acknowledging the intrinsic value of “non-human” nature and ecosystems and not for the potential services they provide to human beings (Batavia and Nelson, 2017).

EcoHealth An approach that is committed to fostering the health of humans, animals, and ecosystems and to conducting research which recognizes the inextricable linkages between the health of all species and their environments (EcoHealth Journal Online).

Ecological resilience The ability of a system to absorb impacts before a threshold is reached where the system changes into a different state (Gunderson, 2000). See also 'Resilience'.

Ecosystem A dynamic complex of plant, animal, and micro-organism communities and their non-living environment interacting as a functional unit (CBD, 1992).

Ecosystem (or ecological) functions All of the physical, chemical, and biological actions performed by organisms within ecosystems. Some of these functions are ecosystem services, including production, pollination, nutrient cycling (e.g., decomposition, N2-fixation), and carbon storage that directly benefit humans (MEA, 2005). Other examples include photosynthesis, predation, scavenging, and herbivory.

Ecosystem restoration The process of managing or assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed as a means of sustaining ecosystem resilience and conserving biodiversity (CBD, 2016).

Ecosystem services Ecological processes or functions having monetary or non-monetary value to individuals or society at large (i.e., the benefits people obtain from functioning ecosystems). These include i) provisioning services such

	as food, water, timber, and fibre; (ii) regulating services that affect climate, floods, disease, wastes, and water quality; (iii) cultural services that provide recreational, aesthetic, and spiritual benefits; and (iv) supporting services such as soil formation, photosynthesis, and nutrient cycling (MEA, 2005).
Endemic	A disease that is consistently present but limited to a particular region, for example, malaria (CDC online).
Epidemic	An unexpected increase in the number of disease cases or behaviours in a specific geographical area, for example West Nile virus and obesity (CDC online).
Epidemiology	The study and analysis of the distribution (who, when, and where), patterns and determinants of health and disease conditions in a defined population (Porta, 2014).
Equality (and its opposite: Inequality)	The ‘sameness’ of a distribution of attributes, such as income or consumption, across a whole population (i.e., the state of being equal) (Haughton and Khandker, 2009; Harris and Nisbett, 2018). A popular measure of (in)equality is the Gini coefficient, which ranges from 0 (perfect equality) to 1 (perfect inequality), but is typically in the range of 0.3 to 0.5 for per capita expenditures.
Equity (also its opposite: 'Inequity')	Refers to how capabilities (e.g., access to health, education, and good nutrition) are distributed within a certain group of individuals (Mora and Muro, 2018). Inequity is the unequal distribution of capabilities (Sen, 1999).
Food security (also its opposite ‘food insecurity’)	A situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO et al., 2014). In contrast, ‘food insecurity’ exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development, and an active and healthy life. It may be caused by the unavailability of food, insufficient purchasing power, inappropriate distribution, or inadequate use of food at the household level. Food insecurity may be chronic, seasonal, or transitory (FAO et al., 2014).
Forest	Land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use (FAO, 2010). Forests include both natural forests (sensu CPF, 2005) and planted forests (sensu FAO, see below). It also includes areas temporarily unstocked, e.g., after disturbance, that are expected to revert back to forest.
Forests, trees and green spaces	For the purposes of this report defined as “forests and land, partly or completely covered with trees, shrubs, grass or other vegetation, including parks, street tree plantings, community gardens and cemeteries, but also rooftop gardens and vertical gardens, meadows and woods”.
Forest conversion (also ‘conversion of forests')	For the purposes of this report defined as “Clearance of natural forests for other land uses, such as plantations, agriculture, pasture for cattle settlements, mining, and infrastructure/urban development.” This process is usually irreversible.

Forest degradation	Changes within the forest which negatively affect the structure or function of the stand or site, and thereby lower the capacity to supply products and/or services (FAO, 2001, 2010). Also, when a forest delivers a reduced supply of goods and services from a given site and maintains only limited biological diversity; it has lost the structure, function, species composition, and/or productivity normally associated with the natural forest type expected at that site (ITTO, 2002).
Forest-dependent (-reliant) people (also 'communities')	For the purposes of this report, defined as "People that have a direct relationship with forests and trees and live within or adjacent to forested areas, and rely on them for their subsistence and/or income".
Forest fragmentation	For the purposes of this report, defined as "Any process that results in the conversion of formerly continuous forest into patches of forest separated by non-forested lands".
Forest health	Forest health can be defined as a condition of forest ecosystems that sustains their complexity and resilience while simultaneously providing for human needs (O'Laughlin et al., 1994; Teale and Castello, 2011).
Forest management	The processes of planning and implementing practices for the stewardship and use of forests and other wooded land, aimed at achieving specific environmental, economic, social, and/or cultural objectives. Includes management at all scales such as normative, strategic, tactical, and operational level management (FAO, 2004).
Forest plantation	Forest stands established by planting and/or seeding in the process of afforestation or reforestation. They are either of introduced species (all planted stands), or intensively managed stands of indigenous species, which meet all the following criteria: one or two species at plantation, even age class, regular spacing (FAO, 2004). (See also 'Plantation forest')
Forest resource	Those resources found in forests and other wooded land, and as trees outside forests (FAO, 2004).
Forest restoration	See 'Restoration of forests'
Forest services	Ecosystem services derived from forests.
Forest-based (or '-related livelihood)	For the purposes of this report, defined as "Deriving all or part of one's livelihood from the use of resources from forests and trees".
Governance	Interactive processes through which society, the economy, and the environment are steered towards collectively negotiated objectives (Ansell and Torfing, 2016). The concept includes the formation and stewardship of both formal and informal rules that regulate the public, market, and civil society actors that make and implement them (Hydén and Mease, 2004).
Health	Health is a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity (WHO, 1946).
High-Income Countries (HIC)	A group of countries classified as high income based on gross national income estimates using the World Bank Atlas method (World Bank, 2023). High-income economies are currently defined as those with a GNI per capita of USD 13,205 or more in 2023 (See also 'Low- and Middle-Income Countries')

Human wellbeing	An individual's experience of their life as well as a comparison of life circumstances with social norms and values (WHO, 2012a).
Illegal logging	For the purposes of this report, defined as: Practices of harvesting trees inconsistent with the national and subnational law.
Landscape	Area in which entities, including humans, interact according to rules (physical, biological, and social) that determine their relationships (Sayer et al., 2013). The European Landscape Convention defines 'landscapes' as part of the land, as perceived by local people or visitors, which evolves through time as a result of being acted upon by natural forces and human beings (ELC, 2000).
Life-course approach	Key stages in people's lives have particular relevance for their health. The life-course approach is about recognizing the importance of these stages (WHO, 2011).
Livelihood	The assets (natural, physical, human, financial, and social capital), activities, and access to them (mediated by institutional and social relations) that together determine how an individual or household makes a living (Scoones, 1998). This definition emphasises means rather than outcomes of making a living, whereas poverty is typically an outcome measure of livelihood performance (Sunderlin et al., 2005).
Local knowledge (also Indigenous Technical Knowledge, Traditional Knowledge (TK), Indigenous Technical Knowledge (ITK), Local Knowledge (LK), and Indigenous Knowledge System (IKS))	See 'Traditional ecological knowledge'
Low- and Middle-Income Countries (LMIC)	A group of countries classified as low-income or middle-income based on gross national income per capita estimates using the World Bank Atlas method (World Bank, 2023). Low-income economies are currently defined as those with GNI per capita of USD 1,085 or less. Middle-income countries consist of two groups: lower middle-income countries with a GNI per capita between USD 1,086 and USD 4,255 and upper middle-income countries with a GNI per capita between USD 4,256 and USD 13,205. (See also High-Income Countries)
Mitigation (of climate change)	A human intervention to reduce emissions or enhance the sinks of greenhouse gases (IPCC, 2022).
Morbidity	Refers to having a disease or a symptom of disease, or to the amount of disease within a population (National Cancer Institute online).
Mortality	Refers to death rate, or the number of deaths in a certain group of people in a certain period of time (National Cancer Institute online)..
Non-Timber Forest Product	see 'Non-Wood Forest Product'

Non-Wood Forest Product (NWFP) (also 'non-timber forest products (NTFP)')	All biological materials other than wood, which are extracted from forests, other wooded land and trees outside forests for human use. In addition to trees, forest products are derived from all plants, fungi, and animals (including fish) for which the forest ecosystem provides habitat (FAO, 2008).
Normalised Difference Vegetation Index (NDVI)	A remote-sensing based method that quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs) (NASA website, 2000).
One Health	An integrated, unifying approach that aims to sustainably balance and optimise the health of people, animals and ecosystems (OHHLEP, 2021).
Pandemic	An epidemic occurring worldwide, or over a very wide area, crossing international boundaries and usually affecting a large number of people (CDC online).
Payments for ecosystem (or environmental) services (PES)	A type of economic compensation (monetary or otherwise) offered to ecosystem managers as an incentive to apply practices that increase or maintain the flow of goods and services provided by the land they manage (Grima et al., 2018). These incentives are typically provided by those who benefit from environmental services, including local, regional, and global stakeholders, but can also come from other sources such as tax revenues.
Planetary boundaries	Limits to self-regeneration of planetary resources and global ecosystems in response to human resource use and modification (Rockström et al., 2009).
Planetary Health	The achievement of the highest attainable standard of health, wellbeing, and equity worldwide through judicious attention to the human systems – political, economic, and social – that shape the future of humanity and the Earth's natural systems that define the safe environmental limits within which humanity can flourish (Whitmee et al., 2015).
Plantation forest	Planted forests that have been established and are (intensively) managed for commercial production of wood and non-wood forest products, or to provide a specific environmental service (e.g., erosion control, landslide stabilisation, windbreaks) (Carle and Holmgren, 2003). (See also 'Forest plantation')
Poverty alleviation	A lessening of deprivation or disadvantage such that wellbeing is improved. This lessening may include movement above a certain income or consumption threshold, such as international or country-specific poverty lines (termed 'poverty reduction' or 'poverty elimination'). It may also include a lessening in the degree of poverty experienced or avoiding falling into poverty (termed 'poverty mitigation') (World Bank, 2001).
Public health	The art and science of preventing disease, prolonging life, and promoting health through the organised efforts of society (Acheson, 1988).
Quality of Life	An individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns (WHO, 2012b).

Randomised Controlled Trial	A form of scientific experiment used to control factors not under direct experimental control, thereby reducing bias and providing the highest possible level of evidence (Concato et al., 2000).
Reforestation	Re-establishment of forest through planting and/or deliberate seeding on land classified as forest after a temporary period (< 10 years) during which there was less than 10 percent canopy cover due to human-induced or natural perturbations (FAO, 2010). According to the definition used by the UNFCCC, reforestation can occur on land that was forested but that has been converted to non-forested land.
Resilience	The capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganising in ways that maintain their essential function, identity and structure. Resilience is a positive attribute when it maintains capacity for adaptation, learning and/or transformation (Arctic Council, 2016).
Restoration of forests	For the purposes of this report defined as: Management applied in degraded forest areas which aims to assist the natural processes of forest recovery in a way that the species composition, stand structure, biodiversity, functions, and processes of the restored forest will match, as closely as feasible, those of the original forest.
Social-ecological systems	Systems in which the interrelation and interdependence between social and ecological subsystems is explicitly acknowledged and subject to feedbacks (Ostrom, 2009).
Sustainable forest management	A dynamic and evolving concept. Aims to maintain and enhance the economic, social, and environmental values of all types of forests, for the benefit of present and future generations. The seven thematic elements of sustainable forest management are: (a) extent of forest resources; (b) forest biological diversity; (c) forest health and vitality; (d) productive functions of forest resources; (e) protective functions of forest resources; (f) socio-economic functions of forests; and (g) legal, policy, and institutional framework. The thematic elements are drawn from the criteria identified by existing criteria and indicators processes, as a reference framework for sustainable forest management (UN, 2007).
Tenure	Systems of tenure define and regulate how people, communities, and others gain access to land, fisheries, and forests. These tenure systems determine who can use which resources, for how long, and under what conditions. The systems may be based on written policies and laws, as well as on unwritten customs and practices (FAO, 2012).
Traditional Ecological (or forest-related) Knowledge (TEK)	The knowledge that an Indigenous (local) community accumulates over generations of living in a particular environment. This definition encompasses all forms of knowledge – technologies, know-how skills, practices, and beliefs – that enable the community to achieve stable livelihoods in their environment. A number of terms are used interchangeably, including Indigenous Knowledge (IK), Traditional Knowledge (TK), Indigenous Technical Knowledge (ITK), Local Knowledge (LK), and Indigenous Knowledge System (IKS). It is unique to every culture and society, and it is embedded in community practices, institutions, relationships, and rituals. It is rooted in a particular community and situated within broader cultural traditions (UNEP, 2008).

Urban area For the purpose of this report, an urban area (or urban agglomeration) is defined as "a human settlement with a high population density and infrastructure of built environment (all structures built by man to support human activity (Portella, 2014))".

Urban Heat Island An urban or metropolitan area that is significantly warmer than its surrounding rural areas due to human activities (Oke, 1973).

Zoonotic disease, zoonosis A disease or infection that is naturally transmissible from vertebrate animals to humans (WHO online, 2020).

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