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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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:

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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.

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Content Editor

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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

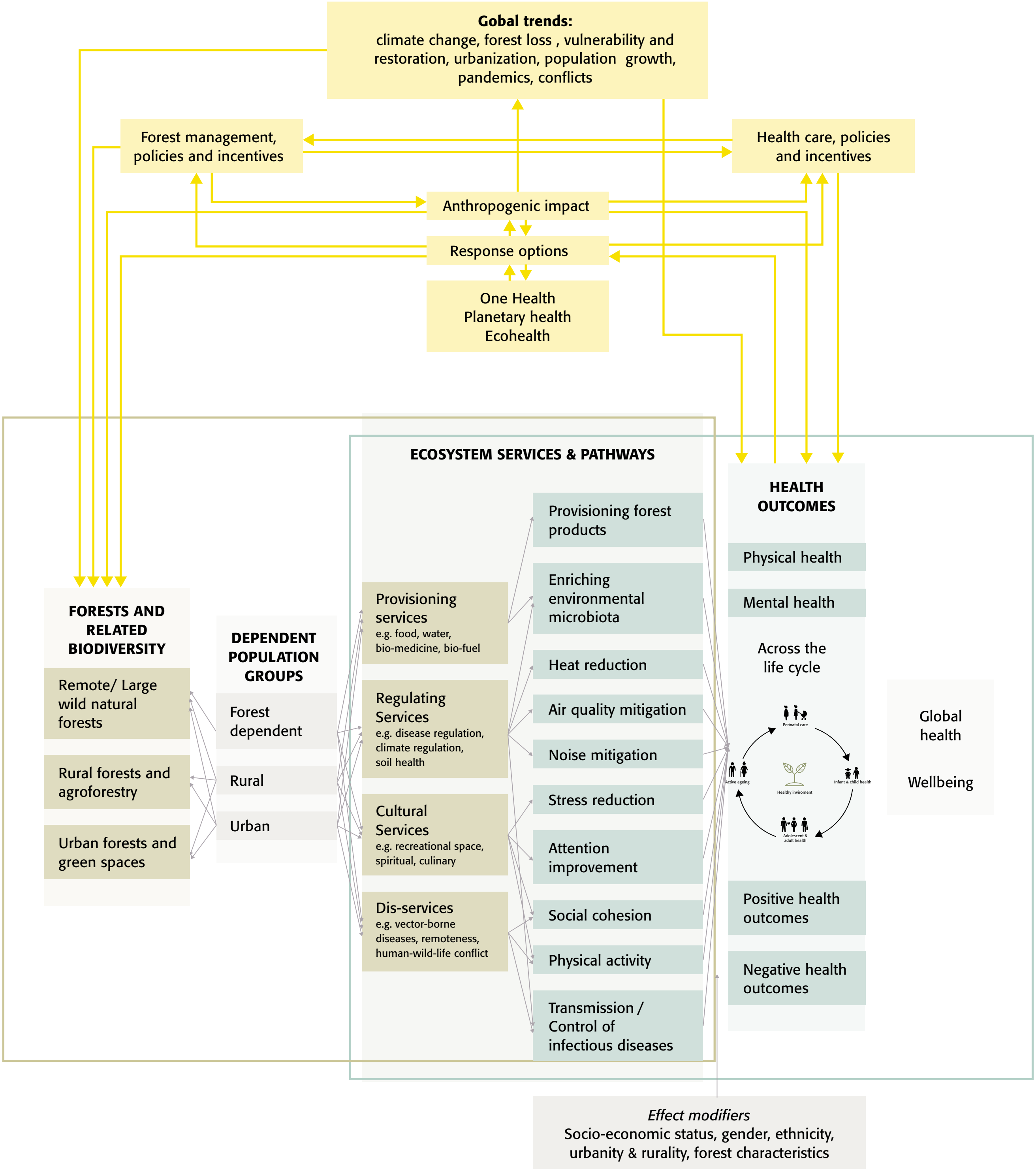
A boy and a girl sitting on a tree stem in the forest on a sunny summer day
Photo © Olya Humeniuk

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.

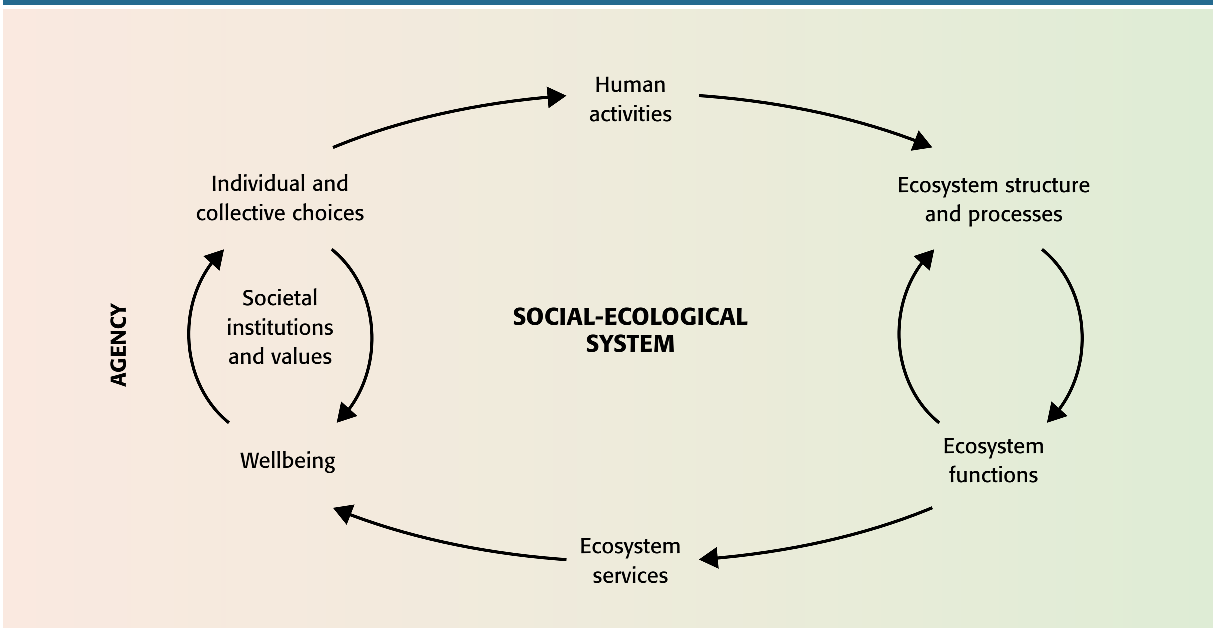
2.6 Human Health and The Environment - Central Frameworks and a Systems Approach

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).

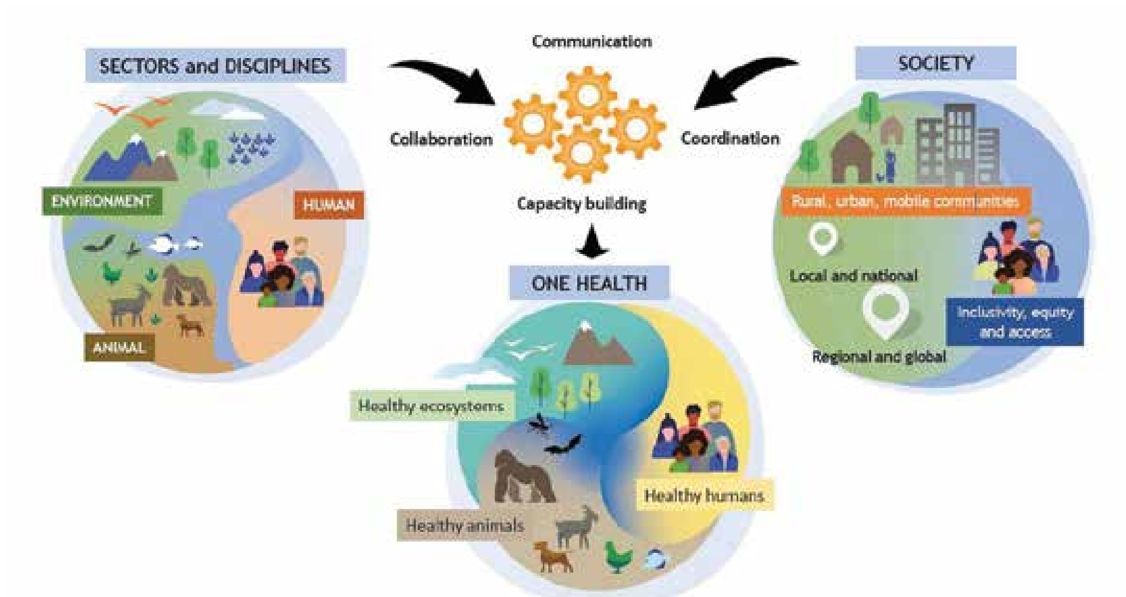
The concept emphasises the consequences, responses and actions at the ecosystem-animal-human interface, for emerging and *endemic zoonoses*. Responsible for a greater burden of disease in the low- and middle-income countries, these zoonoses cause major social implications in resource-poor settings and 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).

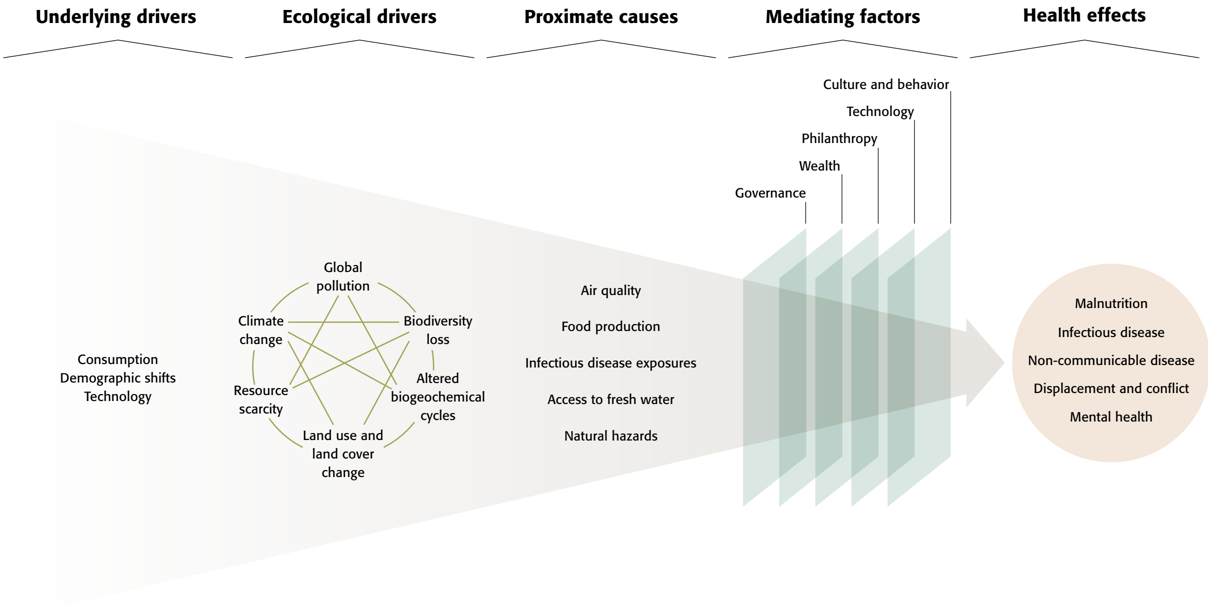
Each of these dimensions interacts with the others in complex ways, altering the quality of air, water, food and the habitability of the planet. Changing environmental conditions also alter exposures to infectious diseases and natural hazards such as heat waves, droughts, floods, fires and tropical storms. 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.

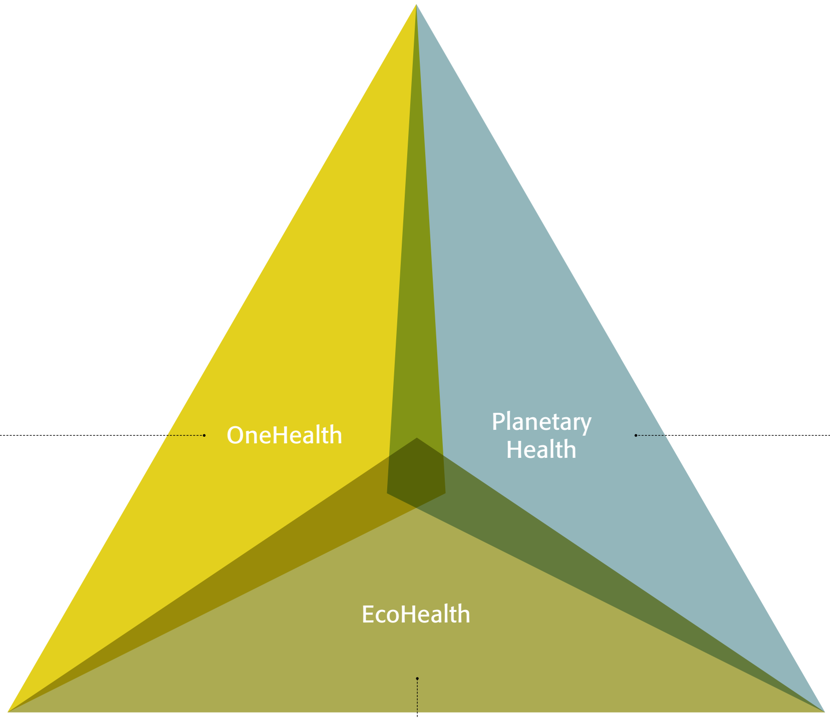
In this report, we build on resilience thinking as part of a pragmatic systems approach to better engage in complex contexts of forests-human health interactions. We thereby consider for example critical dynamics and vulnerabilities of forest-human health relationships (see Chapter 4 for further details), 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	EcoHealth	Planetary Health
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.	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.	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

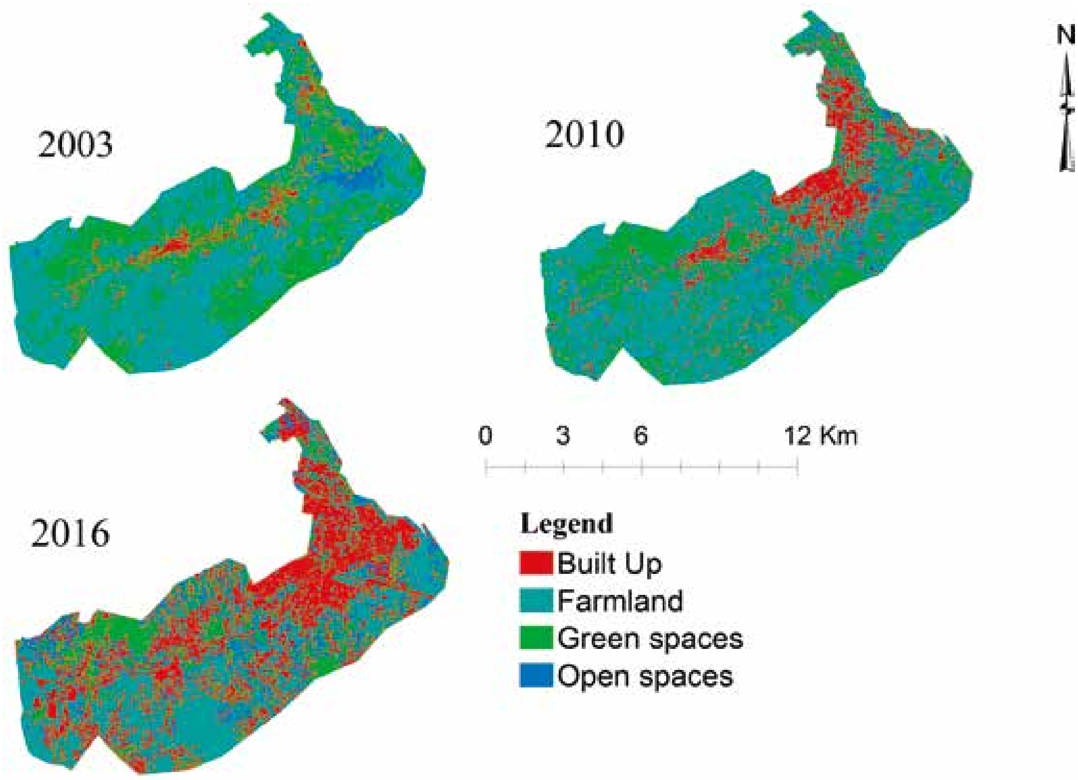
2.7.1 Disconnect between humans and forests

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 man-made 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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