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Invited background document on biodiversity and health for the Global Sustainable Development Report 2019 drafted by the Independent Group of Scientists

Jiska van Dijk, David Carss, Hans Keune, Suvi Vikström, Lucette Flandroy, Graham Rook, Tari Haahtela, Marion Mehring,
Barbara Birzle-Harder, Friederike Reuss, Ruth Müller, Sandra Luque,
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Abstract

Van Dijk, J., Carss, D., Keune, H., Vikström, S., Flandroy, L., Rook, G., Haahtela, T., Mehring, M., Birzle-Harder, B., Reuss, F., Müller, R., Luque, S. & Rodrigues, J.G. 2019. Invited background document on biodiversity and health for the Global Sustainable Development Report 2019 drafted by the Independent Group of Scientists. NINA Report 1555. Norwegian Institute for Nature Research.

The key findings and key messages from the regional assessment for Europe and Central Asia of the interlinkages between health and biodiversity are given in this background paper, as an overview of the main conclusions in this field. In addition, this paper highlights the links between biodiversity and health at various spatial and temporal scales, further elaborated upon in a diversity of cases. These cases, ranging from issues around microbiota, Asian bush mosquitos, forest and marine ecosystems, and biodiversity and health issues at a national scale, emphasise not only the diverse range of ways by which biodiversity can have an impact on health and social well-being, but also the importance of integrating the issue of biodiversity and health into our efforts to meet the Sustainable Development Goals by 2030. The first case on microbial biodiversity is directly linked to human health issues, and is also expected to have implications for the next generation. The current invasion of the Asian bush mosquito in Europe impairs physical health as the mosquito is a vector of various pathogens. Both forest and marine biodiversity are shown to affect a combination of physical and mental health, as well as social wellbeing and the 'OneHealth/EcoHealth' approach is described in the national case from as a transdisciplinary effort to implement actions that promote adaptive health management across human, animal and ecosystem interfaces.

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Sammendrag

Van Dijk, J., Carss, D., Keune, H., Vikström, S., Flandroy, L., Rook, G., Haahtela, T., Mehring, M., Birzle-Harder, B., Reuss, F., Müller, R., Luque, S. & Rodrigues, J.G. 2019. Invited background document on biodiversity and health for the Global Sustainable Development Report 2019 drafted by the Independent Group of Scientists. NINA Rapport 1555. Norsk institutt for naturforskning.

Nøkkelfunnene og -informasjonen fra den regionale vurderingen for Europa og Sentral-Asia av sammenhenger mellom helse og biologisk mangfold er gjengitt i denne bakgrunnsrapporten som en oversikt over nåværende kunnskapsstatus på dette forskningsfeltet. Rapporten gir også de viktigste funnene om sammenhengen mellom biodiversitet og helse i ulike romlige og tidsmessige skalaer, eksemplifisert i ulike studier. Studiene, som spenner fra problemstillinger tilknyttet mikrobiota, asiatiske buskmygg, skogs- og marine økosystemer og biologisk mangfold og helseproblemer på en nasjonal skala, legger ikke bare vekt på den mangfoldige måten som biologisk mangfold kan påvirke helse og sosial velvære på, men også viktigheten av å integrere problemstillingen i vårt arbeid for å møte bærekrafts-målene innen 2030. Studien om mangfoldet av mikrober er direkte tilknyttet helseproblematikk som også vil påvirke senere generasjoner. Den nåværende invasjonen av den asiatiske myggen *Aedes japonicus* i Europa forringer fysisk helse fordi myggen er en vektor for ulike patogener. Både skogs- og marinbiologisk mangfold påvirker en kombinasjon av fysisk og psykisk helse, så vel som sosial velvære, og OneHealth/EcoHealth-tilnærmingen er adressert i den nasjonale studien fra Belgia.

Jiska van Dijk[1], David Carss[2], Hans Keune[3,14], Suvi Vikström[4], Lucette Flandroy[5], Graham Rook[6], Tari Haahtela[7], Marion Mehring[8,9], Barbara Birzle-Harder[8], Friederike Reuss[9], Ruth Müller[10,11], Sandra Luque[12], João Garcia Rodrigues[13]

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Contents

Foreword

The impact of biodiversity on human health was seen as vague and narrow until recently. During recent years, novel research has shown the wide spectrum of connections between biodiversity and various dimensions of human health: from mental to physical health, from microbial to the landscape level, from rural to urban contexts, from children and young adults throughout the lifespan into old age, and from individuals to groups of people – indeed, to humanity as a whole.

The UN High Level Political Forum[1] for Agenda 2030 (HLPF), which has been mandated by the United Nations' member states for the follow-up of the 2015 agreed Sustainable Development Goals (SDGs)[2] decided one year later that a science-based global report on sustainable development was to be produced every four years to support the implementation of the Agenda2030, universally. The first report (GSDR2019) which will come out in September 2019 has been produced by the Independent Group of Scientists (IGS)[3].

As part of the writing process, the IGS invited background reports of those research topics which the group identified as newly arising issues that had not yet been thoroughly synthesized. One of the issues identified was the linkage between human health and biodiversity. A Long-Term Biodiversity, Ecosystem and Awareness Research Network (ALTER-Net)[4] was seen as a broad and well established research network with high quality, societally relevant, biodiversity research and had shown activity especially in this topic. Thus, the IGS invited ALTER-Net to produce a background report on the state of the art on biodiversity-human health relationships, including elucidating cases.

This report discusses the direct and indirect linkages and focuses the scattered knowledge through concrete cases where the biodiversity-health link, being naturally formed or brought into light through planning mechanisms, has shown its power.

This report served as useful background material when various chapters of the GSDR2019 report were planned and considered. The report is, however, useful in many other purposes, as well. I thus encourage all actors from policy to planners, from teachers to entrepreneurs, to become familiar with the content of this report, get inspired by the issues discussed, and implement practical, positive changes in practice. Understanding the link between biodiversity and human health is an eye-opener into sustainable development which can itself only be achieved when the interlinkages between the various dimensions of the human and natural worlds and understood, acknowledged and utilized.

[1] https://sustainabledevelopment.un.org/hlpf
[2] http://www.un.org/sustainabledevelopment/sustainable-development-goals/
[3] https://sustainabledevelopment.un.org/globalsdreport/2019
[4] http://www.alter-net.info/

The IGS has been very pleased with the collaboration with, and this contribution from, ALTER-Net. On the behalf of the IGS, I want to thank the network for its efforts in writing the background document, as well as the Norwegian Institute for Nature Research (NINA) for making the report available for broader use in the form of this report.

Eeva Furman
27.8.2019

Member of the IGS
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Global Sustainable Development Report 2019: The Future is Now – Science for Achieving Sustainable Development, (United Nations, New York, 2019). https://sustainabledevelopment.un.org/globalsdreport/2019)

Introduction

Jiska van Dijk and David Carss

The global and regional assessments from the IPBES highlight numerous issues regarding the interlinkages between health and biodiversity (for full assessment reports, see: [5]). The key findings and key messages from the regional assessment for Europe and Central Asia are given in this background paper, as an overview of the current status of knowledge in this field of research. In addition, this paper gives the key findings on the links between biodiversity and health at various spatial and temporal scales, further elaborated upon through a variety of case examples. These cases, although not comprehensive, emphasise the diverse range of ways whereby biodiversity may have an impact on health and social well-being, and the importance of integrating this issue in our effort to meet the UN Agenda 2030. The background paper is jointly prepared by researchers from several partners within ALTER-Net, Europe's ecosystem research network[6].

[5]https://www.ipbes.net/global-assessment-biodiversity-ecosystem-services; https://www.ipbes.net/assessment-reports/eca
[6]www.alter-net.info

Key findings from the IPBES Regional Assessment for Europe and Central Asia,

Hans Keune

The IPBES Regional assessment report on biodiversity and ecosystem services for Europe and Central Asia (ECA) assessment (Rounseveld et al. 2018), chapter 2 (Martín-López et al., 2018) included a systematic review on medicinal plants, as well as systematic reviews of general nature–health linkages from the published literature, building upon the 2015 State of Knowledge review on Biodiversity and Health by the World Health Organisation (WHO) and Convention on Biological Diversity (CBD) (WHO & CBD, 2015).

Literature review

For reviewing the general nature-health linkages literature, we built on the WHO and CBD (2015) work and did a literature search for the period 2014 – February 2017 in order to update the State of Knowledge. In order to include and assess the literature on medicinal plants we performed a separate systematic review. For more detail on the literature review methodology, see the appendices to the IPBES–ECA assessment report (Keune et al. 2018a; Keune et al. 2018b).

Expert elicitation

We performed expert elicitation to interpret the outcomes of the literature reviews, both for the general nature-health linkages and, specifically, for medicinal plants. As in the ECA assessment, only a small review team was available for the general nature-health linkages assessment (one lead author and two contributing authors). Expert elicitation was thus chosen as a method to broaden the expert base needed to assess the complexity of those linkages and to tackle the vast amount of literature and topical issues. Similarly, the same method was applied for medicinal plants because of the limited expertise available in the health assessment team (one lead author and three contributing authors).

The expert elicitation focused on characterization of the scientific evidence and on key messages. Scientific evidence from the literature reviews was summarized in ‘key findings’ and the IPBES confidence terms (Keune et al. 2018a) were then assigned to these to characterize the ‘strength’ of the evidence for these key findings. Key messages were then described by the authors coordinating this nature–health assessment, which were proposed to the experts for them to assess, add and prioritize key outcomes of the health assessment. For more detail on the expert elicitation methodology, see the appendices to the IPBES–ECA assessment report (Keune et al. 2018a).

General nature – health linkages results

An initial set of eight draft key findings from the literature review was prepared and submitted to an expert panel for consideration. These were then assigned to a specific category of evidence characterisation (Table 1).

Table 1. *Key findings from the nature - health literature review.*

Key finding	**Evidence characterization***
The importance of biodiversity and ecosystem services to human health is well-established in some areas of health research, for example with regards to the contribution of biodiversity to food and nutrition security, to contemporary and traditional medicine, and linkages to infectious disease risk.	*"Well-established" - "established but incomplete"*
The phenomenon known as the "dilution effect", whereby increased biodiversity within a particular setting can reduce the likelihood of transmission of a pathogen to competent hosts and therefore potentially reduce the risk of disease outbreak in human populations, has been confirmed in some parts of Europe.	*"Unresolved" - "inconclusive"*
The precise nature of relationships between biodiversity/ecosystems and human health can be highly variable for some other aspects of health research, such as whether, or to what extent, biodiversity loss may increase the risk of infectious disease emergence, and the impact which exposure to nature can have on mental and physical well-being. In these cases, social, economic and cultural factors may be at least equally important.	*"Unresolved"*
Increased urbanization in Europe poses significant challenges for human health – including a rise in non-communicable diseases associated with modern lifestyles, such as obesity, cardiovascular diseases, depression and anxiety disorders, diabetes, etc. Efforts to increase the access by urban dwellers to green space and open countryside may help to address some of these health issues.	*"Unresolved"*
Differentials in the ways in which some communities (including indigenous and local communities) or groups within wider society (e.g. women, people suffering from poverty) experience and interact with biodiversity and ecosystems may result in differences in the influence of biodiversity and ecosystems on their health status, with the potential for group-specific or community-specific dependencies and risks.	*"Unresolved"*
Biodiversity can play a role in nutrition security, supporting dietary health by providing a wide food resource base, diversifying	*"Well-established"*

sources of macro- and micro-nutrients, and helping to meet nutritional needs in times of social or economic instability, including during natural or man-made disasters.	
There is compelling evidence from multiple studies that a healthy functioning immune system is supported by exposure to biodiversity. For example, exposure to environmental microbiota has been associated with reduced risks of allergy, chronic inflammation and certain other autoimmune diseases.	*"Unresolved"*
By reducing threats of biodiversity loss and increasing opportunities for exposure to nature and natural environments, the designation, enforcement and increasing connectivity of protected areas may help to support public health policy goals.	*"Unresolved"*

* Evidence characterization was derived from evidence being traceable (i.e. grey literature, peer reviewed literature and evidence through 'paper trail'. IPBES assessments use a four-box model of confidence based on evidence and expert agreement that gives four main confidence terms: "well established" (much evidence and high agreement), "unresolved" (much evidence but low agreement), "established but incomplete" (limited evidence but good agreement) and "inconclusive" (limited or no evidence and little agreement)[7].

An initial set of six draft key messages was prepared and submitted to the expert panel for consideration. These key messages are presented in Table 2 but have been slightly adapted here for improvement of precision and clarity, they have also been re-ordered for better flow of content. This Table also shows the consensus ranking derived from the individual expert rankings. It should be noted that experts sometimes disagreed substantially on the ranking of key messages, and this 'consensus ranking' should not be considered as an outcome of any negotiation among experts. Indeed it was derived merely from processing by means of a ranking program (Keune, Springael, & Keyser, 2013).

Table 2. *Key messages on nature - health linkages.*

Expert ranking	*Key message*
1	*Development of more, and better integrated, approaches to addressing nature-human health linkages are required across research, policy and practice.* Knowledge exchange across a wide range of socioeconomic sectors and research disciplines, and engaging directly with local and indigenous communities, is essential to addressing evidence gaps and devising appropriate responses. Key themes which can facilitate integration include the intersections between health, biodiversity and climate change, and associated economic implications.

[7] See for more information https://www.ipbes.net/system/tdf/downloads/pdf/IPBES_MEP_8_5_for%20posting_0.pdf?file=1&type=node&id=15103 and http://www.ipbes.net/sites/default/files/downloads/pdf/ipbes-5-inf-6.pdf

2	*Dedicated IPBES assessments should be considered to look at nature–human health linkages in ECA and other regions*, in order to better assess the quality and scope of the evidence base, to more completely illuminate the scope and complexity of biodiversity-health relationships and their importance to health outcomes, and to better target guidance to decision-makers across the various relevant disciplines.
	More focus must be given to understanding the degree to which social, cultural and economic factors influence the relationship between biodiversity/nature contributions to people and human-health outcomes. This should include research into the ways in which socio-economic status, age, gender and ethnicity (*inter alia*) can mediate both health risks and the benefits of nature. Such research can help to illuminate how health-biodiversity relationships are framed or understood by different communities or vulnerable groups.
3	*The development of cross-cutting indicators and of multi-disciplinary data collection programmes relevant to nature–health linkages should be encouraged.* This can include multi-sector partnerships for monitoring and reporting changes in biodiversity and nature contributions to people of specific relevance to health outcomes, health policy and health care systems, and of health issues (e.g. disease outbreaks) which may alert us to previously unrecognized impacts of ecosystem change.
	There is an urgent need for research into the specific relevance of individual ecosystems to health. Recent demographic changes, and increasing urbanization in particular, highlight the importance of considering the impact of biodiversity and nature contributions on the health of urban communities, and of opportunities for improving health by encouraging access to biodiversity. Other key ecosystems include High Nature Value farmland, marine and coastal ecosystems, forests, and wetlands.
4	*Further detailed research on the human immune system-natural environment linkage should be supported.* Recent studies indicate that human immune function is supported by exposure to a natural environment; further epidemiological studies should explore the importance of such exposures for different communities (e.g. urban vs. rural), and the interaction with other factors (e.g. nutritional status), and whether there is a “critical period” for such exposures.

Medicinal plants results

An initial set of eight draft key findings from the medicinal plants literature review was prepared and submitted to an expert panel for consideration (Keune et al., 2018b). These were then assigned to a specific category of evidence characterisation (Table 3.). The key messages as presented in this table below are slightly adapted for improvement of precision and clarity, and they were re-ordered to have a better flow of content.

Table 3. *Key findings medicinal plants literature review.*

Key finding	**Evidence characterization**
Indigenous and local knowledge plays an essential role in creating greater understanding of the potential benefits to human health of many plant species.	*"Well-established" - "established but in-complete"*
Collection of plants from the wild and loss of habitat due to physical development and land use change are the most significant threats affecting medicinal plants in Europe and Central Asia.	*"Well-established"*
Ethnobotanical research is crucial for a better understanding of the medicinal potential of medicinal plants in the ECA-region.	*"Well-established"*
There is a high rate of decline of traditional medical knowledge in the ECA region.	*"Well-established"*
Because of increasing inward migration into the ECA region from other regions, there is an urgent need to increase understanding of traditional medicinal practices within national public health care systems.	*"Established but in-complete"*

An initial set of four draft key messages were then described by the authors coordinating the medicinal plant assessment, which were proposed to the experts in order for them to assess, add and prioritize. These key messages are presented in final Table 4 and, as above, this table also shows the consensus ranking derived from the individual expert rankings. Again, it should be noted that experts sometimes disagreed substantially on the ranking of key messages, and this 'consensus ranking' should not be considered as an outcome of any negotiation among experts. Indeed it was derived merely from processing by means of a ranking program (Keune, Springael, & Keyser, 2013).

Table 4. *Key messages regarding medicinal plants.*

Expert ranking	*Key message*
1	*The impact of existing conservation measures and land use strategies on medicinal plants and associated cultural diversity should be further explored.* This knowledge could help to improve planning for the conservation and sustainable use of medicinal plant species. For example, in some areas the loss of medicinal plant diversity has been linked to disappearance of traditional farming systems. However, little is known about the potential for High Nature Value farmland and related agrobiodiversity conservation strategies to support the sustainable management of these species.
	Inventories of medicinal plant species, with details of their conservation status, use and related trends should be maintained at national and regional levels. Information currently available on medicinal plants, their potential benefits, threats to their conservation and the legal basis for their collection and use in the ECA region is incomplete. Improved national efforts for collating relevant information from different sources within and across countries would support more integrated conservation planning at national, regional and international level, and also help to assess the various health, ecological, environmental, cultural, legal, and socio-economic aspects.
2	*A broader interdisciplinary approach is required for policies and practical strategies for the conservation of medicinal plant species and associated cultural diversity.* This should include development of appropriate education systems, professional assistance and aligned legislations, to ensure safe, sustainable and rational use of herbal products in order to protect human health and the biodiversity of medicinal plants. In particular, greater involvement of the health sector in policy development and implementation on issues related to traditional medicinal knowledge and medicinal plant use is important.
	More integrated research approaches would be beneficial to better explore the potential health benefits of medicinal plant species, and related issues surrounding safety and sustainable use. This would ideally include topical and methodological integration, for instance experimental and ethnobotanical studies, but also collaboration between different relevant disciplines.

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Case 1. Interlinkages between microbiota and the health of humans and ecosystems

Suvi Vikström, Lucette Flandroy, Graham Rook, Tari Haahtela

What we eat, drink, breathe and touch have all changed, and in a very short period of time. This case reviews how the microbial biodiversity that we are exposed to is linked to human health now and for the next generation.

The biodiversity hypothesis of health proposes that reduced contact with the natural environment and biodiversity may adversely affect the human symbiotic microbiota and its immunomodulatory capacity (von Hertzen et al. 2011, Hanski et al. 2012, Haahtela et al. 2013, Rook et al. 2014, Flandroy et al. 2018, Haahtela 2019). This hypothesis is based on the observation that two dominant socio-ecological trends – the loss of human contact to biodiversity and the increasing incidence of inflammatory diseases – are correlated. Immunologically-dependant, non-communicable diseases have indeed become increasingly common in recent decades especially in urbanized communities (ISAAC 1998, WHO 2005), while urbanization and its ways of living increasingly lead to poor intra-urban biodiversity, including microbial diversity, and loss of connection between humans and the natural environment. While correlation is no proof of cause-effect links, scientific data, among others through animal experiments, have started to prove cause-effect relationships between inflammatory diseases and poor microbial diversity (synthesized data in: Flandroy et al. 2018).

Microbes of the natural environment influence various aspects of human health

Many immunological inflammatory diseases such as allergies, diabetes and inflammatory bowel diseases have become increasingly common in countries with a high standard of living and modern Westernised lifestyles (von Hertzen et al. 2011, Pawankar 2014). One reason for this is presumably that, along with degradation and fragmentation of habitats, lifestyle changes and urbanization, people now encounter fewer microbes from the natural environment (Flandroy et al. 2018, Ruokolainen et al. 2016; Rook 2013, von Hertzen et al. 2011). There are obviously less allergy symptoms in children grown up in natural environments rich in microbial biodiversity than in children in urban areas (von Mutius and Vercelli 2010). Exaggerated daily hygiene does not seem to be the main cause of microbiota impoverishment (Bloomfield et al. 2016), but rather antibiotic use, western diet, caesarean birth, and reduced exposure to the natural environment (Flandroy et al. 2018). Here, the term ‘microbes from the natural environment’ is used to refer to all microbes, especially those which are not pathogens or parasites. In low income countries, even parasites have a beneficial role in the regulation of the immune response (Yazdanbakhsh et al. 2002), although it is not clear whether the diminishing load of parasites in high income settings is relevant to health (Rook et al. 2017).

The core message of the 'biodiversity hypothesis of health' is that it is essential to the development of our immune system that we are sufficiently exposed to diverse natural environments, and especially to the microbes in them (von Hertzen et al. 2011, Hanski et al. 2012, Haahtela et al. 2013). The microbes present in our surroundings influence our microbiota (see various relationships in: Flandroy et al. 2018) which, in turn, is connected to the functioning of our immune system. Furthermore, immunological disorders are an underlying cause of inflammatory diseases. One function of microbial exposures is to train the developing immune system to distinguish between actual threats and 'harmless' molecules (Ruokolainen et al. 2016). This immunoregulatory effect of microbes has been shown to be related to upregulation of regulatory T lymphocytes and downregulation of pro-inflammatory mediators' (cytokines, various hormones or their derivatives) production in the host. This is induced by microbial biologically active molecules that are known to have a role as modulators of immune and neuroendocrine systems (Tan et al. 2016, Zeng and Chi 2015, Erdman and Poutahidis 2016, Poutahidis et al. 2013, 2014, Vanan et al. 2016, Yano et al. 2015). Moreover, an additional essential role of microbial biodiversity is to develop the catalogue of memory T cells of our immune system. Encountering harmless microbes increases the ability of the immune system to react promptly against more pathogenic microbes harbouring similar antigenic structures (Su et al. 2013, Flandroy et al. 2018).

Although the immune system often appears central in connecting microbial effects to other physiological impacts, through interrelations between immune, endocrine and central nervous systems and their mediators, the role of microbiota on our health is not limited to its impact on the immune system (Carabotti et al. 2015; Marsland, 2016; Moloney et al. 2014). This could explain positive effects of microbial biodiversity on cancer (Erdman and Poutahidis 2015, Poutahidis and Erdman 2016) and impairment of cerebral functions, by lack of microbial stimulus, in depression (see Box 1.) and other neurological disorders (Dinan and Cryan 2013) and potentially also in autism (Vuong and Hsiao 2017) and in Alzheimer's disease (Fox et al. 2013). Microbes also regulate the development of our organs, including the brain (Cryan and Dinan 2012), and the small intestine (Yu et al. 2016). They participate in our protection against toxics by metabolizing a number of chemicals (Claus et al. 2016). During the evolution of all vertebrates, including humans, many body functions have thus been 'outsourced' to microbiota, in a symbiotic or co-evolutionary relationship. Studying animal models can teach us unsuspected positive roles of microbes on our health and/or their mode of action (see examples in: Flandroy et al. 2018).

Importantly, the role of the natural environment on our health is not limited to the biodiversity hypothesis of health emphasised here. The beneficial effects of exposure to natural environments are likely to have two separate but interacting components. In addition to the effects of physical exposure to microbial biodiversity, there are well-established rapid psychological effects that might be explained by an evolved psychological reward from “contemplating the ideal hunter-gatherer habitat” (Rook 2013). Multiple physiological consequences of exposure to the natural environment, such as sunlight enhancing production of vitamin D (Milaneschi et al. 2013) and encouraged physical exercise (Maas 2008), are thought to supplement the immunoregulatory effects of microbial biodiversity (Rook 2013).

Box 1. MICROBIOTA AND DEPRESSION
Depression is rapidly becoming the most important human ailment, according to WHO (2018). A chronically raised level of systemic inflammation (raised blood CRP, IL-6 etc.), even in the absence of any apparent inflammatory lesion, predisposes people to depression (Miller and Raison 2016). Moreover, there is good epidemiological evidence that psychiatric disorders are more frequent in urban communities (Peen 2010), and that this is not because psychiatrically disturbed people gravitate towards urban centres (reviewed in Rook et al. 2014). A recent study found that a standardized laboratory stressor caused more release of inflammatory mediators in subjects with urban versus rural upbringings, and, more specifically, that this phenomenon was correlated with lack of proximity to animals during early life (Bobel et al. 2018). Thus, just as has been demonstrated for allergic conditions, exposure to rural environments and animals drives immunoregulation. When such immunoregulation fails, a given level of stress can drive a greater and more persistent systemic inflammatory response which, in some individuals, will increase the risk of depression (Miller & Raison 2016).

Prevention of inflammatory diseases and maintenance of health through exposure to microbes

Mild inflammation and immunological imbalance are characteristic of a group of chronic non-communicable diseases and disorders that threaten public health (Flandroy et al. 2018). These include asthma, allergies, auto-immune disorders, diabetes, inflammatory bowel diseases, metabolic syndrome, cardiovascular diseases, cancer, neurological diseases and mental disorders. Prevention of many of these diseases has been improved by affecting known risk factors, but they explain only a fraction of chronic diseases and have not revealed the underlying reasons for the increasing incidence of allergies (Jousilahti et al. 2016). Traditionally, the natural environment has been viewed in relation to managing the threats it poses. For example, the incidence of several infectious diseases has decreased because of improved levels of hygiene. Formerly, a recommended treatment for allergies was to avoid exposure to allergens and to microbiota, but now exposure is known to be required for the development of tolerance (Lynch et al. 2014). While increasing ‘healthy exposure’ to microbes it is essential to acknowledge and reduce the risk of being exposed to pathogens in order to achieve the benefits.

We are exposed to microbes through many different routes, the most important of which are the respiratory tract, digestive system and skin (von Hertzen et al. 2011, Flandroy et al. 2018). The habitat(s) we live in and the food we eat greatly influence our microbiota (Ruokolainen et al. 2016, Flandroy et al. 2018), whilst our lifestyles and associated choices — how we live, eat, move, and our recreational activities — impact upon the amount of valuable exposure we have to microbes. The building materials that surround us could thus also influence our internal microbiota and health (NESCent Working Group, 2015), in addition to the potential effects of indoor plants and their microbiomes (Berg et al. 2014)

The impacts of diet on human microbiota composition deserve considerable further study (see synthetic view in Flandroy et al. 2018). Current knowledge indicates that the "Western-style" diet, with its ultra-processed food, is associated with lower microbial diversity and increased chronic disease risks (Broussard and Devkota 2016; Mozaffarian, 2016). Agro-ecological cultivation produces vegetables that are richer in microbial diversity, but any associated impacts on chronic diseases remain to be studied. More studies are also needed on the impact of differences in microbial content between diets rich in vegetables or in meat products, as well as the potential influence of eating seasonal and locally grown food rather than similar 'standardized' food throughout the year. Here, the amount, as well as the diversity of microbial exposure are likely to be essential factors (Valkonen et al. 2015).

Studies show an obvious shift of microbiome profile when comparing human communities from rural to urban areas (Winglee et al. 2017). In summary, populations of current city dwellers show evidence of chronic inflammation as a result of weakening immune regulation (Rook 2013). For example, Finnish youths living in Northern Karelia and Russian youths living in Russian Karelia have significantly different skin and nose microbiotas (Ruokolainen et al. 2017a). At the same time, there are significant differences in inflammatory diseases: e.g. the occurrence of allergies and asthma was manifold in Finnish compared to Russian youths. Similar differences in the incidence of allergies, correlated to different microbial diversities, have been observed between Finnish children living in differing urban or rural environments (Lehtimäki et al. 2017). The gut microbiotas of individuals living in Finland and Russia also differ markedly and this correlates with susceptibility to Type 1 diabetes, which is much more prevalent in Finland and for which probable mechanisms have been elucidated (Vatanen et al. 2016).

Microbial exposure of future mothers and children, and throughout life

The microbiota effectively 'trains' the human immune system, with consequent systemic effects, particularly in the perinatal period. In early life (including *in utero*) there is a window of opportunity when the microbiota diversity needs to be present and adequate for optimal establishment of the immune, endocrine and metabolic systems in particular via epigenetic and developmental processes. During this period, modulation of the genome by environmental factors, including 'bad' maternal diet and antibiotic use, may pre-dispose individuals to specific disease susceptibility via epigenetic effects mediated by distorted gut microbiota (Alenghat 2015, Cortese et al. 2016, Majnik and Lane 2015, Neu 2016, Cox et al. 2014, Heard and Martenssen 2014, Rando and Simmons 2015, Supic et al. 2013, Vickers 2014, Poutahidis et al. 2015). A baby is exposed to its mother's microbes during pregnancy, birth and breastfeeding. The nutrition and way of life of expecting mothers, as well as chosen ways of giving birth and feeding, have a remarkable effect on the development of the baby's immune system (Dominguez-Bello et al. 2010) and small choices can have major impact on individual health. Vaginal birth and breastfeeding are influential ways to increase the exposure of a baby to its mother's microbes and therefore to further the development of its immune system (Salminen et al. 2004, Huurre et al. 2008).

Whilst perinatal and early life exposure to microbial biodiversity is the most crucial, the immune system continues to develop throughout childhood and therefore regular microbial exposure is essential for children. Lack of forests and fields near home has been shown to be connected to unbalanced skin microbiota amongst children and youths (Ruokolainen et al. 2016). Kindergartens and schools are functional places to increase microbial exposure because, in countries of high income and low microbial exposure, they are able to encompass a large proportion of the age group. From a public health point of view, it would be functional to focus on sufficient microbial exposure in kindergartens and schools, so that exposure is not solely reliant on the families' ways of life.

Even if childhood period is essential for that, all age groups will benefit from being exposed to the microbes of the natural environment (David et al. 2014, Cabieses et al. 2014). Later in life, the microbiota is more stable (probably through dietary and general living habits), and transient effects on the gut microbial population have less effect. Concurrently, the pre-dispositions acquired by early life microbial impacts can be modulated by chronic administration of some probiotics (Poutahidis et al. 2015) or by a diet influencing gut microbial secretions (Krautkramer et al. 2016, Snijders et al. 2016). Nevertheless, loss of microbial diversity is still associated with ill health, and causes increasing inflammation - even in old age (Claesson et al. 2012): the training of the immune system may need to be regularly renewed by exposure to microbial diversity (Rook et al. 2014) to avoid noncommunicable diseases potentially linked to dysregulation of the immune system. An individual’s lifestyle, way of life, and choices related to housing, nutrition and movement as well - as support by society - play an essential role in that exposure. Immune system function weakens with age and therefore regular contact to natural environment is also important for elderly people (Ruokolainen et al. 2017b). The ageing immune system also generates increasing inflammatory responses (‘inflammageing’) that are exacerbated when the biodiversity of the gut microbiota is reduced (Claesson et al. 2012). Therefore, contact with nature is to be encouraged for ageing people, but it is also important for there to be a natural environment rich in biodiversity in the neighbourhoods of older or disabled people who might not be able to walk in nature-rich environments.

Administrative measures in urban contexts and changing behaviour among different sectors

While urban structure is condensing through urbanization, it is important to conserve urban biodiversity. From the viewpoint of the biodiversity hypothesis of health, urban planning should take into account both the holistic health and wellbeing benefits of microbial biodiversity and the possibilities for citizens to be exposed to biodiverse natural environments, various natural living elements including for instance pets, and their microbes, including accessibility to 'green areas'. Exposure takes place functionally near homes and on people's daily routes. In a city centre there are usually fewer areas with trees than in the suburbs, but parks and various built natural elements can also be utilized in highly constructed areas. Greening cities with a monoculture of grass is not the best solution to offering adequate biodiversity, but it can be a first step to attract urbanized people's interest in nature and its biodiversity. Much research is still needed to define what would be an ideal microbial environment for most people in a given geographical situation, and what associations of plants and animals could bring this biodiversity of microbes to favour (rather than to impair) public health, simultaneously with other benefits brought by urban "green" biodiversity. Meanwhile, current knowledge suggests that, in absence of dominating pathogens to be avoided, biodiversity (would it be from animals, plants, or microbes) is, by essence, a means of equilibrium in nature; planting a variety of trees and herbaceous plants with their accompanying microbes should thus be more favourable than planting nothing or planting monocultures of trees and flowers in cities.

For children and the elderly, the quality of the environment is particularly important when considering their contact with it, as their 'mobility circle' is more limited than that for the working-age population. Functional natural elements in the yards of kindergartens, schools, sheltered homes and retirement homes could for example include cultivation boxes, fruit trees, berry bushes, green roofs and walls, gardens and pets. Woodlands and parks must be located close enough for ease of use in everyday life, during lessons and walks. Deadwood can be left undisturbed in woodlands and parks to promote biodiversity and inspire exploration and movement. Self-sufficient mobility of the elderly could be supported by sufficient density of benches for resting for instance. The planning of healthy habitats requires cooperation between sectors — at the very least including zoning, recreation and exercise, management of green and blue infrastructure, construction, environment, health care, and education.

As Flandroy et al. (2018) conclude, policy makers should also support the education of both the public and concerned professionals about new insights into the functioning of microbiotas and the new opportunities this is creating for novel applications and behaviours supporting better human health and wellbeing. While we clearly need to affect the public's way of thinking, we also need to avoid exaggerated, sensational, and scientifically unsound press coverage (e.g. reporting apparent miracles resulting from microbiota). Similarly, misguided press reports that suggest a general reduction of hygiene practices should be particularly avoided in this period where various societal changes and rapid travel favour the emergence and diffusion of pathogens. We also need to consider other drivers that affect human behaviour towards exposure to environmental microbiota. For example, there are health programmes which inform about the risk of disease arising from contact with nature, including those spread by ticks and other vectors. Researchers, authorities and policy makers should thus make recommendations which take these risks into account, explain them in relation to the numerous benefits of contact with nature and its associated microbiota.

There are already some examples of the real-life intervention approach described above. One of them, the Finnish Allergy Programme 2008-2018 turned a strategy that emphasised avoidance of exposure into a tolerance strategy and started to encourage use of the term 'Allergy Health', placing more emphasis on health and less on allergy. The mid-term results of the ongoing Finnish campaign indicate that the burden of allergic conditions in focal community under investigation has started to decline (Haahtela et al. 2017). Focusing on severe allergies and emphasising health rather than mild problems has also encouraged a more efficient use of healthcare resources (Haahtela et al. 2017). However, it is too early yet to determine whether the programme has resulted in biological changes in the population.

Interlinkages with Agenda 2030

Linkages between practices enhancing diverse microbiota and the Sustainable Development Goals (SDGs) have been proposed in the synthesis by Flandroy et al. (2018). Primarily, reaching Goal 3 (Good health and well-being) (that includes reduction of communicable and non-communicable diseases) can be facilitated by addressing health in a holistic way including host-microbiota interactions. Moreover, operationalisation of knowledge of the microbiome, improved by complementary research, could contribute to integrated realisation of several SDGs. Regarding the evidence base compiled by Flandroy et al. (2018), it could indeed contribute towards reaching Goal 2 (Zero hunger), Goal 6 (Clean water and sanitation), Goal 11 (Sustainable cities and communities), Goal 14 (Sustainable use of life in aquatic environments) and Goal 15 (Preservation, restoration and sustainable use of terrestrial ecosystems). Microbial level biodiversity in terrestrial, marine, fresh water and urban ecosystems is linked to health and to transgenerational benefits to our off-spring. Humans, other animals, plants and the environment continuously exchange microbiota, whereas microbiotas can be damaged by antibiotics, agricultural and industrial chemicals and human lifestyles. Moreover, through influence on the previous goals, reaching other SDGs could be helped, such as Goal 1 (No poverty nowhere), Goal 8 (Decent work for all and sustainable economic growth), Goal 9 (Industry, innovation and infrastructure), Goal 10 (Reduced inequalities), and Goal 13 (Action against climate change and impacts). There are also SDGs that could help to materialise these goals, such as Goal 4 (Quality education) and Goal 17 (Partnership for the goals).

Needs for further understanding

It is not yet clear what amount of exposure to the natural environment and its microbiotas is needed, how precisely the microbes get into the human system, and what the relationships are between different microbes. Is visiting natural environments occasionally enough or should we be exposed to the microbes of the natural environment in our everyday life? (cf. Flandroy et al. 2018). How precisely can we influence our microbiota and consequent health through our diet, agricultural systems, built surroundings, and our physical activity? However, it is evident that we get multiple health and wellbeing benefits from the natural environment and in particular its microbial component (Keniger et al. 2013, Kabisch et al. 2017). Despite the present situation of incomplete knowledge and understanding of the biodiversity hypothesis of health, it has been proposed that we should still take it into account in urban and regional planning and so build healthy and biodiverse cities (Flandroy et al. 2018).

Importantly, there is still a clear need for studies into the potential impacts of chemicals on microbial biodiversity, for us to enable the microbiome to keep its supposed positive effects on our health and not have negative impacts (Flandroy et al. 2018). Data already reveal bacterial biodiversity disturbance (in humans, other animals, or the environment) caused by chemicals either (a) considered toxic (their toxicity on our health could thus occur through effects on the microbiome), or (b) those whose toxicity is currently disputed, or (c) that we encounter in our daily life and that are not considered toxic[8]. Complementary studies are needed and risk assessment of products could subsequently be adapted to take into account the potential toxic effects on “good” microbes.

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Case 2: Environmentally friendly and sustainable control of the Asian bush mosquito in Western Europe

Marion Mehring, Barbara Birzle-Harder, Friederike Reuss, Ruth Müller

This case refers to both rural and urban areas in Western Europe, but particularly to Germany. The current invasion of the Asian bush mosquito impairs physical health, as the mosquito is a vector of various pathogens.

In Europe, the Asian bush mosquito (*Aedes japonicus japonicus*) is an exotic mosquito species that has spread over the last decade in Germany, particular the federal states of Baden-Württemberg, Bavaria, Hesse, Rhineland-Palatinate, North Rhine-Westphalia and Lower Saxony (Werner et al. 2012, Schaffner et al. 2009, Kampen et al. 2016, Zielke et al. 2015, Huber et al. 2014, Schneider 2011, Kampen et al. 2012, Melaun et al. 2015). It occurs primarily in human settlements, especially on their periphery, in cemeteries and in allotment gardens for instance (Bartlett-Healy et al. 2012). Rain barrels or flower vases offer ideal breeding grounds for the mosquitoes' larvae. Under laboratory conditions, the Asian bush mosquito is the vector of various pathogens, including the virus of Japanese encephalitis (Takashima & Rosen 1989) and West Nile fever (Sardelis & Turell 2011). There are currently no pathogen-specific drugs for either of these viral diseases. Infections can therefore only be prevented prophylactically by mosquito control measures, such 'hygienic measures' reducing the likelihood of infecting humans or animals. Insecticide use combats mosquitoes, but at the same time can have a damaging effect on the environment or poses a health risk for humans. As part of the AJAP II project (*Aedes japonicus japonicus* - Environmentally friendly and sustainable control of the Asian bush mosquito), the insecticidal effect of different substances such as essential oils (clove and lavender) will be tested outdoors. This project aims to assess the suitability of environmentally friendly measures to combat Asian bush mosquitoes and also examine how the human population can be involved in the implementation of the measures and how these measures are accepted.

According to Medlock et al. (2012) the Asian bush mosquito was transported to Western Europe as a result of globalization processes such as international trade and transport or tourism activities. The species may tend to be locally abundant (a 'nuisance' mosquito) (Medlock et al. 2012), a potential disease vector (Takashima & Rosen 1989, Sardelis & Turell 2011), and also a competitor to native fauna (Armistead et al. 2008). Therefore, control actions may be needed in the future.

Potential solution pathways are foreseen for both governance and behavioural perspectives. Municipalities (e.g. urban green space planning office, cemetery administration) will need to be effectively integrated into the implementation of both prevention and control measures. Furthermore, individuals in local communities (e.g. cemetery visitors or allotment gardeners) will need to be addressed, as they are the ones who might well need to change their daily routines when identified ‘control’ measures are being implemented.

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Case 3: Forests and human health

Sandra Luque

This case refers to both rural and urban forested areas globally with a special focus on Western Europe, and the tropics. It addresses a combination of physical health, mental health and social wellbeing.

Forests are more than trees, and are fundamental for food security and improved livelihoods. They thus form a crucial element not only of landscapes but also of human living conditions. Covering nearly a third of the earth's land surface (Box 2), they stabilize surface soil, prevent erosion, help to regulate air pollution and play an essential role in water resource management at the watershed and local levels. At the same time, they are an important resource for regional economies (e.g. wood production, recreation and tourism) and are a significant cultural and social heritage of the local and regional human activities (FAO 2018). Forests provide habitats for a multitude of animal and plant species and are essential for the biological diversity in forest ecosystems over large areas (Luque and Iverson 2016). They regulate climate and improve air quality, yet the value of the effects of trees and forests on air quality and human health across the Globe still remains unknown. Tropical forests, in particular, also provide essential foods, medicines, health care and mental health benefits to people all over the world. The amount of these benefits generally increases with human proximity to the forest. However, forested areas with their human inhabitants or adjacent human communities are not high on the agenda of most governmental health care institutions, often because the human populations involved are small and the logistics of serving these small settlements remain challenging.

BOX 2. Forests worldwide: An important resource

The world has just under 4 billion hectares of forest, or 30.3 % of its total land area. At present, we count 1.6 billion people whose livelihoods depend on forests. One billion of them are among the poorest in the world (FAO, 2018). Forests and their derived products have played a substantial role in the development of civilization, providing humans with building materials and fuel for thousands of years. The long history of wood utilization dates back at least 400 000 years – the age of the oldest carbon dated wood spear, found in Germany (Grabner and Klein, 2014).

Key points on the intertwined relationship between human health and forested landscapes

Research on the **therapeutic aspects of forests** is still scarce but the role of outdoor recreation in healthy living and as a remedy against the shortcomings of modern life in a world separated from nature seems clear. Research has explored the role of urban green spaces in the rehabilitation of disabled people, in alleviating stress and depression related to urban living, and in the integration of marginalized sections of society. All in all, health and the positive experience of nature is a well-recognized process. A good example is the best-selling book of Richard Louv (2008), that documented, some 10 years ago, that decreased exposure to nature in American children produced "*nature-deficit disorder*" that had harming effects on both children and society. The book examined research and concluded that direct exposure to nature was essential for healthy development in children (Louv 2008).

Based on existing evidence, further research should be undertaken to learn more about the interlinked relationships between humans and forests and how forests improve human well-being in the long term. These include (i) the physical and mental health costs and benefits of forests and trees for individuals and populations, (ii) the physical, behavioural, psychological and social processes by which trees and forests affect individuals and populations, and (iii) how variations in trees and forests might influence these processes. It can also be argued that improvements in human health, as part of general human well-being, are a prerequisite for accomplishing a sustainable use of forested landscapes.

Traditional health care systems are based on significant **local knowledge of medicinal plants**, and mainly occur in all major tropical areas. These health care systems are important, particularly where formal health care services are absent (Colfer et al. 2006; Balick 2016). The market for traditional medicines is large and expanding, and much of it worldwide is in the hands of women, who should be better recognized for their roles (FAO 2018).
Many forest plants and forest-dwelling animal species produce a myriad of health-related products like fungicides, antibiotics and other biologically active complexes having medicinal uses. Numerous western pharmaceutical products are derived from tropical forest species, for example quinine from Cinchona spp.; cancer-treating drugs from rosy periwinkle (*Catharanthus roseus*); medicine for treating diabetes from *Dioscorea dumetorum* and *Harungana vismia* (Colfer et al. 2006). The economic value of traditional medicines is considerable; indeed, the market for traditional medicines is large and expanding, involving less commercially valuable medicinal plants (Carrasco et al. 2014; Moradi et al. 2017). There is also growing scientific evidence of the efficacy of some of these widely used traditional remedies (Balick 2016).

At the same time, medicinal plants are threatened globally. Other than deforestation, other threats include slow growth patterns of desirable species, loss of traditional mechanisms that contribute to sustainable use, and competing uses of the same species, in tandem with growing commercialization and global markets (Moradi et al. 2017). More training in ethnobotany is needed, including changing research approaches to the study of the relationships between plants, people and culture.

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Case 4: Safeguarding marine ecosystems to enhance human wellbeing and health

João Garcia Rodrigues

This case refers to marine ecosystems worldwide. It addresses contributions of marine ecosystems and their biodiversity to human wellbeing and presents evidence towards transformation and positive change in marine social-ecological systems using marine protected areas and fisheries management tools. In this case, human wellbeing is understood as a broader concept encompassing human health.

Humans are deeply dependent and connected with marine ecosystems – the most widespread ecosystems on the planet. In many areas of the world, attributes of human wellbeing (Breslow et al. 2016) such as subsistence, food security, employment and income are inextricably linked to marine ecosystems and their biodiversity (Berkes 2011, Béné et al. 2016). Moreover, marine ecosystems also contribute with a wide range of non-material benefits to humans such as cultural identity, physical and mental health, formal and informal knowledge, inspiration, spirituality, tranquility and discovery (Garcia Rodrigues et al. 2017, Russel at al. 2013). On a planet where one-third of the world's human population lives in coastal areas (Brown et al. 2006), and increasingly depends on marine resources (FAO 2016), safeguarding human wellbeing cannot go without protecting and conserving marine ecosystems and their biodiversity.

Marine ecosystems support fisheries, which are the most important activity of many coastal populations. Marine fisheries are estimated to support 260 million jobs worldwide in the direct and indirect sectors (Teh and Sumaila 2013) and are especially important for developing nations, where an estimated 78% of fisheries workers live (Teh and Sumaila 2013). Dyck and Sumaila (2010) assessed direct, indirect and induced economic effects in the world capture fisheries sector and arrived at a total economic impact of about 240 billion US dollars annually, and 63 billion US dollars per year of household income. Without fisheries, some of the world's poorest people would not have a safety net for cash income and nutrition, especially during times of financial hardship.

Healthy fisheries contribute to the food security and wellbeing of many nation states and coastal communities (Garcia and Rosenberg 2010). Fish is the source of nearly 20% of the average per capita intake of animal protein for more than 3.1 billion people (FAO 2016). Moreover, the consumption of fish is linked to a 36% reduced mortality risk from heart disease (Mozaffarian and Rimm 2006), while the intake of 60 g of fish per day is associated with a 12% reduction in mortality from all causes (Zhao et al. 2016). Fish is also a key source of essential micronutrients such as iron, zinc, omega-3 fatty acids and vitamins. Iron deficiency affects nearly one-third of the human population (FAO 2016) and one-fifth of maternal deaths are connected to anemia during pregnancy (Micronutrient Initiative 2009). Seventeen percent of the world population is zinc deficient (Golden et al. 2016), causing an estimated 800,000 child deaths per year (FAO 2016). Vitamin A deficiency is the main cause of preventable blindness, affecting between 250 and 500 million children, half of whom will die within a year of vision loss (Bailey et al. 2015). The consumption of fish is thus crucial to overcome the micronutrient malnutrition that affects an estimated two billion people (IFPRI 2016).

Despite the social and health benefits generated by fisheries and fish consumption, 89.5% of commercial fish stocks were either overfished or fully fished in 2013 (FAO 2016). Due to stagnating global wild fish catches and increasing seafood demand, aquaculture is assuming a leading role in the seafood production sector (FAO 2016). Yet aquaculture raises many sustainability issues because it is increasingly dependent on terrestrial crops and wild fish for feeds, it depends on freshwater and land resources for its aggregate production, and it can be harmful to aquatic ecosystems and fisheries (Hall 2011, Smith et al. 2011, Troell et al. 2014). While aquaculture has an important role to play in supporting food security and economies worldwide, further research and operational improvements need to be done urgently to mitigate its negative impacts on ecosystems and biodiversity.

The current state of many ecosystems and commercial fish stocks threatens the social wellbeing of millions of people by jeopardizing their access to nutritious food, employment, and income, amongst other constituents of human wellbeing. To overcome these negative prospects, researchers, decision-makers and practitioners need to identify what works and what does not, have to implement informed and participated policies to protect and conserve marine biodiversity, and re-establish functional ecosystems and rebuild fish stocks. At the same time, special attention should be paid to the access of coastal communities to marine resources in order to avoid unjust outcomes for those whose livelihoods are most dependent on the ocean. In this respect, cases where transformation and positive change have occurred are particularly useful to learn from and to inform decision-makers and practitioners.

Transformation and positive change are context dependent. For example, to design effective fishery management tools and improve biological outcomes, Selig et al. (2017) highlight the importance of understanding and identifying local fishery characteristics (e.g., low-mobility species, multiple target species) and enabling conditions (e.g., strong local leadership, presence of fisher cooperatives). These authors pinpoint that greater biological success, (i.e., increased or maintained abundance or biomass, reductions in fish mortality or improvements in fish population status) can be achieved by implementing a combination of management tools, adapted to the local context. Successful combinations of management tools include catch limits with quotas and limited entry to the fishery; gear restrictions with catch limits; time-area closures with marine protected areas (MPAs); and the use of MPAs with fishing effort restrictions. Moreover, the authors indicate three design considerations that are particularly important for successful outcomes, namely, a legitimate rule-setting process; an understanding of the governance structure where the management tool is applied; and a process that engages local communities.

MPAs are a particularly important management tool to conserve and protect marine biodiversity, re-establish functional ecosystems and improve fisheries (Lester et al. 2009, Edgar et al. 2014, Guideti and Claudet 2010). These areas are widespread management tools, covering 7.3% of the ocean (UNEP-WCMC and IUCN 2018). They are diverse, ranging from multi-use areas to no-take zones where harvesting is forbidden. Most of the evaluated MPAs worldwide have positive, but variable, ecological outcomes on fish populations (Lester et al. 2009, Gill et al. 2017). MPA design, management and compliance play a crucial role to bring transformation and positive change for the social-ecological systems where they are embedded. Effective marine protected areas often have no-take zones, are well-enforced, old (> 10 years), large (> 100 km^2), and isolated by deep water (> 25 m) or large extents of sand (Edgar et al. 2014). Compared to fished sites, MPAs with these features show higher large fish species richness, greater large fish biomass, and more sharks (Edgar et al. 2014). Additionally, investment in staff and financial capacity in MPAs is crucial to bringing optimal conservation outcomes (Gill et al. 2017). Compared to MPAs reporting inadequate or no-capacity, Gill et al. (2017) found out that those MPAs with adequate staff and budget capacity to support tasks such as monitoring, enforcement, administration, community engagement and tourism activities, showed almost three times greater mean fish biomass per unit area.

'Bright spots' are promising places to look at and learn from to instigate transformation and positive change elsewhere. The concept was used by Cinner et al. (2016) for assessing coral reefs worldwide. These are ecosystems upon which millions of livelihoods depend (Moberg and Folke 1999). The authors classified as bright spots those places where coral reefs were considerably better than expected, according to the environmental conditions and socioeconomic drivers they were subjected to. Contrary to expectations, several of these bright spots were identified in fished and populated areas. The authors suggest that bright spots are more likely to have high levels of local engagement in the management process; high dependence on marine resources; strong sociocultural governance institutions, namely customary tenure or taboos; and located near deep water, which may serve as refuge for fish and corals. Moreover, they found that coral reefs were generally better in countries with a high Human Development Index, and that marine reserves, where compliance is high, are able to sustain reef fish biomass.

On the contrary, 'dark spots' were characterized by intensive fishing practices facilitated by capture and storage technology such as fish freezers, accompanied by a recent history of environmental shocks such as coral bleaching and cyclones. Here, Moberg and Folke (1999) also showed that reef fish biomass decreased as the size and accessibility to markets increased. In this sense, transformation and positive change have the potential to be fostered by developing novel interventions that dampen the negative influence of markets on resource exploitation.

Learning from what works, and what does not, to protect and conserve marine biodiversity, re-establish functional ecosystems and improve fisheries, should be a pre-requisite in the design and implementation of new management tools aiming at fostering transformation and positive change in marine social-ecological systems. Although there are no panaceas (Ostrom et al. 2007), and the local context should always be taken into consideration, there are effective tools and successful stories that can inspire future interventions in marine ecosystems worldwide. Enhancing human wellbeing and health goes hand-in-hand with protecting and conserving marine ecosystems and their biodiversity.

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Case 5: Integrating biodiversity and health issues at the national level, an example from Belgium

Lucette Flandroy

This case refers to the implementation of biodiversity and health issues in Belgium. Through Belgian national specificities, it addresses general challenges that still exist despite science-based evidence and the growing awareness and understanding amongst decision-makers and the wider public of the interlinkages between nature and biodiversity and physical and mental health in society. The case also highlights successes in common management of biodiversity and health policies. It tackles physical and mental health issues, social wellbeing and the so called OneHealth/Eco-Health approach. OneHealth/EcoHealth is a transdisciplinary effort that brings together scientists, citizens, government and private sectors to implement contextualized actions that promote adaptive health management across human, animal and ecosystem interfaces (Duboz et al. 2018).

Further details on this case have been presented at the regional capacity-building workshop on biodiversity and human health of the CBD (Convention on Biological Diversity – European Region[9]).

In most countries around the world, the traditional vertical and hierarchical structures of government ministries that exist make it difficult for interdisciplinary/trans-sectoral management approaches. Belgium is a small country but complex in its political structure where most competences are shared between federal, regional, and communitarian governments. This political complexity adds still more barriers to deal with coordinated policy management of problematic situations, such as interlinked biodiversity and health issues. However, the country's small size helps in offering the potential for motivated people to meet easily and regularly and establish good personal contacts in order to develop collaborations necessary to overcome these official barriers, be they from the policy, scientific, or field association sectors. In this context, multi-sectoral policy platforms (such as the Belgian CIMES, *Commission inter-ministérielle des ministres de l'environnement et de la santé*) where environment and health ministers from all policy levels have to approve decisions prepared by multi-sectoral civil servants and expert platforms (such as the Belgian National Cell for NEHAP – National Environment/Health Action Plan – and its invited case by case experts) can be very useful. The fusion (even if primarily for financial reasons) of different sectoral institutions should also favour trans-sectoral working (e.g. the federal human health, animal health, and environment ministries are part of a super-ministry called Federal public Service Health,

[9] https://www.cbd.int/health/european/presentations/default.shtml

Food Chain Safety and Environment). The National Scientific Institute for Public Health – ISP/WIV - recently merged with the National Veterinarian and Agronomic Study and Research Centre to form a new institution called Sciensano.[10]

Like all Parties of the CBD who have endorsed the Biodiversity Strategy 2011-2020, Belgium promoted direct or indirect links with health in its last National Biodiversity Strategy (NBS). This was prepared by Belgium's National Biodiversity Steering Group which is composed of policy makers in charge of biodiversity issues, from different sectors and levels. The NBS operates through integration of biodiversity in other sectors; through support to traditional medicines, soil productivity and diversified agricultural surfaces; through attention being given to disease emergence as a result of biodiversity/ecosystem disturbance; and through the encouragement of interdisciplinary research and educational programs.

As such, a monitoring plan for exotic mosquitoes (an increasing threat due to climate change and elaborated upon earlier in Case 2) was recently adopted by the Belgian CIMES (Environment and Health inter-ministerial Commission). It was developed, with advice from scientific experts, by the coordination body of the National Environment-Health Action Plan (NEHAP) which comprised civil servants from the environment and health departments at the federal level and various federal entities in the country. Financial realities had to frame the limits of such plan unavoidably below the ambitions of scientists. Pre-existing separate environmental and health monitoring activities were taken into account; both environment and health criteria were respected to complete with new requirements, leading to an exemplar 3 year pilot monitoring project called MEMO.

The One World – One Health concept, rising on the international agenda, was adopted in early 2016 by the Direction Committee of the Federal Public Service Health, Food Chain Safety and Environment. The problem of antimicrobial resistance was chosen as a first issue to be tackled in a One Health perspective by the different departments of this complex ministry. Antimicrobial resistance is indeed involving human medical and social problematics, animal health aspects, and still poorly understood environmental dimensions of antimicrobial resistance genes diffusion/persistence/transmission, that have to be tackled together to reach efficient results (cf. concerned session in the European OneHealth/EcoHealth workshop 2016[11]). This One Health evolution was certainly favoured by the historical accumulation of different departments (related to human and animal health and environment) in this one large ministry. The adoption of the One Health concept also helped this ministry become the main co-organizer of a European OneHealth/EcoHealth workshop hold in Brussels in October 2016[11]. Collaboration between the DG Environment of this large Belgian ministry and the federal public Service for Policy Science programming (Belspo) resulted in defining research calls on studies that deepen the analysis and understanding of interlinkage between health and ecosystems integrity. (BRAIN.be program of Belspo 2013/2014/2015:

[10] https://www.sciensano.be/fr
[11] http://www.biodiversity.be/4036/

Study the interlinkages and improve the interface between health (domestic animals, wildlife, plant and human health) and ecosystem integrity).

The same DG Environment of this large ministry (called Federal Public Service Health, Food Chain Safety and Environment) spontaneously initiated links between biodiversity and health issues in their work taking benefit of:
(A) the wide "*ecosystem service of biodiversity*" concept, to rally several departments towards common goals, for example:

- A federal Plan for Bees was published which aimed at a better understanding around causes of mortality, establishing monitoring programs, developing tools to better combat bees diseases, and reinforcement of national coherence. The report was a co-production between human/animal health, pesticides and animal drug departments. It focussed on the important pollination ecosystem service of bees and other pollinators, essential for food production and thus basic human health.
- A common Belgian position, including several departments, was adopted about the European legislation on endocrine disruptors.

(B) data provided by biodiversity/ecosystem disturbance studies that show negative impacts on health and thus encourage preventive health measures. Examples of this are, for instance:

- the bushmeat illegal import project: qualitative and quantitative determination of illegally imported animal products for raising awareness on the potential health risk because of pathogens linked to this illegally imported wild meat and with the ultimate aim to reinforce import controls
- the Invasive Alien Species (IAS) legislation and its risk assessment requirements: the ministry of environment took the lead for the transposition of EU legislation to limit import of IAS. The DG Environment invited human health, animal health, plant health departments to develop evaluation protocols for IAS not only on the basis of risk assessments for environment, but also for human health, animal health and plant health.

At the level of the Brussels Capital Region, several projects have been initiated and rapidly developed in the last decade, that simultaneously promote urban biodiversity, local agriculture, and healthy food, in both networking projects and associations. Several of these projects were either initiated by policy makers or by Non-Governmental Organisations (NGOs). Examples of these are:

- ecologically managed community gardens and true productive urban farming within the framework of Good Food Brussels[12]
- a "sustainable food" network under the RABAD (*Réseau des Acteurs Bruxellois de l' Alimentation durable, which is a n*etwork of Brussels' stakeholders in sustainable

[12] https://goodfood.brussels/

food[13]) ensuring exchanges between concerned producers, distributors, consumers, restaurants

- a “citizens sustainable neighbourhoods” project (*quartiers durables citoyens*[14]), financed by the Region but proposed and managed by citizens and aimed to improve local natural environment (including water management with the help of biodiversity[15]), social and economic aspects.

Various of these projects were recently gathered under the designation of “*Inspirons le quartier*” which translates as ‘Let’s inspire the neighbourhood’[16].

While these projects have until now been mainly initiated by environment departments and are very reliant on the voluntary investment of citizens, those participating in them understand that they are simultaneously good for nature and for physical and mental health. Several investigations[17] reveal that people participate mainly for social contacts, to be in close contact with nature and to have healthy, outdoor physical activity while living in an urban environment and working most of the week inside and sedentary.

The Flemish and Walloon regions of Belgium are also involved in initiatives making the link between biodiversity and health[18]. It is noteworthy that therapeutic gardens are also rapidly developing in Belgian hospitals and senior care homes recently. This is particularly, but not only, under the initiative of psychiatric sections and experts[19]. On the basis of the long observed positive effects of nature on psychiatric patients although more precise scientific studies are still needed[20], therapeutic gardens are used and aimed at accelerating recovery after medical/chirurgical interventions. These places are seen as transition steps for patients to be able to rehabilitate, as peaceful places for quiet exchanges between patients, family, and therapists, and as places to re-establishing contact with the natural reality and sensations, especially for elderly or psychiatric patients (e.g. through smell, taste, touch, vision of colours).

Through the experience of biodiversity and health interlinkages established in several governmental reports and events in Belgium it was seen that, because of specific objectives and/or constraints of different stakeholders, it is challenging to reach results in transdisciplinary working. However, a good dialogue process, a fair repartition of tasks, responsibilities

[13] http://www.rabad.be/
[14] http://quartiersdurablescitoyens.brussels/
[15] http://www.egeb-sgwb.be/
[16] https://environnement.brussels/thematiques/ville-durable/mon-quartier/inspirons-le-quartier-lappel-projets-citoyens
[17] see for instance at http://www.food4sustainability.be/
[18] https://www.cbd.int/health/european/presentations/default.shtml
[19] http://www.his-izz.be/fr/hopitaux-iris-sud/actualites/le-jardin-therapeutique-du-site-moliere-long-champ-a-ete-inaugure_953; http://biodiversante.be/; https://fr.medipedia.be/alzheimer-news/les-jardins-therapeutiques-un-projet-original-en-maisons-de-repos; http://www.gembloux.ulg.ac.be/institution/chaire-francqui-2015/
[20] https://lebonheurestdanslejardin.org/tag/therese-rivasseau-jonveaux/; http://www.actusoins.com/276438/quand-les-jardins-guerissent.html

and recognition are tools to allow mutual benefits in the cross-sectoral dealing of biodiversity and health issues.

It should be noted that environment departments in particular are pioneers in establishing links between biodiversity and health in issues to be managed transdisciplinarily. One of the reasons for this might be a prospective, preventive, widely open approach more frequently inherent to environment experts than to health experts. Links between the environment and public health or epidemiology departments can be easier to establish than those with other health departments. In a world facing financial crisis and to reach the UN Sustainable Development Goals, prevention of diseases should be a tool and a priority. Integrative management of biodiversity and health issues can also avoid duplication of monitoring activities and be more efficient in time and budgets. Altogether, in any case, those various Belgian initiatives clearly help reaching a diversity of the Sustainable Development Goals.

Reference Case 5

Duboz, R., Echaubard, P., Promburom, P., Kilvington, M., Ross, H., Allen, W., Ward, J., Deffuant, G., de Garine-Wichatitsky, M., Binot, A. 2018. Systems Thinking in Practice: Participatory Modeling as a Foundation for Integrated Approaches to Health. 2018-December-17:5.

The Norwegian Institute for Nature Research, NINA,
is as an independent foundation focusing on environmental research, emphasizing the interaction between human society, natural resources and biodiversity.

NINA was established in 1988. The headquarters are located in Trondheim, with branches in Tromsø, Lillehammer, Bergen and Oslo. In addition, NINA owns and runs the aquatic research station for wild fish at Ims in Rogaland and the arctic fox breeding center at Oppdal.

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