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The integration of biodiversity into One Health

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Summary

A better understanding of the links between biodiversity, health and disease presents major opportunities for policy development, and can enhance our understanding of how health-focused measures affect biodiversity, and conservation measures affect health. The breadth and complexity of these relationships, and the socio-economic drivers by which they are influenced, in the context of rapidly shifting global trends, reaffirm the need for an integrative, multidisciplinary and systemic approach to the health of people, livestock and wildlife within the ecosystem context. Loss of biodiversity, habitat fragmentation and the loss of natural environments threaten the full range of life-supporting services provided by ecosystems at all levels of biodiversity, including species, genetic and ecosystem diversity. The disruption of ecosystem services has direct and indirect implications for public health, which are likely to exacerbate existing health inequities, whether through exposure to environmental hazards or through the loss of livelihoods. One Health provides a valuable framework for the development of mutually beneficial policies and interventions at the nexus between health and biodiversity, and it is critical that One Health integrates biodiversity into its strategic agenda.

Keywords

Biodiversity – Ecosystem services – Global health – Infectious disease – Microbiota – Non-communicable disease – Nutrition – One Health.

Introduction

Biodiversity can be considered as the foundation for human health. As defined by the Convention on Biological Diversity (CBD), biodiversity is 'the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems' (1). It is the source of our food crops, and most of our medicines (both traditional medicine and pharmaceuticals). The ecosystems on which we depend for fresh water and for regulating climate, floods and diseases would not function without biodiversity. It also supports our physical and mental well-being, offers cultural and spiritual enrichment, and provides livelihoods, particularly those of the rural poor (1, 2, 3).

Biodiversity is threatened by land use change, habitat alteration and land degradation, overexploitation, pollution, invasive alien species, climate change and ocean acidification. As biodiversity is lost, ecosystem services are compromised, and, in some cases, there is a risk that some thresholds will be passed, undermining the functioning of the Earth's support system. Ultimately, biodiversity loss and degradation have negative impacts on the well-being of all people. However, these are particularly severe, and more immediate, on the poor and vulnerable, women, children and indigenous peoples (1, 2).

The links between biodiversity and health are intricate, multifaceted and complex and are manifested at various spatial and temporal scales. Some of the smallest organisms of the microbial world drive some of the largest-scale phenomena on the planet, including photosynthesis and nitrogen cycling, essential for life on Earth (4). Our food production systems depend on these and a whole host of organisms: primary producers (photosynthesisers), herbivores, carnivores, decomposers, pollinators, pathogens, natural enemies of pests. At a more intimate level, the human microbiota – the commensal microbial communities present in our gut, in our respiratory, oropharyngeal and urino-genital tracts and on our skin – contribute to our nutrition, help regulate

our immune system, and prevent infection. At the same time, biodiversity is the origin of the majority of infectious diseases, invasive alien species and agricultural pests, as well as strains of resistant bacteria.

Understanding these biodiversity–health links is more important than ever as we try to manage biodiversity and ecosystems to feed a population predicted to exceed 9.6 billion by 2050 (5), meet the demands of rapid urbanisation, adapt to and mitigate climate change, and reduce the burden of disease.

It is therefore a critical goal for a number of organisations and initiatives to address the links between biodiversity and health (6). A common framework for action within which this relationship can be addressed is the Strategic Plan for Biodiversity 2011 to 2020 and its 20 Aichi Biodiversity Targets, adopted by the Parties to the CBD in 2010 (www.cbd.int/sp/). All targets have direct or indirect impacts on, and provide opportunities to improve, both global human health and ecosystem health. The need to strengthen this nexus was also expressed by the Parties calling for stronger collaboration on these issues with the World Health Organization (WHO), as well as the World Organisation for Animal Health (OIE), the Food and Agriculture Organization of the United Nations, and the International Union for the Conservation of Nature, and others.

In this article, the authors argue that a better understanding of the relationships between biodiversity, health and disease presents major opportunities for policy development, and can enhance our understanding of how health-focused measures influence biodiversity and how conservation measures affect health. The breadth and complexity of these relationships, and the socio-economic drivers by which they are influenced, in the context of rapidly shifting global trends, reaffirm the need for an integrative, multidisciplinary and systemic approach to the health of people, livestock and wildlife in the ecosystem context (7, 8). One Health provides a valuable framework within which public health and biodiversity benefits can be explored (9, 10). Indeed, the integration of biodiversity-related issues into One Health strategies is crucial to attaining the stated goal of 'optimal health for people, animals and our environment' (11).

The links between biodiversity and health are numerous. The sections that follow will focus on some of those most directly relevant to One Health, emphasising the contribution of biodiversity to food security and nutrition; the connections between biodiversity, non-communicable diseases and microbial communities; and the intricate interplay between biodiversity–health links and the emergence of infectious diseases. As the sum of these sections will demonstrate, there are significant synergies to be realised between conservation and health policies. Sometimes there are 'win–win' solutions; in other cases, there are necessary trade-offs demanding careful management.

Biodiversity, food security and nutrition

The sustainable use of biodiversity for food and agriculture provides a range of simultaneous benefits for human and ecosystem health. For the health sector, it is an opportunity to promote dietary diversity and traditional food cultures, and to raise levels of nutrition, while combating micronutrient deficiencies and reducing the overall burden of non-communicable and infectious diseases, including foodborne diseases.

The provision of adequate nutrition, clean water and long-term food security depends directly on functioning agro- and other ecosystems and indirectly on the regulating ecosystem services of the biosphere (2). Many agricultural species rely on the services of pollinators, which affect approximately one-third of the global food supply (12), and crop productivity is frequently greater in areas with a greater diversity of native bees (13). Widespread declines of pollinator species – up to 70% in some areas (3) – have sometimes been associated with pesticide use (12), with potentially critical implications for agricultural productivity, food security and the functioning of ecosystems. Pesticides and other chemicals that are increasingly used in industrial agriculture have also been linked to increased cancer risks for consumers and farmers, as well as endocrine disruption and reproductive dysfunction (14). The erosion of life-supporting services from overexploitation and unsustainable practices (e.g. industrial animal production, herbicide use, excessive use of fertilisers) (14) can both threaten biodiversity and pose significant health risks.

The 'nutrition transition' has involved a shift away from diverse, nutritionally rich plant and animal foods towards high-energy and high-fat diets (15). From a health perspective, the shift towards a modern simplified diet has intensified micronutrient deficiencies, led to the consumption of excess energy, and compounded the escalating problem of non-communicable diseases (15, 16). Dietary diversity can improve nutritional status, while also improving immune function and micronutrient bio-availability (16). As discussed in the next section, a link between diet, microbiota and the health status of the elderly has also been established (17).

Some traditional crop varieties may contain higher levels of nutrients than modern varieties. For example, there are large differences in nutrient composition among varieties of rice. However, many of the varieties which are higher in nutrient content are less favoured in the current market, which is driven by yield. Too often, nutritional considerations rank far lower than other aspects of crop production (18).

Wild food sources remain important sources of nutrition. A recent study on the potential health benefits of wildlife consumption in children has shown that the elimination of wild animal sources of food can lead to significant macro- and micronutrient deficiencies, such as iron deficiency; a manifestation dubbed 'hidden hunger', due to its frequent absence of visible symptoms (19). On a global scale, chronic micronutrient deficiencies have been estimated to affect over two billion people worldwide (15). Wild foods can be instrumental in redressing this nutritional imbalance, particularly in less developed countries. Also, wild foods remain important in traditional food cultures, which are often based on non-cultivated, non-commercial foods, high in micronutrients (20).

From an ecological perspective, dietary diversity can promote awareness of the value of biological diversity for food and nutrition and lead to the improved protection of species, their genetic diversity and ecosystems (21). It is also an opportunity to protect and promote agricultural biodiversity, sustainable production harvesting and the conservation of wild food sources. However, for these practices to be truly sustainable, local food production must be encouraged, equitable access to a diverse range of agricultural products must be ensured, and alternatives to unsustainable practices must be provided. Indeed, local food production is not only an important source of food security, cultural resilience and nutrition, it is also essential to livelihoods (22) and traditional food cultures.

Moderating our consumption of animal products and encouraging more sustainable agriculture, fisheries and forestry practices, coupled with more sustainable use of existing cleared land, not only reduces biodiversity loss but also provides essential ecological services (21, 23). Sustainable practices, such as forest protection, play an important role in promoting soil fertility, protecting water resources, regulating climate, stabilising agricultural output, and providing habitats for wild food sources, predators of agricultural pests and wild pollinators, all of which play an important role in agricultural productivity (24).

Sustainable intensification may also provide biodiversity and health co-benefits, when it does not limit our dietary options by increasing our dependence on a limited number of high-yielding crops that favour productivity over nutritional content (25). Crop diversification also contributes towards climate change adaptation and mitigation strategies, increases agro-ecosystem resilience, and supports dietary diversity, food security and nutrition. This is especially valuable among vulnerable groups, such as women, indigenous communities and the poor, when resources and benefits are shared equitably.

Biodiversity, non-communicable diseases and human–microbial communities

Non-communicable diseases represent the largest proportion of the global burden of disease. According to WHO, they are now responsible for more deaths worldwide than all other causes combined, totalling an estimated 63% of all deaths in 2008. They are most prevalent in low and middle-income countries, where almost 80% of all non-communicable disease deaths occur, and where the greatest increase is expected (26). A large percentage of non-communicable diseases are preventable through the reduction of major behavioural risk factors (e.g. physical inactivity and unhealthy diet), but underlying factors can sometimes be linked to biodiversity and other environmental and social factors. The relationship between ecosystem change and the social drivers that influence the inequitable distribution of health-damaging experiences is often reciprocal (6, 22). A more complete understanding of how environmental factors interact with the social determinants of health has emerged, in that access to preventive and curative health services both shapes and is shaped by the persistent burden of diseases of poverty and the emerging challenge of non-communicable diseases (6).

Ecosystem approaches that apply scientific methodologies focused on levels of biological organisation and the integrated management of land, water and living resources (27) are especially relevant when addressing a range of emerging health concerns, including those of vulnerable populations (28). They are also consistent with broader One Health approaches that embrace the interconnectedness of people (and human development), wildlife and ecosystems to improve global health outcomes. While the One Health approach has been successful in identifying the relevance of ecosystem-based approaches when addressing the human–animal–ecosystems interface (29), it is equally useful to the development of holistic public health strategies and applied research on non-communicable diseases.

Rapid urbanisation has a considerable impact upon lifestyle through greater exposure to shared risk factors, such as air pollutants, decreased physical activity and unhealthy dietary changes. The loss and degradation of urban and peri-urban green spaces could have adverse effects on both ecosystems and human health. Several studies have examined the contribution of green spaces to healthy environments and their physiological, psychological and endocrinological health benefits, as well as potential socio-economic advantages (30, 33).

Microbial diversity and disease

Microorganisms are both the least visible and most abundant form of biodiversity on earth. The interactions of microbes within their complex ecological communities have significant implications for human health, influencing both our physiology and susceptibility to disease. Microbes have been described as the 'under-appreciated link between biodiversity and human health' (31). While changes to the composition of microbial species and their link to infection are well documented, changes in the diversity of microbial species have traditionally received less attention (32, 33).

The microscopic bacteria, viruses, fungi and protozoa of which microbes are composed play an important role in the processes that link environmental changes and human health. Recent scientific advances in research on the composition and function of the human microbiota (32, 34) and the impacts of biodiversity loss on microbial communities, coupled with advances in genomics technologies, have led to new insights on infection and disease, allergies and other chronic inflammatory diseases, antibiotic resistance, autoimmune dysfunction, non-communicable diseases, chronic non-genetic diseases, and nutrition (17, 31, 35, 36). The development of barrier functions and immunological tolerance in humans depends upon commensal and environmental microorganisms, though further research is needed to clarify causal relationships (31, 33).

Understanding the mechanisms that underlie functional and compositional changes in the human microbiome can contribute to the development of therapies that address the gut microbiota and corresponding diseases (33, 34). Claesson *et al.* (17) demonstrated the relationship between diet, microbiota and health status: a positive correlation was established between the healthy food diversity index developed by Drescher *et al.* (37) and three indices of gut microbiota diversity (17). The full range of links between biodiversity in the farming food system, biodiversity-based dietary diversity and dietary diversity, as measured by the healthy food diversity index, are an important subject for further investigation. Moreover, experimental studies evaluating the effects of microbial diversity in plants and animals (including humans) have shown that increasing microbial biodiversity may, in some cases, prevent the colonisation of invasive pathogens (32) or protect against infections. Antibiotic-associated diarrhoea due to *Clostridium difficile*, for example, is believed to reflect the 'colonization of a disrupted microbial community by the pathogen' (38). Such studies support the conclusion that preserving and restoring microbial communities may have important implications for the development of novel public health strategies and alternative therapies (38), and could reduce the transmission and prevalence of non-communicable diseases, including chronic diseases (31, 33).

Evidence also suggests that biodiversity loss in the wider environment may lead to 'microbial deprivation', i.e. reduced diversity in the human microbiota (31), which in itself can lead to immune dysfunction and disease, including a range of chronic inflammatory disorders (35). Urbanisation and the loss of access to green spaces are not only increasingly being discussed in relation to non-communicable diseases such as obesity, type II diabetes, depression and cancer, they have also been linked to a failure of the immune system to adapt to environments that are microbe-poor (31). Half of the world's population already lives in urban areas and this number is projected to increase markedly in the next half-century, with the most rapid increase taking place in low and middle-income countries. The full range of health, socio-economic and environmental impacts of urbanisation is also likely to be a central feature in the emerging post-2015 development agenda.

These and other findings (31, 34, 35) provide support for the 'old friends' hypothesis (33), a reformulation of the closely related 'hygiene hypothesis', according to which our inadequate exposure to microbial agents, coupled with the use of antibacterial products and antibiotics, may be linked to an increase in allergies, such as asthma and eczema (39). Certain environments, such as those found in relatively urban and affluent communities, do not support the development of a healthy microbiota. Limiting the use of antimicrobial agents could provide potential co-benefits to health and biodiversity, by reducing chronic inflammatory diseases through a healthier and more diverse human microbiota while also, more broadly, reducing the risk of re-emerging diseases from antibiotic-resistant strains and the potential impacts of antibiotics on ecosystems.

Moreover, the old friends hypothesis suggests that our physiological requirements for microbial biodiversity are evolutionarily determined, and lifestyle changes, such as urbanisation, have led to an inadequate exposure to micro- and macroorganisms (i.e. old friends). In turn, this has, at least in part, contributed to the reduced efficiency of immunoregulatory mechanisms and poorly regulated inflammatory responses (33).

The potential health and biodiversity benefits that could result from the more limited use of antibiotics and antimicrobials extend beyond the human microbiome and could also be applied to agricultural practices and food production systems. Current industrial agricultural practices not only contribute to ecosystem degradation, air and water pollution and soil depletion: industrial animal agriculture also generates considerable pollution (from animal waste) and relies heavily on the use of antibiotics, which may lead to antibiotic resistance and reduced efficacy in their subsequent use in medicine (14).

Biodiversity and infectious diseases

Infectious diseases are a manifestation of interactions among species. As such, changes in the abundance and composition of biodiversity may affect human exposure to and the transmission of infectious diseases. Numerous studies discuss the multifaceted role of biodiversity in pathogen transmission; it can increase or decrease disease transmission by affecting the abundance, behaviour or condition of hosts or vectors (32, 40, 41, 42).

Emerging infectious diseases are widely cited as examples of the intimate and direct links between biodiversity and health. This may be primarily due to the fact that over 70% of zoonoses are of wildlife origin (43, 44), and are therefore a product of biodiversity. Increased human contact with wildlife can increase the risk of diseases being transmitted across species. High levels of biodiversity and anthropogenic influence correlate most directly with the risk of disease emergence (44).

In some cases, anthropogenic changes, such as land-use change, the wildlife and livestock trade, and increased human infringement on wildlife habitat, have been found to increase the rate of transmission of infectious diseases such as West Nile virus (*Flavivirus)* (45); Hantavirus pulmonary syndrome (46); and widely cited examples of Lyme disease (aetiologic agent: *Borrelia burgdorferi*), frequently transmitted by infected blacklegged ticks of the genus *Ixodes scapularis* (32, 41). In other cases, forest loss has been correlated with a reduced incidence of Lyme disease, and forest restoration with an increased incidence (42). Such findings have even led to the development of public health programmes that focus on removing or controlling the wildlife reservoirs of specific pathogens (21, 42).

However, some disease ecology models have found that high species diversity may reduce the risk of certain wildlife diseases, as it may provide a balance between predators and prey, hosts, vectors and parasites. One such model, which has been extended to a growing number of human, plant and wildlife diseases, is commonly referred to as the 'dilution effect', in which scenarios of high biodiversity lead to a reduction of disease (13, 45, 46, 47, 48, 49). For example, in the case of Lyme borreliosis, high tick-host diversity has been found to dilute the impact of competent hosts – including the ecologically resilient white-footed mouse (*Peromyscus leucopus*), which can carry the spirochete bacterium that causes Lyme – on disease prevalence, due to a reduction in host–parasite interactions and subsequent disease risk (13, 45, 47, 48, 50). While this pattern has been extensively documented, there is much uncertainty over the underlying mechanisms and its general applicability (42, 51). With the notable exception of a study demonstrating a consistent link between species richness, community competence and infection risk to amphibians (49), surprisingly few studies appear to have used direct measures of biodiversity (such as species richness and infection prevalence) to study the dilution effect, relying instead primarily on measures of habitat fragment size, host abundance, other indirect measures used as proxies for biodiversity, or indirect measures of disease risks to humans (42). While generalisations about the effects of biodiversity and disease transmission cannot be made, these relationships and their corresponding global health and biodiversity policy implications remain a vital avenue of future research.

The common thread in the divergence of views on the role of biodiversity in disease reduction or transmission is the complexity of this crucial relationship, which, the authors argue, must be re-examined using a broad spectrum of spatial and temporal scales while also considering the 'contact processes' between people and wildlife (52). In line with One Health approaches to disease emergence, an examination of this complex relationship must also consider contributions from other disciplines, including the biological, physical and social sciences (7, 53). Collaborative work with disciplines that examine the social determinants of health, such as poverty, can also provide valuable insights on the drivers of disease emergence and spread, identifying previous patterns of disease risk and helping to predict future risks (53). Such collaborative work, and a better understanding of ecosystem–biodiversity–health links, should also inform the management of the landscape (54).

A study on the interplay among infectious diseases, biogeographical and ecological factors, and economic prosperity has confirmed the importance of both biodiversity and anthropogenic disturbance for disease risk (55, 56). Tropical countries, which often have high levels of poverty and biodiversity, also tend to have higher disease burdens than temperate countries. Using structural equation modelling, and based on *per capita* income for 139 countries, the authors distinguished between this effect and the parallel relationship between *per capita* income and latitude. In analysing the socio-economic factors that alter pathogen dynamics, they found that the burden of vector-borne pathogenic disease is determined by ecological conditions, and that a rise in the burden of several diseases often coincides with biodiversity declines, and has significant consequences for *per capita* income (55). Integrated approaches such as these are valuable in understanding the causal links between ecological processes, economic development, and disease emergence.

Conclusions

Health is our most basic human right and therefore one of the most important indicators of sustainable development. At the same time, the conservation and sustainable use of biodiversity is imperative for the continued functioning of ecosystems at all scales, and for the delivery of ecosystem services that are essential for human health. There are many opportunities for synergistic approaches that promote both biodiversity conservation and the health of humans and livestock. However, as this article notes, in some cases there must be trade-offs among these objectives. Indeed, because of the complexity of interactions among the components of biodiversity at various tropical levels (including parasites and symbionts), and across ecosystems at various scales (from the planetary-scale biomes to human-microbial interactions), positive, negative and neutral links are quite likely to occur simultaneously. An enhanced understanding of health–biodiversity relationships will allow for the adjustment of interventions in both sectors, with a view to promoting human well-being over the long term.

Mainstreaming this vital nexus in both scientific research, and biodiversity and public health policies, in line with integrative One Health approaches, creates timely opportunities to identify the health benefits of biodiversity and sustainable ecosystem management, jointly promote the numerous co-benefits of these intricate interactions, and develop coordinated, preventive and forward-looking policies which are crucial to the development and implementation of sustainable global health goals in the context of the emerging post-2015 development agenda.

Intégrer la biodiversité dans le cadre du concept « Une seule santé »

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Résumé

Une meilleure connaissance des liens entre la biodiversité, la santé et les maladies est un atout majeur pour l'élaboration des politiques dans ces domaines parce qu'elle permet d'élucider leurs interactions réciproques, à savoir l'impact des actions dans le domaine de la santé sur la biodiversité et l'influence sur la santé des mesures de conservation de la nature. L'ampleur et la complexité de ces interactions et les moteurs socio-économiques en jeu dans un contexte d'évolution rapide des principales tendances sont autant de confirmations de la nécessité d'adopter une approche intégrée, pluridisciplinaire et systématique de la santé humaine, de la santé du bétail et de celle des animaux sauvages au sein de leurs écosystèmes. Le déclin de la biodiversité, la fragmentation des habitats et la disparition des cadres de vie naturels menacent l'intégrité des services vitaux fournis par les écosystèmes à tous les niveaux de la biodiversité (d'espèces, génétique et des écosystèmes). La perturbation des services rendus par les écosystèmes a des conséquences directes et indirectes sur la santé publique, qui risquent d'exacerber les inégalités existantes dans le domaine de la santé en raison de nouvelles expositions à des risques environnementaux ou de la disparition des moyens de subsistance. Le concept « Une seule santé » fournit un cadre précieux pour explorer les bénéfices simultanés de la santé et de la biodiversité ; il est donc fondamental que la biodiversité soit mise au cœur de la stratégie « Une seule santé ».

Mots-clés

Alimentation – Biodiversité – Maladie infectieuse – Maladie non transmissible – Microbiote – Santé mondiale – Services rendus par les écosystèmes – Une seule santé.

Integración de la diversidad biológica en «Una sola salud»

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Resumen

Un mejor conocimiento de los vínculos entre la diversidad biológica, la salud y las enfermedades presenta importantes oportunidades para la elaboración de políticas, y puede también mejorar nuestra comprensión del impacto de las medidas sanitarias sobre la biodiversidad y, recíprocamente, de cómo las medidas de conservación afectan a la salud. La amplitud y complejidad de estas relaciones, así como los factores socioeconómicos que influyen en ellas, en un contexto en el que las tendencias mundiales evolucionan rápidamente, confirman la necesidad de abordar desde un planteamiento integrado, multidisciplinario y sistémico, la salud de las personas, el ganado y la fauna salvaje en el contexto de los ecosistemas. La pérdida de biodiversidad, la fragmentación de los hábitats y la desaparición de espacios naturales amenazan toda la gama de servicios ecosistémicos esenciales para la vida en todos los niveles de la diversidad biológica (diversidad de especies, genética y de ecosistemas). La perturbación de los servicios ecosistémicos tiene consecuencias directas e indirectas sobre la salud pública, que seguramente acentuarán las inequidades sanitarias ya existentes, ya sea por la exposición a peligros ambientales o por la pérdida de medios de subsistencia. Los planteamientos de «Una sola salud» proporcionan un valioso marco de referencia para el desarrollo de políticas e intervenciones de beneficio mutuo en el nexo entre la salud y la diversidad biológica. En este sentido es imprescindible que el concepto de «Una sola salud» integre la diversidad biológica como elemento central en su agenda estratégica.

Palabras clave

Diversidad biológica – Enfermedad infecciosa – Enfermedad no transmisible – Microbiota – Nutrición – Salud mundial – Servicios ecosistémicos – Una sola salud.

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