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The Role of Biodiversity in Disease Regulation as Function of Ecosystem Service Systematic Review

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Abstract
Biodiversity, ecosystems, and the important services they provide are fundamental to all life on Earth, including human life. Food and critical nutrients, pharmaceutical chemicals, fuel, energy, livelihoods, and cultural and spiritual enrichment are all available from them. They also contribute to the provision of safe drinking water and clean air, as well as important services ranging from pest and disease control to climate change and natural disasters. Each of these functions has direct and indirect implications for our health and well-being, and each is a critical piece of the epidemiological puzzle that we face in our attempts to combat infectious and noncommunicable diseases. The inextricable relationships between biodiversity, ecosystems, and the supply of these advantages, as well as human health, are well-established. Biodiversity is appreciated, maintained, restored, and properly employed in order to maintain ecosystem functions, maintain a healthy world, and provide benefits to all people. The World Health Organization is aware of the mounting evidence that biodiversity loss is occurring at unprecedented rates. There is a growing awareness that this poses a serious threat to the healthy and stable ecosystems that support all elements of our societies. Biodiversity loss can destabilize ecosystems, cause infectious disease epidemics, and jeopardize development, food security, and natural catastrophe protection. Protecting the public's health from these threats falls outside of the health sector's usual responsibilities. It is based on collaborating with partners who are involved in conservation, as well as the responsible use and management of natural resources.
Keywords: *biodiversity, ecosystem, health, diseases, conservation.*

Introduction

Biodiversity is the term used to describe the variety of life on earth, including animals, plants and microbial species. Biodiversity encompasses not only the vast number of species found on the planet, but also the genetic variations and traits found within species, as well as the assemblage of these species within ecosystems found in agricultural and other landscapes like forests, wetlands, grasslands, deserts, lakes, and rivers. The multiple interconnections within and between ecosystems form the web of life, of which humans are an integral part and upon which they depend for their very survival. It is the combination of these life forms and their interactions with one another, and with the surrounding environment, that makes human life on earth possible (CBD 2006).

Biodiversity extends beyond the simple measurement of species numbers to include the complex network of interactions and biological structures that sustain ecosystems (McCann 2007; Maclaurin and Sterelny, 2008). Although "species richness" is one of biodiversity's key components. The widely accepted definition of biodiversity adopted by the CBD is flexible, inclusive, and reflective of the levels and complexities of biotic and abiotic interactions. It recognizes levels of variability within species, between species, and within and between ecosystems as integral to the ecological processes of which they are a part (Mace et al. 2012).

The World Health Organization (WHO) defines health as "a condition of complete bodily, mental, and social well-being, not only the absence of disease or infirmity," according to its constitution. Health is a fluid notion that is influenced by a variety of social, biological, physical, economic, and environmental elements that interact. Human health and biodiversity are intertwined in numerous ways. Sandifer et al. (2015) propose a variety of pathways through which biodiversity can benefit people's health and well-being: psychological (e.g. green spaces and iconic wild-life), physiological (directly through the human microbiome, and indirectly through exercise in green spaces, regulation of the transmission and prevalence of some infectious diseases, provision of food and good health), and economic (e.g. regulation of the transmission and prevalence of some infectious diseases, provision of food and good health). Individuals, groups, and landscapes all play a role in the interconnections between biodiversity and health, as does the planetary scale.

1. **Biodiversity, Ecosystem Functions, Services and Regulating Disease**

1.1.Effects of Biodiversity Loss on Human Health Ecosystem Services

The impacts of biodiversity loss on ecosystem functioning have increased considerably in the past two decades (Balvanera et al. 2014; Cardinale et al. 2012; Reis et. al. 2013; Naeem and Wright 2003), as well as corresponding knowledge of its implications for public health (Myers et al. 2013). There is strong evidence of the relationship between biodiversity and ecosystem functioning and, in some cases, we can directly link this to the ecosystem services necessary to regulate humandiseases (Balvanera *et al*. 2014). The full range of impacts of biodiversity loss on ecosystem functioning is not fully understood (Hooper et al. 2005).

The provision of essential goods and services, including those essential to sustaining human life, is reliant on the properties, processes and maintenance of ecosystems (Naeem and Wright 2003; Balvanera *et al*. 2006; Reiss *et al*. 2009, 2010). The quality, quantity and security of the essential services that we derive from ecosystems are determined by several dynamic and interlinked factors, including different components of biodiversity, underlying physical and biological processes, and complex responses to environmental stressors such as pollution and climate change (Mace 2012; Balvanera et al. 2006). The specific components of biodiversity (e.g., genes, species) and attributes (e.g., variability, composition) that underpin the ecosystem services that, in turn, support human health and well-being may differ among the services or goods in question, and on the processes upon which they rely. Cardinale et al. (2012) argue that diverse communities are more productive both because they contain essential species that have a major impact on productivity and because differences in functional features between organisms boost overall resource acquisition (light, water).

2.1.1. Water resources: an essential ecosystem service for diseases regulation

Freshwater is a provisioning ecosystem service and is important for several aspects of human health. All terrestrial freshwater habitats, forests, wetlands, soil, and mountain ecosystems play a role in regulating nutrient cycling and soil erosion, as well as managing pollution (Russi et al. 2012; Coates and Smith, 2012). (Schwarzenbach et al. 2010; Horwitz et al. 2012). Many of the world's largest rivers start in the mountains, and more than half of the world's population depends on the fresh water that flows from them.

It is widely accepted that water purification services provided by biodiversity ecosystems underpin water quality, which is a universal requirement for maintaining human health. For example, the hydrological, chemical and biological processes of wetlands significantly ameliorate water quality. Groundwater is also a major source of water for drinking and/or irrigation but also a potential source of pathogenic microorganisms (Gerba and Smith 2005; Lapworth et al. 2012). While biodiversity, including species variety, can be a source of disease development, in some situations, great species diversity in vertebrate vector hosts can be helpful by preventing domination by specific species that serve as major pathogen reservoirs (Ostfeld and Keesing 2000).

2.1.2. Social costs of impaired water quality

Ecosystems play an essential role in regulating water quantity and quality, which are also primary factors affecting food production, essential for sustaining human health and livelihoods (Horwitz et al. 2012). There are multiple mental health benefits of experiencing a natural environment, including, for example, the contribution of spiritual and recreational values of wetlands to human psychological and social well-being.

Impaired water quality results in significant social and economic costs, and ecosystem degradation is a major cause of declines in water quality. Rectifying poor-quality water through artificial means (such as water treatment plants) requires substantial investment and operational costs. Left untreated, poor-quality water results in massive burdens on human health, with women, children and the poor being the most affected. Reflecting this priority, many protected areas and special reserves have also been established to protect water supplies, including fresh water for urban areas (Blumenfeld et al. 2009).

2.1.2. The role of species diversity on diseases regulation

Filter feeders play an important role in the elimination of suspended particles from water and its purification (Newell 2004; Ostroumov 2005, 2006). Bivalve molluscs of both marine and freshwater environments have the ability to filtrate large amounts of water (Newell 2004; Ostroumov 2005). It has also been found that molluscs may reduce pharmaceuticals and drugs of abuse from urban sewage (Binellia et al. 2014). The mussel species *Diplodon chilensis chilensis*, Hyriidae, native of Chilean and Argentinean freshwater habitats, play a key role in reducing eutrophication, both by reducing total phosphorus (PO_4 and NH_4) by about one order of magnitude and also by controlling phytoplankton densities. These mussels also contribute to increasing bottom heterogeneity and macro crustacean abundance, and attract predatory fish. Thus, the mussels provide energy and a nutrient source to the benthic and pelagic food webs, contributing to more rapid recycling of organic matter and nutrients (Soto and Mena 1999).

Biodiversity conservation or restoration can be an effective, efficient and cost-effective way of improving water quality and wastewater management. Plant and algae species diversity enhances the uptake of nutrient pollutants from water and soil (e.g., Cardinale et al. 2012), and some animals (such as copepod *Epischura baikalensis* in Lake Baikal, Russia; see Mazepova 1998) and plant species enhance the purity of water. For example, *Moringa oleifera* seeds and *Maerua decumbens* roots are used for clarifying and disinfecting water in Kenya (PACN 2010).

2.2. Impacts of vegetation on air quality

There are three main ways in which plants affect local air pollution levels: via effects on local microclimate and energy use, removal of air pollution, and emission of chemicals. Increased air temperature can lead to increased energy demand (and related emissions) in the summer, increased air pollution and heat-related illness. Vegetation, particularly trees, alters microclimates and cools the air through evaporation from tree transpiration, blocking winds and shading various surfaces. Local environmental influences on air temperature include the amount of tree cover, number of impervious surfaces in the area, time of day, thermal stability, antecedent moisture condition and topography (Heisler et al. 2007). Vegetated areas can cool the surroundings by several degrees Celsius, with higher tree and shrub cover resulting in cooler air temperatures (Chang et al. 2007).

Temperature reduction and changes in wind speed in urban areas can have significant effects on air pollution. Lower air temperatures can lead to lower emission of pollutants, as pollutant emissions are often related to air temperatures (e.g., evaporation of VOCs). In addition, reduced urban air temperatures and shading of buildings can reduce the amount of energy used to cool buildings in the summer time, as buildings are cooler and air conditioning is used less. However, shading of buildings in winter can lead to increased building energy use (e.g., Heisler 1986). In addition to temperature effects, trees affect wind speed and mixing of pollutants in the atmosphere, which in turn affect local pollutant concentrations. These changes in wind speed can lead to both positive and negative effects related to air pollution. On the positive side, reduced wind speed due to shelter from trees and forests will tend to reduce winter-time heating energy demand by tending to reduce cold air infiltration into buildings. On the negative side, reductions in wind speed can reduce the dispersion of pollutants, which will tend to increase local pollutant concentrations.

2.2.1. Removal of air pollutants

Trees remove gaseous air pollution primarily by uptake through the leaves, though some gases are removed by the plant surface. For O_3, SO_2 and NO_2, most of the pollution is removed via leaf stomata.[3] Healthy trees in cities can remove significant amounts of air pollution. The amount of pollution removed is directly related to the amount of air pollution in the atmosphere (if there is no air pollution, the trees will remove no air pollution). Areas with a high proportion of vegetation cover will remove more pollution and have the potential to effect greater reductions in air pollution concentrations in and around these areas. Pollution removal rates by vegetation differ among regions according to the amount of vegetative cover and leaf area, the amount of air pollution, length of in-leaf season, precipitation and other meteorological variables.

One of the most important vegetation attributes in relation to air quality is the amount of leaf area. Leaf area varies by plant form, with leaf area indices of agricultural areas typically around 3–5 and leaf area indices of forests typically between 5 and 11 (Barbour et al. 1980). Thus, the magnitude and distribution of vegetation types (e.g. grasses, shrubs, and trees) affect air quality. In general, plant types with more leaf area or leaf biomass have a greater impact, either positive or negative, on air quality. The second most important attribute related to air quality is vegetation configuration or design. Tree canopies can potentially prevent pollution in the upper atmosphere from reaching ground-level air space. Under normal daytime conditions, atmospheric turbulence mixes the atmosphere such that pollutant concentrations are relatively consistent with height. Forest canopies can limit the mixing of upper air with ground-level air, leading to below-canopy air quality improvements. However, where there are numerous pollutant sources below the canopy (e.g. automobiles), the forest canopy could increase concentrations by minimizing the dispersion of the pollutants away at ground level (Gromke and Ruck 2009; Wania et al. 2012; Salmond et al. 2013; Vos et al. 2013). However, standing in the interior of a forest stand can offer cleaner air if there are no local ground sources of emissions (e.g. from automobiles). Various studies have illustrated reduced pollutant concentrations in the interior of forest stands compared to the outside of the forest stands (Dasch 1987; Cavanagh et al. 2009).

Pollution Removal: in addition to total leaf area of a species, species characteristics that affect pollution removal are tree transpiration and leaf characteristics. Removal of gaseous pollutants is affected by tree transpiration rates (gas exchange rates). Species with dense and fine textured crowns and complex, small and rough leaves would capture and retain more particles than open and coarse crowns, and simple, large, smooth leaves (Little 1997; Smith 1990). Evergreen trees provide for year-round removal of particles.

2.3. Bioindicators

A bioindicator is a quality of an organism, population, community or ecosystem used for indicating the health or status of the surrounding environment. Bioindicators especially lichens and bryophytes are widely used for monitoring air quality.

The benefits of direct measurements of air quality include long-term integration of pollution levels over time and lower operational costs (often by orders of magnitude per study site). Biodiversity metrics, such as the number of sensitive species, relative abundance of functional groups, or genotypic frequencies, for example, are successfully employed for air quality biomonitoring in many nations (Markert et al. 1996; Aničić et al. 2009; Cao et al. 2009). Measuring pollutant concentrations in lichen and bryophyte tissues is another means of air quality mapping (Augusto et al. 2007; Augusto et al. 2010; Liu et al. 2011; Root et al. 2013).

Lichens were first described as "health meters for the air" in 1866, when a Finnish botanist noted that certain species were restricted to a large city park in Paris (Nylander 1866). While many organisms exhibit a measurable response to pollution, lichen and bryophytes (i.e. mosses and liverworts) are the most widely utilized bioindicators of both environmental and human health. Biodiversity-based indices, including richness, relative abundance or dominance of sensitive lichen and bryophyte species are commonly used for mapping deposition of nitrogen (N) - and sulphur (S)-containing pollutants. Species' sensitivities to H_2S, SO_2, acidic deposition, HNO_3, NH_3, NO, and the N- and S-containing aerosols have been well established through field studies and controlled fumigation experiments (Riddell et al. 2008; Riddell et al. 2012). Biodiversity measures are interpreted as an integrated response to 'air quality' in general (Castro et al. 2014), which may provide a useful representation of human exposure as the human body integrates pollution from multiple sources.

2.5. Wild foods and diet diversity

Wild biodiversity has an important role in contributing to food production and security in many agro ecosystems worldwide (Scoones et al. 1992; Johns and Maundu 2006; Termote et al. 2011; Turner et al. 2011; Dogan 2012). Ickowitz et al. (2014) found a significant positive relationship between tree cover and dietary diversity, suggesting that children in Africa who live in areas with more tree cover have more diverse and nutritious diets.

Wild foods include varied forms of both plant and animal products, ranging from fruits, leafy vegetables, woody foliage, bulbs and tubers, cereals and grains, nuts and kernels, saps and gums (which are eaten or used to make drinks), mushrooms, to invertebrates such as insects and snails, honey, bird eggs, bushmeat from small and large vertebrates, reptiles, birds, fish and shellfish (Bharucha and Pretty 2010; Shackleton et al. 2010). These various wild foods invariably add diversity to the diets of people and communities who make extensive use of them. Ocho et al. (2012) reported that 120 wild plant species were listed as foods by residents of a single village in southern Ethiopia, with an average of 20 species per household.

However, caution is needed when analyzing the extent to which wild biodiversity is available and that actually consumed and contributing to dietary diversity. In some instances, wild foods can constitute a large portion of the diet while in others, actual consumption is limited (Powell et al. 2015). The use of wild foods is especially relevant where agricultural production is primarily centered on one or two cereals or tuber-based staples that contribute the bulk of daily calorie requirements, but provide limited micronutrient and dietary diversity.

Wild foods are an essential and preferred dietary component in both rural and urban households in many parts of the world. Aberoumand (2009) reports that approximately one billion people around the world consume wild foods, but it is likely to be much higher.

Generally, higher values of vitamins and minerals boost immunity against diseases (Himmelgreen et al. 2009). Golden et al. (2011) reported that bushmeat hunting by households in northeastern Madagascar had a significant impact (by approximately 30%) in lowering the incidence of childhood anemia and this was more pronounced in poorer households than wealthier households.

Most development agencies dealing with food security accept that there is a strong relationship between dietary diversity generally and health and nutrition status, founded on a number of studies globally (Ruel 2003; Arimond and Ruel 2004; Steyn et al. 2006). Thus, the inclusion of even small amounts of wild foods adds to the diversity of the standard diet in many countries, with beneficial effects on health outcomes.

2.6. Biodiversity and biomedical discovery

Many of the diseases that affected or killed most people a century ago are today largely curable or preventable. Antibiotics rank among the most significant breakthrough that has considerably improved human health in the twentieth century. Death from pneumonia was so prevalent in the early twentieth century. With the arrival of penicillin and its descendants, rates of death from pneumonia plummeted (Podolsky 2006). Percentages of antivirals and antiparasitic derived from natural products approved during that same period are similar or higher.

For as long as we know, humanity has relied upon compounds from nature designed to treat what ails us. Reliance upon biodiversity for new drugs continues to this day in most domains of medicine. More than half of the 1355 newly approved drugs by the US Food and Drug Administration between 1981 and 2010 had natural product origins (Newman and Cragg 2012).

The success of drug development from natural products manifests the common molecular currency of life on earth. Species as diverse as *Conus geographus*, *Penicillium citrinum*and *Taxus brevifolia*– a meat-eating marine snail, ricefungus and boreal conifer – produce molecules that in humans relieve pain, reduce cholesterol, and treat breast, ovarian, lung and other cancers, respectively, because organisms, as diverse as they are, communicate within themselves and other creatures using common molecular currencies (Chivian and Bernstein 2008).

Plants have been the single greatest source of natural product drugs to date, and although an estimated 400 000 plant species populate the earth, only a fraction of these have been studied for their pharmacological potential (Hostettmann et al. 1998). For example, one of the largest plant specimen banks, the natural products repository at the National Cancer Institute, contains ~60 000 specimens (Beutler et al. 2012).

Plant species as diverse as the Himalayan yew, *Taxus wallichiana* (and other *Taxus* spp.) or Africancherry, *Prunus africana*, long used in traditional medicines, have been threatened by factors such as overharvesting and international trade, driven by high consumer demand (Hamilton 2003). Both are listed under the Convention of International Trade in Endangered Species of Flora and Fauna (CITES). The establishment and enforcement of effective management and trade of wild-collected species, both by governments and corporations, remains a critical need in plant conservation (Phelps et al. 2014).

2.6.1. Biodiversity, the microbiome and antimicrobial resistance

Antibiotic use, aside from its potential to cultivate resistance, also carries the potential to disrupt relationships between hosts and their symbiotic microbes. The human microbiome contains tenfold more microorganisms than cells that comprise the human body and antibiotic use can dramatically alter its composition and function (Cho and Blaser 2012). Although much of the microbiome and its relationship to its host remains unknown, it is already apparent that changes to the variety and abundance of various microorganisms, as can occur with antibiotic use, may affect everything from the host’s weight and the risk of contracting autoimmune disease, to susceptibility to infections (Petersen and Round 2014).

Table 1: Examples of potential impacts of health-care activities on ecosystems

Issue	Example	Potential impacts
Energy use	Energy demand for health-care facilities can be significant, with 24-hour requirements for medical equipment, lighting, heating and air-conditioning.	Energy demand is associated with the consumption of fossil fuels, emission of greenhouse gases and other pollutants.
Water use	Hospitals and other health-care facilities can use large quantities of water, particularly for patient hygiene, surface cleaning, food preparation and general sanitation.	This adds significantly to community demand for water resources, potentially impacting on aquatic ecosystems or water- dependent habitats.
Water quality	Health-care facilities use significant amounts of a wide variety of pharmaceuticals and personal care products (PPCPs), as well as sanitizers, and other chemicals, such as X-ray contrast media. Many of these are not fully degraded by modern wastewater treatment systems and end up in natural waters.	Release of PPCPs into the soil or aquatic environments, including some that act as endocrine- disrupting compounds, is implicated in a range of impacts upon ecosystems and upon animal health and behavior.
Air quality	Many hospitals have incinerators to deal with hazardous and/or biological waste, which may release contaminants into the local atmosphere. Emissions associated with health- care-associated transport can also be significant.	

Source: Adapted from COHAB 2014

2.7. Traditional medicine

2.7.1. Traditional medicine and biological resources

Biological resources have been used extensively for health care and healing practices throughout history and across cultures. Such knowledge is often specific to particular groups living in distinct environments, and is usually passed on over generations (Shankar 1992; Balick and Cox 1996; Vandebroek 2013).Traditional knowledge in health care can range from home-level understanding of nutrition, management of simple ailments or reproductive health practices, to treating serious chronic illnesses or addressing public health requirements. In local communities, health practitioners trained in traditional and non-formal systems of medicine often play an instrumental role in linking health-related knowledge to affordable health-care delivery (Montenegro and Stephens 2006; Reading and Wien 2009).

2.7.2. Trends in demand for biological resources

Plants used in traditional medicine are not only important for local health practices, but also for international trade, based on their broader commercial use and value (Fabricant and Farnsworth 2001). Globally, an estimated 60 000 species are used for their medicinal, nutritional and aromatic properties and, every year, more than 500 000 tones (UN Comtrade 2013) of material from such species are traded. The value of the global trade in plants used for medicinal purposes may exceed US$ 2.5 billion, and is increasingly driven by industry demand (UN Comtrade 2013).Fauna and their products are also extensively used in traditional medicine; assessments of the use of fauna and their products are mostly region-, country- or taxa-specific (Alves 2011; Nunkoo et al. 2012). A variety of animal body parts and secretions are included in traditional medicine pharmacopoeia (Alves and Rosa 2005).

Increasingly, there is a reverse “re-engineering” or “reverse pharmacology” process being undertaken by researchers, where novel medicines or medical therapies are being developed using traditional processes. Furthermore, institutionalized traditional medicine manufacturers are investing in developing new products that are value additions over existing forms of medicinal formulations (Unnikrishnan and Suneetha 2012).The demand for herbal medicines is rising drastically, fuelled by factors such as cost– efficacy and higher perceptions of safety.

Table 2: Correlation between plants used and reported outcome in a study on traditional treatments for malaria in Mali

Plant	Total number of people used on	Healed	**Failed**	**% Healed (95% CI)**	***P* (Fisher exact)**
Argemone mexicana	30	30	0	100% (88–100)	Reference
Carica papaya	33	28	5	85% (68–95)	0.05
Anogeissus leiocarpus	33	27	6	82% (64–93)	0.03

Source; Rao et al. 2010

2.8. Contribution of biodiversity and green spaces to mental and physical

2.8.1. Biodiversity and mental health

Mental health is defined by WHO as "a state of well-being in which every individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to her or his community" (WHO 2001). In addition to an increase in the incidence of NCDs such as as heart disease, chronic obstructive pulmonary disease, stroke and cancer, mental disorders contribute to a significant proportion of the global disease burden (Beaglehole and Bonita 2008; Beaglehole et al. 2011).

Promoting physical activity in people and knowing more about where people with mental health problems should recreate could, therefore, be more of a public health priority. Little is known about the types of environments that can best support physical activity in this population or what types of environment alleviate or aggravate psychotic symptoms. Green spaces in urban settings are linked to stress reduction (Roe et al. 2013; Ward Thompson et al. 2012), neighborhood social cohesion (Maas et al. 2009), reductions in crime and violence (Branas et al. 2011; Kuo and Sullivan 2001; Garvin et al. 2013), and a range of other health benefits associated with psychological, cognitive and physiological health (Sandifer et al. 2015; Logan 2015 and Rook et al. 2013).

Nature connectedness refers to the degree to which individuals include nature as part of their identity through a sense of oneness between themselves and the natural world (Dutcher et al. 2007; Schultz 2002). People with high nature connectedness tend to have frequent, long-term contact with nature and spend the most time outdoors (Chawla 1999), exhibit ecologically aware attitudes and behaviors (Nisbet et al. 2009).It is not only the availability and quantity of greenery that matters, but also the quality and depth of the green spaces, in terms of species richness and heterogeneity (Werner and Zahner 2010; Sandifer et al. 2015). The design of urban landscapes that jointly promote the mental health benefits of exposure to green spaces and biodiversity (including microbial diversity).

2.8.2. Biodiversity, Green Space, Exercise and Health

The relationships between biodiversity and good physical health are inherently complex and multidimensional, with multiple confounding and interrelated sociocultural, geographical and economic mediators. In the few studies in which a direct causal relationship between biodiversity and physical and mental health has been sought, it is frequently the case that precise physiological elements of physical health have not been correspondingly measured, few studies rigorously measure both biodiversity and specific physiological effects on physical health.

2.8.3. The Contribution of Biodiversity to Cultural Ecosystem Services That Regulate Disease and Support Human Well-Being

An accepted characterization for cultural services is provided by the Millennium Ecosystem Assessment (MEA) (2005), described as the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic values. Pretty et al. (2008) explored how biological and cultural diversity intersect, describing "nature" as "the setting in which cultural processes, activities and belief systems develop, all of which feedback to shape the local environment and its diversity "and human health. The WHO Quality of Life Assessment (WHOQOL) was devised as a method to determine an individual's quality of life in the context of their culture and value systems; use of the WHOQOL method has shown that the environmental domain – including aspects of safety, security, access to resources and interaction with local environments – is an important part of the quality-of-life and regulation of diseases concept (WHOQOL Skevington 2009).

Clark et al. (2014) conceptualized the *direct* linkages between biodiversity and human health via disease regulation and pollution control, and the *indirect* linkages between biodiversity and human health as being "cultural", where biodiversity yields cultural goods, cultural values are placed on those goods, and when they are derived there is a well-being benefit and therefore a human health outcome.

2.8.4. Indigenous Health and Well-Being

Therapeutic and biocultural landscapes are an important dimension to achieve health at the local level. Survival and vitality of knowledge and resources depend on the sociocultural contexts in which they are embedded. Indigenous knowledge and resources are found to be most vibrant among communities (specifically, indigenous and local communities) close to culturally important landscapes. These could relate to socioecological production landscapes or conservation systems or therapeutic landscapes. Such landscapes and related traditional knowledge practices contribute to health and well-being.

Gorenflo et al. (2012) suggest that, in many instances, co-occurrence between biological and linguistic diversity may hint at some form of functional connection – perhaps founded in a need to describe culturally or nutritionally important species, habitats or landscape elements. But indigenous peoples also often have an intimate knowledge of the other valuable living resources available in their biodiverse settings – including medicines and foods that are vital for global and local health.

Table 3: Some key biodiversity-health linkages

Biodiversity and Health Topic	Health Sector Opportunity
Water Water quantity Water quality Water supply	direct responsibility; Integrate ecosystem management considerations into health policy Indirect responsibility; Promote protection of ecosystems that supply water and promote sustainable water use.
Food and nutrition Species, varieties and breeds including domesticated and wild components Diversity of diet Ecology of production systems Total demand on resources Sustainability of o take, harvesting and trade of species used for food	Direct responsibility: Recognize and promote dietary diversity, food cultures and their contribution to good nutrition Recognize synergies between human health and sustainable use of biodiversity (e.g. moderate consumption of meat) *Indirect responsibility:* Promote sustainable production harvesting and conservation of agro biodiversity

Diseases Disease source and regulation services Ecosystem integrity and diversity	Direct responsibility: Integrate ecosystem management considerations into health policy *Indirect responsibility:* • Promote ecosystem integrity
Medicine • Traditional medicines • Drug development (genetic resources and traditional knowledge) • Chemical/ pharmaceutical accumulation in Ecosystems. • Sustainability of o take/harvesting and trade of medicinal species. • Changing status of species used for medicine.	Direct responsibility: • Recognize contribution of genetic resources and traditional knowledge to medicine. *Indirect responsibility:* • Protect genetic resources and traditional knowledge • Ensure benefit t sharing
Physical, mental and cultural dimensions of health • Physical and mental health • Cultural/spiritual enrichment	Direct responsibility: • Integrate value of nature into health policy *Indirect responsibility:* • Promote protection of values, species and ecosystems.
Adaptation to climate change Ecosystem resilience Genetic resources (options for adaptation) Shifting reliance to biodiversity with climate change shocks	*Indirect responsibility:* Promote ecosystem resilience and conservation of genetic resources Decrease vulnerability of people reliant on important food and medicinal species which are likely to be impacted by climate hange.

3. Conclusion

Biodiversity provides fundamental contribution to essential life-supporting services, such as air and water quality and food provision. It also requires mapping the role of biodiversity in human health on many other fronts, including nutritional composition; micro- and macronutrient availability and NCDs; its applicability in traditional medicine and biomedical supply that relies on plants, animals and microbes to understand human physiology; and its relationship with processes affecting infectious disease regulation.

The increase in food production achieved over the past decades has been accompanied by significant losses in agricultural biodiversity, as production systems (crop and animal) have become more uniform and dependent on externally derived chemical inputs. The loss of agricultural biodiversity has been associated with reductions in ecosystem service provision, often accompanied by negative impacts on human health. It is clear that agricultural biodiversity can make significant contributions to improving food security, nutrition and human health, and will play an essential role in achieving sustainable food production and improving the productivity needed to meet the challenges of climate change. The chapter points to a number of areas of work that can help to improve the contribution of agricultural biodiversity to food security and human health. These are listed below.

The importance of diversity-rich production systems and diversification is widely recognized in respect of their contribution to food security, sustainability, adaptation to change and human health.

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