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Conservation and Sustainable Use of Plant and Animal Genetic Resources for Better Human Health

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Definition

Gene banks are biorepositories of genetic material. They are organizational units which are involved in the conservation and management of genetic resources. Gene banks are routinely involved in the conservation of different types of genetic material, among them seeds, pollen, embryos, meristems, cells, DNA, semen, ova, and even entire plants and animals. This entry mainly focuses on the conservation and use of plant genetic resources and to a small extent highlights the conservation of animal genetic resources.

Introduction

The right to health is enshrined in the World Health Organization constitution as a fundamental right of every human being (WHO 2006). While some medical practitioners define human health simply as the absence of diseases, the World Health Organization gives health a broader definition as ". . . a state of physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO 2006, p. 1). In this entry, we adopt this latter definition as it encompasses a broad array of issues and interactions that in totality determine human health and well-being. Biodiversity is of fundamental importance in the attainment of sustainable development goals (SDG) and is specifically at the heart of efforts aimed at achieving improved health and well-being. This is mainly achieved through its role in food security and nutrition, with the diverse adverse effects of food insecurity and malnutrition on human health being well known and documented (FAO et al. 2017). In addition, biodiversity contributes to human health through its role in traditional medicine and provision of various ecosystem services among others. As a bedrock for sustainable agricultural production systems, the contribution of biodiversity to improved productivity, enhanced livelihoods, and human health cannot be overstated.

The critical role played by biodiversity in ensuring human health is however being constrained by the accelerated genetic loss that these resources are undergoing due to natural calamities as well as anthropogenic causes. The anthropogenic pressures that are impacting biodiversity include destruction of natural habitats due to agricultural expansion and infrastructural

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development, overharvesting, and overgrazing, thereby leading to significant land degradation. The key natural calamities that are causing accelerated genetic loss include prolonged droughts, desertification, and erratic floods, all of which appear to be exacerbated by climate change and variability. In addition, agricultural policies that have largely promoted the cultivation of high-yielding varieties of main crops have led to the displacement of traditional crops and varieties leading to their genetic erosion. As will be highlighted later, these traditional foods and diets are in most cases more nutritious and result in more healthy outcomes than most major crop species. The conservation and use of these indigenous crops is therefore of utmost priority. If biodiversity is to play its role in enhancing food security and nutrition, improving human health and well-being, as well as promoting economic development, then greater efforts are needed to ensure its proper conservation and sustainable use.

In this entry, like Romanelli et al. (2015) and Mace et al. (2012), a broader view of biodiversity is taken that includes not just the species richness and intraspecific genetic diversity but also the associated habitats and ecosystems, all of which constitute biodiversity components whose interaction impacts human health in varied ways. In addressing the status and need of biodiversity conservation and use, this article broadly considered both the direct and indirect effects of biodiversity on human health. The story of the valuable role that biodiversity plays in human health would be incomplete without mention of the huge burden, and important reciprocal role that local communities play in ensuring these resources are properly conserved for present and future generations. This entry therefore gives special focus on the various approaches that are employed by the local communities, global scientific community, and other stakeholders in biodiversity conservation.

Overview of the Role of Plant and Animal Genetic Resources in Ensuring Human Health

The important role played by biodiversity in ensuring human health and well-being is increasingly being realized, appreciated, and documented (Sandifer et al. 2015). Increasing access to a variety of nutrient-dense foods has been identified as an important approach to reducing cases of stunting and malnutrition by improving the nutrient quality of foods available to poor communities. However, due to increased homogenization of agriculture to a monocrop-based system that relies on a few crops, farmers have abandoned their traditional crops and lost most of their valuable diversity. Yet the importance of traditional foods to health and food security has increasingly been recognized over the years, and their cultivation, conservation, and sustainable use need to be promoted. The increased incidences of lifestyle diseases have led to widespread changes in dietary shifts with greater preference being given to foods with health benefits. Increased consumption of traditional leafy vegetables in high-level hotels and restaurants as well as by urban households over the recent past is such one major dietary shift. For example, *amaranthus* (one of the traditional vegetables which is highly nutritious and has been found to have 200 times more vitamin A and 10 times more iron than an equivalent size of cabbage) (McGarry and Shackleton 2009) is increasingly becoming a preferred vegetable. Indigenous African rice has higher amylose content than Asian rice and could be a natural source of slowly digestible starch, thereby conferring it with potential health benefits (Wambugu et al. 2018). Baobab fruit (*Adansonia digitata*), a wild fruit species, has been reported to have six times higher levels of vitamin C than oranges (Fentahun and Hager 2009). Edible insects such as mopane worms (*Imbrasia belina*) have been reported to have protein levels which are approximately double those in beef (Greyling and Potgieter 2004). These examples serve to show the important role that some of the largely neglected plant

and insect biodiversity have on human nutrition and health.

A variety of crop and animal species and their associated diversity in terms of varieties and breeds underpin dietary diversity. Diet diversification is key to improved nutrition and health by providing a variety of nutrients, micronutrients, and bioactive compounds. The continued loss of important biodiversity seriously hampers the achievement of a high dietary diversity thereby compromising the health and nutrition of the consumers. Due to improved living standards and increased affluence across the world, large segments of the human population are increasingly getting conscious of the quality of food that they consume. Greater efforts should therefore be made to enhance access to a diversity of nutritious foods for this population that is increasingly getting aware of the importance of healthy eating habits. It is important that communities are supported in the conservation of biodiversity so that they are able to access planting materials of a variety of genetically diverse nutrient-dense food crops.

Another great contribution of biodiversity to human health is as a source of traditional medicine. It is estimated that about 70% of the population in sub-Saharan Africa do not have access to modern healthcare system and therefore depend on traditional medicine for their primary healthcare (Lambert et al. 2005). These statistics are replicated in other parts of the world. However, genetic resources of these medicinal plants most of which are mainly harvested from the wild are rapidly declining. This disappearance is mainly due to overexploitation through unsustainable harvesting methods. This genetic erosion of important diversity of medicinal species is undermining the livelihoods and health of a large proportion of poor people who depend on them and needs to be arrested.

Capacity to provide quality healthcare services is dependent on economic stability. Indeed there is a positive correlation between economic strength and quality of healthcare services. Considering that agriculture continues to be the mainstay of many economies in sub-Saharan Africa as well as other parts of the globe, to grow these economies so as to ensure continued provision of quality healthcare, agriculture must grow. Indeed the importance of agriculture as a tool and vehicle for economic development has been well illustrated by a positive correlation between agriculture and nonagricultural activities. Estimates in the past have shown that an increase in growth rate of the agricultural sector results in a corresponding increase in the overall economic growth. As biodiversity has been shown to be the foundation for agricultural growth and environmental stability, it therefore follows that these economies are primarily dependent, albeit precariously, on biodiversity. Genetic resources which are a critical component of biodiversity act as the building blocks that breeders and other scientists utilize to generate technologies that drive agricultural productivity. Therefore, continued provision of quality healthcare is, to a large measure, dependent on how best these agricultural-dependent economies harness this natural wealth including plant and animal genetic resources in agricultural development. In the section that follows, an overview of the status of biodiversity conservation and highlight on the various approaches that are employed in the conservation of biodiversity for improved human health are provided.

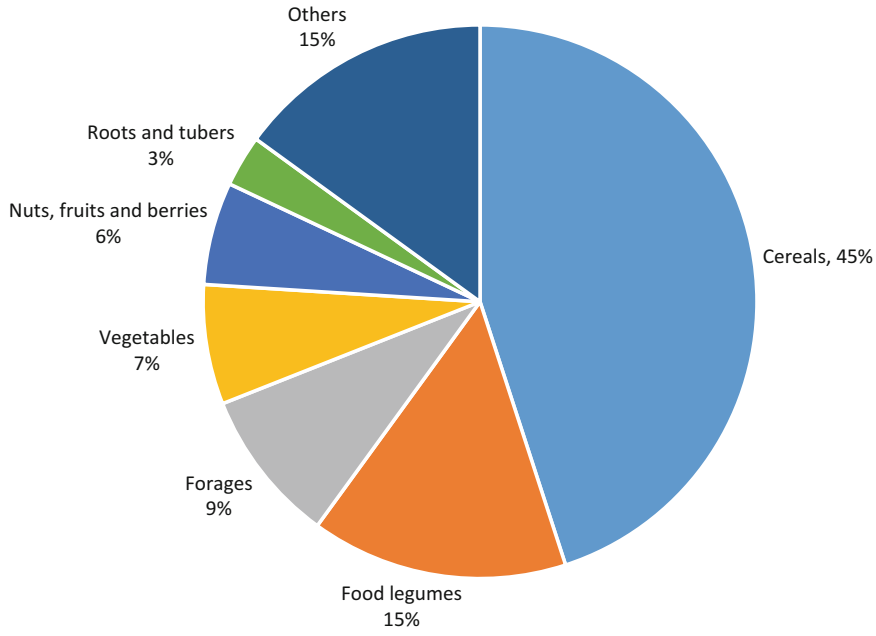
Germplasm Conservation Approaches and Their Relevance to Human Health

Generally, there exist two main germplasm conservation approaches. These include in situ and ex situ conservation, though over the years, on-farm conservation has increasingly been recognized and treated as an important and distinct genetic resources conservation approach. These conservation approaches complement each other in safeguarding biodiversity.

Ex Situ Conservation

Seed Banks and Food Security

Increased recognition of the importance of plant genetic resources coupled with the alarming loss of these resources has catalyzed efforts toward their conservation. As reported by FAO (2010),



Conservation and Sustainable Use of Plant and Animal Genetic Resources for Better Human Health, Fig. 1 Contribution of major crop species to ex situ conservation. (Source: Adapted from FAO 2010)

huge strides have been made in the conservation of plant genetic resources globally, with an estimated 7.4 million accessions being conserved in about 1625 gene banks spread across the world. These conserved genetic resources constitute a vital resource that will act as building blocks for breeding more healthy and nutritious foods. In addition to enhancing household dietary diversity, these diverse genetic resources provide the basis for adapting to variable climatic conditions. Past conservation efforts have mainly focused on the major crops, with cereals forming the bulk of the germplasm conserved in ex situ facilities (Fig. 1).

Germplasm holding records indicate that 9 of the top 10 largest collections conserved in seed banks represent the major crop species. These conservation efforts reflect the role the global community attaches on these main species to food security. Maize, rice, and wheat which constitute some of the largest collections provide about 50% of the global dietary protein and energy (Wood et al. 2005). While the main crops play a critical role in global food security and nutrition, there exist numerous other minor, neglected, and underutilized species which potentially serve an even greater role to human health as they provide a more diverse, nutritious, and balanced diet. Records indicate that the major crops are well represented in ex situ collections, while the minor as well as the neglected and underutilized crops are less well represented. Owing to the nutritional and health importance of most of the minor, neglected, and underutilized species, they deserve urgent and special attention in ensuring their genetic diversity is properly conserved and sustainably utilized. Similarly, there exist significant gaps in the conservation of crop wild relatives (Castañeda-Álvarez et al. 2016) despite these species increasingly being exploited for food and medicinal value. Systematic global efforts are required in order to collect these species before they are lost from their natural habitats.

Botanical Gardens

It is estimated that there are about 2500 botanic gardens located in about 150 countries which in total conserve about six million accessions representing about 80,000 plant species (FAO

Conservation and Sustainable Use of Plant and Animal Genetic Resources for Better Human Health, Table 1 Top 10 medicinal species conserved in botanic gardens globally

Genus	Species	No. of ex situ sites worldwide
Ginkgo	*biloba*	347
Cornus	*mas*	242
Quercus	*robur*	229
Taxus	*baccata*	221
Hamamelis	*virginiana*	220
Achillea	*millefolium*	214
Pinus	*strobus*	214
Morus	*alba*	213
Thuja	*occidentalis*	208
Juglans	*nigra*	207

Source: Botanic Gardens Conservation International's Plant Search database

2010; Hawkins 2008). As observed by Hawkins (2008), botanic gardens play a special role in the conservation of medicinal species, with the early botanic gardens having been established solely for medicinal plants cultivation and research. They remain perhaps the most important agencies for the conservation of these medicinal taxa as their conservation may not be the priority of other conservation bodies. A total of about 1800 medicinal plant taxa are conserved in botanic gardens globally (BGCI 2018). Table 1 shows the top 10 medicinal taxa held in botanic gardens and the number of ex situ sites conserving them. The continued genetic loss of valuable medicinal plants underscores the need for communities to be supported through training and other capacity building initiatives to ensure proper conservation and sustainable use of these species.

Other than ex situ conservation, botanic gardens also support conservation of medicinal species by raising awareness on the value of these resources and the importance of conserving them. Open days can be held where training programs on diverse areas of conservation such as plant propagation and general agronomic techniques can be undertaken. Collaboration with the local community is important in identifying medicinal species facing specific threats and prioritizing those that require conservation. In addition to helping identify priority species, traditional herbal practitioners can work with botanic gardens in treating people at botanic garden sites as well as documenting indigenous knowledge applied in herbal medicine. Botanic gardens also conserve a variety of other plant species that impact human health through their role in human nutrition. Among these are crop wild relatives which harbor valuable diversity that can be used for breeding for more nutritious crop varieties. Crop wild relatives have, for example, been used to breed potato varieties with increased calcium content, durum wheat with higher protein content, and tomatoes possessing provitamin A (Bioversity International 2006).

Urban Green Spaces

Majority of the world population both in developed and developing countries are currently living in urban areas (Lepczyk et al. 2017). The need for infrastructure and facilities to support this increased urban population is causing immense biodiversity loss due to the associated anthropogenic developments. This rapid urban expansion is having a significant impact on ecological processes which may ultimately deny the urban population some of the much needed ecosystem services. City living is associated with increased anxiety, depression, stress, and stress-related health disorders such as mental health challenges (Cox et al. 2017). There is a growing body of evidence that suggests that interaction with nature through urban green spaces can have profound physiological and psychological health benefits (Sandifer et al. 2015). In order to enhance the quality of life in cities and therefore positively impact human health, there is need for robust and well-planned strategies on the conservation

and management of biodiversity in urban green spaces.

Urban green spaces can take the forms of urban forests, woodlands, urban lawns, urban parks, and gardens and provide critical habitats for conserving global biodiversity. Studies have found that urban areas present a largely neglected opportunity for conserving endemic and threatened species. Although urban areas are widely thought to have low species diversity, studies indicate that in some cases they may harbor a higher proportion of native species compared to equivalent nonurban areas (Ives et al. 2016). Biodiversity practitioners should take advantage of the opportunities presented by urban green spaces to enhance biodiversity conservation for improved human health and well-being. In order to enable biodiversity to flourish in urban green species, there is need to improve habitat quality through effective management as some existing management techniques are detrimental to biodiversity conservation (Aronson et al. 2017).

Conservation of Animal Genetic Resources and Human Well-Being

The current situation on the loss of plant genetic resources mirrors that of animal genetic resources where many indigenous breeds are facing extinction or are under continuous genetic dilution. According to the state of the world's animal genetic resources for food and agriculture (FAO 2007), out of a total of 7616 livestock breeds that are currently documented, it is estimated that about 20% of them are threatened. Moreover, most of the ancestors and wild relatives of livestock breeds are already extinct or facing serious risks of extinction. It is estimated that almost one breed is getting extinct each month, a trend that is seriously worrying. While many countries have made great efforts in the conservation of plant genetic resources, the same is not the case with animal genetic resources. Most countries lack facilities for conserving animal genetic resources and an enabling policy environment to guide and support conservation of these resources. The genetic loss of livestock species and breeds hampers the animal-based diversification of diets. A diversity of animal breeds is especially important from a health and nutritional perspective as significant differences in meat and milk nutritional content have been reported between breeds of the same animal species (Medhammar et al. 2012). In order to enhance nutrient adequacy and diet diversification, it is imperative that efforts are made to conserve as much diversity of animal species and breeds as possible before they become extinct.

As already highlighted, lack of proper programs for conservation of animals has seen an increased loss of animal diversity. Among these include loss of animal pollinators whose continued decline has significant impact on human health. Pollination is a strong determinant of not only the yield but also the nutritional content of pollination-dependent crops. With animal pollination being responsible for key micronutrients and directly contributing approximately 43% yield increase in some vegetables and fruits (Eilers et al. 2011), the loss of pollinators will negatively impact food security, human nutrition, and health. It is estimated that about 56% of the population face a new risk of vitamin A deficiency as a result of continued decline in pollinator population (Ellis et al. 2015). While conservation and effective management of ecosystems will play a useful role in reversing the current alarming trend of loss of pollinators, specific conservation measures targeted at genetic resources of animal pollinators will need to be implemented.

On-Farm Conservation of Genetic Resources

On-farm conservation refers to the cultivation and management of genetic diversity in farmers' fields. On-farm conservation has particular advantages over ex situ conservation as it allows the evolutionary processes to continue, thereby providing the genetic basis for adapting crops to diverse biotic and abiotic conditions. Moreover, unlike seed banks where genetic resources are usually stored under low-temperature conditions with no active human consumption, on-farm conservation provides a more dynamic approach with direct impact to human health as the genetic resources are actively being cultivated, conserved, and consumed. It is mainly conducted in home gardens which are an important agro system that

supports an estimated 1 billion people (Heywood 2013). Due to increased recognition of the important role that home gardens play in food security, human health, and sustainable household livelihoods, interest in home gardens as a key germplasm conservation tool has increased significantly over the last decade.

Home gardens play a particularly important role in human nutrition as they usually hold a variety of vegetable, fruit, spices, and medicinal species. Cultivation and conservation of as high as 100 different species per home garden have been reported (Heywood 2013). Studies have revealed a relationship between plant diversity in home gardens and dietary diversity, with home gardens contributing significantly to household dietary diversity (Akrofi et al. 2010). High household dietary diversity leads to increased nutritional adequacy which in turn is associated with positive health outcomes. These gardens provide an opportunity to conserve and promote utilization of neglected and underutilized semidomesticated and wild species that provide a large quantity and quality of nutrients that are easily accessible to households (Freedman and Stoilova 2015). Additionally, they provide an avenue for local communities to domesticate and thereby conserve priority wild species such as tamarind (*Tamarindus indica* L) and baobab (*Adansonia digitata* L) whose superior nutritional value has been reported (Romanelli et al. 2015).

Home gardens usually harbor unique and rare genetic diversity making them particularly valuable from a germplasm conservation perspective. For example, in Cuba, *Phaseolus lunatus*, a nutritious legume possessing a range of minerals which make them healthy, is only found in home gardens, with the ex situ collection having been lost. Similarly, *Pouteria sapota*, an important fruit species that has phenolic and carotenoid compounds which may have health benefits, is also largely conserved in home gardens with little evidence of ex situ conservation (Castiñeiras et al. 2002). These examples demonstrate the important role that home gardens play in the conservation and sustainable use of species that have beneficial health effects. Indigenous fruit species in sub-Saharan Africa are fast disappearing due to overexploitation and land use changes. Natural habitats that are home to these species are fast disappearing. Promoting the cultivation of these fruit species in home gardens will contribute to their conservation and ease pressure on natural indigenous fruit tree stands from where a lot of fruits are collected. School gardens serve a similar role to home gardens and are important in ensuring the health of school children by enhancing access to diverse nutrient-rich foods.

In addition to the cultivation and conservation of edible genetic resources, home gardens also harbor useful diversity of medicinal plant resources. Local communities being the greatest beneficiaries of traditional healthcare system can reap immensely by participating in conservation and sustainable management of medicinal plant species in home gardens. They can, for example, undertake commercial cultivation of selected priority species for income generation. An example of such an initiative is the Muliru Farmers Conservation Group in Western Kenya where a total of 360 smallholder farmers are undertaking commercial production of *Ocimum kilimandscharicum* as an income-generating venture. In addition to supporting biodiversity conservation by investing part of their proceeds in forest conservation, these home herbal gardens help to ease pressure on natural populations of indigenous medicinal species (Romanelli et al. 2015).

Various projects and initiatives aimed at supporting on-farm conservation primarily by broadening farmers' biodiversity options have been conducted around the globe. One of the most significant ways through which institutions can support farmers in conservation of genetic resources is by helping them access and select their farmer-preferred varieties and subsequently providing them with inexpensive seeds of these genotypes. Crowdsourcing and citizen scientist approaches are some of the ways that are being used in assisting farmers to access wide genetic diversity and select their preferred genotypes in a participatory fashion (Jacon 2011; Shawn and Louise 2016). In order to access planting materials of diverse genetic resources, farmers have been supported to conserve their germplasm through

community level seed saving initiatives such as community seedbanks (Vernooy et al. 2014). Community actions such as diversity fairs, diversity kits, food fairs, and seed exchanges are important strategies that help in promoting access, conservation, and use of a wide range of local crop diversity that is important for human health.

In Situ Conservation

This is the practice of conserving biodiversity in its natural habitat. It is a dynamic conservation approach that allows the natural evolutionary processes to continue. Natural ecosystems hold valuable diversity of crop wild relatives and other edible wild plant genetic resources that may be of value to human health. As already stated, where the crop wild relatives may not be edible, they may also play a role in human health as a source of genes to breed for healthier and more nutritious foods. Significantly more progress has been made in the conservation of wild taxa in protected areas compared to the conservation of these species outside protected areas (FAO 2010). In situ conservation could be targeted at selected species, or it could be ecosystem-based as some species can only be conserved as part of the ecosystem in which they exist. An example of an ecosystem-based approach is the conservation and restoration of mangroves, an ecosystem that acts as a natural source of food, fish, shells, fruits, and medicines (Romanelli et al. 2015). Botanic, ethnobotanic, and ecogeographical surveys as well as inventories surveys are necessary in designing robust conservation strategies of important nutrient-rich wild plants as they help determine their distribution and conservation status.

In situ conservation can also be undertaken through the conservation and restoration of biodiversity in degraded habitats. Biodiversity underpins the proper functioning of ecosystems and hence the provision of ecosystem services. The key ecosystem services provided by biodiversity include pollination, air and water purification, regulation of pests and diseases, as well as soil erosion control among others. The presence or absence of these ecosystem services has both direct and indirect effects on human health. As already highlighted, there is continued severe degradation of habitats that is leading to alarming loss of biodiversity. This is negatively impacting human health as the degraded ecosystems lack the capacity to provide important life-sustaining services. Lack of proper water and air purification may lead to severe pollution of these important natural resources. If functional ecosystems are to be assured, it is imperative that efforts are made to undertake ecological restoration of affected habitats. Community participation is critical if restoration programs are to be successful and to meet the intended biodiversity conservation objectives as well as address the priority biodiversity utility needs of the local community. This is evidenced by the successful large-scale restoration of the Sahel region under the Great Green Wall (GGW) for the Sahara and the Sahel initiative (Moctar and Nora 2016). Out of the 170 native species that were prioritized by the local community to be used in the restoration program, the largest proportion amounting to about 24% consisted of plants with medicinal value. The prioritization of species to be used in the program underscores the importance that local communities attach to biodiversity-based traditional healthcare system. It also reflects the important role that biodiversity conservation and restoration programs can have on human health through provision of medicinal plant resources and ecosystem services.

Community participation promotes ownership in the conservation and restoration programs. The prioritization of wild species by local communities is based on indigenous traditional knowledge which plays a useful role in supporting conservation of wild plants (Sujarwo et al. 2014), and all efforts should be made to ensure it is validated and well documented. Another major in situ conservation of medicinal plants has been undertaken in India where one of the largest global in situ conservation networks has been established through public-private partnership (PPP) arrangements (Romanelli et al. 2015). These examples highlight the importance of involving multiple stakeholders in order to enhance the chances of achieving successful conservation programs. Restored or conserved

habitats play a useful role in carbon sequestration and therefore help reduce greenhouse warming. Maintenance of diverse landscapes and diversification of agro systems has been found to have suppressive effects on pests therefore reducing the need for use of chemical pesticides (Zhang et al. 2018). This has an indirect effect on human health as most of these chemicals are toxic and are associated with negative health effects including serious illnesses, diseases, and other lifelong health challenges.

Overview of Biodiversity Policies of Relevance to Human Health

Several biodiversity-related instruments that have an impact on human health have been developed in various sectors both at the national and international levels. The two key international instruments that perhaps have the greatest relevance to human health as well as food and nutritional security include the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) and the Convention on Biological Diversity (CBD). Although the ITPGRFA does not explicitly refer to human health, it provides for facilitated access to a selected set of taxa which are of great importance to global food security and therefore potentially impact human nutrition and health. The CBD expressly recognizes the important role that biological diversity plays in meeting the health needs of the population. The Strategic Plan for Biodiversity 2011–2020 and the Aichi Biodiversity Targets provide an overarching UN-wide framework for addressing biodiversity issues (CBD 2011). In addition, the strategic plan also includes a vision for 2050 and five strategic goals. The 2050 vision recognizes the role of biodiversity in human well-being: "By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people." Of the five strategic goals, goal D is perhaps the most important to human health and well-being as it aims to "enhance the benefits to all from biodiversity and ecosystem services." Under this goal, Target 14 is specifically relevant to human health: "By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded. . .. . .." Nationally, the strategic plan is implemented through National Biodiversity Strategy and Action Plans (NBSAPs). At the national level, there is need for policies to mainstream biodiversity for nutrition and human health. This is particularly important for cultivated indigenous neglected and underutilized species as well as wild ones. In order to inform policy and gain support of policy makers, there is need for empirical evidence on the value of these resources. An assessment of the nutritional composition of prioritized native edible species would be important in demonstrating their nutritional value and hence their importance in human health. Policies to mainstream biodiversity for food and nutrition have been enacted in Kenya and Brazil, both being countries under the Biodiversity for Food and Nutrition Project.

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