A farmer in Peru displays many different varieties of potatoes. Biodiversity reduces the risk of crop failure due to climate or other shocks, and is also critical to nutrition and health. (H. Holmes/RTB)

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Biodiversity: an Essential Natural Resource for Improving Diets and Nutrition

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Introduction

Biodiversity is one of the most important natural resources underlying healthy and thriving agriculture and food systems. Without this resource, we would not have the wide range of foods grown across landscapes that feed our increasing demand for varied diets. While the abundance of species around the globe is extraordinary, the loss of those species is devastating. This loss puts the quality and diversity of global diets at risk: that is, diets made up of foods containing energy, macro- and micronutrients that are necessary to sustain life, support physical activity, and attain a healthy body composition. Ideally, these diets should consist of nutrient-dense foods such as vegetables, fruits, legumes, nuts and seeds, whole grains and cereals, dairy, and animal- and plant-based proteins, that are unique to the geographical location and cultural context.

This chapter characterizes the biodiversity on the planet and stresses the importance of biodiversity for agriculture. It then highlights the latest research on the decline in biodiversity and its impact on food supplies, and how biodiversity links to diets. It describes some challenges in ensuring that agrobiodiversity is central to sustainable development. Finally, it identifies the gaps in knowledge that remain and some potential solutions to push biodiversity to the forefront of the 2030 sustainable development agenda.

Definitions and Concepts

Biodiversity and agrobiodiversity

Biodiversity (also known as biological diversity) constitutes the variety of life on the planet including plants, animals, fungi, and microorganisms. The planet's biodiversity is vast. As of 2015, 2 million species of animals, plants, and other kingdoms have been discovered and estimates suggest that another 6 million are yet to be identified, particularly from certain ecosystems such as the oceans (Horton, 2017).

Biodiversity is often defined at three levels (FAO–PAR, 2011):

1. **Species diversity:** the variety of different species that make up plants, animals, fungi, and microorganisms.

2. **Genetic diversity:** the variety of genes contained in those plants, animals, fungi, and microorganisms. This variety can be examined between species but also within species.

3. **Ecosystem diversity:** the variety of habitats on the planet that have different relationships with living and non-living components (like other natural resources including sunlight, water, and soil nutrients).

Agrobiodiversity (also known as agricultural biodiversity) includes all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute agricultural ecosystems, also termed agroecosystems (FAO, 1997). Agrobiodiversity consists of many different species in plant, animal, and other kingdoms. Plant genetic resources include crops, wild plants harvested and managed for food, trees on farms, pasture, and rangeland species. Animal genetic resources include domesticated animals, wild animals hunted for food, wild and farmed fish, and other aquatic organisms (FAO, 2010). Agrobiodiversity also includes microbial and fungal genetic resources.

These three types of genetic resources support the ecosystem services upon which agriculture relies. Services include nutrient cycling, pest and disease regulation, pollination, pollution, erosion and sediment control, maintenance of the hydrological cycle, and carbon sequestration. These genetic resources also support socioeconomic and cultural benefits of food and agriculture, because many people depend on genetic diversity for their livelihoods.

While these are often taken in abstract terms, agrobiodiversity is essential to food systems because it serves as the basis of sustaining life – the diverse traits revealed among crops, animals, and other organisms used for food and agriculture, as well as the web of interactions that bind these forms of life at the genetic, species and ecosystems levels. The wide range of landscapes is what diversifies, and thus minimizes, risk. Diversity in landscapes and conservation of agrobiodiversity can serve to protect against crop loss from weather or disease, which could be especially important in the face of climate change. Different species and varieties also offer a large spectrum of nutrients found in foods, as varieties and species contain different

nutrient compositions of essential macro- and micronutrients (Swiderska *et al.*, 2011).

Terms such as underutilized, neglected, orphan, minor, niche, wild, local, indigenous, and traditional crops or foods are frequently used interchangeably with biodiversity and agrobiodiversity to describe potentially useful plant and animal species. However, rather than being interchangeable, they are complementary and important food sources that make up the diversity of our food system. Some of these species are strongly linked to the cultural heritage of their places of origin, or are highly adapted to marginal, complex, and difficult environments, or have contributed significantly to diversification and resilience of agroecological niches (Bharucha and Pretty, 2010; Padulosi *et al.*, 2011). Many of these underutilized foods are often not considered ‘mainstream’ or prioritized in global agriculture agendas, and in some cases they require protection (Fanzo *et al.*, 2016).

Biodiversity hotspots and the importance of biodiversity for agriculture and food supplies

There are some regions with a high number of endemic species that are difficult to find anywhere else on earth. These places have been termed biodiversity hotspots. A hotspot must be home to at least 1500 vascular plants that are endemic,

and it must contain 30% or less of its original vegetation, an indication that it is threatened by habitat loss and other human activities (Conservation International, 2018). Conservation International has classified 35 hotspot regions (Fig. 4.1) around the world, comprising just 2.3% of the earth's land surface (Conservation International, 2018). This small total area supports more than half of the world's plant species and 43% of bird, mammal, reptile, and amphibian species (Conservation International, 2018).

Some argue that agriculture ‘is one of the greatest enemies of biodiversity, yet agriculture itself depends on biodiversity’ (Maxwell *et al.*, 2016). Agriculture can indeed be devastating to biodiversity. The Millennium Ecosystem Assessment concluded that extensive growth of agriculture is a significant driver of habitat loss across landscapes and is the primary threat to biodiversity loss worldwide (Millennium Ecosystem Assessment, 2005), with certain ecosystems such as lowland seasonal forests and grasslands being particularly vulnerable.

More than two-thirds of Mediterranean forests and temperate forest steppes, and more than half of all temperate broadleaf forests, tropical dry forests, grasslands, shrublands and savannas had been converted to agriculture by the end of the 20th century.

(Perrings and Halkos, 2015)

Yet as discussed earlier, agriculture also depends on biodiversity. In terms of the biodiversity

Fig. 4.1. Biodiversity hotspots (Conservation International, 2018).

found within farmed landscapes, there is still much debate on which production systems (large-scale versus small-scale, local versus centralized, mono-cropping versus mixed, or organic versus inorganic) are the most advantageous for maximizing food availability and meeting nutritional needs without wreaking havoc on the environment and natural capital, such as biodiversity.

A study by Herrero *et al.* (2017) found that large farms (> 50 ha), located predominantly in North America and South America, Australia, and New Zealand, produce 75–100% of all cereal, livestock, and fruit in these regions. In contrast, smaller farms (< 20 ha) found in Africa south of the Sahara, South Asia, South-east Asia, and China produce 75% of food commodities globally, and 50–65% of the production volume of major food groups. Very small farms (< 2 ha) in those same regions and located in diverse landscapes produce approximately 30% of most food commodities.

The majority of vegetables (81%), roots and tubers (72%), pulses (67%), fruits (66%), fish and livestock products (60%), and cereals (56%) are produced in diverse landscapes. Plantation-based crops, such as sugarcane and oil palm, are produced in less diverse, large-scale landscapes. Landscapes with more agrobiodiversity produce more nutrients. The diverse production systems of small farms contribute 53–81% of key micronutrients (such as zinc, iron, vitamins A and B12, and folate) and 57% of protein into the global food supply (Herrero *et al.*, 2017). These nutrients are essential for human health, but are often lacking in the diets of vulnerable populations (Fanzo, 2017). [Figure 4.2](#) shows the distribution of key nutrients by farm size and the diversity of foods by nutrients in each region.

What these data show is that the diversity of agricultural production and, hence, nutrient output diminishes as farm size increases. However, areas of the world with higher agricultural diversity produce more nutrients, irrespective of farm size. Efforts to maintain production diversity as farm sizes increase seem to be necessary in order to maintain the production of diverse nutrients, ensure viable, multifunctional, sustainable landscapes; and increase the supply of nutrient-rich foods in the global food system.

Summary of Recent Research

Declining diversity of agricultural production and food supplies

FAO (2010) estimates that of the approximate 300,000 plant species that exist in the world, 10,000 plant species have been used for human food since the origin of agriculture. Out of these, only 150–200 species have been commercially cultivated, with four – rice, wheat, maize and potatoes – supplying 50% of the world's energy needs and 30 crops providing 90% of the world's calorie intake.

During the past 50 years, the composition of countries' food supplies (defined as the number and relative abundances of crops and animal products that contribute to energy, protein, fat and food weight) have become more similar to one another, with variation between food supplies in different countries decreasing on average by 69%. While the availability of energy, protein, and fat have increased in almost all countries' food supplies, the global population more and more relies on a handful of major food crops, mostly wheat, rice, sugar, maize and soybeans (Khoury *et al.*, 2014). Cereal and starchy (and more traditional) root staples such as sorghum, millets, rye, cassava, sweet potato, and yam have become more marginalized. At the same time, agricultural practices are increasingly moving towards intensified monocultures, which improve grain yields in the short term, but put constraints on the biological diversity necessary for high-quality diets (Graham *et al.*, 2007; Negin *et al.*, 2009; Khoury *et al.*, 2014).

Remans *et al.* (2014) found that the nutritional diversity of national food supplies is important for key nutrition outcomes. Controlling for per capita availability of calories and national income, they found a significant negative relationship between the diversity of national food supplies and the national prevalence of child stunting, wasting, and underweight. The prevalence of overweight increased as the calories available per capita increased and was independent of food supply diversity. In low-income countries, the diversity of agricultural commodities produced by a country is strongly associated with its food supply diversity. On the other hand, in middle- and high-income countries, national

Fig. 4.2. Nutrients produced by farm size and by regions (Herrero *et al.*, 2017). (a) Distribution of nutrients by farm size. Very small, < 2 ha; small, 2–20 ha; medium, 20–50 ha; large, 50–200 ha; very large, > 200 ha. (b) Diversity is represented by the Shannon diversity index, *H*, which represents how many different types of foods are produced in a pixel and how evenly these different types are distributed. The higher the Shannon index, the higher the diversity.

income and trade play more significant roles in influencing food supply diversity (Remans *et al.*, 2014). Evidence suggests that the quality of the food supply also matters for nutritional status outcomes. Data from 1970 to 2010 show that dietary energy from staples and non-staples in the food supply, as an underlying determinant, has contributed to reductions in the global prevalence of stunting (Smith and Haddad, 2015). Another study showed that the prevalence of

inadequate micronutrient intakes has declined during the past 50 years in all regions with the exception of Africa south of the Sahara (Beal *et al.*, 2017).

Drivers of loss of diversity in food supplies

There are several reasons for loss in diversity within our food supply. Intensification of

agricultural systems due to monocropping of major staple grains and cash crops has led to a substantial reduction in the genetic diversity of domesticated plants and animals in agricultural systems (Khoury *et al.*, 2014; Herrero *et al.*, 2017). Some of these on-farm losses of crop genetic diversity have been partially offset by the maintenance of genetic diversity of seed and animal resource banks since the 20th century as a way of salvaging future sources (Peres, 2016). There are, for example, approximately 1400 seed banks around the world: local banks usually focus on indigenous crops while larger banks, such as the Global Crop Diversity Trust, focus on seeds of plants deemed to have global significance. Under the International Plant Treaty, CGIAR has a legal obligation to conserve and make available 750,000 accessions of crops and trees (CGIAR, 2018).

In addition to the extinction of species, the loss of unique populations has resulted in the erosion of genetic diversity (Millennium Ecosystem Assessment, 2005). Yet the implications of this loss for the biodiversity and quality of the global food supply is scarcely understood or measured from an economic or nutritional perspective. Historically, there have been several high-profile examples of the importance of genetic diversity to staple crops, such as the use of wild progenitors of cultivated species in cross-breeding disease resistance. For example, in the 1970s, scientists discovered a wild teosinte species, an evolutionary cousin of maize, which carried genes for resistance to viral diseases that impact domestic maize; scientists subsequently used these genes to breed virus-resistant maize varieties. Cross-breeding was also used to successfully combat wheat rust for decades until 1999, when rust-resistant varieties in Africa began succumbing to the Ug99 fungus.

Human-related or anthropogenic effects on the environment also threaten the earth's species and ecosystems. These threats are often shaped by migration patterns and the density and pressure of human populations, income and livelihood needs, globalization and, with that, modernization. As incomes and the population grow, the demand for land increases. Demand for land and, in turn, land use changes due to residential and commercial development, agricultural expansion, wetland draining, and forest loss, are associated with declining biodiversity in many parts

of the world, including the biodiversity hotspots identified above (Veach *et al.*, 2017). Habitat loss and degradation pose the most direct threats to animals and birds, by decreasing the size of the area that a species can occupy, and its abundance. Tilman *et al.* (2017) suggested that approximately 80% of all threatened terrestrial bird and mammal species are classified as imperiled, and another 21,000 species of plants and other animals are threatened with extinction, by agriculturally driven habitat loss, logging, urbanization, overhunting, invasive species mismanagement, mining, and the establishment of transport corridors.

Demands for certain types of foods are also impacting biodiversity. As incomes increase and people move to urban centers, their dietary diversity improves in gross terms, a shift that also includes an increased demand for animal-source foods. Diets characterized by heavier animal consumption are land-intensive, contribute to diet-related non-communicable diseases, and have been associated with increased emissions of greenhouse gases (Tilman and Clark, 2014). Extrapolating rates of production and use of land for cattle, pigs, and chickens, Machovina *et al.* (2015) found that the consumption of animal-source foods and bushmeat by humans is one of the most powerful negative forces affecting the biological diversity in the world's biodiversity hotspots (Myers *et al.*, 2000). At the same time, it should be noted that even some plant foods have large water and land footprints, depending on how and where they are grown and shipped, highlighting the importance of a life-cycle assessment of food.

There are also economic and social reasons for declines in biodiversity, especially indigenous food species declines. Many indigenous foods cannot compete economically with commodity cereal crops; their producers encounter difficulties in accessing land; there are perceptions of traditional, indigenous or wild foods as being 'food for the poor'; there is a loss of knowledge on how to use or cook these foods; there is a significant work burden to collect, prepare, process and cook these foods; there are inefficiencies in processing and value addition; and there is low market demand or disorganized market value chains (Jaenicke and Virchow, 2013; Kuhnlein *et al.*, 2009; Bharucha and Pretty, 2010).

Linking biodiversity to dietary diversity

Because many poor and undernourished people are smallholder farmers, it is often assumed that diversifying production and conserving biodiversity on small farms would improve dietary diversity within households. However, the impact pathways linking farm production systems to diets and, eventually, health outcomes can be indirect and long, and are still under debate. What does the emerging evidence tell us about these assumptions?

Although evidence gathered to date does not indicate conclusive links, studies have shown positive associations between farm diversity and dietary diversity (Kerr *et al.*, 2007; Figueroa *et al.*, 2009; Murshed-E-Jahan and Pemsil, 2011; Remans *et al.*, 2011; Masset *et al.*, 2012; Jaenicke and Virchow, 2013; Jones *et al.*, 2014; Pellegrini and Tasciotti, 2014; Carletto *et al.*, 2015; Cuc, 2015; Kumar *et al.*, 2015; Olney *et al.*, 2015; Jodlowski *et al.*, 2016). Access to markets and the types of agricultural biodiversity of species grown on farms may also play roles in improving dietary diversity (Carletto *et al.*, 2015; Sibhatu *et al.*, 2015; Koppmair *et al.*, 2016; Fanzo, 2016; Jones, 2017). Nutritional functional diversity (NFD) is a metric that assesses plant species composition on farms as well as the nutritional composition of those plants, thus capturing the diversity of nutrients on farm landscapes. Using this metric, one study performed in rural Kenya, Malawi, and Uganda found no significant correlations at the farm level between the NFD of the crops grown and household dietary diversity. There was, however, a significant association found between the number of foods bought and sold at local markets and household dietary diversity (Remans *et al.*, 2011). Another study using household dietary consumption data in Malawi found that the NFD varied depending on how far households were from markets. Households located farther from markets had lower overall diversity and accessed relatively more of their diversity from home production than did households located closer to markets (Luckett *et al.*, 2015). A third study, also undertaken in Malawi, used a related metric, crop species richness (CSR), to assess the relationship between on-farm diversity and diets. The study showed that dietary diversity was positively associated with CSR and

in this case distance to markets did not alter the relationship between CSR and household diet diversity. This latter study showed that on-farm diversity is an important contributor to improving dietary diversity and quality and provides a potential income-generation mechanism to sell those foods in local markets (Jones, 2017).

In many traditional production systems, farm diversity comes from indigenous and often underutilized agrobiodiversity and forests. It is thus assumed that agrobiodiversity is expected to influence the dietary diversity of populations using traditional systems by providing them access to a wider variety of foods. A study in rural DR Congo showed that many of these types of households did not actually utilize the huge diversity of wild edible plants with interesting nutritional characteristics freely available in the forest, the fallow lands, or around their homesteads (Termote *et al.*, 2012). Similar results were found in southern Benin (Boedecker *et al.*, 2014) and in Kenya: in areas with higher agrobiodiverse landscapes, this diversity did not translate into differences in diet diversity for more vulnerable populations such as mothers or their children (Mituki *et al.*, 2017).

Challenges in Leveraging Agrobiodiversity

There are a few core challenges in leveraging the potential of agrobiodiversity in smallholder systems for food and nutrition security. The first of these challenges relates to poverty. It is often assumed that if farmers are given a choice of what to grow on their land, they will choose the option that nets them the most income (Isakson, 2011). At the same time, there is a notion that if some farmers instead choose to conserve biodiversity, as opposed to, say, grow cash crops, they will remain poor, or that they will stave off hunger by planting energy-dense crops (e.g. cassava) (Scherr, 2000; Christiaensen *et al.*, 2011). Barrett *et al.* (2011) articulated four linkages between the conservation of biodiversity and the perpetuation of poverty traps. They are: (i) dependence on inherently limited natural resources; (ii) shared vulnerabilities; (iii) lack of informed adaptive management; and (iv) failure of social institutions. However, the sustainable use of biodiversity, for example within niche-value market chains,

could potentially be a pathway to increasing incomes and changing farmers' views on the value of biodiversity. Quinoa, for example, was once a niche crop and is now a cash crop. In such cases, the maintenance, conservation, and sustainable use of biodiversity may be viewed as a viable way of escaping poverty.

The second challenge facing agrobiodiversity is agriculture transformation. As stated earlier, agricultural extensive growth, as driven by the need to provide food, fuel, and fiber to a growing population, is oftentimes responsible for habitat and biodiversity loss (Lopez, 1992; Dasgupta, 1993).

While growth in the demand for food in high-income countries has generally stimulated the intensification of agriculture, in low-income countries it has frequently led to extensive growth. Specifically, where traditional land tenure and resource access regimes prevail, and where credit markets are poorly developed, increasing demand for food can only be met by land clearance.

(Perrings and Halkos, 2015)

The expansion of land use for agriculture is often undertaken at the expense of other species (both animal and plant).

The third core obstacle relates to planetary boundaries, a central concept in the earth system framework, which aims to define a 'safe operating space for humanity' as a precondition for sustainable development. Once human activity has passed certain tipping points, there is a risk of abrupt and irreversible environmental change (Rockstrom *et al.*, 2009). Humans are rapidly altering their livelihoods and demands for food, water, and natural resources, and as a consequence, ecosystems are being permanently changed. The end result is biodiversity loss at an increased rate, which not only impacts ecosystems themselves but also negatively affects the diversity available to humans within their diets (Vermeulen *et al.*, 2012). These mainly human-induced tipping points have left our planet in a vulnerable state and it will be a significant struggle to regain the biodiversity that has already been lost.

Knowledge Gaps and Opportunities Linking Biodiversity to Human Nutrition

Questions remain on how employing and generating demand for agrobiodiversity can contribute

to healthier diets and more sustainable production practices. The knowledge gaps include the following (Fanzo *et al.*, 2016):

- What is the evidence base on how biodiversity in food systems can be managed to increase the livelihoods and incomes of smallholders, as well as improve the nutritional quality and environmental sustainability of diets?
- What are the best practices for 'smart' biodiversity management, such as integrated systems that increase productivity while also improving nutritional value and ecosystem services (CFS, 2016)?
- How can value be added to nutrient-dense niche or traditional crops to make them competitive in the marketplace?
- What are the synergies and trade-offs among dietary diversity, agrobiodiversity, and associated ecosystem functions (Allen *et al.*, 2014; Remans *et al.*, 2014)?
- How do we assess these synergies and trade-offs among income, nutrition, ecosystem, and social outcomes for smallholders as they make farming decisions?
- What other studies (those with rigorous design, robust power, and analytical objectivity) are necessary to assess the impact of household food-production strategies on diets?
- What indicators, metrics, and guidelines are needed to aid decision-making processes at the regional and national levels (Allen and Prosperi, 2014)?

Despite the knowledge gaps, there are many opportunities to improve agrobiodiversity for diets. First, investing in agricultural research and development (R&D) may help governments to identify policies that could be scaled up to improve production practices and supply chains, with the potential to improve diets (Perez and Rosengrant, 2015). Although increases in productivity may have the unintended consequence of making highly processed nutrient-poor foods cheaper, investing in R&D specifically for nutrient-rich crops such as fruits and vegetables, legumes, and neglected foods could lead to improvements in nutrition (Fanzo *et al.*, 2016). Second, by combining nutritional traits with environmental traits, such as tolerance to drought and salinity, as well as to seasonal availability, farmers can

begin to see the multiple benefits of their conservation and use (Fanzo *et al.*, 2016). Third, improvements in dietary diversity and quality will only be possible if agrobiodiversity is given attention by agricultural extension services (Mituki *et al.*, 2017).

At the United Nations Conference on Sustainable Development (Rio+20) in 2012, member states reaffirmed the intrinsic value of biodiversity as the foundation for sustainable development and well-being (UN, 2012, paragraphs 197–204). The Sustainable Development

Goals (SDGs) answered that call – and biodiversity is firmly embedded within multiple goals on the 2030 Agenda for Sustainable Development (adopted in 2015). Nutrition is also central to SDG2. Biodiversity is the backbone of our society – without it, we would not have food, fiber, fuel, and the diversity, in all its facets, of the planet. This biodiversity underlies every aspect of diets around the world, from quality to flavor. The central question is how to conserve and sustainably use biodiversity, now and in the future.

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