

6. Biodiversity and Nutrition

1. Introduction

Malnutrition remains one of the greatest global health challenges we face and women and children are its most visible and vulnerable victims. Agricultural production is theoretically able to feed the world's population in terms of calories (FAOSTAT, 2014), yet it is estimated that half the world's population still suffers from one or more forms of malnutrition. In all its forms, malnutrition is closely linked to disease – as both a cause and effect – and it is the single largest contributor to the global burden of disease (WHO 2012a).

Countries are increasingly facing complex multiple burdens of malnutrition, with undernutrition and micronutrient deficiencies coexisting with overweight and obesity in many parts of the world, often even within the same population or family (Shrimpton 2013). Based on data released in 2014, 161 million children under the age of five are estimated to be stunted, almost 1.5 billion people are estimated to be overweight, over 600 million to be obese (Ng et al. 2014) and two billion are estimated to be deficient in one or more micronutrients, a phenomenon referred to by some as “hidden hunger”. These conditions all have severe consequences for survival, for morbidity, and for the ability of individuals, the economy and society to thrive (IFPRI 2014). Nutrient

deficiencies alone can lead to several global health and development challenges, impaired intellectual and psychomotor development, reduced physical growth, and a range of other problems. It has also been found to increase morbidity from infectious diseases in infants and young children (see Muthayya et al. 2013 and references therein).

In recent years, the direct and indirect dependence and impact of human nutrition on biodiversity has been increasingly acknowledged by the health (WHO 2012b; UN SCN 2013 and ICN2), agriculture (FAO 2013a) and environment sectors (UNEP 2012; CBD 2014). These activities have included landmark research efforts, innovative development programmes and projects, policy initiatives, and advocacy campaigns.

Biodiversity is a key source of food diversity and provides a natural richness of nutrients (macronutrients such as carbohydrates, proteins and fats, and micronutrients [vitamins and minerals] and bioactive non-nutrients for healthy human diets (Blasbalg et al. 2011; Fanzo et al. 2013). In addition, biodiversity also underpins critical supporting ecosystem services, such as pollination and soil fertility, essential to food production, both in terms of quantity and quality.

In the field of nutrition, food is seldom dealt with independently of the nutrients it contains, the

whole diet of which it is a part and the ecosystems it is derived from. Taking a whole diet approach enables the use of different combinations of diverse foods, and their many interactions, to improve dietary quality and meet nutritional needs. It also takes into account local knowledge – threatened in many parts of the world (Sujarwo et al. 2014) – and cultural acceptability and culinary traditions.

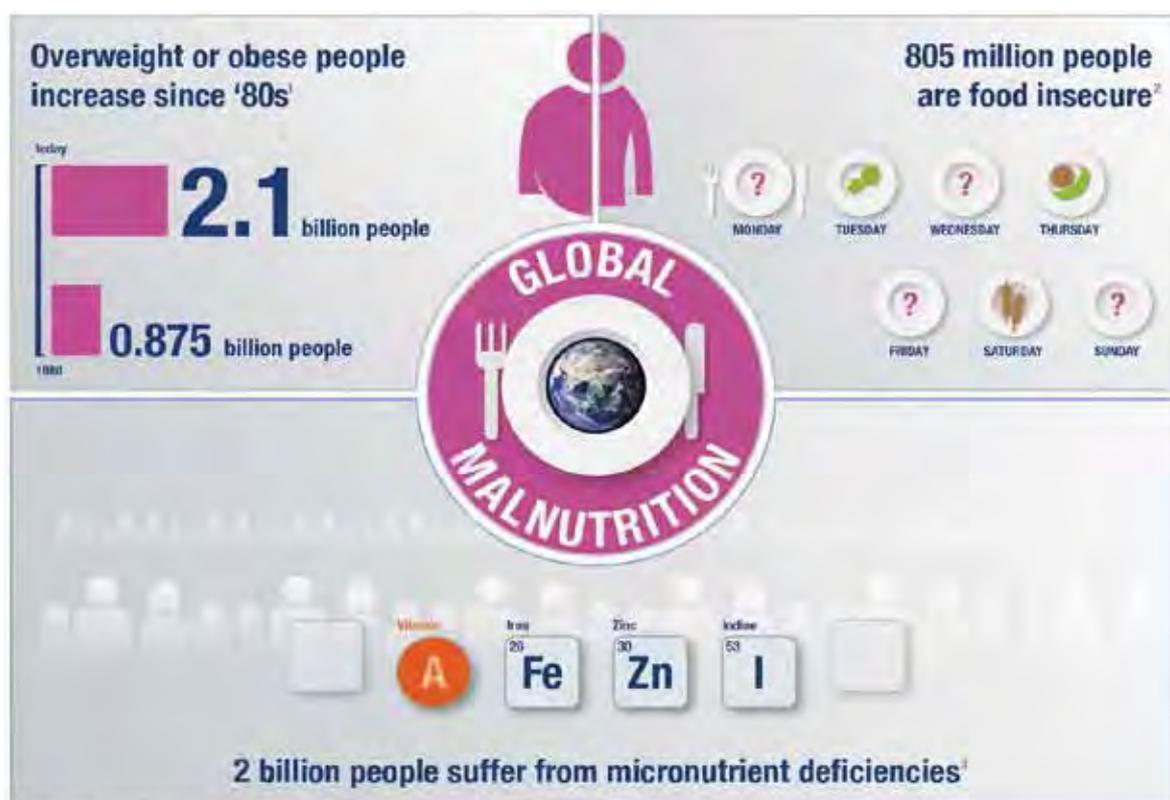
Biodiversity for human nutrition therefore includes the diversity of plants, animals and other organisms used in food systems, covering the genetic resources within and between species, and provided by ecosystems. In nutrition science, however, the diversity of diets covers mostly the inter-species biodiversity, and the intra-species biodiversity is a still underexplored dimension from a nutritional perspective.

Despite the increased recognition of the potential of biodiversity for nutrition, national global food supplies have become more homogeneous in composition, being largely dependent on a few global crops (Khoury et al. 2014).

Agricultural programmes and policies often focus on increasing the production of a few staple crops, and their success is measured in terms of the food quantity or dietary energy supply. Ample quantity does not necessarily ensure appropriate nutritional quality, with staple crops unable to provide the diversity and adequate amounts of nutrients to meet human requirements, especially much-needed micronutrients. This has led to numerous calls demanding new approaches to agriculture for improved nutrition outcomes, often referred to as “nutrition-sensitive agriculture” (Ag2Nut CoP, 2013; Turner et al, 2013; McDermott et al. 2015).

Notwithstanding the productivity successes achieved in the agricultural sector in the past several decades, it is becoming increasingly clear that current methods and levels of food production and consumption are not sustainable, (FAO 2013b) and that finite natural resources and genetic diversity are being corroded or lost in the process. A reduction in biodiversity is a prime example (Toledo and Burlingame 2006; Wahlqvist and Specht 1998).

GRAPH 1: Global malnutrition



1 Ng M, Fleming T, Robinson M, et al. 2014 2 FAO: The State of Food and Agriculture 2014 3 Global Hunger Index 2014

At the time of going to press the global figure of the number of people undernourished globally was estimated at 795 million (SOFI 2015) <http://www.fao.org/3/a-i4646e.pdf>

In view of these trends, monitoring and ensuring biological diversity in global food systems for nutrition and other outcomes is increasingly important and intimately tied to the underlying objectives of the post-2015 Development Agenda (see also Section 11 in this chapter as well as Part III chapters in this volume).

This chapter provides an overview of our knowledge on food composition and the diversity of food production systems. It also examines the contribution of wild foods and traditional food systems and cultures to dietary diversity and nutrition as well as the rising trend known as nutrition transition and Noncommunicable diseases (NCDs). The chapter will further discuss examples of initiatives for biodiversity and nutrition, including in the context of urbanization. Finally, relevant global policy initiatives and future directions relevant to the post-2015 Development Agenda are explored.

2. Biodiversity and food composition

Food composition, i.e. the analysis of nutrients and other bioactive components in food, was traditionally the domain of the agriculture sector, with FAO taking an early leadership role as early as the 1950s, and the US Department of Agriculture developing the single largest national food composition database. In recent decades, the health and nutrition sectors have become the main users of food composition data in studies exploring the relationship between nutrient or dietary intake and diseases.

Given the inherent difficulties in collecting information about people's diets, many national dietary surveys have recorded food intake at a very aggregated level, sometimes using the common name of the species (e.g. spinach) without specifying genetic variety, sometimes as a food type without specifying species (e.g. leafy greens), and sometimes simply as a broad category with no indication of the food itself (e.g. vegetable).

The goal of food composition to date has been to provide nutrient data at that same aggregate

level, and strive for “year-round, nation-wide mean values”, with all compositional differences related to agro-ecological zone, seasonality and, most significantly, biodiversity being obscured. This has been the lamentable trend, despite knowledge among food composition professionals that nutrient content differences among varieties of the same species can be greater than the differences between species.

The scientific literature reports significant intraspecific differences in the nutrient content of most plant-source foods (FAO/INFOODS, 2013a). Significant nutrient content differences in meat and milk among different breeds of the same animal species have also been documented (Medhammar et al. 2012; Barnes et al. 2012; Hoffmann and Baumung 2013). The differences are statistically significant, and more importantly, nutritionally significant, with 1000 and more-fold differences documented. For example, consumption of 200 g of rice per day can represent less than 25% or more than 65% of the recommended daily intake (RDI) of protein, depending on the variety consumed (Kennedy and Burlingame 2003). One apricot variety can provide less than 1% or more than 200% of the RDI for vitamin A. Variety-specific differences can represent the difference between nutrient deficiencies and nutrient adequacy in populations and individuals (Lutaladio et al. 2010).

Many countries, such as Bangladesh with its diversity of inland water bodies and ecosystems, are rich in fish biodiversity (see Box 2 of the agricultural biodiversity chapter). Freshwater aquaculture is also rapidly growing with many households now having access to a pond. Fish, especially small indigenous species, are an irreplaceable rich source of food in the diets of millions. They contain essential, highly bioavailable nutrients, including high-quality protein, essential fatty acids and micronutrients. Some, such as hilsa (*Tenualosa ilisha*), have a high fat content and high levels of polyunsaturated fatty acids. Common small indigenous species such as mola (*Amblypharyngodon mola*), chanda (*Parambassis baculis*), dhela (*Rohtee cotio*) and darkina (*Esomus danricus*) also have a high content of vitamin

A as the eyes and gut are consumed. Because many small indigenous species are eaten whole, including bones and head, they can also represent a very rich source of highly bioavailable calcium, along with high iron and zinc content. The edible parts of larger cultured fish such as silver carp (*Hypophthalmichthys molitrix*), tilapia (*Oreochromis niloticus*) and panga (*Pterogymnus laniarius*) do not contain vitamin A, iron or zinc, and as the bones of large fish are discarded as plate waste, they do not contribute to calcium intake (Thilsted 2013).

Several studies illustrate well the importance of understanding the nutrient composition of biodiversity. For example, in the latter part of the twentieth century, vitamin A deficiency was identified as a serious public health problem among many Pacific Island nations, with over 50% of children manifesting stunting, night blindness, Bitot spots, xerophthalmia causing blindness, and severe repeated respiratory infections (see Box 6). Despite the fact that this was attributed to decreased consumption of traditional, local vitamin A-rich foods, interventions promoted since the 1980s were fortification of margarine and distribution of vitamin A capsules (Schaumberg et al. 1995). Food composition research in the Pacific later revealed that local varieties of familiar species were often superior in their nutrient content to the commonly consumed varieties that dominated the marketplace (Englberger and Johnson 2013, Table 1).

In a study by Huang and co-workers (1999), the nutrient content of different variety of sweet potato was analysed, showing dramatic variety-specific differences, with high-carotenoid varieties containing 65 times more β -carotene than the low-carotenoid varieties. The pro-vitamin A carotenoid content of some local banana varieties was more than 8000 μg per 100 g, compared to the common Cavendish variety with about 25 micrograms per 100 grams (Englberger et al. 2003a, b). After the publication of data on the nutrient richness of local foods in Pacific Island countries (see Table 1), it was clear that agricultural biodiversity could provide more sustainable and culturally acceptable solutions to several of the problems of malnutrition in the region (Englberger et

al. 2003a, 2003b, 2003c, 2006, 2008, 2009; Kuhnlein et al. 2009, 2013; Burlingame and Toledo 2006; Rubiang-Yalumbing et al. 2014). As more and better data become available, food biodiversity, covering thousands of varieties of fruits, vegetables, grains and legumes, animal species and breeds, edible insects and fungi, is being recognized for its high nutritional value and great potential for improving the nutritional status of local communities. Furthermore, many varieties of aibika (*Abelmoschus manihot* L.) are consumed in the Pacific region as a common leafy vegetable particularly in Papua New Guinea (PNG) where a recent study (Rubiang-Yalumbing et al. 2014) has highlighted its high nutritional value and potential for improving the nutritional status of local communities. This study has also highlighted genotype and environment interactions that significantly influence the micronutrient concentrations of even the same accessions from year to year, even when planted in the same area.

The selective specialization in a smaller number of crops and crop genotypes has made some crops less resilient to diseases and has limited the range of available nutrients. Decades of research shows that while yields of staple crops such as maize, wheat and rice are increasing, their nutritional contents tend to be decreasing (Jarrell and Beverly 1981; Simmonds, 1995). Moreover, as highlighted in the chapters on agricultural biodiversity and climate change in this volume, climate change may significantly influence biodiversity resources, food production and food contamination, including the incidence of aflatoxins, with implications for food security, diets and nutrition (Cotty and Jaime-Garcia 2007; Tirado et al. 2013). Climate change is also expected to cause significant reductions in the nutritional content of certain foods, particularly C3 grains and legumes, which provide a large portion of the global population with their primary source of iron and zinc. Increasing CO_2 concentrations may lead to reductions ranging between 5% and 10% in the iron and zinc content of the edible portion of these crops (Myers et al. 2014).

Table 1: Carotenoid content of selected traditional staple food varieties compared to rice ($\mu\text{g}/100\text{ g}$ edible portion) in Pohnpei, FSM

Variety	Species	Flesh colour ¹	β -carotene	α -carotene	β -crypto-xanthin	β -carotene equivalents ²	RE ³	RAE ⁴	Total carotenoids ⁵
Banana									
<i>Utin lap</i>	<i>Musa spp</i>	Orange: 15	8508	na	na	8508	1418	709	na
<i>Karat</i>	<i>Musa spp</i>	Yellow/orange: 8	2230	455	30	2473	412	206	4320
Giant swamp taro									
<i>Mwahng Tekatek Weitahta</i>	<i>Cyrtosperma merkusii</i>	Yellow: 1	4486	na	na	4486	748	374	na
<i>Mwahngin Wel</i>	<i>Cyrtosperma merkusii</i>	Yellow: 4	2930	2040	120	4010	668	334	5630
Breadfruit									
<i>Mei Kole</i>	<i>Artocarpus mariannensis</i>	Yellow	868	142		939	132	78	na
Pandanus									
<i>Luarmwe</i>	<i>Pandanus tectorius</i>	Yellow	310	50	20	345	58	29	5200
Imported food									
Rice, white or brown	<i>Oryza sativa</i>	White	na	na	na	0	0	0	0

na- not analysed * below detection limits

Notes: Analyses were conducted at different laboratories, see published papers. All used state-of-the-art techniques, including high performance liquid chromatography (HPLC). Samples were as eaten: raw ripe (banana, pandanus); cooked ripe (breadfruit) and cooked as mature (taro). All samples were composite samples: 3–6 fruits or corms per sample, collected from Pohnpei State, Federated States of Micronesia. Data are from: Englberger et al. 2009a (pandanus), Englberger et al. 2008 (giant swamp taro), Englberger et al. 2006 (banana), Englberger et al. 2003a (breadfruit). Imported food: rice: Dignan et al. 2004. Imported rice has now become a common staple food in Pohnpei.

¹ Raw flesh color was described visually and estimated using the DSM Yolk Color Fan, numbers ranging from 1 to 15 for increasing coloration of yellow and orange.

² β -carotene equivalents: content of β -carotene plus half of α -carotene and β -cryptoxanthin.

³ Retinol equivalents (conversion factor 6:1 from β -carotene equivalents to RE).

The estimated recommended dietary intake (RDI) for a non-pregnant, non-lactating female is 500 μg RE/day and for a child 1–3 years old is 400 μg /day (FAO/WHO 2002).

⁴ Retinol activity equivalents (conversion factor 12:1 from β -carotene equivalents to RAE)

⁵ This includes estimates of identified and unidentified carotenoids level but is unrelated to vitamin A content.

Source: Englberger and Johnson, 2013

Food composition and food consumption indicators for biodiversity (see Box 1) can help track the extent to which food biodiversity is being documented for the purposes of human nutrition. While progress is being made in this area and more data on the nutrient composition of food biodiversity are required, enough evidence exists to warrant actions to provide biodiversity-based solutions to solve some of the persistent problems of malnutrition (Burlingame et al. 2009).

3. Systems diversity and human nutrition

A shared axiom of ecology and nutrition is that diversity enhances the health and function of complex biological systems (DeClerck et al. 2011; DeClerck 2013; Khoury 2014).

A diverse diet should contain many different foods consumed in sufficient amounts. A healthy human diet is composed of many hundreds of beneficial bioactive components, a small subset of which have been characterized and identified as nutrients. A varied diet is the only way to ensure adequate

Box 1. Food composition and food consumption indicators for biodiversity

Specific indicators for biodiversity are needed to understand, quantify, and monitor the role of biodiversity in human diets, and the impact of biodiversity-related nutrition interventions and initiatives. Among relevant activities under the Cross-cutting Initiative and within the framework of the Biodiversity Indicator Partnership, FAO, INFOODS and Bioversity International convened a series of meetings and expert consultations to propose, develop and monitor nutrition indicators for biodiversity.

During two technical meetings, two nutrition indicators were developed: Indicator 1 on food composition (FAO, 2008) and Indicator 2 on food consumption (FAO 2010).

Indicator 1 relates to the availability of compositional data, i.e. nutrients, bioactive non-nutrients, and contaminants, on foods meeting the criteria of biodiversity. The criteria include food items reported at the taxonomic level below the species level, along with wild, neglected and underutilized species. In 2008, the baseline report counted 5519 foods for Indicator 1. In subsequent years, between 835 and 5186 foods were added annually (FAO/INFOODS 2013). Researchers worldwide are submitting their data to the FAO/INFOODS Food Composition Database for Biodiversity (FAO/INFOODS 2013a), which serves as an international repository of analytical data on biodiversity of sufficient quality. These data are freely available, widely disseminated, and frequently cited.

Indicator 2 refers to a count of the number of biodiverse foods reported in food consumption or similar surveys (FAO 2010). In 2009, the baseline report counted 3,119 foods. In the two reporting periods that followed, 1,827 and 1,375 foods were added. A secondary survey indicator was developed as a count of the number of food consumption and similar surveys taking biodiversity into consideration in their design and/or reporting, with at least one reported food meeting the criteria for Indicator 2 (FAO/INFOODS 2013).

These indicators have proven useful in stimulating the collection and dissemination of biodiversity data for food composition and consumption. They are also advocacy tools to policy-makers and programme managers for effectively raising awareness of the importance of biodiversity for nutrition and providing documentation of the ever-increasing knowledge of biodiversity and human nutrition.

Reference: <http://www.fao.org/infoods/infoods/food-biodiversity/it/> (accessed 5 March 2015)

intakes of these nutrients and related compounds. Researchers use different methods to determine the adequacy of diets of individuals, households and communities, including the simple and easy to administer Diet Diversity Score (DDS), which is defined as the number of food groups consumed by an individual or family over a certain time period, mostly 24-hours. Many studies carried out among different age groups show that an increase in individual DDS is related to increased nutrient adequacy, health and micronutrient density of diets of non-breastfed children, adolescents and adults (Hatloy et al. 1998; Ruel et al. 2004; Steyn et al. 2006; Kennedy et al. 2007; Mirmiran et al. 2004; Foote et al. 2004; Lobstein et al. 2015 and references therein; Arimond and Ruel 2004; Kant et al. 1993; Slattery et al. 1997; Levi et al. 1998) and food security (Ruel 2003).

Similarly, in ecology, species diversity has been shown to stimulate productivity, stability, ecosystem services, and resilience in natural (Cadotte et al. 2012; Gamfeldt et al. 2013; Hooper et al. 2005; Zhang et al. 2013; Hooper et al. 2012) and agricultural ecosystems (Kremen and Miles 2012; Davis et al. 2012; Kirwan et al. 2007; Picasso et al. 2008; Bonin and Tracy 2012; Mijatovic et al. 2013; Hajjar et al. 2008).

Community ecology has demonstrated that increases in biodiversity can lead to increases in plant community productivity when species complement each other, or use resources differently. Many studies of biodiversity and ecosystem function have demonstrated that there is much variance that cannot be explained by species richness (DeClerck et al. 2011). For example, does it matter that an ecosystem has five species, or would it be more important that a system has five different functional groups? Is a field with maize, rice, wheat, sorghum, and millet the equivalent of a field with maize, beans, squash, sweet potato and guava? Both have five species, but the latter contains five functional distinct species from a nutritional point of view in contrast to the former where all of the species are from the grass family, high in carbohydrates, but poor in essential nutrients.

Though ecologists have focused increasingly on the relationship between biodiversity and ecosystem functioning, there has been little but increasing focus on the capacity or role that ecosystems play in providing the essential elements and nutrients of the human diet, as proposed through the concept of “eco-nutrition” (Deckelbaum et al. 2006; DeClerck et al. 2011). While diet diversity has long been recognized as important for adequate nutrient intake and human health, the concept of nutritional diversity has yet to be integrated into planning, assessments, and policies and programmes of agricultural and food systems.

In the past, food-based interventions have been mostly oriented toward single nutrients (Frison et al. 2006). This may in part be attributed to a lack of knowledge in earlier years of the interactions among nutrients in human physiology and metabolism. From various recommendations for high-protein diets (Brock et al. 1955) and later for high-carbohydrate diets (McLaren 1966; McLaren 1974) to more recent efforts directed at the elimination of micronutrient deficiencies (UN committee on nutrition, 2000; Ruel and Levin 2002), the attention has generally concentrated on single nutrient approaches. The introduction of crops focusing on single-nutrients serves as an important means to address specific nutrients (macro or micronutrients), but caution must be exercised as any single crop, including a fruit or vegetable crop, does not assure the complex nutritional requirements needed to ensure good health (Graham et al. 2007, DeClerck et al. 2011).

Deeper, less obvious, interactions and relationships which affect nutritional outcomes and have long been important in traditional food cultures are at play. The nutritional complementarity of the traditional “American three-sisters” polycultural system, which involves planting maize, beans and squash in the same hole, is a combination that is almost nutritionally complete, with carbohydrates and energy provided by maize, protein by beans and vitamin A by squash (DeClerck and Negreros-Castillo 2000; DeClerck 2013). Mayan farmers when eating meals comprising these plants do so with condiments prepared with lime juice, which is

very important in making the niacin present in the beans bioavailable. So much so in fact, that when maize was introduced outside of Latin America without the accompaniment of beans or lime, these dietary interactions were lost leading to negative nutritional outcomes including pellagra (DeClerck 2013). Dietary interactions such as these are often overlooked but play a major role in improving the bioavailability of certain minerals (see Box 2).

A recent methodology applies ecological diversity to nutritional traits, resulting in a metric coined nutritional functional diversity or Nut FD (Figure 1; DeClerck et al. 2011; Remans et al. 2011). Household, landscape and national-level assessments (DeClerck et al. 2011; Remans et al. 2011; Jones et al. 2014; Remans et al. 2014) illustrate the importance of such diversity in local and national food systems for dietary diversity

and key nutrition health outcomes. Thereby these studies offer a potential intermediate indicator in the biodiversity–nutrition nexus that environment, agriculture and nutrition strategies can consider and monitor towards using a systems approach, not replacing but complementing dietary diversity indicators and agrobiodiversity indicators.

Diversity in production and food systems can impact nutrition not only through the diversity of nutrients made available for human consumption but also through other aspects of the production and food system that influence nutrition-related outcomes more indirectly. Crop plants that depend on pollinators are key sources of vitamin A, C and folic acid, and on-going pollinator decline may exacerbate current challenges of accessing a nutritionally adequate diet (Box 3; see also sub-section on pollination in the agricultural biodiversity chapter). Species diversity has

Box 2. Increasing small fish intake in pregnant and nursing women in rural Bangladesh

In Bangladesh, a fish chutney was developed to increase the contribution of essential nutrients from an animal-source food in the first 1000 days of life, to supplement the diet of pregnant and breastfeeding poor, rural women in Bangladesh, and promote growth and development in infants and young children. The chutney is based on a traditional “achar” or pickle recipe which is commonly served with boiled rice and curry vegetables. The chutney contains 37% dried small fish, 15% oil, 37% onion, 7% garlic and 4% chili. The recommended serving is one heaped tablespoon of fish chutney (equal to 30 g containing 60 g of raw fish), to be eaten with the main meal. The fish chutney is well-liked by women and is a good source of micronutrients such as iron, calcium, zinc and vitamin B12, as well as animal protein and essential fatty acids. The particular relevance of the latter for cognition in the first 1000 days is especially important. In addition, the fish itself enhances the bioavailability of minerals from the plant-source foods (rice and vegetables) in the meal.

The fish chutney, produced by a women’s group, is presently being distributed to 150 pregnant and lactating rural women in Sunamganj, north-eastern Bangladesh, through a project aimed at improving the livelihoods of poor rural households. The small fish used is sourced from the wetlands and sun-dried by local women. Assistance, training and supervision have been provided to ensure safe and hygienic conditions for processing, storage and transportation. Women receiving the fish chutney report producing “a lot of milk” and their children “getting more milk, being satisfied and growing well”. Partners have shown interest in using the product in national food programmes, emergency response food rations, school feeding programmes and for sale in local and urban outlets.

This project demonstrates that food processing is important for highly perishable products such as fish, fruit or vegetables. They may increase food safety, market opportunities, the geographical and temporal usage, as well as the livelihood of small-scale producers.

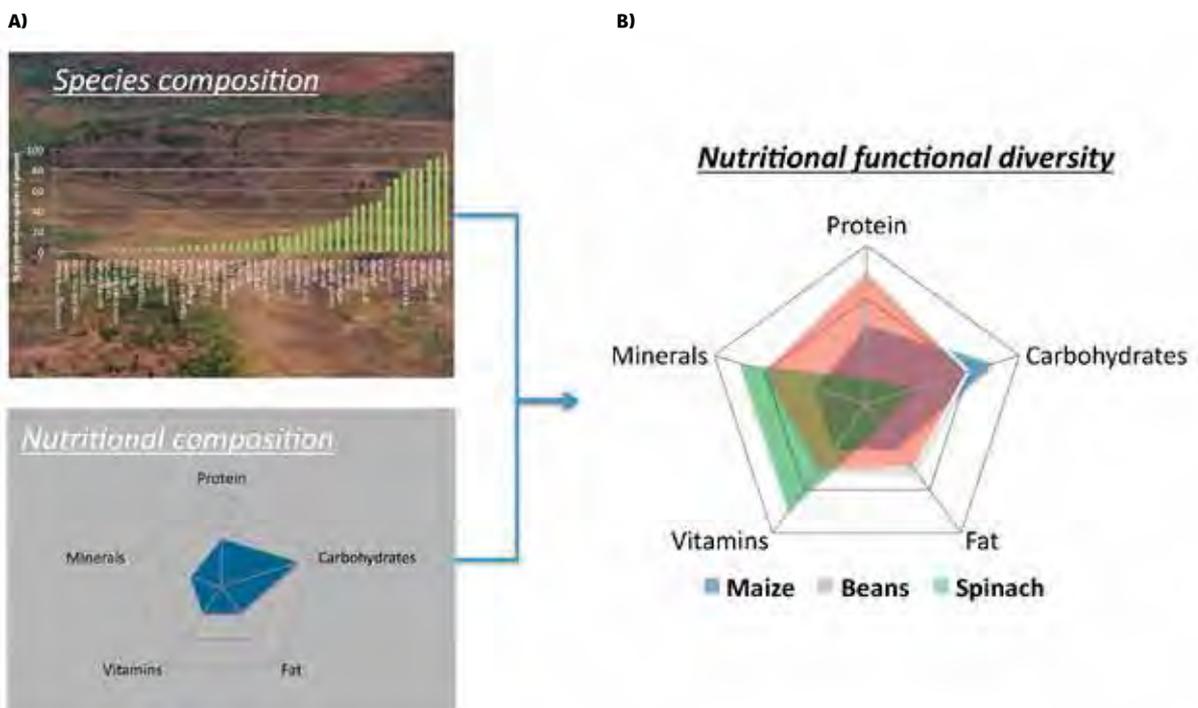
been shown to stimulate productivity, stability, ecosystem services, and resilience in natural and in agricultural ecosystems (Cadotte et al. 2012; Gamfeldt et al. 2013; Zhang et al. 2012; Kremen and Miles 2012; Khoury et al. 2014). In general, increasing the number of species in a community or system will enhance the number of functions provided by that community, and will reinforce the stability of provision of those functions (DeClerck et al. 2011).

By using diversity metrics in agriculture–nutrition strategies, synergies as well as trade-offs with other outcomes, e.g. environmental benefits, can be evaluated and taken into account. In view of global national food supplies that have become more homogeneous in composition (Khoury et al. 2014), monitoring and ensuring diversity for nutrition and other outcomes seems increasingly important.

A CGIAR initiative, nutrition-sensitive landscapes (NSL), applies such systems approaches to concrete low-income settings. The NSL initiative

is about setting nutritional, environmental and agricultural targets together, and identifying mechanisms to achieve these using a systems approach. The overall objective is to create synergies and minimize trade-offs between reducing malnutrition of vulnerable populations and restoring and employing ecosystem services. NSL does not imply that the environment can produce all the nutrients required for adequate human nutrition; it does, however, mean a focus on building biological diversity into the landscape, diet, market and food system to provide multiple sources of nutrients, and contribute to environmental and population resilience. NSL is currently strongly embedded with the farming systems research of the CGIAR in a diversity of settings, from aquatic agricultural systems, to humid tropics and forest areas. Across these diverse settings, biodiversity and dietary diversity sit at the nexus of environment, agriculture and nutrition, and serve as the entry point for this landscape-based approach.

FIGURE 1: Schematic presentation of the nutritional functional diversity metric, based on (1) species composition in a given farm or landscape and (2) nutritional composition of these species. Thereby the nutritional FD metric provides a way to assess complementarity between species for their nutritional function. **B:** Nutritional functional diversity plotted against species richness for 170 farms in three Millennium Villages project sites, Sauri in Kenya, Ruhira in Uganda and Mwandama in Malawi.



Source: Remans and Smukler 2013

“Landscape approaches” have gained prominence in the search for solutions to reconcile multiple objectives, particularly in the field of conservation and development trade-offs (Sayer 2009). In general, “landscape approaches” seek to provide tools and concepts for allocating and managing land to achieve social, economic, and environmental objectives in areas where agriculture, mining, and other productive land uses compete with environmental and biodiversity goals (Sayer et al. 2013). In NSL, “landscape” refers, it is referred to the spatial extent that influences both nutrition and the environment in the study areas, including socioeconomic features such as locations of markets and transportation

networks, and biophysical features such as watersheds. Households and farming systems in rural areas, especially in low-income settings, are often strongly dependent on resources available in the landscape. In the social-institutional domain, households and communities continuously interact with each other and with markets, political and social institutions. These interactions have a strong influence on household functioning and food provisioning. Combining multi-objective modelling and participatory research, NSL searches for and tests potential synergies between improving availability, access and demand for a diversity of nutritious foods and managing ecosystem services.

Box 3. Pollinator declines, human nutrition and health

Declines in animal pollinators are a subset of biodiversity loss that have been well documented around the globe (Vanbergen 2013; Burke et al. 2013; Potts et al. 2013). Over the past decade, the human health implications of these declines have received increasing attention. Pollinators are estimated to be responsible for roughly one third of human caloric intake (Kleine et al. 2007) as well as up to 40% of the global nutrient supply (Eilers et al. 2011). Regions where pollinators contribute most heavily to nutrient production may also be those where human populations are suffering from the largest burdens of micronutrient deficiency diseases (Chaplin-Kramer et al. 2014). In the first published analysis of human vulnerability to pollinator declines based on an evaluation of population-level dietary patterns, Ellis et al. (2015) found that as much as 56% of a population could be placed at new risk of vitamin A deficiency as a result of the loss of animal pollinators.

Perhaps even more significant in terms of global health is the potential impact of pollinator declines on the yields of food groups whose intakes, as a whole, have recently been shown to have very large impacts on the global burden of disease. If pollinators’ work would need to be done manually by mankind, additional economic costs would appear for a work less efficiently performed. The recent assessment of the global burden of disease has emphasized a global pandemic of NCDs including cardiovascular diseases, diabetes, and diet-related cancers (Lim et al. 2010). Because their intakes reduce the risk of these diseases, low intakes of fruit, nuts and seeds, and vegetables have been shown to rank fourth, twelfth, and seventeenth on the list of global risk factors for burden of disease. Yields of each of these food groups are highly pollinator dependent. A recent analysis involving a member of our authorship group is currently in press at the *Lancet* and suggests very large global burdens of disease would result from reduced intake of these food groups as a consequence of animal pollinator declines. This analysis also emphasizes that large numbers of people around the world would additionally be placed at risk for folate and vitamin A deficiency, and many who are already deficient would become more deficient. Thus, animal pollinator declines could lead to substantial new disease burdens from both micronutrient deficiencies and chronic diseases.

4. Wild foods and human nutrition

3.1 Wild foods and diet diversity

Wild biodiversity has an important role in contributing to food production and security in many agroecosystems worldwide (Scoones et al. 1992; Johns and Maundu 2006; Termote et al. 2011; Turner et al. 2011; Dogan 2012; Termote et al. 2012a; Mavengahama et al. 2013; Vinceti et al. 2013; Powell et al. 2014; Achigan-Dako et al. 2014; Vira et al. 2015). More than 10 millennia after the emergence of settled agriculture, millions of rural smallholders in most geographical regions of the world are still reliant on wild products from foraging forests and wild lands for their subsistence and livelihoods (Wunder et al. 2014), although a recent study of wild product harvesting by 32 indigeneous communities in the Ecuadorian Amazon showed this was declining (Gray et al. 2015). 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. In a comparative analysis of environmental income data collected from some 8000 households in 24 developing countries, Angelsen et al. (2014) highlighted that environmental income accounts for 28% of total household income, with 77% coming from natural forests. Food products (wild fruit and vegetables, fish, bushmeat, mushrooms) were the second most important category (over 30%) and likely to help meet the nutritional, medicinal, utilitarian and ritual needs of many households.

A recent survey summarizing information from 36 studies in 22 countries highlights that wild biodiversity still plays an important role in local contexts with around 90–100 wild species per location and community group. Based on some estimates, the use of wild food reached up to 300–800 species, although actual consumption and dietary intakes were not studied (Bharucha and

Pretty 2010). Xu et al. (2004) reported that 283 different species of edible vegetables were found in the markets of Xishuangbanna in southwest China and the trade in wild vegetables contributed between 15% and 84% of market income for different groups. This represented between 4% and 13% of total household income. Notably, the mean price of wild vegetables was 72% higher than that of cultivated vegetables. In South Africa, Shackleton et al. (1998) found that 25% of households sampled in nine villages sold wild vegetables. To investigate the importance of wild foods in Europe, Schulp et al. (2014) analysed the availability, utilization and benefits of wild game, wild plants and mushrooms in the European Union (EU). They recorded a wide variety of game (38 species), vascular plants (81 species) and mushrooms (27 species) collected and consumed throughout the EU.

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.¹ These examples also reflect broad groups and not the dozens of species included within each wild food type.² Abu-Basutu (2013) reported that the species “commonly” used across two villages in southeast South Africa included 17 mammal, 14 bird, 6 fish, 10 leafy vegetables and 7 fruits species. In comparison, 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.

¹ In another example, across a sample of 14 rural villages in South Africa, on average, 96% of households consumed wild spinach, 88% ate wild fruits, 54% ate edible insects, 52% consumed bushmeat and 51% ate honey (Shackleton and Shackleton 2004).

² For example, more than 100 different plant species are consumed as wild vegetables in South Africa overall (Dweba and Mearns 2011). In northeast South Africa, 45 leafy vegetables and 54 fruits were recorded in a household survey across nine villages (Shackleton et al. 1998, 2000).

However, caution is needed when analysing 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). In Benin, for example, the contribution of wild edible plants to total dietary intake was relatively low (Boedecker et al. 2014). More research is needed to determine the conditions and factors that actually determine the utilization and consumption of wild foods and the reasons for which consumption among communities in some biodiverse regions may be low. The use of wild foods is especially relevant where agricultural production is primarily centred 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.³ Aberoumand (2009) reports that approximately one billion people around the world consume wild foods, but it is likely to be much higher. It is not only rural communities that make use of and may have preference for wild foods. There are many wild foods in large urban markets. Examples include wild vegetables in West Africa (Mertz et al. 2001; Weinberg and Pichop 2009), Croatia (Luczaj et al. 2013), Turkey (Dogan 2012), Brazil (Kobori and Rodriguez-Amaya 2008), Lebanon (Batal and Hunter 2007), Morocco (Powell et al. 2014), Italy (Turner et al. 2011), and China (Xu et al. 2004), bushmeat in central Africa (Edderaï and Dame 2006; van Vliet et al. 2012), fish in the Democratic Republic of Congo (de Merode et al. 2004), and mopane worms in southern Africa (Greyling and Potgieter 2004). These findings show that the consumption of wild foods is not driven solely by need or poverty, but also by culture, tradition and preference.

While the above data and examples show a wide diversity of wild species and food types in diets, the actual proportion of daily nutrient requirements

supplied by wild foods relative to grown or bought foods remains largely unknown. It is likely to be significant, however, as many wild food species are much richer in vitamins, micronutrients or proteins than many conventional domesticated species that dominate agricultural or home-garden production (Yang and Keding 2009; Bharucha and Pretty 2010). Kobori and Rodriguez-Amaya (2008) showed the higher carotenoid levels of wild native Brazilian leafy green vegetables compared to commercially produced leafy vegetables. Protein levels in edible insects such as mopane worms (*Imbrisia belina*) are approximately double those in beef (Greyling and Potgieter 2004). The same applies to mushrooms, such as *Psathyrella atroumbonata*, which has 77% more protein than beef (Barany et al. 2004). Vitamin C levels in baobab fruits (*Adansonia digitata*) (see Box 4) are also six times higher than oranges (Fentahun and Hager 2009); *Amaranthus*, a widely used green leafy vegetable, has 200 times more vitamin A and ten times more iron than the same-sized portion of cabbage (McGarry and Shackleton 2009b).

Importantly, 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 anaemia 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 (e.g. Ruel 2003; Arimond and Ruel 2004; Steyn et al. 2006). Thus, the inclusion of even small amounts of wild foods add to the diversity of the standard diet in many countries, with beneficial effects on health outcomes.

Dealing with the declining intake of grown food types by increasing the quantity and diversity of wild foods in the diet is a common strategy in

³ For example, the diets of the Turumbu people in the Democratic Republic of Congo are mainly composed of cassava, which they grow, but are supplemented on a daily basis with wild foods such as wild leafy vegetables, bush meat, wild fish, wild mushrooms, caterpillars, ants and honey, depending on the season (Termote et al. 2010).

some parts of the world. For example, da Costa et al. (2013) describe how wild foods increase in prominence in the diet as stores of staple carbohydrate crops decline (maize, rice and cassava) in Timor-Leste. This was regarded as one of the primary food coping strategies for approximately two months of the year. More detailed results are reported by de Merode et al. (2004) for seasonal uses of crops and wild foods in northeastern Democratic Republic of the Congo. They found that during the four-month hungry season the consumption of own agricultural produce declined by 46%, while the use of wild foods increased markedly, 475% for fish, 200% for wild plants and 75% for bushmeat. The value of wild foods traded in the market also increased during the lean season, a 365% increase in fish, 233% increase for wild plants and 155% increase for bushmeat trade. The storing of wild foods has been observed for both plant- and animal-based foods.⁴

Wild species often contain essential nutrients, but information on the composition and consumption of these foods is limited and fragmented (Burlingame et al. 2009) or of poor quality (McBurney et al. 2004). It is therefore difficult to evaluate the contribution of underutilized wild foods to dietary adequacy. Knowledge on the compositional data of these foods is essential in order to promote, market and expand the use of underutilized wild foods, for example, in nutrition-related projects, programmes and policies in the agricultural and environmental sectors. While forest foods cannot be a panacea for global issues related to food security and nutrition, in some specific geographic contexts, they can play a significant role as shown in Box 4.

Box 4: Indigenous fruit trees: the African baobab

Forests and their non-timber forest products (NTFPs), either through direct or indirect provisioning for human nutrition, can contribute to food security, particularly in developing countries. The potential of indigenous food, is mostly derived from wild and underutilized cultivated species, has largely remained untapped due to scant information on the nutritive and economic value of these foods. For example, combining different indigenous fruit tree species in agroforestry systems based on the seasonal calendar of fruit availability could result in a year-round supply of key nutrients (Vinceti et al. 2013; Jamnadass et al. 2013; Kehlenbeck et al. 2013a, b; Jamnadass et al. 2011). A study by Kehlenbeck et al. (2013a) in sub-Saharan Africa shows that consuming 40–100 g of berries from *Grewia tenax* (Forssk.) Fiori could supply almost 100% of the daily iron requirements for a child under 8 years of age. In addition to micronutrients, the high sugar content of fruits such as tamarind (*Tamarindus indica* L) and baobab (*Adansonia digitata* L) make them important sources of energy. The fruits of *Dacryodes edulis* (G. Don) H.J. Lam, and the seeds of *Irvingia gabonensis* (Aubrey-Lecomte ex O'Rorke) Baill., *Sclerocarya caffra* Sond. and *Ricnodendron rautanenii* Schinz have a higher fat content than peanuts (Vinceti et al. 2013; Johnson et al. 2013).

The occurrence and distribution of the African baobab (*Adansonia digitata*) in drier habitats of Africa, commonly found in savanna, scrubland and semi-desert, has great potential to support communities in more vulnerable dryland ecosystems and in the face of climate variability. The baobab is a majestic tree in the landscape but it is not only its physical presence that exhibits diversity within

⁴ For example, Shackleton et al. (1998) reported that the majority of households in rural northeast South Africa dried one or more wild vegetable species and between 20% and 50% dried wild fruits for use in the off season. The role of traditional knowledge associated with wild foods is also important in helping communities cope with lean periods as well as supporting the conservation of wild foods (Sujarwo et al. 2014; Pardo-de-Santayana and Macia 2015).

and between its trees but also the high nutritional value of its fruits. The most important food from baobab is the fruit pulp, which is rich in vitamins and minerals. It can provide far higher amounts of vitamin C, calcium and iron than more common tropical fruits such as mango and orange (Kehlenbeck et al. 2013a). However, there is a large variability in the levels of vitamin C in fruits of different individual baobab trees – from 126 to 509 mg per 100 g edible portion (Stadlmayr et al. 2013) – but even the lowest figure identified is far higher than in many other fruits. In addition to the fruit pulp, baobab also produces leaves that are used as nutritious vegetables and edible seeds, from which oil for consumption and cosmetic purposes are produced (Caluwe et al. 2010).

The potential of baobab for nutrition and income generation is a good example of a new product with high potential in European market, given the acceptance of baobab as a novel food in 2008. Due to its high nutrition potential and demand in consumer markets, research is ongoing in East Africa by the World Agroforestry Centre (ICRAF) to identify populations of baobab, distribution across landscapes, variation in genetic and morphological characteristics, and the diversity of nutritional content within and between wild populations. Information on nutrient content may facilitate the selection of priority fruit tree species for domestication programmes aiming at improving food and nutrition security and for income generation.

While baobab is one example, there are hundreds of other wild food trees in Africa with similar importance for food and nutrition security. Developing and disseminating nutrient-sensitive processing techniques for indigenous fruits can further contribute to rural livelihoods through diversification of income-generating activities and by extending the shelf-life and availability of tree-based food products for consumption during off-seasons. Markets need to be developed for these new products, and processors linked to domestic and international markets to further improve value chain opportunities. However, the abundance of indigenous fruit trees is said to be decreasing in many parts of sub-Saharan Africa due to changes in ecosystem equilibrium and loss of biodiversity as a result of changes in land use, increasing urbanization and climatic shocks, among others. All of these result in shifts in species distribution, altered pest and disease occurrences, and possibly a lack of pollinators (see Box 3) for sufficient fruit tree diversity and occurrence. Domestication and increased cultivation of the most important indigenous fruit tree species may help to both conserve biodiversity and provide rural communities with better livelihood options.

3.2 Sustainable harvest and consumption of wild foods

Wildlife resources such as bushmeat or wild meat (here encompassing non-domesticated terrestrial mammals, birds, reptiles and amphibians harvested in the wild for food) constitute the main source of animal protein in many tropical forested landscapes (Kothari et al. 2015), though the availability of bushmeat resources around urban centres may decline substantially, corresponding with a prevalence in child stunting (Fa et al. 2015). Bushmeat also supplies many important micronutrients in much higher amounts or with higher bioavailability than plant source foods

(Vinceti et al. 2013). A study from Madagascar estimated that the loss of bushmeat from the diet of children, without substitution by other sources, would result in a 29% increase in children suffering from iron deficiency anaemia (Golden et al. 2011). It must nonetheless be noted that various activities associated with the handling of bushmeat, its consumption and (illegal) trade also involve varying levels of health risks for disease emergence (Wolfe et al. 2005). In particular, these include activities associated with unsafe hunting, butchering and transport of some species, especially primates (see also chapter on infectious diseases). Moreover, the over exploitation of certain wild animal populations is leading to the

depletion of some species (Nasi et al. 2011) and constitutes a rising concern for conservation (Kothari et al. 2015). The resulting mass declines in wildlife, documented by Nasi et al. (2008), is threatening the food security and livelihoods of some forest communities (Heywood 2013), especially where home subsistence consumption is more common than the trade in bushmeat. Interestingly, a study in Liberia, West Africa has found that regions with access to affordable fish protein had higher chimpanzee population densities (Junker et al. 2015) and highlights the importance of integrated approaches to better inform conservation actions. Wild foods such as edible insects also contribute nutritional value to the diet of people in certain regions (van Huis et al. 2013).

Over exploitation or over harvesting is also an area of concern for wild edible and medicinal plant species (see chapter on traditional medicine within this volume), and measures to avert this have been integrated into tools such as FairWild Standard, most often used for medicinal plants, the development of species management plans, plant conservation areas, genetic reserves, community agreements, common property agreements, and so forth (Kothari et al. 2015; Dulloo et al. 2014; Hunter and Heywood 2011; Heywood and Dulloo 2005).

3.3 Wild foods as a coping strategy

Use of wild edible plants and animals (wild foods) is a key coping strategy for many rural households, including in response to shocks, such as crop failure, drought (or other natural disasters), loss of cash income, illness or death of the breadwinner. This coping strategy can be mobilized by one or more of three strategies (Shackleton and Shackleton 2004). The first is for households to increase the direct consumption of wild foods that are already part of their regular diet. For example, a household that normally consumes wild leafy vegetables 2–3 times per week may increase their consumption to 5–6 times per week when faced with a shock that renders them unable to procure the usual purchased or grown foods. The second mechanism is to take up consumption of a wild

food that was not normally, or rarely, part of the diet. For example, a household may normally rarely eat bushmeat or wild caught fish, but in the aftermath of a shock may use it as their primary, or only, source of meat until they have recovered. Thirdly, households may collect wild foods and sell them on local or nearby urban markets. The cash earned is then used to help in relieving the impact of the shock.

While many national or regional food security indices or models focus on the net yields of key crops and average those across population demand or calorie needs, these overlook the potentially high variability in the timing of food availability from crops. The colloquially labelled “hungry season” or the “lean season”, when food stores from the previous cropping season begin to dwindle, and the new season’s crops have not matured is typified by declining calorific intake and a low diversity of grown foods in the diet. During the same period, food prices are high because stocks from the previous cropping cycle have diminished. This combination can result in clear patterns of seasonal nutritional status or malnutrition, exemplified by Devereux and Longhurst (2010) for malnutrition in northern Ghana. This period may also be a time of peak labour demand for the preparation, planting, weeding and tending of the new crops. Tetens et al. (2003) recorded a 17% drop in mean energy intake by adults between the peak season and the lean season in rural Bangladesh. Such seasonal patterns may also be evident in urban populations because of food price increases during the lean season (Becquey et al. 2012). Seasonal nutritional or energy shortfalls can also exacerbate existing health issues such as HIV/AIDS (Akrofi et al. 2012).

There is ample evidence of wild foods being used as coping mechanisms in the face of a household shock. Challe and Price (2009) showed how there was a major shift in primary livelihood strategies of HIV/AIDS-afflicted households in southern Tanzania, from a largely agrarian livelihood (90% of non-affected households; 3% of afflicted households) to a gathering one (0% of non-affected households; 68% of affected ones). This is typically interpreted as a result of the loss

of labour for agriculture to grow food (Drimie 2003; Yamano and Jayne 2004). The number of weekly trips to collect wild edible orchids (to supplement their diets or as cash income) also doubled in HIV/AIDS-affected households relative to unaffected ones. McGarry and Shackleton (2009a, b) recorded the use of wild animal foods by children in households with high HIV/AIDS proxy measures relative to households with low, or no, proxy measures. Hunting of wild animals, birds and insects was significantly higher in affected households. In a two-week monitoring period, the consumption of wild mammals was three times higher, wild birds two times higher, reptiles almost double and insects four times higher. Species consumed over the two-week period include two red data species. Over 40% of households also sold some of the wild catch to supplement income.

Hunter et al. (2007) provided qualitative evidence on how surviving members of a household, following an HIV/AIDS death of an adult, turned to procuring a larger proportion of their diets from wild foods. Surviving members stressed the difficulties of food shortages, including reports that “*locusts are now our beef*”. The findings also confirmed that food shortages increased as a consequence of severe household shocks, and that household food security generally decreased after the mortality of an adult, with increased reliance on wild foods. Wild foods may also be a coping response to other types of household shocks. For example, the ethnobotanical literature is replete with references to famine foods, namely, those wild foods that were traditionally used in times of drought and crop failure. While dependence on these may have declined to some extent with modern national-scale responses, this reliance persists in some cases. For example, Ocho et al. (2012) list 120 different wild plant species used by people in Konso in southern Ethiopia, of which 25 were generally used in times of food shortages. Similarly, the Yanomani Indians in Venezuela regularly use 20 wild plant species in their diets but consume an additional 20 species during food shortages (Fentahun and Hager 2009). In Botswana, when there is crop failure due to drought, wild fruits also contribute to food

security until conditions improve (Mojeremane and Tshwenyane 2004).

5. Biodiversity and traditional food systems

Indigenous peoples’ food systems and cultures are good examples of the complexity and remarkable diversity of food availability and utilization. They additionally represent important repositories of knowledge from long-evolved cultures and patterns of living with local ecosystems (Kuhnlein et al. 2009). For centuries, communities of Indigenous peoples have been the custodians of the vast majority of the planet’s food and genetic resources, and stewards of the diverse ecosystems and cultures that have shaped these resources. Indigenous peoples’ food systems and cultures have often provided for healthy and resilient diets, which have had minimal impact on the environment prior to colonization and development, and for many generations have ensured food security and nutrition. These food systems have not developed in a vacuum and are strongly influenced by the forces of globalization and development (Kuhnlein et al. 2013). The traditional foods they provide are also under threat from the impacts of climate change (Lynn et al. 2013).

Indigenous peoples are often the most disenfranchised, marginalized and poorest members of wider society, and they are targeted by most governments for health improvement and development. Such development often leads to dietary change, including increased reliance on “market foods”, which are more often than not highly processed and contribute to increased risk of chronic disease, including obesity and diabetes. This reduced reliance on traditional foods has also led to an erosion of traditional food resources and associated indigenous knowledge. With obvious outcomes for food security, this has significantly affected the welfare, vulnerability and marginalization of indigenous communities. This could be moderated with increased attention to the principles of diet and health already contained within the culture, and with the recognition of the nutrient properties of traditional food resources,

and how these foods can be used to best advantage for health promotion (Egeland and Harrison 2013).

Indigenous and local communities have created an enduring relationship with the landscape and its complement of flora and fauna (Turner et al. 2013).⁵ Regardless of geographical location, indigenous peoples suffer higher rates of health disparities and lower life expectancy compared with non-indigenous peoples (Egeland and Harrison 2013). Poor diet is a significant contributor to premature death among Indigenous Australians and is considered a significant risk factor for cardiovascular disease, type 2 diabetes, renal disease and cancer. A study into the burden of disease in Indigenous Australians (Vos et al. 2007) attributed 11.4% of the total burden of disease in the indigenous population to high body mass and 3.5% to low fruit and vegetable consumption. In 2012–13, 66% of indigenous Australians over the age of 15 years were overweight or obese, 42% were eating the recommended daily intake of fruit (2 serves) and 5% were eating the recommended daily intake of vegetables (5–6 serves) (Australian Bureau of Statistics 2014). In New Zealand, statistics consistently show Māori as being over-represented in key health areas such as cardiovascular disease, cancer and diabetes, with much of this attributed to lifestyle and dietary choices. New Zealand's latest nutrition survey (2011) highlights that the country's obesity epidemic has increased dramatically over the past decade or so. This survey found that among Māori, over 40% of men were obese while 48% of Māori women were obese. It also found that eight out

of the world's top ten countries where obesity is now a problem are in the Pacific region (Ministry of Health 2012).

A study led by the Centre for indigenous peoples' Nutrition and Environment covering 12 indigenous communities in different global regions confirmed the diversity and complexity of indigenous peoples' food systems and diets (Kuhnlein et al. 2009).⁶ Strengthening and leveraging these food systems is a strategy that should be considered to improve diets and reverse negative food-related health outcomes. This includes interventions that aim to identify nutritionally rich traditional foods and to promote, mobilize and deliver these foods to target populations. Not only do these food-based approaches potentially improve nutrition and health in a sustainable manner, they also help revive traditional knowledge, biocultural heritage and contribute to the conservation of biodiversity.

A corollary to this is the almost ubiquitous decline in intergenerational transmission of local cultural values, beliefs, institutions, knowledge, practices and language regarding local biodiversity, and the foods and food systems it underpins.

Despite significant animal and plant biodiversity, it cannot always be assumed that a biodiversity-rich environment or landscape necessarily contributes to better diet or enhanced nutrition of individuals living in close proximity (Termote et al. 2012b). Linking biodiversity assessments with quantitative dietary assessments in biodiverse environments should promote more ethnobiological studies to better understand why some local communities do

⁵ For example, New Zealand, the southernmost landmass of the Pacific region, has a temperate but unpredictable climate with extremes from sub-tropical in the north to sub-Antarctic in the south. Māori, the indigenous people of Aotearoa-New Zealand, on settling in New Zealand from the more tropical Pacific islands to the north, had to adapt their horticultural practices to this new environment and its many limitations. Much of their lifestyle was based on a subsistence approach, including both cultivated and uncultivated plants, and the seasonal harvesting of birds and fish. In light of the growing prevalence of obesity and NCD among the Māori, how to recapture and retain traditional knowledge on traditional food systems is now a high priority for many Māori communities (Roskruege 2014; McCarthy et al. 2014).

⁶ For example, in Pohnpei, there was major diversity and availability of local species and foods, with 381 food items being documented including karat, an orange-fleshed local banana variety and pandanus varieties rich in carotenoids. The Ingano diet revealed the utilization of over 160 types of food, ranging from roots to insects to palm tree products with milpesos palm, yoco liana, bitter cane and cayamba mushroom found to be a priority for maintaining local health. The Dalit food system revealed a diet highly reliant on wild plant foods with a recorded total of 329 plant species or varieties providing food (Kuhnlein 2009).

not make more effective use of edible biodiversity (Penafiel et al. 2011). Possible barriers include negative perceptions of indigenous wild foods; excessive women's workloads and distances involved for collection; food preparation times; and poor knowledge among local populations about the nutritional value of the indigenous wild foods in their immediate environment. If we are to promote more effective biodiversity interventions it is important to address these barriers by generating and maximizing use of quality data on nutrient composition; increasing awareness of and nutritional education on the benefits of edible biodiversity; domesticating priority species and facilitating their integration into home gardens; and developing guidelines for improved use of nutritionally rich foods from local biodiversity, including recipes adapted to modern lifestyles.

6. Biodiversity and the nutrition transition

Globalization, poverty, modern agricultural practices and changes in dietary patterns have led to a "nutrition transition". The nutrition transition is the process by which development, globalization, poverty and subsequent changes in lifestyle have led to excessive dietary energy intakes, poor-quality diets and low physical activity (e.g. Agyei-Mensah and Aikins 2010). A shift from traditional foods and healthy diets towards consumption of poor-quality processed foods, often available at lower prices, has taken place in many countries (see Box 5). Often this has resulted in the significant loss of biodiversity, and the agroecosystems and knowledge that nurture it, much of it nutritionally superior to the energy-rich and nutrient-poor food products that comprise the more simplified diets resulting from this transformation (Dora et al. 2015). Such dietary shifts are among the complex range of factors that have contributed to the alarming levels of overweight and obesity observed in over 2 billion people globally (Ng et al. 2014), as well as the rise in diet-related chronic diseases such as diabetes and hypertension, which have huge impacts on personal, social and economic development. It has been estimated that the costs of dealing with diet-related NCDs globally between 2011 and 2030 will

be around US\$ 30 trillion (Bloom et al. 2011). The complex issues contributing to the alarming rise in obesity and equally complex approaches to reversing the obesity pandemic are dealt with in detail in The Lancet Obesity 2015 Series (see, for example, Swinburn et al. 2015; Lobstein et al. 2015 in that issue).

The nutrition transition is particularly prevalent among indigenous peoples, who tend to suffer higher rates of health disparities and lower life expectancy, regardless of geographical location (Egeland 2013) and across many other populations in low-and middle-income countries. A recent study out of Australia (Australian Bureau of Statistics 2014) found that compared with the non-indigenous population (and after adjusting for age differences), aboriginal and Torres Strait Islander people were:

- more than three times as likely to have diabetes (rate ratio of 3.3);
- twice as likely to have signs of chronic kidney disease (rate ratio of 2.1);
- nearly twice as likely to have high triglycerides (rate ratio 1.9), more likely to have more than one chronic condition, for example, both diabetes and kidney disease at the same time (53.1% compared with 32.5%).

In many parts of the world, this nutrition transition is accompanied by increased consumption of meat, total fat and trans-fatty acids, sugar and sodium, components that have contributed to the dramatic emergence of obesity and associated chronic diseases (Ho et al. 2008; Eilat-Adar et al. 2008; Haddad et al. 2014). Others also highlight that the links and interactions between diet and obesity may be more complex than this, with diets excessively high in sugars and carbohydrates altering the gut microflora to selectively favour bacterial groups such as *Firmicutes*, which are better at processing these types of foods and converting them to calories with the consequence that the obese gut microflora is much less diverse (DeClerck 2013; Clark et al. 2012; Delzenne and Cani, 2011). As the chapter on microbial diversity within this volume

Box 5: Diet simplification in the Philippines

Results from the Philippine National Nutrition survey suggests that the nation's diet is consistent with the world phenomenon of diet simplification, that is, less complex and high-energy diets (Frison et al. 2010). Food consumption data from 1978 to 2003 show the dietary pattern of Filipinos comprised rice, fish and vegetables. Changes in proportions of these food items, however, led to energy-dense density diets. Alongside this, there is a downward trend in the consumption of fruits and vegetables. Intake of starchy roots and tubers was halved from 1978 to 2003 (Pedro et al. 2006). On the other hand, there is increased consumption of meat, fats and oil, milk and sugars. This pattern, described as the nutrition transition, is also seen in other developing countries (Popkin 2001; Popkin et al. 2012). Recent diet diversity studies among Filipino children also reflect simplified diets as diet diversity score results are found to be below cut-off points (Kennedy et al. 2007; Talavera et al. 2011). It should be noted that low scores indicate unsatisfactory nutrient adequacy (Hoddinott and Yohannes 2002; Ruel et al. 2004; Steyn et al. 2006). This lack of diet diversity is multi factorial (i.e. lack of purchasing power, unavailability in the markets, unfamiliarity with certain food items, lack of know-how on to prepare/consume them). The nutrition transition, together with intensive agriculture and environmental pressures, is also attributed to reduction in dietary diversity and the accompanying loss in agricultural biodiversity and associated traditional knowledge (Gold and McBurney 2012).

also indicates, further exposure to the microbial diversity in the environment may also contribute to the development of *Firmicutes*, particularly lactobacilli and the regulation of immune responses (Lewis et al. 2012). More recently, scientists have shown that the gut microbiome is much more diverse in rural Papua New Guineans compared to people living in the United States and attributed this to a western lifestyle, hygiene and diet (Martinez et al. 2015). Similar observations regarding gut microbiota diversity have been made among pre-contact Yanomami Amerindians in the Amazon (Clemente et al. 2015). As also noted in the chapter on agricultural biodiversity within this volume, shifts to livestock intensification and diets dominated by meat consumption also impact negatively on ecosystems and biodiversity, and are associated with an increased risk of NCDs, including cardiovascular disease and some types of cancer (World Cancer Research Fund 2007).

Some of the highest rates of obesity and growing burden of NCDs can be observed in the Pacific region (Snowdon and Thow 2014) where many small island states have undergone major changes in traditional diets, to the extent that they are largely reliant on less healthy food imports (see

Box 6). In this region, it is estimated that NCDs account for 75% of deaths, while there are signs that life expectancy in some countries is slowing, even declining, as a consequence of NCDs (Snowdon and Thow 2014).

Key recommendations from The Lancet Obesity 2015 Series include efforts to ensure healthy food environments and food systems through approaches that protect healthy food preferences from market intrusion – such as policies that promote healthy food services in schools and early childhood settings – and approaches that allow people to satisfy their healthy food preferences through food policies that place taxes on unhealthy foods or support good access to fresh nutritious foods (Swinburn et al. 2015; Lobstein et al. 2015). In Mexico – where the proportion of overweight women between the ages of 20 and 49 years increased from 25% to 35.5%, and where almost 30% of children between the ages of 5 and 11 years are considered overweight – the government, under pressure to address the growing health crisis, passed a bill to apply taxes on high-calorie packaged foods (including peanut butter, sweetened breakfast cereals and soft drinks). More sustainable and complementary actions

Box 6: Dietary change and the rise of NCDs in the Pacific

The Federated States of Micronesia (FSM) have witnessed significant dietary shifts from nutritious and diverse local staples to an increased dependence on imported, often unhealthy, foods in the past few decades, with up to 40% of all imports being food imports in 1986 (Englberger et al. 2003d; 2011). In 2007, it was the second most obese country in the world, with pockets of vitamin A deficiency being among the highest worldwide, despite its abundance of local nutritionally rich local foods, including 133 varieties of breadfruit, 55 of banana, 171 of yam, 24 of giant swamp taro, nine varieties of tapioca and many varieties of pandanus in the state of Pohnpei alone (Englberger and Johnson 2013). There was little evidence of malnutrition, diabetes or hypertension before the 1940s, with vitamin A deficiency not documented until 1998, indicating the likelihood that these were not problems. Englberger et al. (2003d) argue that it was not until a number of US initiatives started in the 1960s that issues of dependency on imported foods and dietary shifts began and, by 1985, the national school feeding programme provided meals to 30% of its population based largely on food imports. While access to more diversified foods is not without its benefits, an over reliance on imported foods threatens food security, sometimes leading to foods with lower nutritional quality, and can contribute to the chronic NCD burden (borne by an already overburdened national economy), and undermine traditional coping mechanisms and contingency planning developed by communities to deal with periods of food insecurity. Unfavourable food and trade policies often exacerbate these problems. Imported chicken and turkey tails are commonly eaten in FSM. These are fatty off-cuts, which are not marketed or consumed in their countries of origin because they are considered “health damaging products” and the practice of selling in the Pacific is seen as a form of “food inequality” considered by some as inappropriate “food dumping” (Hughes and Lawrence, 2005; Jackson, 1997). Such practices in the Pacific have prompted a range of trade-related food policy initiatives aimed at creating a healthier food environment (Thow et al. 2010; Snowden and Thow 2014).

to encourage healthy local food alternatives are needed (GRAIN 2015), despite the government’s efforts to put in place food regulations that aim to improve the availability and accessibility of healthy foods in schools (Roberto et al. 2015). One example of an initiative to create healthy food environments in schools has been the Brazilian government’s changed food procurement policies during President Luiz Inacio Lula da Silva’s term, which favour and support the production and consumption of non-processed, fresh and locally produced foods and provide greater equity to

farming families (Roberto et al. 2015). Swinburn et al. (2015) also point out that the early momentum to better link agriculture and nutrition⁷ must be maintained in order to achieve the goal of healthy, sustainable, equitable and economically viable food systems. Among other things, this should include efforts to concentrate on the preservation and strengthening of national food sovereignty and agro-food biodiversity, and the creation of sustainable diets. They also emphasize the need to include global goals to reduce obesity and NCDs in the UN’s Post-2015 Development Agenda.

⁷ See Key recommendations for improving nutrition through agriculture and food systems. http://www.fao.org/fileadmin/user_upload/nutrition/docs/10Key_recommendations.pdf

7. Nutrition, biodiversity and agriculture in the context of urbanization

By 2050, it is estimated that about 6.3 billion people will inhabit the world's towns and cities, marking a rise of 3.5 billion from 2010, and the total urban area is expected to triple between 2000 and 2030 (CBD 2012). This will present great challenges for sustainable food production and consumption, and food systems in general. A 2014 study using spatial overlay analysis, integrating global data on croplands and urban areas, estimates the global area of urban and peri-urban irrigated and rainfed croplands to be about 24 Mha (11% of all irrigated croplands) and 44 Mha (4.7% of all rainfed croplands), respectively. This clearly demonstrates an important role for food production and security in urban areas (Thebo et al. 2014). As urbanization continues to rise, both terrestrial and aquatic ecosystems may be increasingly threatened (Boelee 2011). This urbanizing trend has corresponding implications for food and nutrition security, as estimates indicate that urban inhabitants are likely to shift to diets that are more energy, calorie and protein intensive, further exacerbating the risks of obesity, including in low-and middle-income countries (Popkin et al. 2012). Despite these risks, urban spaces also present considerable opportunities to promote greater conservation and use of biodiversity, including mainstreaming of biodiversity into city landscapes and city food systems, as exemplified by recent discussions for an urban food policy pact (UFPP); an emerging global initiative to “feed cities” in a more just, healthy and sustainable way.⁸ Peri-urban locations may already be important areas where crop diversity survives (Elyse Messer 2015).

It is estimated that around 15% of the world's food is currently grown in urban and peri-urban areas, including backyards, roof-tops, balconies, community gardening in vacant lots and parks, urban fringe agriculture and livestock grazing

in open spaces (Gerster-Bentaya 2013). A case study to determine the potential of rooftop garden vegetable production in the city of Bologna found that it could satisfy 77% of its residents' needs and that besides this contribution to food security and nutrition of the city, the potential benefits of rooftop gardens to urban biodiversity and ecosystem service provision could also be substantial by facilitating green corridors connecting biodiversity-rich areas across and close to the city (Orsini et al. 2014).

There is a direct relationship between biodiversity and food security in cities. Biodiversity and small-scale production in urban food systems play a critical role in the fight against hunger and diet-related health problems, and is pivotal in developing resilient city-regional food systems. Yet the rapid growth of cities is challenging the provisioning capabilities of agriculture and modifying food systems at local and global levels, while at the same time, a shift in urban diets to less diverse and more processed foods has increased the incidence of NCDs such as obesity and diabetes. The expansion of urban populations will dramatically increase global demand for food of a non-subsistence nature while continuing urbanization will put pressure on existing food production, potentially increasing land-cover change and threatening biodiversity unless carefully managed. Increasing biodiversity in our existing food systems is critical to maintaining healthy global food systems and the ecosystem services they depend on, and to improving global food security (CBD 2012).

With increasing urbanization and rural-to-urban migration, the provision of a healthy and balanced diet will require an increase in urban agriculture. In the Kibera slums of Nairobi, Kenya, households have recently begun a new form of urban agriculture called “sack gardening” in which neglected and underutilized but highly nutritious indigenous vegetables can be planted into large sacks filled with topsoil, which can

⁸ At the time of writing, discussions were under way on the implementation of the UFPP, which will be implemented by Milan's city government over the next five years. It was being drafted through a broad participatory process, beginning with an assessment of the strengths and weaknesses of the city's food system. See for example: <http://www.ipsnews.net/2015/04/expo-2015-host-city-promotes-urban-food-policy-pact/>

contribute to household food security, increase dietary diversity and reduce the need to resort to other coping mechanisms used during food shortages (Gallaher et al. 2013). One of the remarkable success stories of linking agricultural biodiversity to urban markets have been African leafy vegetables (ALVs). A project to promote ALVs in urban markets in Kenya in 2003 resulted in significant impacts and outcomes. Growers around Nairobi who were trained to produce high-quality ALVs for city supermarkets saw their incomes increase twenty fold while sales of ALVs in Nairobi increased by a staggering 1100% (Cherfas 2006). The IndigenoVeg network, targeting urban and peri-urban areas, was also successful in promoting African indigenous vegetables (Shackleton et al. 2009).

The urban street food sector can also play an important role in urban food security and nutrition. For example, the urban vendors in Madurai who sell ready-to-eat, healthy millet-based porridges have improved access to nutritious foods and created livelihood opportunities for

the urban poor (Patel et al. 2014). Roberto et al. (2015) also highlight that local governments are increasingly using urban planning processes to ensure that new residential and commercial developments have adequate access to healthy food markets such as farmers' markets and mobile vendors of healthy foods.

In developed countries such as Australia and the UK, approaches to urban agriculture have focused on biodiversity, localization, farmer's markets, community gardens and the viability of farms that occupy or surround cities. In 2008, the City of Melbourne endorsed the *Future Melbourne Plan* which links production, biodiversity and sustainable consumption by setting out an ambitious target of 30% of food to be either grown within the city or sourced from within 50 km of the city by 2020. There are now over fifty accredited farmers, markets in the larger Victoria area supplied by some 2000 farmers. Twelve of these farmers markets are located within Melbourne's suburbs, eight within 125 km of the city, and the rest in rural and regional areas. Rare



breeds sold at farmer's markets around Melbourne include critical, endangered or vulnerable pig breeds such as the Wessex Saddleback, Large Black and Tamworth as well as "at risk cattle breeds such as the Belted Galloway. Melbourne farmers' markets contain far greater diversity of plant varieties and animal breeds than can be found in mainstream supply chains. A network of community gardens further adds to initiatives that make available additional nutritious fruit and vegetable biodiversity to low-income households (Donati et al. 2013).

In the UK, the Incredible Edible Todmorden initiative encourages the novel concept of open-source food, through "permission gardens" and "guerilla gardens", which consist of picking and eating foods others have planted and nurtured. Under this initiative, forty public fruit and vegetable gardens that promote awareness about the benefits of food biodiversity, dietary diversity and nutrition were created. It also held a variety of communication and awareness-raising events, including street cook-offs, "Tod Talks", targeted campaigns such as "Every Egg Matters", which maps local egg production, cooking courses, the

field-to-plate lunch, and seed swaps. Regular newsletters, an active website, presentations beyond the local district, and veggie tourism also serve to maintain the momentum of the initiative (Paull 2013).

8. Food cultures: local strategies with global policy implications

There is ample evidence of how monocrop, low-diversity agriculture, the shift toward urbanization and the depletion of natural resources, including our marine resources, has led not only to the erosion of our terrestrial, freshwater and marine ecosystems but also of traditional food cultures in many parts of the world (Anderson 2010; Petrini 2013). This has dramatically changed our relationship with food and challenged many of the cultural norms, customs and traditions which have governed how we grow and consume food. This has led to significant changes in our food choices, the amount of different foods we eat, the order in which we eat, when and with whom (Pollan 2008). In some parts of the world this has led to a growing Slow Food movement as described in Box 7.

Box 7. Slow Food and Torre Guaceto, Italy Marine Protected Area: a model to promote food cultures, health and sustainable use

Slow Food, a grassroots organization now spanning over 150 countries, is aimed at preventing the disappearance of local food cultures and traditions, counteracting the rise of "the fast life", homogenizing food production, intensive industrial agricultural crops based on monoculture, and promoting interest in food's origins and cultural traditions at all levels of production and consumption (Petrini 2013; Schneider 2008; Kinley 2012). The selection of Slow Food products is based on an established set of criteria and a continuous exchange of information with local stakeholders to ensure social-cultural, environmental and economic sustainability.

Several approaches have been used to evaluate the sustainability and nutritional impact of these products. Recently, Pezzana et al. (2014) combined nutritional and multi-criteria sustainability to define the Life Cycle Assessment of Slow Food Presidia products. The study found "high levels of sustainability" and additional nutritional value of Slow Food products, and the value of multifactorial approaches in the analysis of the food-health-sustainability relationship (Pezzana et al. 2014).

Presidia products focus on key issues of interest for small-scale agriculture and farming, including the protection of mountain pastures and pastoral farming, defence of traditional landscapes and propagation of traditional seeds by communities, protection of small-scale onshore fishing,

transparent labelling, ecologically sustainable packaging and the preservation of traditional artisanal knowledge linked to processing methods.

Examples include small-scale artisanal fishing, which uses low-impact fishing gear and regulates exploitation; it is part of the Mediterranean identity, employing half-a-million people in the region, promoting sustainable fishing practices and allowing fish stocks to recover. Sustainable fishing also implies the need to consider the conservation of marine species, production chains, ecological communities, and the human communities that support and rely on them for food, nutrition and income.

The 22 km² marine protected area (MPA) of Torre Guaceto is a successful example of the benefits of Slow Food for local communities. Initially established as a no fishing MPA in 1991, its enforcement became effective only in 2000 when the MPA authority and local fishermen struck an agreement to implement a five-year fishing ban, allowing fish to repopulate and habitats to recover (Guidetti 2010). Fishing gear and practices that caused the least damage to marine species and habitats were enforced. By the end of 2005, striped red mullet (*Mullus surmuletus*), large-scaled scorpionfish (*Scorpaena scrofa*) and other taxa also rebounded (Guidetti 2010). Once the reserve partially reopened, local fishermen began to haul in catches more than twice the size of those outside the reserve (PISCO 2011).

Local MPA management authorities can also help fishing communities to increase income opportunities where these are limited by seasonal variations or local preferences. For example, the Torre Guaceto MPA Municipality of Carovigno is far from large markets, some catch, including mullets (family Mugilidae), are not a local favourite year-round, making market value and income highly variable. Collaboration between the MPA Authority, the Slow Food Association and the Fishermen Cooperative of Carovigno in 2014 led to the production of mullet fillets in extra virgin olive oil in glass jars, to stimulate quality and sustainable production of mullet processing for a broader market.

This offers a good example of how local communities benefit from MPAs, which are critical for their protection, and how co-management schemes within protected areas may in turn deliver co-benefits to ecosystems and local communities. These may reduce competition for shared fishing resources, promote foods high in nutritional value, and support livelihoods and the conservation of food cultures. These initiatives are important to jointly increase awareness, sustainability and social acceptance of MPAs, and maximize benefits for local populations.

Pockets of traditional food culture remain strong in many parts of the world despite economic, social and cultural change. Where people still retain a close connection with the landscape. Where biocultural refugia continue to exist, which safeguard the diversity of food-related practices for food and nutrition (Barthel et al. 2013). The East Pokot and Isukha communities in Kenya constitute examples for rich traditional food cultures with manifold associated traditions, beliefs, taboos and practices based on living in a biodiverse environment. More than 130 foods of

plant, animal and fungal origin have been reported, which are used and prepared in many different ways (Maundu et al. 2013a; 2013b; 2013c; 2013d, see also chapter on traditional medicines). Another example of retained traditional food culture can be found in the harsh geography of the Pamir Mountains of Afghanistan and Tajikistan, where biodiversity plays a very large role in sustaining life and the environment has shaped a system that is uniquely suited to this region and which, in turn, has fostered the development of a rich source of skills and resilience in its people (van Oudenhoven

& Haider 2015). In Indonesia, the Centre for Food and Nutrition Studies of the University of Gadjah Mada (UGM) is documenting food diversity and traditional knowledge among communities in Yogyakarta. Closely linked to cultural and religious festivals, food culture is very much alive in rural communities where ten local root crops are still widely consumed by the young and old. Efforts are being made to establish links between these foods and healthier diets and to promote these local alternatives to imported convenience foods⁹.

There are examples where traditional foods and the food cultures which have embraced them have contributed to sustainable and healthy diets as well as healthy lifestyles – in fact, the term diet originates from the Greek *diaita* meaning way of life or lifestyle (UNESCO 2010). The Mediterranean diet has recently been recognized by UNESCO as an intangible heritage of humanity in Spain, Greece, Italy, Cyprus, Croatia, Portugal and Morocco in order to preserve the Mediterranean food culture (UNESCO 2013). The nutritional and cultural model of the Mediterranean diet is characterized by skills, knowledge, practices and traditions that concern obtaining food from the landscape to the table, and that have remained constant over time and space (UNESCO 2013; Petrillo 2012). Besides the nutrition and health benefits of the Mediterranean diet, Tilman and Clark (2014) highlight its environmental benefits by showing, among others, that diet-related greenhouse gas emissions per kilocalorie from “cradle to farm gate” are nearly 25% lower compared to a western omnivorous diet. South Korea is another example of a country that has retained much of its food culture and traditional dietary habits despite change (Lee et al. 2002). It is estimated that more than half of the population still follows the traditional dietary patterns, making the nutrition transition in South Korea unique (Song & Joung 2012; Lee et al. 2002). The traditional diet is characterized by high intake of fruits and vegetables (especially fermented *kimchi* rich in antioxidants, vitamins and minerals) and low intake of total fat (Lee et al. 2002; Lee et al.

2001). In fact, vegetable consumption is among the highest in Asia. There is hardly any Korean dish without vegetables and over 300 types of vegetables are eaten in rural areas, including wild greens like Chinese bellflower and bracken, field-grown greens like shepherd’s purse and wild garlic, and cultivated vegetables like squash, eggplant and cucumber (Lee et al. 2002). The inherent biodiversity of this traditional diet has beneficial health effects resulting, for example, in low adult obesity levels (Lee et al. 2002) as well as a 33% and 21% decreased risk of having elevated blood glucose and elevated blood pressure, respectively, compared to a westernized “meat and alcohol”-based diet (Song & Joung 2012). Okinawa, the most southern prefecture of Japan, is widely known for its population that is characterized by long average life expectancy, large number of persons reaching the age of 100 years, and low prevalence of age-associated diseases. These positive characteristics are mainly associated with the traditional Okinawa diet and its deeply embedded biodiversity, which is nutritionally dense and low in calories due to high consumption of phytonutrient- and antioxidant-rich fruits and vegetables (Willcox et al. 2009). The Okinawa food culture comprises many traditional foods, herbs or spices derived from local ecosystems and consumed on a regular basis (such as white-skinned or purple sweet potatoes, local bitter melons or green seaweed) which are classified as “functional foods” (“food is medicine” is intrinsic of Okinawan culture) due to their, among others, anticancer, antidiabetic, antiviral, anti-inflammatory and immune-enhancing properties (Willcox et al. 2009; Sho 2001).

The New Nordic Diet (NND)¹⁰ was recently developed in Nordic countries in collaboration with a world-leading Copenhagen gourmet restaurant to promote a food-based dietary concept that emphasizes gastronomy, health and the environment (Poulsen et al. 2014). Based on traditional food culture and dietary habits, the NND strongly relies on diverse, regional foods in season such as berries, cabbages, pears,

⁹ See Traditional Root Crops in Indonesia (<http://www.b4fn.org/case-studies/traditional-root-crops-in-indonesia/>) and many other related case studies of food cultures.

¹⁰ <http://newnordicfood.org/about-nnf-ii/new-nordic-kitchen-manifesto/>



apples, root vegetables, oats, rye, and fish – all of them traditional Nordic foods that have been found to have beneficial nutrition and health effects (Poulsen et al. 2014; Olsen et al. 2011). Preliminary evidence shows that compliance with NND and its traditional healthy foods is related to decreased mortality among Danes aged 50–64 years (Olsen et al. 2011), increased weight loss and improved blood pressure reduction in centrally obese individuals (Poulsen et al. 2014), and significantly higher micronutrient intake (e.g. iodine 11%, vitamin D 42%) among schoolchildren aged 8–11 years compared to control groups (Andersen et al. 2014). Furthermore, estimates from Denmark indicate that shifting from the average Danish diet to NND leads to overall socioeconomic savings of €42–266/person per year due to reduced environmental impacts and their associated costs (Saxe 2014). The example of NND shows that culturally appropriate dietary patterns based on local and traditional biodiverse foods can successfully be developed in order to reach societal nutritional goals as well as decrease environmental impacts (Saxe 2014; Bere & Brug 2009).

9. Mainstreaming biodiversity for food and nutrition into public policies

Policy support is essential for making changes sustainable. Nutrition and biodiversity offer better opportunities to mainstream biodiversity into policies, programmes and projects. They include the commitments made at ICN2 of countries to improve nutrition, e.g. by fostering the relation between nutrition and agriculture through “nutrition-sensitive agriculture” where biodiversity has an important role to play. Another major achievement in the agriculture sector is the endorsement of the Voluntary Guidelines for Mainstreaming Biodiversity into Policies, Programmes and National and Regional Plans of Action on Nutrition (Guidelines) in 2015 by the Commission on Genetic Resources for Food and Agriculture (CGRFA)¹¹.

The Food Acquisition Programme (PAA) and the National School Meals Programme (PNAE) in Brazil are two public policy instruments that support family farming by acquiring family farm

¹¹ <http://www.fao.org/3/a-mm464e.pdf>

products and directing them to public programmes and social organizations. Both instruments also provide incentives for greater integration of biodiversity and have demonstrated that public policy can be used to address food security while supporting family farming, improving nutrition and encouraging biodiversity conservation.

By 2014, more than US\$ 3.3 billion had been spent on the purchase of over 3 million tonnes of food under the PAA, with an average of 80,000 farming families/year involved in the programme. The PAA is currently being implemented in approximately 48% of Brazilian municipalities.

In 2014, 619 of Brazilian municipalities (11%) were assisted, reaching more than 3,900 governmental and non-governmental organizations, including schools, child care organizations, nursing homes and community kitchens.¹² An estimated 15 million people/year benefit from food distribution under the programme. The PAA has contributed to promoting dietary diversification (including fruits and vegetables), sustainable management of biodiversity for food and nutrition on family farms, and the recovery and promotion of neglected and underutilized regional and local biodiversity foods. In schools, the PAA ensures that fresh, locally produced, often organic food, more compatible with local food cultures, is also made available in canteens. The programme has also contributed to the validation and documentation of threatened traditional knowledge, food customs and local cultures associated with these foods, and foods such as babassu palm (*Attalea speciosa*) flour, baru nut (*Dipteryx alata*) flour, cupuaçu (*Theobroma grandiflorum*), palm hearts, umbu (*Spondias tuberosa*), maxixe (*Cucumis anguria*) and jambú (*Syzygium* sp.) are being served more frequently in schools and social care organizations (Grisa and Schmitt 2013). While the nutritional impacts have yet to be fully assessed, preliminary PAA survey results indicate improvements in dietary diversity and health status of target families.

The Ministry of Education through the National Fund for Education Development (FNDE) is responsible for the PNAE, which aims to meet the nutritional needs of schoolchildren, and is considered one of the largest school feeding programmes in the world. By 2012, it is estimated that the programme assisted over 43 million schoolchildren. In 2009, the PNAE decreed that at least 30% of the food purchased through its programme must be bought directly from family farmers, which may encourage the use of native species, and promote local and regional biodiversity. The FNDE also supports efforts through the promotion of school gardens to improve awareness about food production and healthy eating habits.

In Brazil, other relevant instruments to mainstream biodiversity for food and nutrition also include the Food and Nutrition National Policy (PNAN), National Plan for the Promotion of Socio-biodiversity Product Chains (PNPSB) and Development of Organic Agriculture (Pro-Organic). A key component of this effort is to carry out nutritional composition analysis of prioritized native edible species, both wild and cultivated, to demonstrate that these species are rich in nutrients and to use this knowledge base to bring biodiversity conservation and its sustainable use into these different public policies, and provide added incentives for procurement and use in school feeding. Brazil, with the assistance of the Biodiversity for Food and Nutrition (BFN) Initiative¹³, will establish the nutritional composition data of over 70 native species prioritized by the Plants for the Future initiative, and those included in the PNPSB. This includes, baru (*Dipteryx alata*), buriti (*Mauritia flexuosa*), cagaita (*Eugenia dysenterica*), mangaba (*Hancornia speciosa*) and pequi (*Caryocar brasiliense*). It also includes Umbu (*Spondias tuberosa*) from the Caatinga biome, and cupuaçu (*Theobroma grandiflorum*) and pupunha (*Bactris gasipaes*) among others. This initiative is also working in partnership with university-based Collaboration Centers on School Food and Nutrition (CECANEs),

¹² http://www.conab.gov.br/OlalaCMS/uploads/arquivos/14_09_15_16_03_05_artigo_evolucao_do_paa_2.pdf, http://www.conab.gov.br/OlalaCMS/uploads/arquivos/15_03_23_15_42_09_sumario_executivo_2014_revisado.pdf

¹³ <http://www.b4fn.org/>

which are linked to the PNAE. To this end, Brazil is building national capacity to facilitate the setting up of “Regional Centres for food composition data” within federal universities to strengthen integration and mainstreaming of biodiversity into relevant policies, programmes, and initiatives focused on food and nutritional security, and on the promotion of a healthy, diversified and sustainable diet. Collaboration is also under way with the FNDE School Garden programme to promote awareness and appreciation of native biodiversity for food and nutrition.

The BFN Project in all participating countries has been active in drawing attention to the importance of biodiversity for food and nutrition in another important national policy instrument aimed at the sustainable use and conservation of biodiversity: National Biodiversity Strategies and Action Plans (NBSAPs).

10. Global policy initiatives

The decades of unsustainable nutrition-related interventions, not to mention outright failures, from both the agriculture and health sectors has prompted new thinking in many relevant areas (McDermott et al. 2015). Nevertheless, mainstream nutrition has largely continued to focus on malnutrition solutions that take little or no heed of long-term sustainability or biodiversity, and have relied principally on supplements, therapeutic formulations, nutrient fortificants for staple or convenience foods, and biofortification through conventional plant breeding or genetic modification (Lancet series 2008, 2013). At the same time, refreshingly new perspectives on these problems and challenges have been emerging from ecologists, among other fields, on the need to better integrate the disciplines of nutrition, agronomy, ecology, economics with nutrition and human health, agriculture and food production, environmental health and economic development to address the multiple goals of reducing malnutrition, promoting sustainable agricultural and food production and environmental protection, often called eco-nutrition (Wahlqvist & Specht 1998; Deckelbaum 2011; Deckelbaum et al. 2006) or nutrition-sensitive agriculture (ICN2).

Sustainability was featured as an important issue in many sectors, but in nutrition it was not clear how to proceed. As the health sector’s individual nutrient approach and the agriculture sector’s food production approach were not leading to improved nutritional outcomes, the focus had to turn to “diets” as the fundamental unit of nutrition.

Biodiversity was the theme of the First International Conference on Sustainable Diets motivated by the growing awareness of the alarming pace of biodiversity loss, ecosystem degradation and their negative impacts on health and development. The Conference provided a forum for consolidating the state of knowledge and advancing the thinking with a multidisciplinary focus. In addition to the scientific sessions, two working groups were convened: one to work on the draft definition of sustainable diets and the other to develop a code of conduct (or code of practice). A consensus definition of sustainable diets, adopted at the First International Conference on Sustainable Diets, acknowledged the interdependencies of food production and consumption with food requirements and nutrient recommendations, and reaffirmed the notion that the health of humans cannot be isolated from the health of ecosystems. Biodiversity was included as an important component of the definition (see Box Definition of sustainable diets).

Definition: Sustainable Diets are those diets with low environmental impacts, which contribute to food and nutrition security and to a healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems; culturally acceptable; accessible; economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources.

At the same time, Working Group 2 prepared a preamble and an outline for what might one day be developed and adopted as a code of conduct or practice. It was modelled on the WHO International Code of Marketing of Breast-milk

Substitutes (WHO 1981). Text from that preamble included the following statements:

- Conscious that food is an unequalled way of providing ideal nutrition for all ages and life stages;
- Recognizing that the conservation and sustainable use of food biodiversity is an important part of human well-being;
- Considering that when ecosystems are not able to support healthy diets, there is a legitimate use of supplements and fortificants; but when ecosystems are able to support healthy diets, nutrition programmes, policies and interventions supporting the use of supplements and fortificants are inappropriate and can create or exacerbate malnutrition, and that the marketing of these food substitutes and related products can contribute to major public health problems.

A platform for action was also conceived at the Conference, with the aim to improving the evidence base for biodiversity and nutrition. This has led to research partnerships involving FAO, the Centre International de Hautes Études Agronomiques Méditerranéennes (CIHEAM), Biodiversity International, INRA (Institut National de la Recherche Agronomique) and others, to develop methods and indicators for the characterization of different agro-ecological zones for sustainable diets (Dernini et al. 2013). These studies are fostering new ideas for building consensus on research and actions needed to link human nutrition with biodiversity, ecosystems and environmental impacts. Some examples include new metrics for nutritional diversity of cropping systems, nutrient diversity within species in major food crops, sustainability of the food chain from field to plate, traditional food system and nutrition security (Ignatius 2012), underutilized fruit for human nutrition and sustainable diets, and conservation systems for plant biodiversity for sustainable diets (FAO, 2012).

The Second International Scientific Symposium on Sustainable Diets featured livestock as its theme (FAO 2013b). The biodiversity of food animal species and breeds was presented, along with the synergies and interdependencies between

livestock and the biodiversity of pasture and grazing lands. Features included new data on the nutrient content of milk and meat from the native horse breed of Mongolia, with its high n-3 fatty acid content; and similarly new data on the n-3 fatty acid content of the pasture plants upon which the horse feeds. Together, the genetic trait of the mare and the grassland species provide the essential fatty acids commonly thought to be found almost exclusively in marine species to the population of this landlocked country (FAO 2013b; Minjigdorj et al. 2012).

The Mediterranean diet is being used in some of these studies as a model for sustainable diets, with “biodiversity” featuring in the most recent version of the Mediterranean diet pyramid (Bach-Faig et al. 2011), and as a key component in developing methods and indicators (Dernini et al. 2013). In their analysis using 50 years of global-level data for over 100 countries to quantify the relationship between diet, NCDs and environmental sustainability, Tilman and Clark (2014) found that dietary changes have considerable potential to reduce both the incidence of NCDs and environmental impacts. Their review illustrates a significant reduction in some selected negative health outcomes, including type II diabetes, cancer incidence and mortality due to heart disease, for three alternative diets: a pescetarian diet; a vegetarian diet; and Mediterranean diet when compared to a reference diet including all food groups. Other studies confirm these conclusions (e.g. Katz and Meller 2014; Maillot and colleagues 2011). Such findings have important implications for both the health and conservation sectors. Further integration of these considerations is needed for the development of robust strategies and policies targeting a reduction in the global burden of NCDs.

The sustainability of a diet is heavily determined by interrelated factors categorized as agricultural, health, sociocultural, environmental and socioeconomic; so changes to one affect the others. This complex relationship makes understanding how sustainable diets can contribute to food security and sustainable development agendas difficult (Johnston et al. 2014). Metrics and

guidelines that form the basis for wider application are needed to aid decision-making processes at regional and national scales (Prosperi et al. 2014), and to better understand the synergies and trade-offs between dietary diversity, agricultural biodiversity and associated ecosystem functions (Allen et al. 2014; Remans et al. 2014).

A clear consensus has been reached in the nexus between agriculture, health and environment, that the sustainable diets rationale, with biodiversity at its core, along with education and policies, is fundamental to the achievement of the broader goals of sustainable development, connecting nutritional well-being of the individual and of the community to the sustainability of feeding the planet (UN 2012). The UN Secretary General's Zero Hunger Challenge, which links sustainable food systems and hunger reduction, is critical, as the world moves from the largely unmet Millennium Development Goals to the post-2015 Development Agenda. And in his final report to the United Nations, the Special Rapporteur on the Right to Food issued a key recommendation, "To reshape food systems for the promotion of sustainable diets and effectively combat the different faces of malnutrition" (Human Rights Council 2014).

In 2004, the CBD's Conference of the Parties (COP) formally recognized the linkages between biodiversity, food and nutrition, and the need to enhance sustainable use of biodiversity to combat hunger and malnutrition. The COP requested the CBD's Executive Secretary, in collaboration with FAO and the former International Plant Genetic Resources Institute, now Bioversity International, to undertake a cross-cutting initiative on biodiversity for food and nutrition (CBD 2004). Later that same year, the Commission on Genetic Resources for Food and Agriculture (CGRFA) also requested that FAO evaluate the relationship between biodiversity and nutrition. In 2005, via the Intergovernmental Technical Working Group on Plant Genetic Resources for Food and Agriculture, eight high-priority actions and another six lower-priority actions were

identified (FAO 2005). In 2006, the COP adopted the Framework for a Cross-Cutting Initiative on Biodiversity for Food and Nutrition (CBD 2006). The Initiative gave a useful profile to some on-going research and development activities, and motivated renewed efforts in establishing and documenting the linkage among agriculture, health and the environment sectors in addressing food and nutrition security with biodiversity as a central feature. For the nutrition, community this represented a major thrust to mainstream biodiversity in nutrition research, projects, programmes and initiatives.

The CGRFA, at its 14th session in 2013 (FAO 2013a), formally recognized nutrients and diets, as well as food, as ecosystem services, in order to further increase the awareness of human nutrition as a concern for the environment sector, and the awareness among human nutritionists of the importance of biodiversity; and requested the preparation of guidelines for mainstreaming biodiversity into all aspects of nutrition, including nutrition education, nutrition interventions, nutrition policies and programmes. These mainstreaming guidelines were adopted at the 15th Session of the CGRFA in 2015 (FAO 2015)¹⁴ to assist countries in mainstreaming biodiversity into different sectors at country and regional levels, and into policies, programmes and plans of action, all with the aim of improving nutrition. Prior to this formalized recognition, similarly important declarations were made, based on collection and analysis of research and traditional knowledge, in order to bring biodiversity and its attendant issues to the forefront of mainstream nutrition thinking. One of these was the AFROFOODS Call for Action (2009). This declaration was motivated in part by the Lancet series (2008), and in part by a prevailing dogma that Africa did not have the affluence or ability to be concerned about biodiversity, or indeed environmental sustainability, as other competing issues took priority (FAO 2009).

The Second International Conference on Nutrition (ICN2), jointly convened by FAO and WHO in 2014, focused on policies aimed at eradicating

¹⁴ <http://www.fao.org/3/a-mm464e.pdf>

malnutrition in all its forms and transforming food systems to make nutritious diets available to all. Participants at ICN2 endorsed the Rome Declaration on Nutrition¹⁵ and the Framework for Action¹⁶. While the ICN2 outcomes do not explicitly mention the potential use of biodiversity or genetic resources for food and agriculture to address malnutrition, some recommendations are highly relevant to promoting the use of biodiversity to address certain nutritional problems. Examples include the following:

- Recommendation 8 on the need to “review national policies and investments and integrate nutrition objectives into food and agriculture policy, programme design and implementation, to enhance nutrition sensitive agriculture¹⁷, ensure food security and enable healthy diets”.
- Recommendation 10 on the need to “promote the diversification of crops including underutilized traditional crops, more production of fruits and vegetables, and appropriate production of animal-source products as needed, applying sustainable food production and natural resource management practices”.
- Recommendation 42 on the need to “improve intake of micronutrients through consumption of nutrient-dense foods, especially foods rich in iron, where necessary, through fortification and supplementation strategies, and promote healthy and diversified diets”.

11. Ways forward: toward a post-2015 development agenda

Food and nutrition insecurity presents a serious and growing global challenge, as does environmental sustainability, and unsustainable and unhealthy food systems. They affect citizens in all countries, everywhere. They are multifaceted and complex issues, with no single way, or single sector, to effectively solve such problems. Interdisciplinary analysis and cross-sectoral

collaboration have been largely absent, with each sector promoting solutions that unleash actual and potential damage to other sectors (McEwan et al. 2013). Examples include agricultural production intensification that causes biodiversity loss (IUCN 2008), food and nutrition interventions that undermine traditional/local agriculture (Frison et al. 2006; Wahlqvist and Specht 1998), and environmental conservation programmes that lead to undernutrition (Kaimowitz and Sheil 2007). While there has been some convergence among the agriculture, environment, health and nutrition communities toward understanding the interdependence between human and ecosystem health, and how agricultural biodiversity and healthy food systems plays a role in maintaining both, more collaboration is needed to simultaneously address the issues and minimize the damage that can arise when sectors work alone (McEwan et al. 2013; Burlingame 2014).

Policy dialogue is also key. Many voices from UN agencies, civil society, academia and the private sector have expressed the need to include biodiversity for food and nutrition in the negotiations for the post-2015 Development Agenda. Calls for Action, Declarations, Recommendations, Codes and Compacts have been put forward to assist the research and development communities in their efforts to address biodiversity for food and nutrition. The draft proposal of the Open Working Group for Sustainable Development Goals presents nutrition together with sustainable agriculture as one goal, and halting biodiversity loss together with protection and sustainable use of ecosystems as another goal (UN 2014). While negotiations on this process are still ongoing, the points raised here are key to informing the critical policy dialogue that is taking place and indeed to the subsequent implementation of the SDGs.

Biodiversity sits at the nexus of improving nutrition and environmental sustainability, and offers unique opportunities to create synergies

¹⁵ <http://www.fao.org/3/a-ml542e.pdf>

¹⁶ <http://www.fao.org/3/a-mm215e.pdf>

¹⁷ <http://www.fao.org/nutrition/policies-programmes/en/>

between human and environmental health. This chapter has reviewed many of the issues pertinent to this and points to a number of areas of concern, which if improved and strengthened can help to improve the contribution of biodiversity to nutrition and human health. These include the following:

1. The current agricultural focus on food quantity requires a paradigm shift to look at ways in which we can maximize food quality and safety. Biodiversity has an important role to play in this. This has many aspects to it, including improving relevant agricultural, trade and food policies. Topical initiatives such as the current interest in nutrition-sensitive agriculture and value chains provide opportunities for biodiversity to contribute to the quality and diversity of agricultural production. Regardless of the many successes of agriculture during the past several decades, it is clear that current methods and levels of food production and consumption are not sustainable, and the finite natural resources of the planet are being exhausted or lost in the process. While agricultural production is theoretically able to feed the world's population, serious malnutrition still persists with an ever increasing diet-related NCD burden, which is going to have major public health cost implications for many countries.
2. If we are to effect such a paradigm shift, moving from a focus on quantity to quality, significant knowledge gaps in our understanding of food biodiversity and its role in improving nutrition, which still remain, will need to be addressed. Among these gaps are: the need for enhanced generation, compilation and dissemination of more food composition data – we still know so little about the nutrient composition of the vast majority of the world's edible biodiversity; the need for whole diets and landscape approaches rather than approaches that focus on specific nutrients or single food approaches; the need for better and more informative research and studies to understand the complex pathways that link biodiversity to human nutrition and health as well as the development of better tools, such as cost of diets and linear

programming, and metrics that help us characterize food systems' and ecosystems' ability to provide sustainable diets; we need more information on tested and proven good practices and interventions that can be scaled up to better mobilize biodiversity to improve nutrition. Addressing these gaps would go a long way in creating a more solid scientific base of reliable evidence that acknowledges food biodiversity's actual and potential role in reducing malnutrition.

3. To benefit from a more improved scientific evidence base of this nature, truly interdisciplinary analysis and cross-sectoral collaboration at the highest level will be essential to ensure the effective mainstreaming of biodiversity into relevant policies, programmes and national and regional plans of action on food and nutrition security. This will require transformative political will, leadership and vision. It will also require considerable resources and budgets. While there has been some convergence between the agriculture, environment, health and nutrition communities toward understanding the interdependence between human and ecosystem health, and how biodiversity plays a role in maintaining both, much more is needed to yield the necessary interdisciplinary analysis and cross-sectoral approaches required to better understand and address nutrition and environmental sustainability. In addition, much more is needed to translate recent policy gains and achievements at the global level to action and implementation at country level.
4. All these changes, shifts and transformations will require major attention to improving awareness and understanding among many actors and stakeholders. It will also require significant attention to capacity building at the global, national and local levels. It will require working with universities to encourage the necessary interdisciplinary approaches to teaching and research. Realizing the creation of a scientific evidence base as elaborated above will require major changes in approaches to how we undertake research. It will require



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novel, innovative ways for individuals, disciplines and organizations to work together. It will also require efforts aimed at increasing the awareness of the general public, policy-makers, decision-makers and of the different stakeholders across all sectors on the importance of foods from different varieties and breeds of plants and animals, as well as wild, neglected and underutilized species, in addressing malnutrition.

5. All of this presents a big agenda; however, the post-2015 Development Agenda presents a big opportunity. As we move forward into the post-2015 Development Agenda we find ourselves on the threshold of an opportunity where humanity can decide to alter course and move beyond business-as-usual, which is really no longer viable, to scenarios that facilitate real substantial transformative change. As we have seen, the challenges of the twenty-first

century are increasingly interconnected. The challenge of achieving good nutrition status in a way that is environmentally sustainable is only now beginning to receive serious attention. A change at scale in how people interact with their environment to fulfil the goals of food and nutrition security is required. As we move forward into the post-2015 Development Agenda, it is increasingly recognized that human nutrition and environmental sustainability should be considered intrinsically linked. But a major question now is “how to practically do so?”. This chapter has gone some way in addressing this question. Innovative scientific methods, pilot studies, metrics and good practices are emerging to help us rise to the challenge. The opportunity is now to ensure that nutrition security and environment are closely linked through biodiversity in the post-2015 Agenda.