2 Overview of agricultural biodiversity and its contribution to nutrition and health

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Introduction

> Agricultural biodiversity is the first link in the food chain, developed and safeguarded by indigenous people throughout the world, and it makes an essential contribution to feeding the world.
>
> (Nakhauka, 2009)

The world's agriculture and its ability to provide food for the ever-growing human population can be regarded as one of the great success stories of human civilization. It developed from our use of the natural capital of wild plant and animal biodiversity through a long period of natural and human selection and breeding of crops and the development of agronomic skills. The use of the diversity of wild species is at the very basis of human development. Across the world, our ancestors' hunter-gatherer nutritional regime depended on local wild species of plants and animals for food while others, mainly plants, provided materials for shelter, fibre and fuel and medicine. The transition from hunting-gathering to agriculture (Neolithic revolution) started some 12,500 years ago when the domestication of a small number of wild plant species in various parts of the world led to the first agricultural revolution that provided us with a relatively secure source of food.[1] This in turn allowed human communities to grow and adopt a more sedentary way of life that paved the way for the development of villages, towns and cities that increasingly dominate our way of life and all the social and cultural changes that this involves. The diversity we have today in these crops and domesticated animals is the result of the interaction between countless generations of farmers and the plants and animals they domesticated, either through farming or aquaculture, and their environment.

The connection between this diversity – agricultural biodiversity – and human nutrition and health is intrinsic, multifaceted and constantly changing. It is complex – reflecting the many dimensions of nutrition, health and agricultural biodiversity – and there is no necessary direct link between the amount or quality of agricultural biodiversity and provision of nutritional and health benefits. While it is incontestable that some elements of agricultural biodiversity such as crop diversity and wild-harvested plants and animals have made and continue to make appreciable contributions to human diets, detailed evidence of their importance in terms of energy intake, micronutrient intake and dietary diversification is scarce and correlating agricultural biodiversity with human nutrition is generally difficult for a number of reasons including human diversity (DeClerck et al., 2011).

Overall, the exploitation of agricultural biodiversity has provided enormous nutrition and health benefits despite the dramatic population growth of the human population during the past 150 years, more recently through agricultural intensification. Yet as we will see, this has incurred overexploitation of some resources and extensive habitat loss as a result of land cleared for agriculture with considerable but largely undocumented loss of species and massive soil erosion. Some of these changes have also had negative impacts on dietary diversity, nutrition and health of some groups of society (Nakhauka, 2009). We are now faced with attempting to assess these impacts, learn lessons and seek a sustainable way forward (IAASTD, 2009). New approaches will be explored in this overview, including what is termed 'econutrition' (see Chapter 1) which aims to integrate environmental and human health, focusing especially on the many interactions between agriculture, ecology and human nutrition (Blasbalg et al., 2011).

Despite the success of the agricultural revolution in providing enough food to feed the world, today we are faced with issues of over- and undernutrition – both forms of malnutrition: more than a billion people today are chronically underfed thus making them more disease-prone while much of the developed world is at the same time facing a crisis of obesity caused by overnutrition aggravated by an unhealthy lifestyle, leading to diet-related diseases, such as cardiovascular disease, hypertension, cancer, diabetes and non-alcoholic fatty-liver disease. This tendency is not confined to the developed world but is also spreading to countries undergoing rapid societal transition – so-called development-driven obesity.[2] Worldwide 30 per cent more people are now obese than those who are underfed. The causes of these nutritional challenges are many and complex as are possible solutions.

It will be argued in this chapter that healthy human nutrition is best achieved by an approach to agriculture that is biodiverse, providing a varied food supply, and ecologically sustainable but as Blasbalg et al. (2011) noted, while such an approach is sound in theory, clear evidence is scarce because of the multiple variables that contribute to such an econutrition model. Such a biodiverse food-based approach should be seen as an element in an overall strategy that also includes continuing improvement of agricultural production, breeding cultivars that are more resistant to disease and stress, nutritional enhancement of crops, industrial fortification, vitamin supplementation and other nutrition–agriculture linkages (Chung et al., 2010).

It is time to broaden our approach even further and explore the linkages between agriculture, food production, nutrition, ethnobiology and ethnopharmacology and the resource base of wild and agricultural biodiversity in the context of accelerating global change (Heywood, 2011). At an institutional level, both globally and nationally, these issues are very loosely (or not at all) coordinated. Such a strategy for agricultural biodiversity and nutrition is proposed by Frison et al. (2011): it requires several different kinds of undertaking, including:

- an evidence-based approach to nutrition and health and sustainable agriculture by small-scale farmers;
- the evaluation and use of local foods and their variety;
- traditional cuisines;
- culturally sensitive methods;
- nutrition education;
- research on novel and improved methods of food storage and processing;
- enhanced attention to marketing.

Agricultural biodiversity defined

Agricultural biodiversity is the variety and variability of living organisms (plants, animals, microorganisms) that are involved in food and agriculture. Such a definition is however too general to be of much practical value and needs to be expanded and analysed if agricultural biodiversity is to be quantified. It can be considered at three main levels – those of ecological diversity, organismal diversity and genetic diversity (Heywood, 1999a), each of which forms a hierarchy of elements (Table 2.1). It is not just a subset of biodiversity but represents an extension of it so as to embrace units (such as cultivars, pure lines, breeds and strains) and habitats (agroecosystems such as farmers' fields and fisheries) that are not normally considered or even accepted by some conservation biologists as properly part of biological diversity. It includes all those species (including crop wild relatives) and the crop varieties, animal breeds and races, and microorganism strains, that are used directly or indirectly for food and agriculture, both as human nutrition and as feed (including grazing) for domesticated and semi-domesticated animals, and the range of environments in which agriculture is practised. It includes not just food as such but diets, food intake and nutritional considerations. Also covered are ingredients such as flavourings, colourants, preservatives, etc. that are used in food preparation, cooking, processing and storage.

Agricultural biodiversity also includes habitats and species outside of farming systems that benefit agriculture and enhance ecosystem functions (Heywood, 2003). In addition to the elements of agricultural biodiversity that are directly managed to supply the goods and services used by humans, other elements are vital because of their contributions to ecosystem services such as pollination (Klein et al., 2007), control of greenhouse gas emissions and soil dynamics (Frison et al., 2011). Production of at least one third of the world's food, including 87 of the 113 leading food crops, depends on pollination carried out by insects, bats and birds (IUCN, 2012). As Westerkamp and Gottsberger (2001) note, 'Pollinator diversity is mandatory for crop diversity' and pollination services have been estimated to contribute €153 billion worldwide in 2005 (Gallai et al., 2009).

Table 2.1 The components of agricultural biodiversity (modified from Heywood 1999a)

Agroecological diversity	*Organismal diversity*	*Genetic diversity*
biomes	kingdoms	gene pools
agroecological zones	phyla	populations
agroecosystems	families	individuals
polycultures	genera	genotypes
monocultures	species	genes
rangelands	subspecies	nucleotides
mixed systems	varieties	breeds
pastures	cultivar groups	strains
fallows	cultivars	pure lines
agroforestry systems	landraces	
agrosylvicultural		
sylvopastoral		
agrosylvopastoral		
home gardens		
forest		
ecosystems		
managed forests		
plantation forests		
seed forests		
fisheries		
fresh water systems		
marine systems		
habitats		
fields		
plots		
crops		

Socio-cultural diversity: human interactions with the above at all levels, including dietary and culinary diversity, food preparation and storage.

Likewise, agricultural biodiversity includes elements that affect crops and food production negatively such as pests and diseases, weeds and alien invasive species.

Agricultural biodiversity is by definition the result of the deliberate interaction between humans and natural ecosystems and the species that they contain, often leading to major modifications or transformations: the resultant agroecosystems are the product, therefore, of not just the physical elements of the environment and biological resources but vary according to the cultural and management systems to which they are subjected. Agricultural biodiversity thus includes a series of social, cultural, ethical and spiritual variables that are determined by farmers at the local community level. These factors played a key role in the process of selection and evolution of new cultivars or of local crops and in the ways in which they are grown and managed. It is important to recognize that 'the relationship that people have with their environment is complex and locally specific. Consequently, environment and development problems may need to be dealt with at the local scale so that remedies can be designed in ways that are culturally, socio-politically and environmentally suited to each local context' (Thomas, 2011).

This chapter will focus on components of agricultural biodiversity that impact most directly on nutrition and health and are directly managed to provide us with goods and services such as:

- the diversity of wild and domesticated plant and animal species used in agriculture, including underutilized and wild-gathered species;
- the ecosystems in which they grow and are grown;
- plant and animal genetic resources, including crop wild relatives (CWR) and domesticated animal wild relatives and the landraces, cultivars and breeds developed from these wild species.

The simplification of agriculture

A remarkable feature of the agricultural revolution was the relatively small number of plant species that were successfully domesticated and of these, the even smaller number which were selected over time because of their relative ease of cultivation, reliability and their ability to be grown in a range of habitats, as well as their nutritional value (Padulosi et al., 2002). On the other hand, over the past 12,000 years, farmers have developed a bewildering diversity of local varieties or landraces of these staples and of minor crops resulting from 'interactions with wild species, adaptations to changing farming conditions, and responses to the economic and cultural factors that shape farmers priorities' (Tripp and van der Heide, 1996). Landraces or primitive cultivars are the products of breeding or selection carried out by farmers, either deliberately or not, over many generations and natural selection. As noted by Harlan (1975), they 'are recognizable morphologically; farmers have names for them, and different landraces are understood to differ in adaptation to soil type, time of seeding, date of maturity, height, nutritive value, use and other properties'.

The number of animal species that were fully domesticated was even smaller and today only some 40-plus livestock species contribute to agriculture and food production. Likewise, the number of breeds that were developed in these domesticates was very much smaller than in the case of plants – FAO's Global Databank for Animal Genetic Resources for Food and Agriculture contains information on a total of 7,616 livestock breeds from 180 countries. Furthermore, as *The State of the World's Animal Genetic Resources for Food and Agriculture* (FAO, 2007) notes, 'With the exception of the wild boar (*Sus scrofa*) the ancestors and wild relatives of major livestock species are either extinct or highly endangered as a result of hunting, changes to their habitats, and in the case of the wild red jungle fowl, intensive cross-breeding with the domestic counterpart. In these species, domestic livestock are the only depositories of the now largely vanished diversity'. It has been estimated that 30 per cent of the world's animal breeds are at risk of extinction.

Agriculture and sedentism gradually led to a significant reduction in our dietary diversity (Ogle and Grivetti, 1985; Diamond, 1987) through our increased reliance on domesticated species and new and improved crops varieties (cultivars) which increased yields and led to intensification of agriculture. Eventually only a tiny number of crop species – the staples – came to dominate our nutritional and calorific intake, and globally the number of wild species that we depended upon directly was dramatically diminished. As Diamond (1987) noted 'While farmers concentrate on high carbohydrate crops like rice and potatoes, the mix of wild plants and animals in the diets of surviving hunter-gatherers provides more protein and a better balance of other nutrients'. While many would cavil at his suggestions that the adoption of agriculture was 'the worst mistake in the history of the human race', there is some evidence that initially it had an adverse effect on human health. For example, in their *Paleopathology at the Origins of Agriculture*, Cohen and Armelagos (1984) reported empirical studies of societies shifting their subsistence from foraging to primary food production which showed that there was evidence for deteriorating health due to an increase in infectious diseases and a rise in nutritional deficiencies that could be attributed to reliance on single crops deficient in essential minerals, amongst other factors (see also review by Mummert et al., 2011). But on the whole, agricultural intensification has been one of the main factors that has allowed much of the human population to enjoy unprecedented levels of health and reduced mortality.

This process of simplification of agriculture led eventually to today's model of food production in which we rely on only around 100 crop species for about 90 per cent of national per capita supplies of food from plants. Of these only 20–30 make up the bulk of human nutrition – the so-called staples (Prescott-Allen and Prescott-Allen, 1990), such as wheat, barley, maize, rice, millet, sorghum, rye, cassava, yams, potato and sweet potato. Modern intensive agriculture not only reduces agricultural biodiversity but, as Frison et al. (2011) point out, is predicated on such a reduction.

The gradual substitution of locally adapted landraces or cultivars by more advanced high-yielding cultivars that were resistant to disease or other factors resulted in the erosion of this pool of diversity and represented a further simplification of agriculture. This genetic erosion of our crop species led to the development of the plant genetic resource movement by pioneers such as Vavilov, Bennett, Frankel, Harlan, Hawkes and others (Bennett 1964, 1965; Frankel and Bennett, 1970; Pistorius, 1997) as an attempt to conserve the remaining diversity in crops and their wild relatives. The scale of loss of landraces reported has been dramatic in some cases although it is not easy to verify due to lack of reliable baseline data and consistent standards of recording. In rice (*Oryza sativa*), for example, 40,000 to 50,000 landraces are estimated to exist but many reports have been published indicating extensive national or local loss of cultivar diversity in the crop. Genetic erosion was reported by about 60 countries in national reports for the *Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture* (FAO, 2010b) although few concrete examples were given. On the other hand, a study by Ford-Lloyd et al. (2008) of germplasm and genetic data in the IRRI genebank collected throughout South and Southeast Asia from 1962 to 1995 was unable to detect a significant reduction of available genetic diversity in the study material, contrary to popular opinion. Likewise, despite the massive loss of landraces reported for several crops, a review by Jarvis et al. (2008) revealed that as measured by richness, evenness and divergence of cultivars, considerable crop genetic diversity continues to be maintained on farm, in the form of traditional crop varieties for a finite number of crops in a small number of countries. Major staples had higher richness in terms of the number of different kinds of individuals regardless of their frequencies and evenness (measuring how similar the frequencies of the different variants are) than non-staples. And in a study of genetic erosion in maize within smallholder agriculture in southern Mexico, van Heerwarden et al. (2009) found that despite the dominance of commercial seed, the informal seed system of local farmers persisted. True landraces were, however, rare and most of the informal seed was derived from modern 'creolized' varieties – developed as a result of exposing improved varieties to local conditions and management and continually selecting seed for replanting and promoting their hybridization with landraces (Bellon et al., 2003). They also showed that genetic erosion was moderated by the distinct features offered by modern varieties.

While acknowledging the undoubted success of modern agriculture, it should be remembered that the great majority of farmers in the developing world are traditional or peasant farmers who rely in varying degrees on small-scale cultivation of staples and various forms of traditional agriculture, including raised fields, terraces, swidden fallows, agroforestry polycultures (e.g. home gardens), semi-domesticated species and wild harvesting of fruits, fibres, medicinals and so on, and on the natural and semi-natural ecosystems that border or are adjacent to the cultivated fields (Altieri, 1999; Altieri and Koohafkan, 2008).

Globally, small-scale agriculture is the dominant form of food provision (IAASTD, 2009). It is estimated that about 60 per cent of the world's agriculture consists of traditional subsistence farming systems in which there is both a high diversity of crops and species grown and of ways in which they are grown, such as polycropping and intercropping, that leads to the maintenance of variation within the crops (FAO, 2010a; Vigouroux et al., 2011). Such traditional agricultural landscapes are estimated to provide as much as 20 per cent of the world's food supply. They are rich in agricultural biodiversity, especially in polycultures and agroforestry systems, thus contrasting with modern intensive industrial agriculture, and are often the product of complex farming systems that have developed in response to the unique physical conditions of a given location, such as altitude, slopes, soils, climates and latitude, as well as cultural and social influences (Phillips and Stolton, 2008). Many of the species grown in such systems are local 'underutilized species' as discussed below and provide nutritional balance to the diet, complementing the staple crops that are grown and providing micronutrients and vitamins. Another advantage of growing a diversity of crops and maintaining genetic diversity within local production systems is that it also favours the conservation of local knowledge (FAO, 2010b).

Home gardens (also known as homestead gardens, yard gardens, kitchen gardens, etc.) are a long-established tradition and offer great potential for improving household food security and alleviating micronutrient deficiencies. The home garden can be defined as a farming system which combines different physical, social and economic functions on the area of land around the family home (FAO, 1995, 1996). They occur in most parts of the world but especially in tropical and subtropical regions (Eyzaguirre and Watson, 2002; Wezel and Bender, 2003; Gebauer, 2005; Kabir and Webb, 2008) and it has been estimated that nearly 1 billion people in the tropics live from the produce of home gardens supported by subsistence agriculture. The essence of such systems is the diversity of species they contain – up to 100 or more species per garden – and their two- to four-layered structure that allows different ecological niches to be exploited by the species planted. Several organizations such as FAO and the Centre for Sustainable Development offer training courses or manuals on home gardens. Home gardens may also provide animal products such as chickens, eggs and livestock, as in the case of the homestead gardens promoted by Bioversity International and Helen Keller International (see Case Studies 2 and 7 in this volume) (Iannotti et al., 2009).

Although numerous reports on the role of home gardens in nutrition are found in the literature, there is little reliable evidence of their value. A systematic review of agricultural interventions, including many on home gardens, that aim to improve the nutritional status of children by improving the incomes and the diet of the rural poor, based on a systematic search of the published and unpublished literature (Masset et al., 2011), concluded that the interventions were as expected successful in promoting consumption of specific foods – in the case of home gardens fruit and vegetables – but very little evidence was available on their effects on nutritional status. On the other hand, the authors note that the absence of any reported statistically significant impact of agricultural interventions on nutritional status found in their review, as well as by other earlier reviews, 'should not be attributed to the inefficacy of these interventions. Rather it is the lack of power of the studies reviewed that could have prevented the identification of such impact, if any'.

The importance of plant diversity for nutrition

> Adequate human nutrition involves regular intake of a wide range of nutrients, some of which must be consumed on a frequent basis, even if in small quantities. As such, dietary diversity (DD), typically measured in the form of a count of food groups or food group frequency, has been suggested as a proxy indicator for nutrient adequacy.
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> (Coates et al., 2007)

We have at our disposal some 400,000 species of plants but, as we have seen, only a small number of these are the staples on which global nutrition depends. This is, however, only part of the picture. The number of cultivated crop species (excluding ornamentals) has been estimated at about 7,000 (Khoshbakht and Hammer, 2008), most of them grown locally and on a small scale. In addition there are many locally used species that are scarcely or only partially domesticated and many thousands more are gathered from the wild (Heywood, 1999b).

The nutritional importance of dietary diversity (DD) is now widely recognized (WHO/FAO, 2003). Growing a range of local crops supplemented by wild-harvested species helps provide such diversity in the diet, especially of poor rural families, and complements the nutrition provided by staples such as maize, rice and cassava. Balanced nutrition in the human diet depends not just on growing a diversity of crops but on the diversity within the crops (Mouillé et al., 2010). The micronutrient superiority of some lesser-known cultivars and wild varieties over other, more extensively utilized cultivars, has been confirmed by recent research. For example, recent analyses have shown that beta-carotene content can differ by a factor of 60 between sweet potato cultivars and the pro-vitamin A carotenoid of banana cultivars can range between 1 μg and 8,500 μg/100 grams (Burlingame et al., 2009; Lutaladio et al., 2010), while the protein content of rice varieties can range from 5 to 13 per cent (Kennedy and Burlingame, 2003). As they observe, 'Intake of one variety rather than another can be the difference between micronutrient deficiency and micronutrient adequacy'. Unfortunately, we lack detailed information about such diversity within most crops at the cultivar level and the role it plays in nutrition because of the general neglect by professionals (Burlingame et al., 2009) and much of the evidence is anecdotal.

Underutilized or orphan crops

The term 'underutilized species' refers to those species whose potential to improve people's livelihoods, as well as food security and sovereignty, is not being fully realized because of their limited competitiveness with commodity crops in mainstream agriculture. While their potential may not be fully realized at national level, they are of significant importance locally, being highly adapted to marginal, complex and difficult environments and contributing significantly to diversification and resilience of agroecosystems. This means they are also of considerable interest for future adaptation of agriculture to climate change (Padulosi et al., 2011).

The importance of underutilized species is now receiving more recognition. The IAASTD (2009) report, for example, recognizes that investments in agricultural knowledge, science and technology 'can increase the sustainable productivity of major subsistence foods including orphan and underutilized crops, which are often grown or consumed by poor people'. Likewise, the Ministerial Declaration 'Action Plan on Food Price Volatility and Agriculture', issued by the G20 Agriculture Ministers from their meeting in Paris on 22–23 June 2011 recognized the importance of making the best use of all available plant genetic resources for food and agriculture, including research on underutilized crops. Underutilized species also received qualified endorsement in the Commission on Sustainable Agriculture and Climate Change's report *Achieving food security in the face of climate change* (Beddington et al., 2012).

Wild-gathered plant species

Despite the simplification of agriculture, wild species still represent a major resource today and form an important part of the diet of societies in both the developed and developing worlds, providing not only variety but also essential vitamins and micronutrients in the form of bushmeat, fruits, vegetables, herbs and spices, beverages and intoxicants, not to mention their use as fibres, fuel, ornament and medicines (Bharucha and Pretty, 2010; Heywood, 1999b, 2008, 2011; Turner et al., 2011). These range from locally consumed species such as leaf greens and wild fruits to economically important non-timber forest products obtained by extractivism, such as palm hearts, Brazil nuts and rubber and the trade – most of it uncontrolled and much of it illegal – in ornamentals including cycads, orchids, cacti and succulents and bulbs. The use of wild plants in most societies forms part of indigenous knowledge systems and practices that have been developed over many generations and which play an important part in decision-making in local agriculture, food production, human and animal health and management of natural resources (Slikkerveer, 1994). Growing vegetables in home gardens and other plots is often supplemented in traditional rural and farming communities by wild harvesting of local greens, fruits, nuts and fungi. The term 'wild food', therefore, is used to describe all plant resources that are harvested or collected for human consumption outside agricultural areas in forests, savannah and other bush-land areas.

The consumption of traditional leafy vegetables ('wild or leafy greens') as an important source of micronutrients is attracting a great deal of attention, notably in the tropics (Etkin, 1994; Chweya and Eyzaguirre, 1999; Price and Ogle, 2008; Afolayan and Jimoh, 2009; Grivetti and Ogle, 2000; Pretty, 2007b; Heywood, 1999b; Flyman and Afolayan, 2006; Uusiku et al., 2010). Often they provide rural poor with most of their daily requirements of essential vitamins and minerals, particularly folate, and vitamins A, B complex, E and C (Guarino, 1997; FAO, 2010a) and in many cases they also have medicinal properties and form part of local health care systems (Etkin, 2006). They are especially important in small children's diets to ensure normal growth and intellectual development (FAO, 2010a).

In the Mediterranean region, the habit of consuming wild food plants is still prevalent, especially for rural people, although it is 'ageing', with fewer traditional vegetables consumed than in previous decades. A circum-Mediterranean ethnobotanical field survey for wild food plants as part of the EU-supported RUBIA project (Hadjichambis et al., 2008) documented 294 wild food taxa. In particular, traditional leafy vegetables ('wild or leafy greens') are widely consumed in several Mediterranean countries such as France, Greece, Italy, Spain and Turkey (Pieroni et al., 2005; Heywood, 2009). They are especially important in Greece (where they are known as *xorta*), especially Crete (where over 92 wild greens have been catalogued (Stavridakis, 2006) and several studies published) and other islands such as Cyprus, Sicily and Sardinia. In recent years, work on economically valuable wild plant species in the Mediterranean region has increasingly focused on the nutritional and health aspects of wild foods (Heinrich et al., 2006a,b). A recent ethnobotanical study showed that as many as 2,300 different plant and fungal taxa are gathered and consumed in the Mediterranean region (Rivera et al., 2006) where they play an important role in human nutrition and can supply most of the necessary daily requirements for vitamins A, B complex and C and provide minerals and trace elements. They may sometimes even be better nutritionally than introduced cultivated vegetables. The so-called Mediterranean diet (Keys and Keys, 1959) or more properly diets that are rich in fruit, vegetables, legumes and olive oil, as well as fish and poultry, but low in meat and animal fats (Heinrich et al., 2006a) often include a range of local wild-gathered plants such as 'wild greens'.

Forests can play an important part in human nutrition, particularly in developing countries (Hladik et al., 1993) and according to the Collaborative Partnership on Forests (CPF), the potential of forests and trees to improve food and nutritional security needs more attention from policymakers and development agencies (FAO, 2011c). It is estimated that at least 410 million people derive much of their food and livelihoods from forests while some 1.6 billion people get some portion of their food and livelihood from forests around the world (ETC Group, 2009). Non-Wood Forest Products (NWFP) include many types of food such as fruits, nuts, leafy vegetables and oils that are widely recognized as contributing to the livelihood of millions of people in many parts of the world, especially in the tropics and subtropics, and contribute to dietary diversity. A six-year global study by CIFOR (2011) has documented for the first time on a broad scale the role that forests play in poverty alleviation and the significant contribution they make to the livelihoods of millions of people in developing countries. The Poverty and Environment Network (PEN) study consists of data from more than 8,000 households from 40+ sites in 25 developing countries. It makes a strong argument for the sustainable management of natural ecosystems to provide health and nutritional benefits.

Domestication programmes are being developed to bring many wild species, both trees and herbs, into cultivation and integrate them into agroforestry systems (Leakey, 1997, 2011; Leakey and Tchoundjeu, 2001). Examples of such species are *Adansonia digitata*, *Barringtonia procera*, *Canarium indicum*, *Gnetum africanum*, *Irvingia gabonensis*, *Sclerocarya birrea* and *Vitellaria paradoxa*. As well as providing 'marketable timber and non-timber forest products that will enhance rural livelihoods by generating cash for resource-poor rural and peri-urban households' and restoring productivity through soil fertility improvement, these species can provide health and nutritional benefits.

Crop wild relatives

While crop wild relatives (CWR) may not play a significant direct role in human nutrition – although there are notable exceptions such as wild yams in Madagascar – they are an essential source of genetic material for the development of new and better adapted crops (Maxted et al., 2011). For example, a recent study using microsatellite markers showed that a wild rice in Vietnam has much greater genetic variation than cultivated rice, with a single wild population showing greater genetic variation than that found in 222 local Vietnamese varieties (Ishii et al., 2011). Moreover, it is now widely recognized that the wild relatives of crops will play a key role in future food security in the face of global change (Guarino, 2010; Maxted et al., 2010; Hunter and Heywood, 2011).

The importance of animal diversity for nutrition

Although much of the focus in this chapter is on plants, animal diversity also plays an important role in human nutrition and dietary diversity, mainly in terms of dairy products, eggs, meat and offal, fish and seafood (see Chapter 3) (Ruel, 2003). Animal products are excellent sources of high quality protein and fat and are an important source of vitamins and minerals such as zinc, iron and selenium as well as calcium and phosphorus. According to a recent FAO report on livestock in food security (FAO, 2011d), 'Livestock contribute around 12.9% of global calories and 27.9% of protein directly through provision of meat, milk, eggs and offal…'.

Although for many people in developing countries, animal food products are not a significant part of their diet, and dietary restrictions prohibit the consumption of certain animal foods, globally they are becoming increasingly important and this trend is expected to continue (von Kaufmann, 2000). In China, which is undergoing rapid nutritional transition, consumption of meat (mainly pork) has increased dramatically over the past 35 years and the country now eats more than a quarter of all the meat produced worldwide. High meat intake has been one of several factors, such as increasing consumption of fast food with a high sodium content and sugar-sweetened beverages and lack of physical exercise, that have been associated with an increase in obesity in the Chinese population (Cheng, 2004; Ko et al., 2010).

According to FAO (2010c), as demand for animal source foods increases, global production of meat is projected to more than double between 1990 and 2050. The Rome-based food agency warns, however, that current industrial livestock production practices may not be sustainable and notes that livestock is currently the single largest user of land in the world, accounting for 70 per cent of all agricultural land and 30 per cent of total land surface.

Wild meat/bushmeat and other wildlife

Although 'bushmeat' is the African term for the meat of wild animals it is now applied to animals that are hunted for subsistence or commercial purposes especially in the tropics of the Americas, Asia and Africa. It is also known as wild meat (as recommended by IUCN) or game. It may be defined as 'any non-domesticated terrestrial mammals, birds, reptiles and amphibians harvested for food' (Nasi et al., 2008) or more widely to include any type of terrestrial wild animal, including reptiles (tortoises, lizards, snakes), birds, mammals,

Box 2.1 Nutritional importance of wild meat

'Bushmeat represents an important protein source in the tropics while gathered plant foods are important dietary supplements to the starchy staple diet. In at least 62 countries world-wide, wildlife and fish constitute a minimum of 20% of the animal protein in rural diets. Wildlife provides significant calories to rural communities, as well as essential protein and fats. … Even where there has been a change from a hunter-gatherer lifestyle to pastoralism or agriculture, hunting and gathering remain important to a high proportion of rural households in tropical forests. Hunting provides between 30 to 80% of the overall protein intake of rural households in Central Africa (Koppert et al.,1996) and nearly 100% of animal proteins. What is known of the nutritional composition of bushmeat species suggests that these provide an equivalent or even greater quality of food than domestic meats with less fat and more protein. The average protein value of wild meat is estimated at around 30 g of protein per 100 g of meat (Ntiamoa-Baidu, 1997). These proteins cannot be substituted by available protein of vegetal origin, such as cassava or gnetum leaves, as they are poorer in amino acids (Pagezy, 1996). They could be replaced by other vegetal sources, dairy products, and/or meat from domesticated animals'.

Source: Nasi et al., 2008

some amphibious or semi-aquatic freshwater animals, such as frogs, turtles and crocodilians and marine mammals such as seals, walruses, whales, dolphins, porpoises and manatees (Roth and Merz, 1996).

The nutritional importance of wild meat, like domesticated livestock, is that it provides protein and fat as well as vitamins in the diet (Box 2.1). Detailed reviews of the importance and role of wildlife in nutrition are given by Hladik et al. (1989, 1996) and Froment et al. (1996). However it must be noted that excessive hunting of some wild animal populations is leading to a bushmeat crisis that is threatening the livelihoods of some forest communities (Nasi et al., 2008).

Fish and crustaceans

Fish and fish products and shellfish provide a major source of nutrition for coastal, lacustrine and riverine communities, especially in developing countries, and play an important role in the diets, livelihoods, and income of many poor population groups who suffer from vitamin and mineral deficiencies (see Chapter 4 and Case Study 4) (Roos et al., 2007). According to FAO about 2,000 fish, crustacean, mollusc, echinoderm and aquatic plant species or species groups are caught annually. But since about 10 million tonnes of unnamed marine fish alone are landed annually, the total number of species harvested is likely to be more than 5,000 (Williams, 2011). Today almost half of all fish eaten come from farmed sources, not wild capture.

In 2007, fish accounted for 15.7 per cent of the global population's intake of animal protein and 6 per cent of all protein consumed (FAO, 2010d). Globally, fish consumption per capita increased by 43 per cent from 11 kg in 1970 to 16 kg in 2000. Fish played an important role in doubling animal protein consumption per capita in developing countries in the same period – from 6.3 kg in 1970 to 13.8 kg in 2000, driven, especially in Asia, by urbanization, income and population growth, while in the developed world fish consumption increased by less than one half between 1970 and 2000 (Ahmed, 2004).

In West Africa fish accounts for 30 per cent of animal protein intake (Neiland, 2006), limited only by its availability, and in Bangladesh the rural population depends on a diet of fish and rice supplemented by small amounts of vegetables to such an extent that as Roos et al. (2007) note, the old proverb 'mache bhate bangali' (fish and rice make a Bengali) is still true today. They also report that while carp polyculture production has been highly successful, small indigenous fish species that are caught, sold, and consumed by the rural population and which contain high levels of protein, vitamins, iron, calcium, zinc and other minerals tend to be ignored and are not captured in official statistics so that the benefits derived from such local fish are poorly documented and their importance can be underestimated.

An interesting example of where a plant-based agroecosystem also provides substantial amounts of animal biodiversity that is used in local nutrition is rice paddies. Perfecto et al. (2009) note that the biodiversity in rice fields may be divided into aquatic invertebrates, terrestrial invertebrates, vertebrates and plants with some rice-based systems containing more than 100 species that are used by local communities.

Changing the paradigm

> The present paradigm of intensive crop production cannot meet the challenges of the new millennium.
>
> (Diouf, 2011)

> What we desperately need is another revolution, one that deals with agricultural productivity for the smallholders … We need to answer these questions: Are we growing the right foods? Are we growing them in the most efficient way with respect to inputs, water and land? Are we growing them in the most suitable way? And what foods are consumers actually eating in terms of quality and quantity, nutrition and food safety?
>
> (Andersen, 2011)

Agricultural intensification continues to pose a serious threat to biodiversity in many parts of the world. For example, a recent study of the impact of crop management and agricultural land use on the threat status of plants adapted to arable habitats in 29 European countries showed a positive relationship between national wheat yields and the numbers of rare, threatened or recently extinct arable plant species in each country (Storkey et al., 2012). This current paradigm of intensive high input, high output intensification of agriculture is now being questioned because of (1) growing concerns about its present impacts on biodiversity; (2) the predicted impacts of global change on agriculture and wild biodiversity; (3) serious issues over energy and water security; and (4) changes in dietary patterns.

Proposals for new paradigms are emerging (Lang, 2009; Thompson and Scoones, 2009; Brussaard et al., 2010; Pretty, 2002, 2007a; Pretty et al., 2010; Clay, 2011; Collette et al., 2011; Brown, 2011). As Frison et al. (2011) point out, 'Almost all of the approaches used to date in agricultural intensification strategies, for example the substitution and supplementation of ecosystem function by human labour and petrochemical products, contain the seeds of their own destruction in the form of increased release of greenhouse gases, depletion of water supplies and degraded soils. We need to build production systems that deliver intensification without simplification.' Sustainable intensification of agricultural production – 'producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environment' (Pretty, 2011; Pretty et al., 2011) – is now widely advocated (Royal Society, 2009; Godfray et al., 2010a, b).

Recent volatility in food prices together with extreme weather events and the projected impacts of climate change have intensified the search for alternative ways of addressing the problem of achieving food security through employing more sustainable and intelligent management of production and consumption as outlined in the UNEP rapid response assessment *The Environmental Food Crisis* (Nellemann et al., 2009). As Achim Steiner writes in the preface to the report, 'Simply cranking up the fertilizer and pesticide-led production methods of the 20th century is unlikely to address the challenge'.

Pretty et al. (2010) consider that 'The goal for the agricultural sector is no longer simply to maximize productivity, but to optimize across a far more complex landscape of production, rural development, environmental, social justice and food consumption outcomes'. For example, FAO has published a policymaker's guide to what is termed 'sustainable intensification of smallholder crop production' (Collette et al., 2011) in which more is produced from the same area of land while conserving resources, reducing negative impacts on the environment and enhancing natural capital and the flow of ecosystem services (see also Pretty et al., 2011). This approach involves:

- building crop production intensification on farming systems that offer a range of productivity, socio-economic and environmental benefits to producers and to society at large;
- using a genetically diverse portfolio of improved crop varieties that are suited to a range of agroecosystems and farming practices, and resilient to climate change;

- rediscovering the importance of healthy soil, drawing on natural sources of plant nutrition, and using mineral fertilizer wisely;
- smarter, precision technologies for irrigation and farming practices that use ecosystem approaches to conserve water;
- achieving plant protection by integrated pest management and avoiding overuse of pesticides;
- bringing about fundamental changes in agricultural development policies and institutions so as to encourage smallholders to adopt sustainable crop production intensification.

The need to maintain and manage ecosystems sustainably so that they continue to provide us with goods and services is critical: as Munang et al. (2011) observe, 'Healthy ecosystems provide a diverse range of food sources and support entire agricultural systems'. Although not new, there are increasing calls today for a more ecological approach to agriculture – sometimes called ecological agriculture (Kiley-Worthington, 1981), eco-agriculture (McNeely and Scherr, 2003; Buck et al., 2004; Scherr and McNeely, 2007; Buck and Scherr, 2011),[3] or regenerative agriculture (LaSalle, 2008) – and also to human nutrition (DeClerck et al., 2011). Such approaches look beyond a focus on production to sustainability, biodiversity protection and the complex dynamics of the agroecosystem in terms of plants, animals, insects, water and soil. A diversity of crops (and where appropriate livestock) is also a characteristic as is a focus on the role of indigenous communities.

So far, calls to promote a more food-based approach to nutrition and health (Levin et al., 2003) have met with resistance from policymakers and governments and as discussed below, the role of species diversity in nutrition and alleviation of poverty has been largely disregarded by mainstream agricultural policy although it is now a subject of considerable discussion.

Assessing the role of biodiversity in alleviating hunger and malnutrition

> …a wider deployment of agricultural biodiversity is an essential component in the sustainable delivery of a more secure food supply.
>
> (Frison et al., 2011)

Although the link between biodiversity and alleviating poverty, including food poverty and malnutrition, has been pointed out by many authors in recent years (e.g. Etkin, 1994; Batello et al., 2004; World Bank, 2007; Chivian and Bernstein, 2008; IAASTD, 2009; Kuhnlein et al., 2009; Lutaladio et al., 2010; Frison et al., 2011; DeClerck et al., 2011) and has been eloquently argued by distinguished figures such as M.S. Swaminathan, the Father of the Green Revolution in India and World Food Prize winner (Swaminathan, 2011), it is much more difficult to convince governments and policymakers and provide clear scientific evidence of a direct link between protecting the natural environment and promoting the interests of poor communities and more specifically between biodiversity and poverty (Roe et al., 2010).

An international symposium on 'Linking biodiversity conservation and poverty reduction: what, why and how?', organized by IIED, UNEP-WCMC and the African Wildlife Foundation, held at the Zoological Society of London, on 28–29 Apr 2010, debated these issues and several speakers questioned the robustness of the scientific evidence for the linkages between biodiversity and poverty (Roe et al., 2010). Some commentators take a more extreme position such as 'Biodiversity doesn't feed people, but GM crops do' which has evoked many responses to the effect that socially it is well documented that biodiversity and poverty are closely related.

It is clear from such exchanges that there is a need to recognize the importance of providing or actually generating good solid evidence on which policy can be based. As a recent editorial in *Science and Development Network* (Dickson and Lewis, 2010) notes, 'without solid evidence that biodiversity conservation can alleviate poverty, politicians simply won't buy into the idea of protecting biodiversity, or will take action that however well meaning, ends up unfocused and ineffective'.

One of the commonest criticisms of advocating a greater use of local agricultural biodiversity in the form of traditional crops, underutilized species and wild-harvested species to address under- or malnutrition is precisely that it is local and it is assumed therefore will have little impact on the global picture. Yet, at least 20 per cent of the world food supply comes from traditional multiple cropping systems, most of them small farm units often of 2 ha or less (Altieri, 2009).[4] There is ample evidence on the ground that local biodiversity and ecosystem services play an essential role in the lives of communities throughout the developing world, by providing a social safety net for food, medicine, fibre, fuel wood etc. that can act as route out of poverty and a source of income generation, prevent people falling further into poverty or in extreme cases as an emergency lifeline through the provision of 'famine food' (Roe et al., 2010). It can also play a major part in addressing some issues of malnutrition (see below).

The main reasons for the lack of attention given to underutilized or wild-gathered species include:

- a lack of information and reliable methods for measuring their contribution to farm households and the rural economy;
- low productivity compared with staples;
- the lack of guaranteed markets, except for a small number of products;
- the irregularity of supply of wild plant products;
- the lack of quality standards;
- lack of standardization of the product;
- the lack of storage and processing technology for many of the products;
- the availability of substitutes;
- the bias in favour of large-scale agriculture

(Heywood, 2006, 2008; Padulosi et al., 2008)

But perhaps the main problem is their low profile with the general public caused by lack of knowledge about what they are and what are their characteristics and value. Solid scientific evidence on the nutritional benefits of indigenous foods is often lacking and much further work is needed to provide a sounder basis for their possible development.

Knowledge gaps

In the case of both underutilized crops and wild-harvested species, much of the evidence on the nutritional or health benefits of particular species is partial or anecdotal and there is a need for critical scientific assessments. A systematic review of the literature on the contributions of edible plant and animal diversity to human diets concluded that local food biodiversity makes an important contribution to nutritious diets, although strong evidence is lacking, and the findings were limited to communities living in areas with high biodiversity (Penafiel et al., 2011). They comment that 'Only future multidisciplinary research, incorporating appropriate biodiversity and nutritional assessment methodologies, would lead to a better understanding of the dietary contributions of local food biodiversity and diets'. Also, as Flyman and Afolayan (2006) comment, 'the chemical, nutritional and toxicological properties of … local wild vegetables, the bioavailability of micronutrients present in these, and their modification by various processing techniques still need to be properly established and documented before their use as an alternative dietary source can be advocated'. This poses a major challenge not just for the proponents of these species but also for ethnopharmacologists and ethnobiologists (Heywood, 2011). A recent report (CIFOR, 2011) notes that 'Many existing tools for assessing poverty and income – such as poverty reduction strategy plans, poverty surveys, the World Bank's Living Standard Measurement Survey and national income accounting systems – fall short of capturing the importance of the income from natural resources, so that its true value in the livelihoods of the world's rural poor remains largely invisible'.

For most wild-collected species, whether for food, medicine or fuel, we have little knowledge of the amount of material that is harvested from the wild or of the effect that such gathering has on the health and survival of populations of these wild plants. Only a few countries have made detailed inventories of these species and the literature is scattered in numerous papers and reports and is often of only local importance. Few syntheses have been published such as *The Hidden Harvest* (Scoones et al., 1992), which is a literature review and annotated bibliography of wild foods and agricultural systems but now rather dated. A review of the roles and values of wild foods in agricultural systems by Bharucha and Pretty (2010) includes some information on the diversity of wild species used. In 22 countries in Asia and Africa, the mean use of wild foods by agricultural and forager communities is '90–100 species per location' while the figures for individual countries such as India, Ethiopia and Kenya can be as much as 300–800 species.

Agricultural biodiversity, nutrition and global change

> Agricultural biodiversity will also be absolutely essential to cope with the predicted impacts of climate change, not simply as a source of traits but as the underpinnings of more resilient farm ecosystems.
>
> (Frison et al., 2011)

The future impacts of the various components of global change – demographic, climatic, land use – on agricultural biodiversity and nutrition will be enormously complex and correspondingly difficult to decipher and predict. What is certain is that inexorable demographic growth during the remainder of this century will require a vast increase in agricultural production and productivity to feed the extra billions. Not only that but it will have to attempt to do so in ways that are sustainable and that address increasing environmental concerns at the multiple impacts of agriculture on our environment and on biodiversity (Foley et al., 2005, 2011) and do not exacerbate already rising world food prices, while also addressing the problems of hunger and malnutrition, satisfying rapidly escalating bioenergy use and tackling the problems of restoring degraded lands and soils. The question has been raised as to whether all these factors will converge, leading to what some authors have called 'a perfect storm' (Buchanan et al., 2010; Hertel, 2011) for global agriculture or whether practical solutions can be devised and implemented successfully (Foley et al., 2011).

The growing human population will inevitably lead to further overexploitation of resources and increase the pressure to convert further land for agriculture. What is much less clear is how the shifts in the climatic components of global change such as temperature, rainfall and greenhouse gases (carbon dioxide, methane, ozone and nitrous oxide) will interact with agricultural production. Global warming is predicted to pose significant threats to agricultural production and trade (UNCTAD, 2010) and to the ability of ecosystems and agroecosystems and their component species to adapt to these changes. The impacts of climate change will vary from region to region.

A report by the International Food Policy Research Institute on the impact of climate change on agriculture and the costs of adaptation (Nelson et al., 2009) draws stark conclusions: 'Crop yields will decline, production will be affected, crop and meat prices will increase, and consumption of cereals will fall, leading to reduced calorie intake and increased child malnutrition'. The report notes that:

- higher temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation;
- changes in precipitation patterns increase the likelihood of short-run crop failures and long-run production declines;
- although there will be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security.

As regards human nutrition, the report also suggests that:

- calorie availability in 2050 will not only be lower than in the no-climate-change scenario – it will actually decline relative to 2000 levels throughout the developing world;
- by 2050, the decline in calorie availability will increase child malnutrition by 20 per cent relative to a world with no climate change. Climate change will eliminate much of the improvement in child malnourishment levels that would occur with no climate change.

Modelling studies have shown that many wild species, including crop wild relatives, will be unable to track climate change and migrate successfully. The expected degradation of ecosystems is also likely to increase the vulnerability of populations to the consequences of natural disasters and climate change impacts (Munang et al., 2011).

Food and nutrition insecurity and climate change, the two major global challenges facing humanity, are inextricably linked. For this reason, the Committee on World Food Security (CFS) has requested its High Level Panel of Experts on Food Security and Nutrition (HLPE) to conduct a study on climate change to 'review existing assessments and initiatives on the effects of climate change on food security and nutrition, with a focus on the most affected and vulnerable regions and populations and the interface between climate change and agricultural productivity, including the challenges and opportunities of adaptation and mitigation policies and actions for food security and nutrition'.

Given that an estimated 70 per cent of the world population (nearly 4.7 billion people) is fed with food produced locally, mostly by small-scale farming, fishing or herding (ETC Group, 2009), it is important to look at the impacts of climate change on traditional farming communities. As Clements et al. (2011) note, 'Strengthening the livelihoods of rural populations is intrinsically linked to poverty reduction efforts and is a key area to focus climate change adaptation strategies in the agriculture sector.'

The role of agricultural biodiversity and its interaction with human nutrition in facing up to the challenges of global change will be vital. Some of the key factors are:

- Increased diversification of crops and livestock will not only enhance nutritional possibilities but will allow farmers to have a greater number of options to face the uncertain weather conditions associated with the increased climate variability (Lotze-Campen, 2011).
- Underdeveloped species are another source of potentially valuable food resources that can be developed for use in a wider range of farming systems and as a source of biofuels.
- The major crops contain many thousands of cultivars with wide variation in their capacity to adapt to a range of climatic conditions.

- Breeders and agronomists will have to make considerable efforts to identify and develop cultivars that will help provide the productivity increases needed for food production.
- In addition, the changing climates will require a massive effort in breeding cultivars that show better adaptation to the new eco-climatic conditions (including drought) that are predicted and crop wild relatives will be an important source of the genetic variation needed (see discussion in Hunter and Heywood, 2011, chapter 14).
- Extension workers will have to assist farmers to evaluate these new cultivars and facilitate their supply and cultivation.
- Major efforts will be needed to assess the adaptive capacity of local crops and wild species that play a significant role in human nutrition to changing climates.
- The support of international and regional aid and development agencies and national governments will be needed to support the efforts of local communities in developing adaptation strategies that help them strengthen their capacity to improve their agronomic and land-management skills, and to diversify their livelihoods through maintaining diversified cropping systems and increasing the productivity of local crops.
- A considerable investment in both *ex situ* and *in situ* conservation of crop wild relatives will be needed.

Conclusions

This chapter has shown the manifold ways in which agricultural biodiversity contributes to food, nutrition and health. While recognizing the enormous human benefits that agricultural intensification has provided, it highlights how traditional food systems that are characterized by rich agricultural biodiversity play an important role in the nutrition of hundreds of millions of people across the world and continue to provide options and resilience for building sustainable livelihoods (Johns and Sthapit, 2004). Local communities seldom depend on local crops and wild biodiversity alone except in extreme famine conditions but depend on a mix of one or more staples, local crops and semi-domesticates and a range of wild species of plants, and animals that add variety to the diet as well as providing micronutrients. Local biodiversity should be recognized as a significant contribution to a sustainable agriculture–food–nutrition strategy alongside improvements in agricultural productivity and agronomic practice, nutritional enhancement of crops, industrial fortification, vitamin supplementation and other nutrition–agriculture interventions.

There is abundant evidence that edible plant and animal diversity contributes substantially to human diets in terms of energy intake and also helps alleviate problems of malnutrition in developing countries through the supply of vitamins and micronutrients. There is also ample evidence that increased production of fruit, vegetables, eggs, poultry and other animal foods in traditional agricultural systems and in particular home/homestead gardens not only raises access to energy, protein and fat but also greatly improves the quality and micronutrient content of diets.

However, there is still a lack of knowledge about the species that are involved. Much of the evidence on their nutritional or health benefits of particular species is partial or anecdotal and there is a need for more critical and well-designed scientific reviews and analyses. Much more attention needs to be given to investigating the composition and nutrient contributions of local foods and the plant and animal resources that have in the past provided many of the nutrients and micronutrients in traditional diets and that are now increasingly deficient in today's diets. Likewise much more work is needed to assess the nutritional diversity of crop cultivars.

Assessments are also urgently needed of the impacts and effectiveness of biofortification, industrial fortification and vitamin supplementation on the lives of the local communities to which they have been applied and also of the contribution that local foods such a leafy green vegetables make so as to help situate such approaches within the larger context of sustainable food-based approaches. An integrated approach, involving the biological, social and environmental dimensions, is needed to address the issues of micronutrition deficiency and the underlying causes, and the role of agricultural biodiversity and community participatory approaches that identify local food resources with nutritional, agronomic and economic advantages to small-scale farmers (Johns and Eyzaguirre, 2007).

Agricultural biodiversity will be an important resource in assuring the availability of adequate nutrition in response to the challenges of global change, such as massive population growth and adapting to changing climatic conditions (temperature, nubosity, rainfall). The genetic diversity present in wild species, especially crop wild relatives, and in the cultivars of both staple and local or underutilized crops will be invaluable in developing new adapted cultivars for the future. As Guarino and Lobell (2011) put it succinctly 'Feeding a growing population in a hotter world will require exploiting a far broader range of crop diversity than now – and that means valuing wild genes'.

Notes

1 Both the transition to agriculture and the domestication process were in fact highly complex (Gepts, 2004; Price and Bar-Yosef, 2011).
2 Lustig et al. (2012) point out that obesity is not the cause of the metabolic syndrome but rather a marker for metabolic dysfunction.
3 See also the website of Ecoagriculture Partners: http://www.ecoagriculture.org/, accessed August 2012.
4 The ETC Group (2009) estimate that at least 70% of the world's population is fed by local people: 12.5% from hunting/gathering; 7.5% share urban food produced by city-dwellers; 50% share world's cultivated food produced by local farmers.

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