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COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

BIODIVERSITY FOR FOOD AND AGRICULTURE AND FOOD SECURITY
An exploration of interrelationships

by

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This document has been prepared at the request of the Secretariat of the FAO Commission on Genetic Resources for Food and Agriculture with a view to facilitate consideration by the Commission of the role of genetic resources for food and agriculture for food security and nutrition, at its Seventeenth Regular Session.

The content of this document is entirely the responsibility of the authors, and does not necessarily represent the views of the FAO or its Members.

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I. INTRODUCTION

The World Food Summit of 1996 defined food security as the condition that exists "when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". Food security is at the core of Sustainable Development Goal *2*: End hunger, achieve food security and improved nutrition and promote sustainable agriculture.

The Commission on Genetic Resources for Food and Agriculture (Commission), at its Sixteenth Regular Session, acknowledged the key role biodiversity for food and agriculture plays for achieving the 2030 Agenda for Sustainable Development and the Sustainable Development Goals (SDGs). The Commission's work contributes to several SDG Targets, particularly under SDGs 2,[1] 14[2] and 15,[3] and to the Aichi Biodiversity Targets that underpin some of them. Of particular relevance for the Commission is the work done in support of the SDG indicators of Target 2.5 that directly address the genetic diversity of populations of plant and animal genetic resources.[4]

The Commission, at its Sixteenth Regular Session, requested FAO to prepare a study addressing the contribution of genetic resources for food and agriculture to the four pillars of food security and to the achievement of relevant SDGs, and to reflect the outcomes of the study in the revised report on *The State of the World's Biodiversity for Food and Agriculture*.[5] In the report, biodiversity for food and agriculture (BFA) was defined as the subset of biodiversity that contributes in one way or another to agriculture and food production, more specifically "the variety and variability of animals, plants and micro-organisms at the genetic, species and ecosystem levels that sustain the ecosystem structures, functions and processes in and around production systems, and that provide food and nonfood agricultural products". Agriculture includes crop and livestock production, forestry, fisheries and aquaculture.[6] *The State of the World's Biodiversity for Food and Agriculture* report (FAO, 2019) describes the close linkages between genetic resources for food and agriculture and the ecosystem services required for their use provided by the associated biodiversity within and around production systems, and highlights the important contributions of wild foods to food security. Some of these aspects are therefore briefly reflected in this paper.

The paper explores different ways in which BFA contributes to achieving the four dimensions of food security – availability, access, utilization and stability. It analyses global data, identifies data gaps and uses literature references where data are not available.

There are different dimensions and stages of a food system in which these relationships need to be examined. These may be classified as:

i. Diversity at the genetic level in crop, forest, livestock and aquatic resources.

ii. Diversity at the species and subspecies levels in crop, forests, livestock and aquatic production systems.

iii. Diversity of microbes and invertebrates, supporting and regulating ecosystem services.

iv. Diversity at different stages of the food system.

[1] Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
[2] Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development.
[3] Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.
[4] Target 2.5. By 2020 maintain genetic diversity of seeds, cultivated plants, farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at national, regional and international levels, and ensure access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge as internationally agreed.
[5] CGRFA-16/17/Report Rev.1, paragraphs 19 and 21.
[6] for detailed explanation of the concepts of BFA, see CGRFA-17/19/7.2, Annex 1

II. APPROACH, MATERIAL AND METHODS

This study puts together statistical evidence from FAOSTAT as well as evidence provided in a large number of national and cross-national studies to explore the relationship between BFA and food security. Detailed baseline assessments of the status of BFA have been carried out at national and global levels by the Commission on Genetic Resources for Food and Agriculture (CGRFA). These include national reports for the forthcoming reports on *The State of the World's Biodiversity for Food and Agriculture* and *The State of the World's Aquatic Genetic Resources for Food and Agriculture* as well as past reports on *The second report on The State of the World's Animal Genetic Resources for Food and Agriculture, The second report on The State of the World's Plant Genetic Resources for Food and Agriculture* and *The State of the World's Forest Genetic Resources.*[6] Using this body of knowledge as the starting point, this study has attempted to further explore the relationships between BFA and food security. Although some of these relationships have been discussed in the existing reports, the attempt here is to bring them together into an overall framework through which the importance of BFA for food security can be studied.

In the assessment of trends in diversity of food supply, we use Food Balance Sheet (FBS) and production (crop and livestock) data from FAOSTAT. FBS provide data on food supply (in terms of weight, and in terms of calorie and protein content). However, FBS data do not use a strictly species-specific categorization of commodities. In the case of crops, a predominant share of production/food supply is covered under categories that comprise a single, or a few, related species. However, for some commodities, such as vegetables and fruit, a large number of different species are combined into a single commodity group. Also, in the case of food produced from terrestrial animals, FAOSTAT uses 12, very broad, categories like bovine meat, mutton and goat meat, poultry meat and milk. In the case of aquatic products, 12 even more broad categories (for example, freshwater fish, demersal fish, pelagic fish, other marine fish and crustaceans) are used.

FAOSTAT data on production of crops provide a more detailed species-specific classification than the FBS. In the case of crops, production data are provided for 168 different commodities. In comparison, FBS provide data for 72 plant-based commodities. Data on production of crops provide information on quantity of production, yield and area harvested. Since production quantities of different crops cannot be compared, we use data on area harvested to analyse the trends in diversity of crop production.

Similarly, FAOSTAT data on livestock production provide a more detailed species-level classification of livestock products, including data on the production of 15 different types of meats, than the FBS. We use data on quantity of production of different types of meats to look at trends in diversification of livestock production.

Species-level data on capture (2010 species) and aquaculture (598 species) production of fish are available from FishStatJ. These data are used to examine trends in diversification of fish production.

In addition to these detailed data on production of crops and livestock available from FAOSTAT and data on fish production available from FishStatJ, data on agricultural production (of all agricultural commodities including crops, livestock and aquatic products) are also available from the FBS. As explained already, the FBS use a less detailed disaggregation of commodities. However, since FBS provide conversion factors to calories and protein for each commodity/commodity group, these can also be used to convert agricultural production into calories and protein, and thus look at the trends in aggregate production in terms of its calorific value or protein content. In this paper, depending on the need, we have used the FBS data on supply and the FBS data on production, as well as more detailed crop, livestock and fish production data from FAOSTAT/FishStatJ.

[6] http://www.fao.org/cgrfa/assessments/global-assessments/sow/en/

For the analysis of diversity of food availability, the paper primarily uses the Simpson Index (also called Herfindahl Hirschman Index) of concentration. The index, which is an inverse measure of diversification, is defined as:

$$\lambda = \sum_{i=1}^{R} p_i^2$$

where p_i is the share of an item in total production/food supply and R is the total number of items. As already discussed, the level of disaggregation and number of food items vary across different datasets.

The Simpson (Herfindahl Hirschman) Index is a simple and widely used measure of concentration that uses information from the entire distribution (across items of food production/supply in the present context). It better captures concentration than measures such as number of items (which ignores their share) or concentration ratios (share of top n items in total production, which ignores the distribution within the top items as well as shares of all the remaining items).

The major focus of this study is on identifying different ways in which BFA plays a part in achieving food security and nutritional outcomes. The study also puts together the evidence available in a large body of existing studies to throw light on different dimensions of this relationship. Submissions by Commission Members to Circular State Letter C/CBD-7 of 22 May 2017 were also taken into account.[7]

[7] CGRFA-17/19/2/Inf.1 *Submissions by Members on the contribution of genetic resources for food and agriculture to the four pillars of food security and to the achievement of relevant Sustainable Development Goals*.

III. BIODIVERSITY FOR FOOD AND AGRICULTURE AND AVAILABILITY OF FOOD

Food availability: The availability of sufficient quantities of food of appropriate quality, supplied through domestic production or imports (including food aid).[8]

There have been dramatic increases in global agricultural production and food availability over the last five decades. As per the FBS data from FAOSTAT, total supply (including crops, livestock and aquatic products) in 2013 was about 3.5 times the supply in 1961 in terms of energy and protein content. In terms of per capita dietary energy, food availability increased from 2 196 kcals/capita/day in 1961 to 2 884 kcals/capita/day in 2013. Protein availability in food supply increased from 61 grams/capita/day in 1961 to 81 grams/capita/day in 2013.

The increase in global agricultural production has also been associated with a change in the shares of different groups of food commodities. Between 1961 and 2013, the share of cereals and sugars in total dietary energy supply fell from 70 percent to about 64 percent; their share in protein supply fell from about 56 percent to about 48 percent. Over the same period, the share of leguminous crops increased from 5.5 percent to 8.8 percent of total energy production and 14 percent to 24 percent of protein production. The share of livestock and other terrestrial animals in total production fell from 10.6 percent to 9 percent in terms of energy and 18.5 percent to 17 percent in terms of protein. The share of aquatic products remained almost constant at 0.8 percent of energy and 3.7 percent of protein production.

In this section, we explore the relationship between increases in food availability and BFA. Food availability and BFA have a two-way relationship. The process through which increases in food availability (in particular, increases in food production) are obtained has a bearing on biodiversity. At the same time, BFA also influences changes in food availability in many different ways. In this section, we explore both these relationships.

3.1 How does biodiversity for food and agriculture contribute to increasing food availability?

There are many different ways in which existing diversity among plants and animals contributes to improving food availability. We have classified these into two categories:

1. Provisioning services: These include different ways in which BFA directly contributes to increased food production and supply.
2. Regulating and supporting services: These include various ecosystem services provided by BFA to support the food systems.

3.1.1 Provisioning services

Use, conservation and breeding of BFA for improving food availability

Genetic diversity provides the raw material for breeding new varieties and hybrids. Farmers and livestock keepers have been actively breeding plant varieties and animal breeds for thousands of years and often hold valuable knowledge about the diversity of landraces and traditional breeds of animals (Bellon and Brush, 1994; Brush, 1991, 1995; Brush and Perales, 2007; Louette, Charrier and Berthaud, 1997).

Modern breeding has played a key role in growth of agricultural yields over the last six decades (Evenson and Gollin, 2003a). Countries that have invested in modern breeding programmes have been able to develop varieties, hybrids and breeds with much higher yields, thus contributing to global and national increases in availability of food. At the global level, the Consultative Group on International Agricultural Research (CGIAR) network has played a crucial role by providing the institutional framework for global partnerships and knowledge sharing that have benefited many countries across the world. There is a large body of literature that demonstrates the impact of modern breeding on agricultural yields. While a comprehensive review of this literature is

[8] FAO (2006).

beyond the scope of the present study, a presentation of some illustrative trends could help put the importance of breeding in perspective.

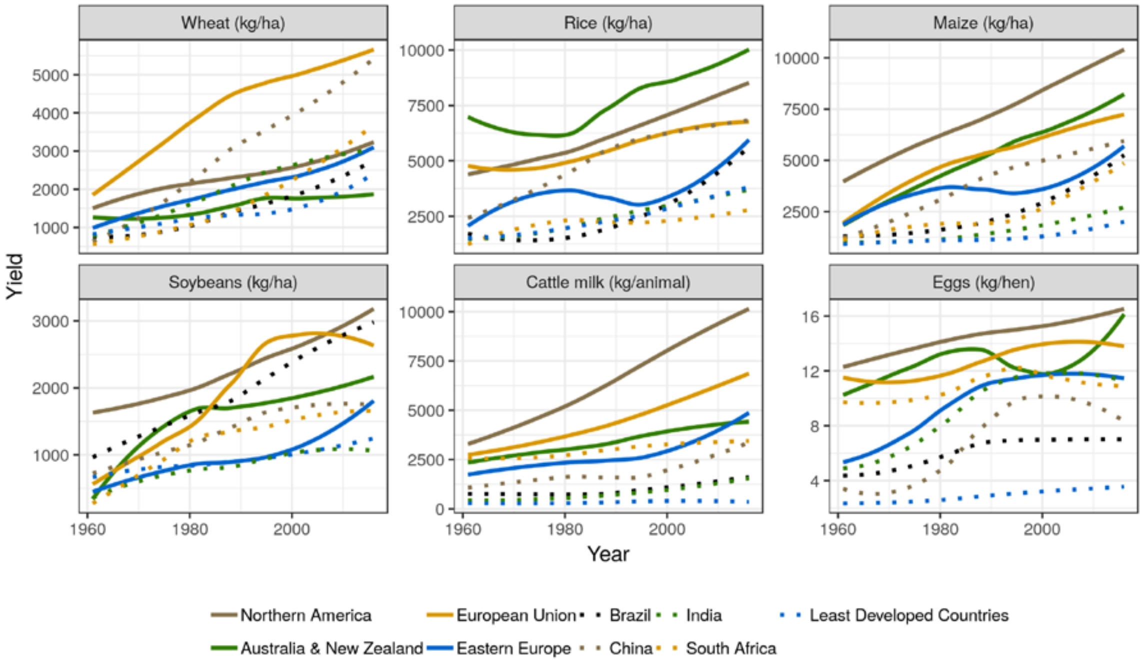
Figure 1 shows trends in yields of wheat, paddy rice, maize, soybean, milk and eggs in advanced economies that have very successful breeding programmes (North America, Australia, New Zealand and the European Union), BRICS countries[9] that have successful breeding programmes for selected crops and livestock species, and least developed countries (LDCs), most of which have had weak national breeding programmes. While levels and growth of yields are related to many factors, the contribution of breeding is key for explaining stark differences in the extent of yield growth achieved in these groups of countries.

This success of modern breeding in raising agricultural yields is founded on genetic diversity. While farmers continue to have a prominent role in development and conservation of genetic resources for food and agriculture, formal specialized breeding has emerged as the key instrument for productivity increase since the early twentieth century. Over this period, heterosis, or the property of hybrids produced by cross-breeding of genetically dissimilar parents to perform better than the parents, and other benefits of genetic diversity, were systematically deployed to obtain a considerable improvement in yield potential of crops and livestock. There is an increasing recognition of the possibilities of participatory crop improvement efforts that combine traditional knowledge of farmers and livestock keepers with modern scientific practices (Almekinders and Elings, 2001; Brush, 1991; Ceccarelli, Guimarães and Weltzien, 2009; Witcombe *et al.*, 1996). The development of modern genetics has further accelerated the use of diversity for development of new varieties and hybrids (Hoisington *et al.*, 1999). It has been estimated that at least half of the yield increases in crop production since the mid-twentieth century have come about on account of modern breeding (Duvick, 1986; Fehr, ed., 1984; NRC, 1993).

In the livestock sector, genetic improvement is estimated to have contributed between 50 percent (Shook, 2006) and 80 percent (Havenstein, Ferket and Qureshi, 2003) to overall productivity increase. Productivity (output per animal) is much higher in countries with commercial breeding programmes than in the rest of the world. Breeds of cattle, sheep, goats, pigs and poultry developed in intensive production systems have higher yields of the primary products based on the use of high levels of external inputs. Although their higher yields are contingent on the use of high levels of inputs as well as climatic conditions in their native habitats, a few of these breeds have spread globally and, in some cases, a very small number of international transboundary breeds account for an ever-increasing share of total production (FAO, 2015a). The control of a few global corporations in the supply of genetic material for breeding of poultry, pig and dairy animals has also contributed to the spread of these breeds (Hoffmann, 2011).

[9] Brazil, Russian Federation, India, China and South Africa.

Figure 1. Trends in yields of selected crops and animal products, selected countries, 1961 to 2013



Source: Based on production data from FAOSTAT.

Contribution of wild foods to food supply

Wild foods – or foods obtained from non-domesticated species including plants, bacteria, animals and fungi – are a direct and obvious contribution of BFA to availability of food (Rao and McGowan, 2002). A large number of naturally growing plants and animals are a source of food (Penafiel *et al*., 2011). Bharucha and Pretty (2010) estimated that, in Asian and African countries, 300–800 species per country are used as wild foods. Boa (2004) identified 1 069 types of wild fungi that are used as foods in different countries. The 2017 edition of a global database of edible insects maintained by Y. Jongema at Wageningen University lists 2111 species of edible insects.[7] It has been estimated that about two thirds of weed species are edible (Cruz-Garcia and Price, 2012; Díaz-Betancourt *et al.*, 1999; Duke 2000; Maroyi, 2013; Scoones, Melnyk and Pretty, 1992). More information on wild foods is available in FAO (2019).

Statistics on consumption of wild foods are patchy and limited as a large part of collection of wild foods is informal and for home consumption (Schulp, Thuiller and Verburg, 2014). Despite this limitation, some attempts have been made to quantify the importance of naturally occurring plants and animals in diets of different communities across the globe. These data suggest that, at the global level, the share of food gathered/captured from natural habitats of plants and animals in total supply of food is low and has been on the decline.

FAO (2014a) estimated that, globally, only about 0.6 percent of dietary energy supply came from food obtained from forests. Of this, about 0.5 percent was sourced from plant foods gathered from forests while the rest was sourced from wild animals (Table 1). In addition, estimates based on FBS data suggest that about 0.68 percent of dietary energy supply comes from captured aquatic plants and animals.[8] It must be pointed out that the contribution of captured food to overall dietary energy intake is likely to be under-reported as most national statistics do not

[7]https://www.wur.nl/en/Research-Results/Chair-groups/Plant-Sciences/Laboratory-of-Entomology/Edible-insects/Worldwide-species-list.htm

[8]Authors' estimate based on FAOSTAT data for 2013.

adequately capture quantity of acquisition of such food (Bartley *et al.*, 2015; Clayton, ed., 2002; Coates, 2002; Van Huis *et al*., 2013).

Table 1. Contribution of non-wood forest produce (NWFP) to food energy supply (percent)

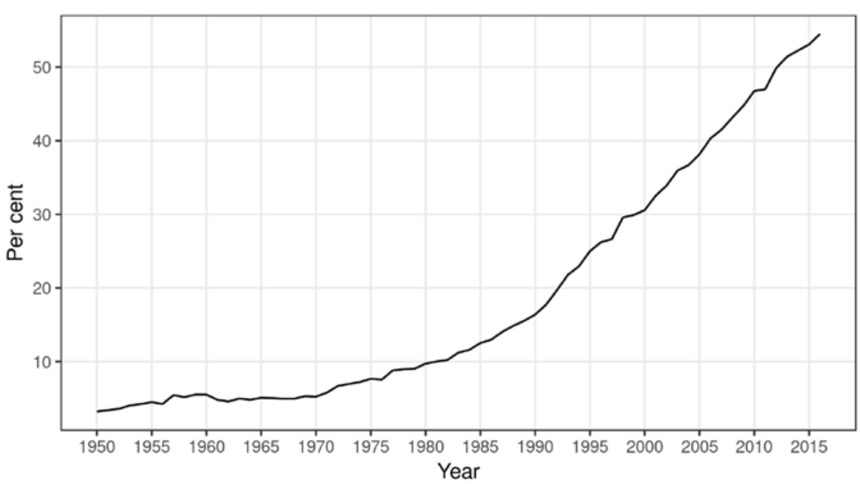
	Animal-based NTFP	Plant-based NWFP	Total
Africa	0.2	0.1	0.3
Asia and Oceania	0.1	0.7	0.8
Europe	0.1	0.2	0.3
North America	0.1	0.2	0.3
Latin America and Caribbean	0.1	0.4	0.5
World	0.1	0.5	0.6

Source: Based on FAO (2014a).

Of all the food commodities, data on production of aquatic species distinguish between quantity produced on aquaculture farms and quantity captured from freshwater and marine habitats. Although the steady growth of aquaculture production over the last four decades has resulted in a relative decline in the share of captured aquatic plants and animals in total supply, captured aquatic animals and plants still accounted for a substantial (about 45 percent) share of the global supply in 2016 (Figure 2).

While capture fisheries remain extremely important for food supply, there is a continued need to improve the regulation and prevent unsustainable fishing practices. It has been estimated that, between 2000 and 2003, about 18 percent of global fish catch originated in illegal, unreported and unregulated (IUU) fishing (Agnew *et al.,* 2009). SDG Target 14.4 calls for ending “overfishing, illegal, unreported and unregulated (IUU) fishing and destructive fishing practices”. In June 2016, the Agreement on Port State Measures, a binding international agreement to target illegal, unreported and unregulated (IUU) fishing, came into force. FAO’s Voluntary Guidelines for Flag State Performance are another important instrument for guiding countries to bring about a reduction in IUU (FAO 2016a; 2018).

Figure 2. Share of aquaculture in global supply of all aquatic species, 1950 to 2016

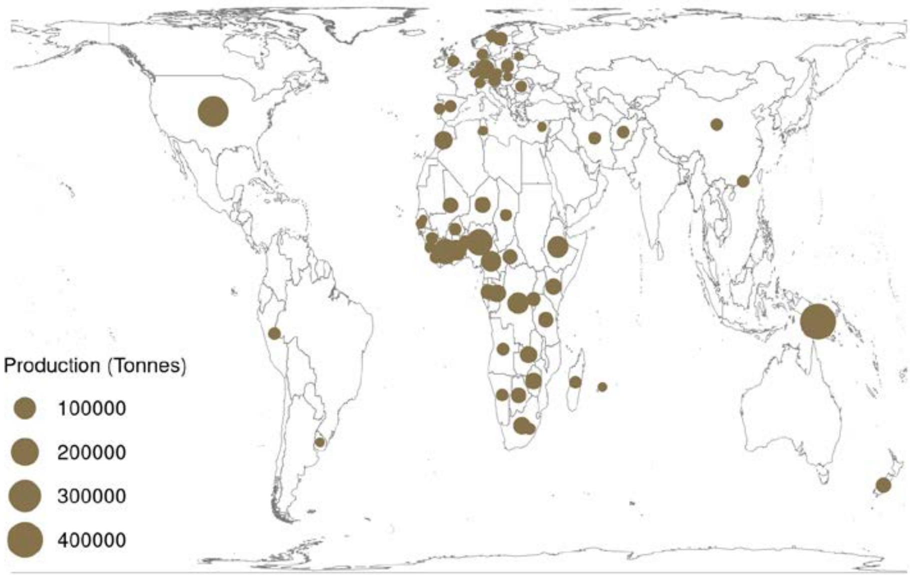


Source: Based on data from Fishery and Aquaculture Statistics, FAO

The meat of wild species has long served as a source of protein and as a source of income for millions of people throughout the world. As many as 2 000 species of invertebrates, amphibians, insects, fish, reptiles, birds and mammals are used as wild meat across the world (Redmond *et al.*, 2006).

Game meat (or bushmeat) refers to the meat and offal of wild animals obtained for human consumption through hunting.[9] Most countries do not have national-level estimates of the supply of game/bushmeat. As a result, global databases on food supply significantly underestimate the contribution of game/bushmeat.[10] Subject to availability of data, estimates of game/bushmeat include meat from the wild as well as from ranching, and cover both legal and unregulated hunting. In FAOSTAT, data on production of game meat are reported in recent years for only about 60 countries (Figure 3). These exclude even countries such as Australia, Canada and the Russian Federation, where a considerable amount of game/bushmeat is sold through formal and legal channels, as well as countries such as Brazil and Colombia, where a considerable amount of game meat is known to be consumed. According to FAOSTAT data, the global production of game meat has been rising over the years and was about 2 million tonnes in 2016 (Figure 4). This was about 0.6 percent of total meat production. Regional distribution of game meat production shows that the production is concentrated in sub-Saharan Africa and Europe. The UNECE region produced around 400 000 tonnes of game meat in 2013, valued at around USD 850 million (at 2004–2006 constant prices). At the country level, FAOSTAT records Papua New Guinea, the United States of America and Nigeria to have the highest production of game meat (Figure 3). In *State of Europe's Forests* 2015, among the reporting countries, Germany (EUR 195 million), Spain (EUR 73 million) and Austria (EUR 15 million) were by far the highest producers of game meat in terms of value (Table 1) (Forest Europe, 2015; UNECE, 2018).

Figure 3. Production of game meat in different countries, 2016



Source: Based on FAOSTAT data (livestock primary, meat, game; meat and offal of wild animals, whether fresh, chilled or frozen).

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9 Although game meat may be defined more generally to include animals that roam in farms and are hunted, major databases on supply of game meat exclude these. In FAOSTAT, game meat refers to "meat and offal of wild animals, whether fresh, chilled or frozen". UNECE defines game meat as "all meat from animals hunted or trapped for meat that is available for consumption; meat from game that roams in farms (a farm has an enclosed space) is excluded" (UNECE, 2018).

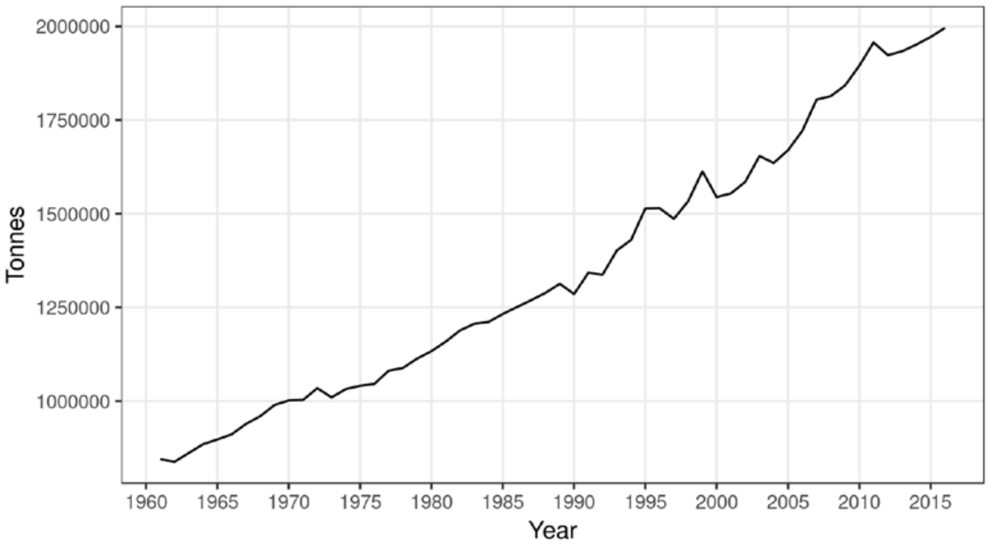
10 See Ziegler (2010) for a detailed evaluation of FAOSTAT data on game meat supply and consumption.

Estimates of supply of game/bushmeat in one-time studies carried out at different locations (and at different points of time) also suggest that the aggregate supply of bushmeat may be considerably higher than what is currently captured in FAOSTAT.

Coad *et al.* (2018) and Jamnadass *et al.* (2015) provide a review of evidence from a number of such location-specific studies on the extent of dependence on bushmeat. For example, annual supply of bushmeat in the Congo Basin has been estimated to be between 1.2 million tonnes (Wilkie and Carpenter, 1999) and 2.2 million tonnes (Fa, Currie and Meeuwig, 2003). In a study of selected urban localities on the fringes of the Amazon in Peru, Colombia and Brazil, Van Vliet *et al.* (2014) found that 3.4 kg of bushmeat per inhabitant was supplied annually to these localities through various channels of trade. Koppert *et al.* (1993) estimated that bushmeat provides 30–80 percent of protein intake in forest-dependent communities of Cameroon. Nasi, Taber and Van Vliet (2011) estimated that a total of 150 000 tonnes of bushmeat are consumed in the Amazon annually. Bennett (2002) estimated that 23 500 tonnes of bushmeat are consumed annually in the Malaysian State of Sarawak.

Bushmeat is consumed in cities and large towns less for its nutritional importance and more as a luxury item and status symbol (Drury, 2011; Ngoc and Wyatt, 2013; Shairp *et al.*, 2016; Wilkie *et al.*, 2016). Urban consumption of bushmeat is reported to be growing among the emerging urban middle class in Asian cities, as its consumption demonstrates a high social status (Nijman 2010; Ngoc and Wyatt 2013; Shairp *et al*., 2016), and, as for Africa, urban wealth is now thought to be a greater driver of hunting in Southeast Asia than rural poverty (TRAFFIC, 2008).

Figure 4. Trend of production of game meat, 1961–2016



Source: Based on FAOSTAT data (livestock primary, meat, game; meat and offal of wild animals, whether fresh, chilled or frozen).

Provision of feed for animal production

Pastures, crops, crop residues and wild plants are all used as feed for livestock and aquaculture production. For people living in (or close to) forests, pastures and grasslands, grasses and wild plants can be an important source of fodder and forage for domesticated animals. It has been estimated that 46 percent of the feed requirements of livestock globally is met by grasses and leaves (Mottet *et al.*, 2017).

In smallholder mixed crop–livestock farms in developing countries, crop residues are the main source of animal feed. In developed countries, feed-grade cereals and legumes are a major component of livestock feed. According to FAOSTAT data, in 2013, about 36 percent of supply of cereals, 7 percent of oil crops (including soybeans), 18 percent of pulses, 22 percent of starchy roots, 14.3 percent of captured seafood and 5.4 percent of offal were used as animal feed (Table

2). It must be noted that these numbers significantly understate the use of plant resources for animal feed since these do not include crop residues that constitute the main source of fodder supply in many developing countries with dominance of smallholder mixed-farming (see Section 3.2.1).

Wild plants can also act as hosts for apiculture bees. Marine fish and other organisms captured from the seas are an important component of feed for aquaculture production. As per FAOSTAT data, about 13 percent of the total supply of aquatic products is used as feed.

Table 2. Share of global plant and animal food supply used as animal feed, 2013 (percent of weight)

Category	Share of global feed supply
Cereals	36.3
Pulses	18.3
Starchy roots	21.5
Oil crops	7.0
Other plant-based products	2.1
Offals	5.7
Fish, seafood	13.9
Other animal products	7.1
All food products	13.2

Source: Based on FAOSTAT.

3.1.2 Regulating and supporting services

Apart from being a direct source of food, forests, oceans, grasslands and other natural habitats of plants and animals also contribute to enhancing food availability in several indirect ways. Here we present two examples, related to soil fertility and forests, and to ecosystems provided by insects. More information is available in FAO (2014b, 2019).

Soil formation and restoration

Land degradation has emerged as a major constraint to the growth of agricultural production and food supply. It has been estimated that about one-third of land is moderately to highly degraded (FAO and ITPS, 2015).[14] Given the lack of adequate data, an estimation of the relationship between land degradation and productivity loss is difficult and contingent on many assumptions. A few attempts that have tried to quantify the impact of soil erosion on productivity suggest that soil erosion results in an annual yield loss of about 0.3–0.4 percent (FAO and ITPS, 2015).

Forests play an important role in soil formation, restoration and prevention of erosion. Agricultural land for swidden cultivation is restored by forest fallows (Sunderlin *et al.*, 2005). Even in the context of sedentary agriculture, forests play an important role by preventing flooding and erosion. The contribution of earthworms and many other subsoil organisms to soil formation and improvement is widely known (Pimentel *et al.*, 1995, 1997; FAO and ITPS, 2015).

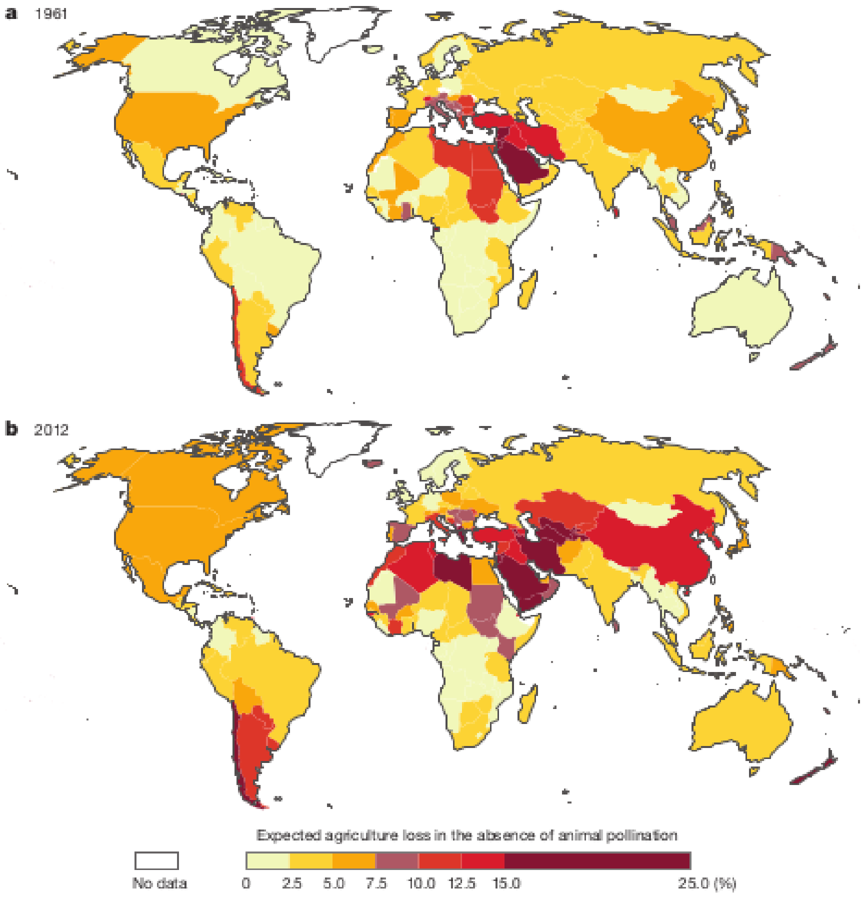
[14] See FAO and ITPS (2015) for a detailed assessment of different forms of land degradation including soil erosion, soil contamination, soil acidification, soil salinization and sodification, depletion of soil biodiversity, soil sealing, depletion of nutrients, and soil compaction and decline in soil humidity.

Livestock dung and droppings are the most important constituent of organic manures in most countries. Green manures and leguminous crops contribute to enrichment of soils while cover crops help prevent soil erosion.

Ecosystem services provided by insects and other animals

Insects, worms, birds and other animals provide various ecosystem services that are important for crop production. For example, insects are the main pollinators for fruits, vegetables, nuts, oilseeds and hay crops (Free, 1993; IPBES, 2016; McGregor, 1976; Pimentel *et al.*, 1997). Aizen and Harder (2009) estimated that the production of pollinator-dependent crops increased by 300 percent between 1961 and 2007 while the production of crops not dependent on animal pollination increased by less than 100 percent over the same period. The share of animal-pollination-dependent crops in total area cultivated and total agricultural output has increased considerably since the 1960s (Aizen *et al.*, 2008, 2009; IPBES, 2016; Losey and Vaughan, 2006; Potts *et al.,* 2016). Potts *et al.* (2016) estimated that about 30 percent of the increase in agricultural output between 1961 and 2012 had been on account of insect pollinated crops (Figure 5). In the case of insect-pollinated crops, a low population of bees can result in reduced and delayed yields as well as poor quality of fruits. On the basis of a detailed review of existing evidence, IPBES (2016) identify a number of factors including land-use changes, urbanization, agricultural intensification and increased use of pesticides that have caused a reduction in population of crop pollinators.[11] They also identify a number of indirect factors such as population growth, increased wealth, globalized trade and technological developments that indirectly affect pollinator population adversely.

Figure 5. Expected production loss in the absence of animal pollination



Source: Potts *et al.* (2016).

[11] Also see Richards (2001).

Beneficial insects are also known to play an important role in reducing crop losses by controlling the population of pests (see Section 6.2). Pimentel *et al.* (1997) estimated that, globally, the value of averted losses to pests on account of natural enemies was about USD 100 billion per year. Losey and Vaughan (2006) estimated that, in the United States of America, the value of averted losses on account of pest control by beneficial insects was about USD 4.5 billion. Losey and Vaughan (2006) also discuss the role of beetles in decomposition of dung, which, in turn, makes forage palatable to cattle. This makes more grazing area available to cattle, and thus translates into higher production – worth about USD 122 million in 2004 for the United States of America as per their estimates – of beef.

3.2 Have increases in global food production been associated with a decline in biodiversity for food and agriculture?

It is often argued that increases in food availability, particularly as a result of modern breeding since the twentieth century, are associated with genetic erosion (see, for example, Frankel, 1970; Harlan, 1972, 1975; NRC, 1972; Thrupp, 2000, 2004; Vellvé, 2009). In this context, it is relevant to ask if global production of food has become more or less diverse over the past decades that have seen a significant increase in global production of food.

Diversity of food production may be expected to decline if agricultural growth is primarily driven by a few items that account for a dominant share of food production, and through increasing reliance on a few cultivars and breeds of these species. On the other hand, if agricultural growth is on account of various crops and animals, in particular of species that do not have a dominant share in the total production, and through reliance on a wide genetic pool of cultivars and breeds, food production can be expected to become more diverse in the process of agricultural growth. In this section, we describe the trends in diversity of supply of different types of food and analyse changes in composition of supply to explain how these trends were obtained.

The empirical evidence on diversity of food production suggests that the trends are complex and do not show a secular decline in diversity. Interspecies diversity of crop and aquaculture production appears to have been on the rise in recent decades while interspecies diversity of animal-based food has declined. While there is some evidence of a continued loss of landraces, latest evidence shows that intraspecies genetic diversity has increased for some major crops. On the other hand, although efforts for conservation of animal genetic resources have gained strength, genetic erosion in major species of livestock remains a problem. Trends of prevalence of crop rotations, polyculture and mixed farming are likely to have been varied across regions and over time. Changes in farming practices for intensification of agriculture, in particular excessive tillage and use of plant protection chemicals, is found to have adversely affected populations of subsoil organisms as well as birds, bees, pests and weeds (see FAO, 2019; FAO and ITPS, 2017).

3.2.1 Production system diversity

As data are lacking on the area grown with varieties or used by breeds in most countries, we try to approach indirectly by identifying the plausible production systems in which specific varieties/breeds are grown because the share of large-scale intensive production is usually linked to “modern” genetic resources for food and agriculture (GRFA). We thus assume that the larger the share of large-scale intensive production, the less is the likelihood of use of local varieties.

For animal genetic resources, FAO (2015a) linked breed types to production systems, and concluded that locally adapted breeds are generally not used in intensive and industrial systems, as their low output of marketable products makes keeping them economically unviable, and that generally, in all fertile, favourable environments, there is a high probability of finding exotic, international transboundary breeds and their crosses.

Herrero *et al. (*2017) analysed spatial data of 41 major crops, 7 livestock, and 14 aquaculture and fish products for the relative contribution of farms of different sizes to the production of different agricultural commodities and associated nutrients. They found that globally, small and medium farms (≤50 ha) produce 51–77 percent of the majority of commodities and nutrients, albeit with large regional differences. The majority of vegetables (81 percent), roots and tubers (72 percent), pulses (67 percent), fruits (66 percent), fish and livestock products (60 percent), and cereals (56 percent) are produced in diverse landscapes. By contrast, the majority of sugar (73 percent) and oil crops (57 percent) are produced in less diverse ones. Efforts to maintain production diversity as farm sizes increase seem to be necessary to maintain the production of diverse nutrients and viable, multifunctional, sustainable landscapes.

In contrast with monocultures and monocropping, practices such as polyculture (the practice of having multiple species of trees and crops on the same land simultaneously), sequential crop rotations (the practice of growing different crops in succession) and mixed farming (the practice of combining crop production with livestock and other activities) are associated with greater diversity. It is difficult to quantitatively establish the nature of trends in respect of use of these agronomic practices but these trends are likely to be varied across different regions, countries and agro-climatic conditions. These trends are also likely to be crucially influenced by farm size and variations in the economic environment faced by farmers. For more information on BFA enhancing management practices, see FAO (2019).

While polyculture, sequential crop rotations and mixed farming are prevalent in many parts of the world, national and global statistical systems do not capture them. Most national and global statistical databases on areas sown/harvested with different crops notionally allocate the area under polyculture to individual crops, thus concealing the extent of prevalence of polyculture. Although availability of remote sensing data has opened up new possibilities of analysing crop rotations, such studies are scattered and few. Similarly, there are only few field-based studies that have documented different forms of polyculture practised in specific locations. Given these limitations, a global quantitative assessment of trends in incidence of polyculture and crop rotations in different parts of the world needs to await better availability of statistics and remote sensing-based evidence.

Countries in North America, Eastern Europe and Oceania, with large industrial-scale farms, are known to have vast areas under monoculture. Although the practice of crop rotation has been gaining prominence in some of these countries, even in such cases, only a few crop rotation cycles are prominent. For example, maize–soybean and wheat–soybean are the most important crop rotation cycles in the United States of America. Trends in the use of even these crop rotation cycles are varied across states and counties with some areas recording a decline in the practice of regular two-year crop rotation cycles (Plourde, Pijanowski and Pekin, 2013) while others have seen an increasing use of crop rotations over leaving the land fallow (Long *et al.*, 2014). Stern, Doraiswamy and Hunt (2012) show that the incidence of the maize–soybean cycle in mid-western United States of America declined when relative prices of maize increased and farmers shifted to sowing maize repeatedly. Using remote sensing data, Conrad *et al.* (2016) found evidence of increased use of crop rotation in cotton growing regions of Uzbekistan. Frolking *et al.* (2002) combined remote sensing data with data from agricultural censuses to show that 43 percent of cropped area in China was cropped under 11 different crop rotation cycles. In many developing countries such as India, with tropical agro-climatic conditions, agricultural intensification after the Green Revolution saw an increasing incidence of crop rotations in irrigated areas comprising two to three crops being grown in a year. Introduction of short-duration varieties and hybrids has also facilitated an increase in the incidence of multiple cropping in many countries over this period.

Although there is little quantitative evidence on the prevalence of polyculture, a few studies have documented various forms in which polyculture has existed in different parts of the world. While a number of studies have documented the impact of different kinds of polyculture practices on yields, disease and pest resistance, cost of production and profitability, studies on the prevalence of such practices are too sparse and inadequate to make any assessment of trends in the prevalence of polyculture. A uniquely detailed assessment of different practices of mixed cropping in India, based on reports specially commissioned by the imperial administration in the early 1940s, was carried out by Aiyer (1950). Aiyer (1950) pointed out that mixed cropping was widely prevalent in rainfed areas of India. He catalogued a vast number of combinations of crops that were cultivated together in different parts of India. These included, for example, rice (25 mixture crops), sorghum (34 mixture crops), pearl millet (20 mixture crops), finger millet (24 mixture crops), wheat (12 mixture crops), barley (14 mixture crops), maize (26 mixture crops) and cotton (22 mixture crops). Unfortunately, no such study has been carried out on this subject in India in the last seven decades. However, an assessment from micro-level field-based reports suggests that mixed-farming practices have declined in many parts of India (for example, the Indo-Gangetic belt) and pure cultivation has emerged as the dominant form of production for some of the major crops (for example, rice, wheat and sugar cane) in contemporary India. In a study in northern Nigeria, Norman (1974) found that 24 different crops were grown on rainfed land in 156 different combinations. Swinton and Dueson (1988) pointed out that 73 percent of the cropped area in Niger was under mixed cropping until the early 1980s. Maize and bean are traditionally grown as intercrops in Latin American highlands (Reeves, Thomas and Ramsay, eds, 2016).

Naturally regenerated forests are important repositories of biodiversity in which a large number of plant and animal species co-exist. Such forests are an important source of non-timber forest products (NTFPs) including wild foods. In contrast, planted forests tend to be monocultures or have a relatively low diversity of trees (FAO, 2016b; HLPE, 2017). Given this, the proportion of naturally regenerated forests can be used as an indicator of prevalence of polycultures and biodiversity in forest resources. Data from the Global Forest Resources Assessments show that there has been a decline in the proportion of naturally regenerated forests in total forest cover globally, from 85.1 percent in 1990 to 83.3 percent in 2015 (Table 3). Of various regions in the world, the proportion of naturally regenerated forests is lowest in Oceania (22 percent) and Asia (63 percent).

Table 3. Share of naturally regenerated forests in total forest cover, by regions, 1990 and 2015

Region	1990	2015
Asia	65.1	62.7
Oceania	20.9	21.8
Africa	93.7	93.1
Europe	92.8	90.9
North and Central America	95.2	93.0
South America	86.5	85.8
World	85.1	83.3

Source: Based on HLPE (2017).

The high growth of meat production over the last few decades has been achieved primarily on the basis of intensive production in large units, use of concentrated feed, increasing mechanization and increased use of pharmaceuticals (Gilbert *et al.*, 2015).[12] It has been estimated that about 63 percent of cattle population in the world is in mixed livestock production systems. Mixed livestock production systems were estimated to account for 78 percent of global beef production and 84 percent of global milk production in 2005 (Opio *et al.*, 2013). In 2005, industrial production was estimated to account for 61 percent of the total production of pigs globally, and in China, the largest producer of pigs, 74 percent of production took place in the industrial systems (MacLeod *et al.*, 2013). In general, industrial production is concentrated in high-income countries while low-income countries have predominantly extensive systems of livestock production (Gilbert *et al.*, 2015). Gilbert *et al.* (2015) note that, while over 75 percent of poultry are raised in

[12] See Figure 9.

backyard systems in Asian countries such as Bangladesh, Cambodia, India, Myanmar and Nepal, the proportion is less than 5 percent in Malaysia, Japan and the Republic of Korea. Backyard poultry production was estimated to account for only about 4 percent of total poultry production and 14 percent of total egg production (MacLeod *et al*., 2013). Recent reports suggest an increasing industrialization of livestock production systems, including rearing of large herds of cattle with limited genetic diversity in feedlots, in many countries (Gilbert *et al.*, 2015).

The evidence on the prevalence of polyculture, in particular of use of practices such as mixed cropping, is very limited. This is an important research gap and there is a great need for conducting more studies on the prevalence of different polyculture practices to understand the trends in use of these practices and the drivers of change in their prevalence.

The new indicator for SDG 2.4.1 (Proportion of agricultural area under productive and sustainable agriculture) will provide more data in future. This farm level survey approach has been proposed by FAO to the Inter-Agency and Expert Group on SDGs in 2018. The indicator is composed of 11 subindicators on the social, economic and environmental sustainability of terrestrial, farm-based agriculture, including one subindicator on the use of biodiversity-supportive practices such as production system diversity, rotations and the use of sub-species diversity[13].

3.2.2 Interspecies diversity of food production

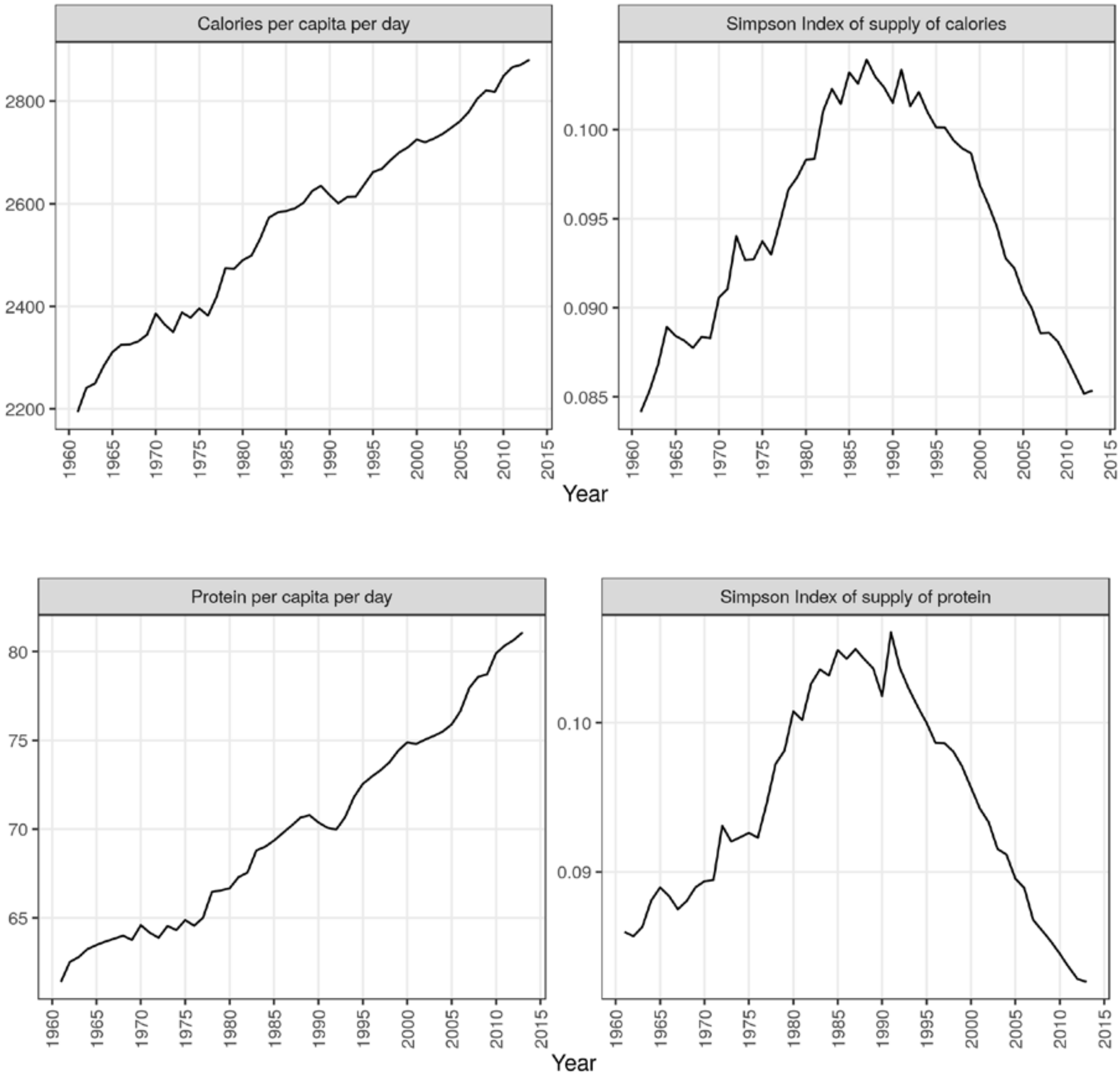
Of about 6 000 plant species that have been used for food and agriculture in human history, only about 150 species account for the diets of most people in the contemporary world. Out of over 50 000 known avian and mammalian species, less than 40 have been domesticated and only six livestock species account for 90 percent of calories derived from animal-based food (Hoffmann *et al.*, 2017).

Although we do not have subspecies level data on food production, diversity of food production across higher levels of classification is approximated in FAOSTAT and can be used for statistical analysis. As mentioned earlier, the classification of commodities in the FBS is highly aggregated. But FBS provide information on food supply in terms of calories and protein, which can be used to compute different indices of diversity and growth for food supply as a whole (including plants, animal and aquatic food). As per these data, the composition of the global supply of food became increasingly more concentrated towards fewer items of food through the 1960s and 1970s. However, this trend has changed since the 1980s, after which, in global supply of calories, one does not see a trend of increasing concentration (Figure 6). If one looks at diversity in sources of protein in the food supply, the turnaround seems to have taken place around 1990, after which the concentration in sources of protein in food supply declined considerably.

This decline in concentration of sources of calories and protein in food supply was primarily a result of increasing diversification of calories and protein sourced from plant-based products. A more detailed examination of data on food supply from the FBS shows that the trends differ considerably between supply of calories (and protein) from plant-based products and from products of terrestrial animal origin.

[13] https://unstats.un.org/sdgs/metadata/?Text=&Goal=&Target=2.4;

Figure 6. Trends in level and concentration (measured as Simpson Index) of global food supply, measured in terms of calories and protein content, 1961 to 2014



Note: 1. Food supply refers to total supply of food commodities (crops, livestock and animal products) used as food. Food supply also accounts for net changes in stocks and net imports. It does not include losses or the part used for feed, seed, processing and other purposes.

2. Annual supply in quantity terms was converted into per capita per day value using conversion factors given in the Food Balance Sheets.

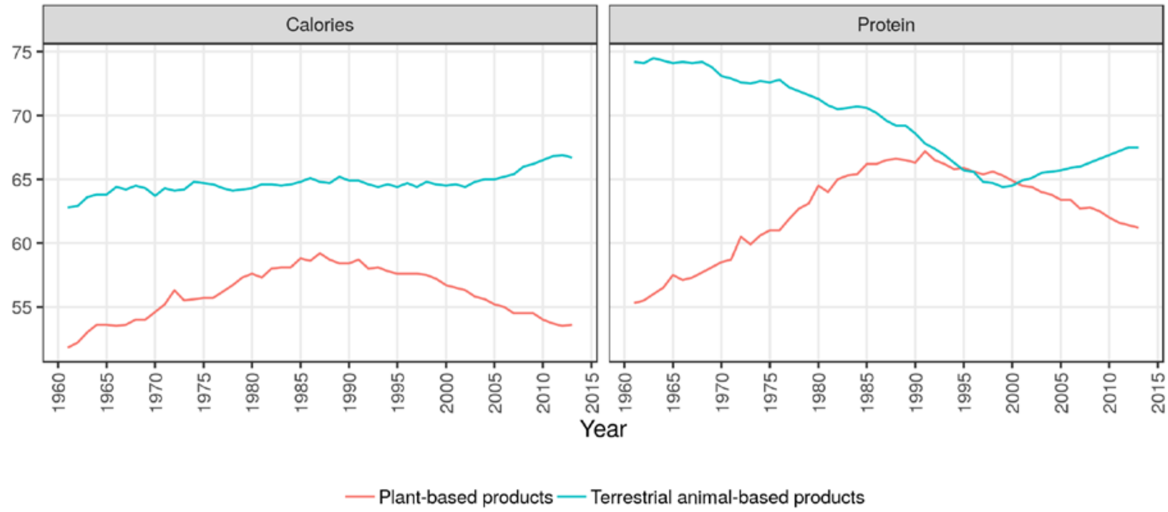
Source: Based on data from FAOSTAT Food Balance Sheets.

As shown in Figure 7, in the case of plant-based products, the share of the top three items in total supply of calories and protein declined after the mid-1980s.[14] On the other hand, in the case of products of terrestrial animal origin, the share of the top three items declined until the late 1990s but increased significantly after that.[15] The trend in supply of calories and protein from animal-based food is a result of the increasing share of poultry in the supply of animal-based food. In

[14] The top three plant-based sources of calories in food supply are wheat, rice and sugar. The top two plant-based sources of protein in food supply are wheat and rice. In different years, the third rank in terms of contribution to protein supply is occupied by pulses, maize and other vegetables.
[15] Until recently, pig milk and bovine meat were the top two animal-based sources of calories and protein in food supply. Over the years, the share of poultry meat in animal-based supply of calories and protein increased, and it replaced bovine meat in the group of top three items in the late 1990s.

future analyses, the shifts in the shares of more than the top three commodities could be investigated.

Figure 7. Share of top three crops in total per capita supply of calories and protein from crops and share of top three food commodities of terrestrial animal origin in total per capita supply of calories and protein from livestock (percent)



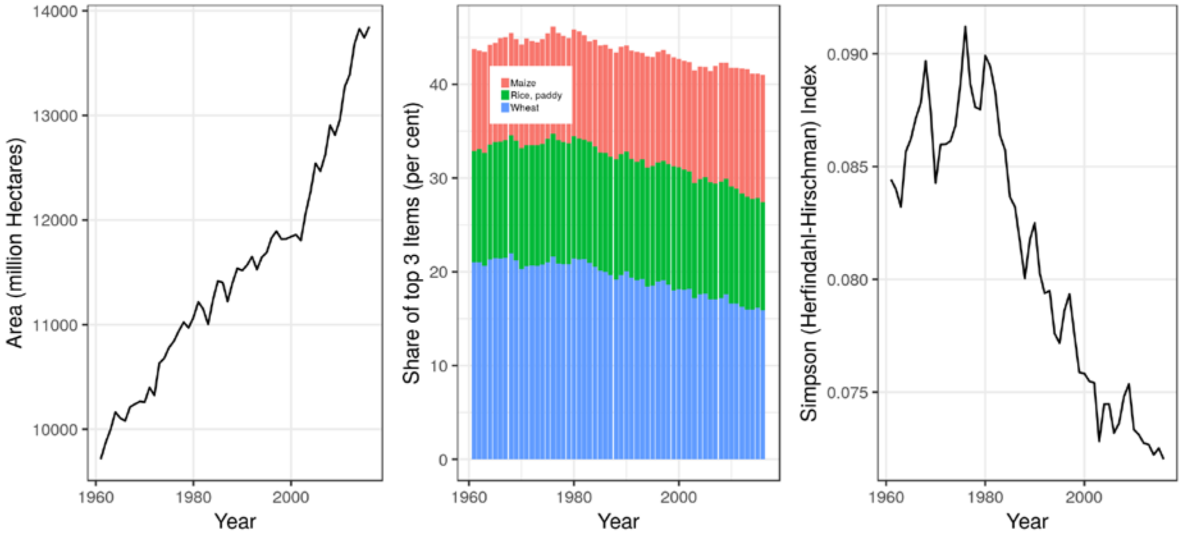
Note: Aquatic products could not be included in the figure because Food Balance Sheet data on aquatic products are too aggregated.

Source: Based on FAOSTAT Food Balance Sheets data.

Data on production of crops and livestock from FAOSTAT and on global production of different aquatic species from FishStatJ provide more detailed species-level classification. However, given that production figures (in weight) of different commodities are not comparable, one has to examine diversification separately for different commodity groups and in units that are broadly comparable. We do this by looking at data on area harvested for crops, data on quantity of meat production from different species for livestock, and data on quantity of production of aquatic products.

As shown in Figure 8, the concentration in allocation of land to different crop species declined after the 1980s. This was on account of a decline in the share of area under cultivation of major cereal crops such as wheat, maize and rice, and an increase in the share of a large number of other crops. The share of wheat, maize and rice in the total area under crop production declined from 46 percent in 1980 to 41 percent in 2016.

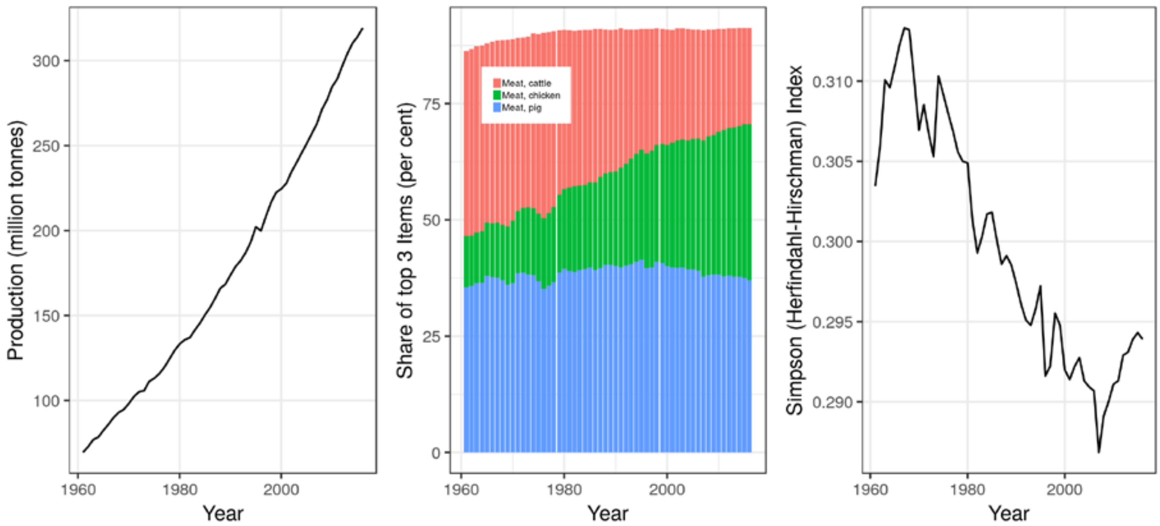
Figure 8. Trends of area harvested (million hectares) and concentration of area under different crops (measured by share of top three crops and Simpson Index), 1960 to 2014



Source: Based on crop production data from FAOSTAT.

In contrast with crop production, production of meat is considerably more concentrated among just a few species. In 1960, pork and cattle meat accounted for about 75 percent of total global meat production. Over the years, the share of chicken meat has increased considerably and the share of cattle meat in total meat production has declined. Since the late-1990s, chicken meat accounts for a greater share in total meat production than cattle meat. Although there was some decline in the concentration of meat production between the 1960s and mid-2000s because of a rise of poultry (Figure 9), these three species continue to account for the bulk of the meat production (Gilbert *et al.*, 2015).

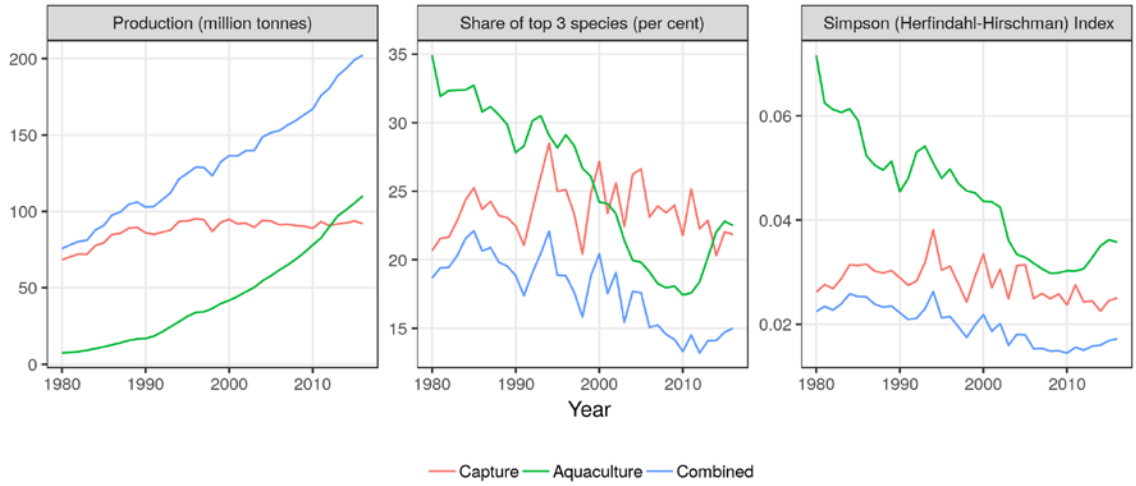
Figure 9. Trends in production (million tonnes) and concentration of production of different kinds of meat (measured by share of top three species and Simpson Index), 1960 to 2014



Source: Based on livestock production data from FAOSTAT.

Data on production of aquatic products of different species from FishStatJ show that production has become considerably more diversified since the mid-1980s. This increase in diversification has been driven by the increasing diversification of aquaculture production, while no clear trend is seen in the concentration of capture fish production (Figure 10). Over the last few decades, there has been a considerable increase in the number of different species that are farmed and in the type of production systems for aquaculture. Aquaculture production takes place in fresh, brackish and marine waters, and is based on wild as well as domesticated strains (FAO, forthcoming). The share of the top three species in aquaculture production decreased from 35 percent in 1980 to 17 percent in 2010 and then increased to 22 percent by 2016. There has been a steady increase in the number of aquatic species that are farmed; at the time of writing this paper, FishStatJ covered data on aquaculture production of 598 species. The database shows that the increase in production of Eucheuma seaweed was a major cause of reduction in interspecies concentration of aquaculture production (and also of the increase in concentration in recent years as its production overtook all other aquatic species). Other major species that have seen an expansion of aquaculture production in the last four decades include Japanese kelp, silver carp and grass carp (white amur).

Figure 10. Trends in production (million tonnes) and concentration of production of aquatic production (measured by share of top three species and Simpson Index) in aquaculture and capture fisheries, 1960 to 2016



Notes: Excludes data on whales, seals and crocodiles, since these are given in the database in numbers and not in weight.

Source: Based on data from FishStatJ (http://www.fao.org/fishery/topic/16003/en).

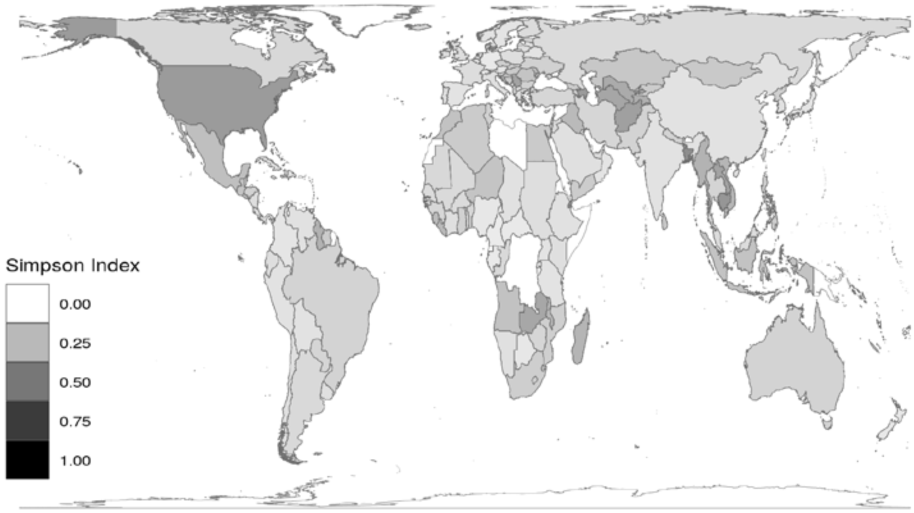
These trends are broadly consistent at regional levels also. Figure 11 shows the trends in concentration of food supply for different regions of the world. These trends show that concentration declined in most of the regions albeit by different degrees. Western Europe, which has a low but marginally rising concentration in food supply, is a noteworthy exception to this trend.

Khoury *et al.* (2014) carried out a detailed country-level analysis of crop-based food supply data from FAOSTAT. Their results are similar to ours, although they draw very different conclusions from them. As in the present study, they also find that, in terms of shares of commodities for which food supply data were reported, the general trend within countries was one of increasing diversity, increasing number of crops being produced in each country and declining dominance of the most important abundant crop commodity. The central conclusion they draw from these results is that, as food supplies become more diverse within many countries, this increasingly diverse supply became more similar across countries. This seemingly opposite conclusion, however, is not inconsistent with increasing diversity of food supply and production that are seen in the data. On the contrary, an increasingly homogeneity across countries is a direct result of increasing diversity within the countries (and thus also globally) that is seen in FAOSTAT data.

Figure 11. Trends in Simpson Index of food supply, by regions, 1961 to 2016

Figure 12 shows the spatial variations in concentration of total supply of agricultural commodities including quantity used for food, feed, seed and other uses.

Figure 12. Simpson (Herfindahl-Hirschman) index of sources of calories in total supply of agricultural commodities (crop, livestock and aquatic), by country, latest years



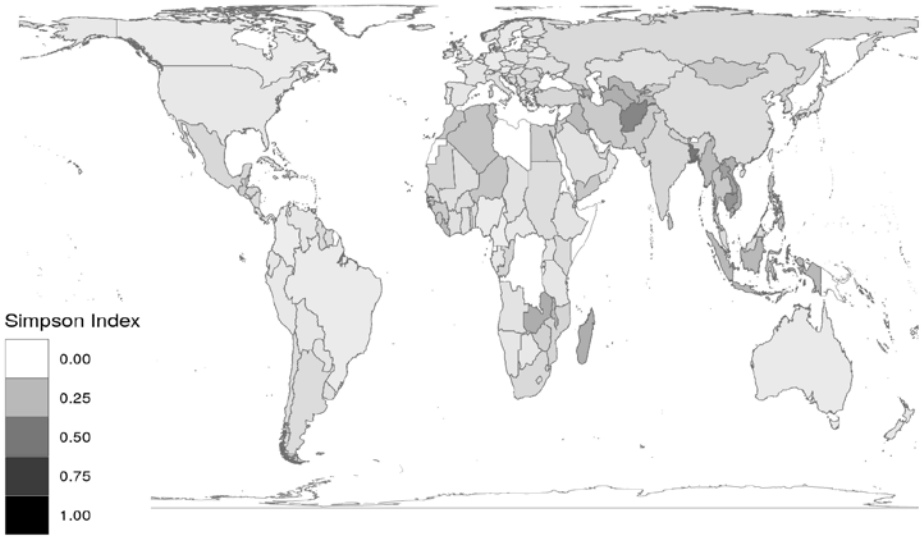
Note: This figure maps the concentration index of total supply including the quantity used as food, feed, seed and for other uses.

Source: Based on data from FAOSTAT Food Balance Sheets.

Figure 13 shows the spatial variations in concentration of food supply. In Figures 12 and 13, data on supply were converted into calorie equivalents to aggregate different commodities. Maps look very similar if supply is converted into protein equivalents. The spatial variation in Figures 12 and 13 is broadly similar to the patterns obtained from spatially-linked databases by Herrero *et al.* (2017). A comparison of the two figures shows that some countries, for example, United States of America, Australia and Brazil, have a high concentration in total supply while the concentration in food supply is not so high. This is because of the high concentration of a few commodities (in particular, soybean) in supply of animal feed.

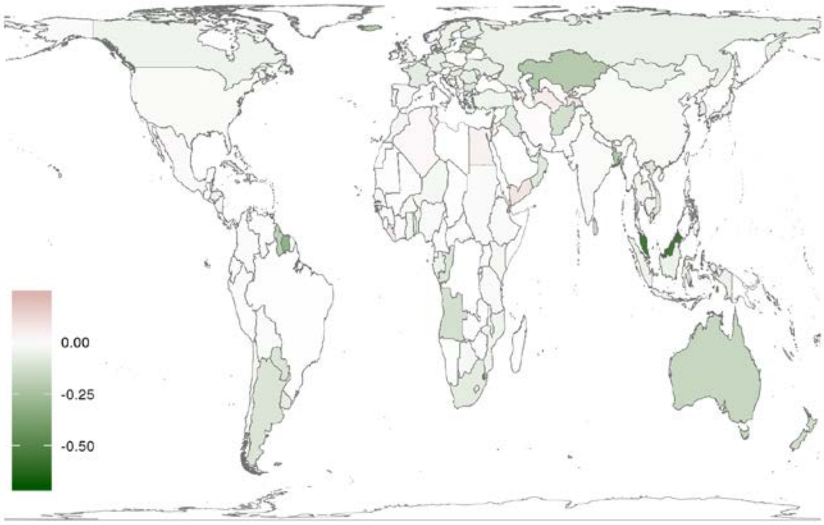
Figure 14 shows the difference between Simpson indices of supply and production of agricultural commodities. This difference between Simpson indices of supply and production reflects the impact of trade on concentration of total supply. The figure shows that, in a vast majority of countries, trade results in a greater diversification of supply. The contribution of trade to improving diversity of supply is particularly significant for countries with a temperate climate as agricultural production in these climates tends to be less diverse than in the tropics and subtropics.

Figure 13. Simpson (Herfindahl-Hirschman) index of sources of calories in food supply, by country, latest years



Source: Based on data from FAOSTAT Food Balance Sheets.

Figure 14. Difference between Simpson (Herfindahl-Hirschman) indices of supply and production of agricultural commodities, 2013



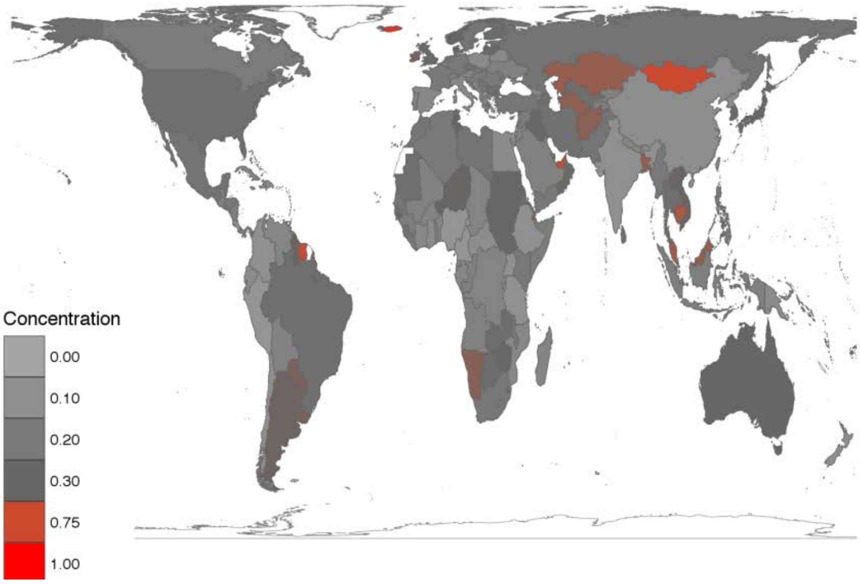
Notes: A positive difference (red colour) implies that trade results in a greater concentration of supply of agricultural commodities in a country while a negative difference (green) implies that trade results in a greater diversification of supply. In a few cases, the difference in a particular year may be driven by changes in stocks.

Source: Based on data from FAOSTAT Food Balance Sheets.

Figure 15 shows that countries with large-scale industrial farming (for example, United States of America, Australia and countries in Eastern Europe) have higher levels of concentration in crop production. In different regions of the world, there are a few countries with an exceptionally high concentration of food production.

On the whole, these results suggest that, in terms of interspecies diversity, production of food has tended to become more diverse at national level in recent decades. This is particularly true of crop production and aquaculture. In comparison, diversity of food production and supply based on terrestrial animals continues to be based on just a few species.

Figure 15. Simpson (Herfindahl-Hirschman) index of area harvested with different crops, by country, latest years



Source: Based on production data from FAOSTAT.

It must also be pointed out that the decline in abundance of the most important food commodities, and thus an increasing overall species diversity seen in our results, is not inconsistent with the considerable evidence of the loss of diversity on the margins. National and global statistical databases on agricultural production and food supply have very limited coverage of what have come to be known as neglected and underutilized species. A substantial body of recent literature shows that a vast number of edible species with considerable nutritive value remain neglected and underutilized (see Bermejo and León, eds. 1994; Hughes, 2013; Padulosi, Thompson and Rudebjer, 2013; Williams and Haq, 2002, for an overview). Some of these species, for example a large number of millets, were important component of diets in the past in many parts of the world but are rarely eaten now. Considerable efforts are being made at the global level, and in many countries at the national level too, to raise awareness about the need to conserve these species, to invest in scientific work on these species, to support their production, to integrate them with the food value chains, and to promote their inclusion in diets (FAO, 2016c).

Putting these two pieces – the statistical evidence from large-scale databases and the body of work on neglected and underutilized species – together, the picture that emerges is of increasing species diversity of food supply at the core comprising major food commodities, though production and trade, and a declining diversity of food supply on the margins comprising neglected and underutilized species.

3.2.3 Intraspecies diversity among crops and livestock

Genetic erosion refers to the loss of diversity of plant and animal genetic resources in the process of development of agriculture. The process and stages of genetic erosion are very different for crops and animals, and must be considered separately.

In the context of plant genetic resources, three different historical phases have been identified.

The first phase was the long period of domestication of various plants as agriculture developed. During this phase, the selection of plant genetic material for desirable properties for domestication resulted in a considerable narrowing of the genetic base. Van de Wouw *et al.* (2010) point out that the extent of reduction in diversity during this phase varied across crops on account of the population sizes of these plants, identification of key traits (for example, fruit size) that were used for selection (thus resulting in a great loss of diversity in genes that control the key trait), and dispersal of plant genetic material (creating isolated branches with limited diversity). Reif *et al.* (2005) carried out a detailed analysis of trends in genetic diversity of wheat and concluded that a loss of genetic diversity in wheat took place during the period of its domestication and during the period of modern breeding since the mid-twentieth century. They concluded that a significant reduction in genetic diversity was achieved during the process of domestication of wheat through genetic drift, natural selection and farmer selection, resulting in isolation of landraces suited to specific local conditions.

The second phase constitutes the period in which replacement of landraces with modern cultivars resulted in a significant genetic erosion. The replacement of landraces occurred at different points of time in different regions and for different crops (see Table 4; Evenson and Gollin, 2003b; Van de Wouw *et al.* 2010a). In North America and Western Europe, the replacement of landraces picked up pace in the late nineteenth century and was almost complete by middle of the twentieth century. In contrast, in most of Asia and Latin America, replacement of landraces with modern cultivars picked up pace from the 1970s onwards for crops that had major national and international breeding programmes. For example, by the end of the twentieth century, almost all of the wheat grown in Asia and Latin America was based on modern cultivars. Smale *et al.* (2002) estimated that only about 3 percent of the global spring wheat-growing area was sown with landraces. FAO (2015a) showed that in Turkey, a centre of origin, local landraces were planted on less than one percent of the total wheat production area, and wheat landraces are being produced by farmers in remote and higher elevation areas for subsistence farming. The rates of adoption of modern cultivars of rice were almost a decade behind wheat but also picked up pace in Asia towards the end of the century. In contrast, breeding and adoption of modern varieties has lagged behind for most protein crops. While adoption of modern cultivars of maize spread widely in Latin America in the late twentieth century, its uptake has been slower in Asia. Sub-Saharan Africa has been slowest in adoption of modern varieties for most crops and continues to lag behind other regions of the world. In sub-Saharan Africa also, adoption of modern cultivars accelerated first for crops such as wheat and maize, which have large international breeding programmes, while adoption in crops such as cassava, that are significant to the regional economy but do not have major international programmes, has been very little.

Table 4. Percentage of area planted to modern varieties for different crops, selected regions of the world, 1970, 1980, 1990 and 1998 (percent)

Crop	Latin America				Asia (including China)				Middle East–North Africa				Sub-Saharan Africa			
	1970	1980	1990	1998	1970	1980	1990	1998	1970	1980	1990	1998	1970	1980	1990	1998
Wheat	11	46	82	90	19	49	74	86	5	18	38	66	5	22	32	52
Rice	2	22	52	65	10	35	55	65					0	2	15	40
Maize	10	20	30	46	10	25	45	70					1	4	15	17
Sorghum					4	20	54	70					0	8	15	26
Millet					5	30	50	78					0	0	5	14
Barley									2	7	17	49				
Lentils									0	0	5	23				
Beans	1	2	15	20									0	0	2	15
Groundnut					0	15	20	50					0	0	20	40
Cassava	0	1	2	7	0	0	2	12					0	0	2	18
Potato	25	54	69	84	30	50	70	90					0	25	50	78
All crops	8	23	39	52	13	43	63	82	4	13	29	58	1	4	13	27

Source: Evenson and Gollin (2003b)

A reduction in area allocated to landraces and reduced numbers of producers of traditional varieties during this phase enhanced genetic erosion and especially the loss of rare alleles. In the first *The State of the World's Plant Genetic Resources for Food and Agriculture* (PGRFA) Report (FAO, 1997), as many as 81 countries reported a loss of plant genetic resources because of replacement of landraces by modern cultivars. For example, it was reported that the number of varieties of wheat that were in use in China fell from about 10 000 in 1949 to only about 1 000 by 1970. The United States of America reported that, of the varieties documented in the nineteenth century, 96 percent of the varieties of apple, 95 percent for cabbage, 91 percent for maize, 94 percent for pea and 81 percent for tomato had been lost (FAO, 1997). *The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture* (FAO, 2010) described continued erosion of landraces in many countries. Of the 60 countries that provided reports on genetic erosion for the second report, 30 reported losses of varieties of cereals, 18 reported losses of varieties of vegetables, 17 of food legumes and 17 of fruits and nuts. The World Information and Early Warning System on Plant Genetic Resources for Food and Agriculture for 2012–14 has records of 23 148 varieties of 808 species surveyed by 51 countries. Of these varieties, 12.5 percent were reported to be threatened.

The third phase constitutes the recent period of base broadening and the introgression of specific genes in existing and new cultivars. Globally, while replacement of landraces of modern cultivars continues for many crops in many regions, crops and regions that have already seen large-scale adoption of modern cultivars have moved into the third phase. Van de Wouw *et al.* (2010) suggest that the most likely scenario for crops is that the rate of genetic erosion slows down after the first two phases, and for some crops may even have been partially reversed. Unlike in the second phase, genetic material sourced from a wide range of resources, mostly maintained in large *ex-situ* genebanks, is used for breeding cultivars that embody a diverse allele composition.

Development of modern molecular and genome sequencing tools over the last two decades has made it possible to study erosion and conservation at the genetic level. Detailed analysis of genetic data by Reif *et al.* (2005) showed that although genetic diversity of wheat was reduced during the early period of modern breeding, from 1950 to 1989, in the phase when landraces were replaced by modern cultivars, genetic diversity of cultivars has increased thereafter. They concluded that: "breeders averted the narrowing of the wheat germplasm base and subsequently increased the genetic diversity through the introgression of novel materials." A detailed meta-analysis of recent studies led Van de Wouw *et al.* (2010) to conclude that modern breeding over the last few decades has contributed to broadening of the genetic base of the crops. In another review of evidence on genetic diversity, Smith *et al.* (2015) conclude that: "there is no evidence over many decades in the twentieth century of a narrowing of the genetic base (in modern varieties). Diversity has increased in some crops due to conscious sourcing of landrace diversity."

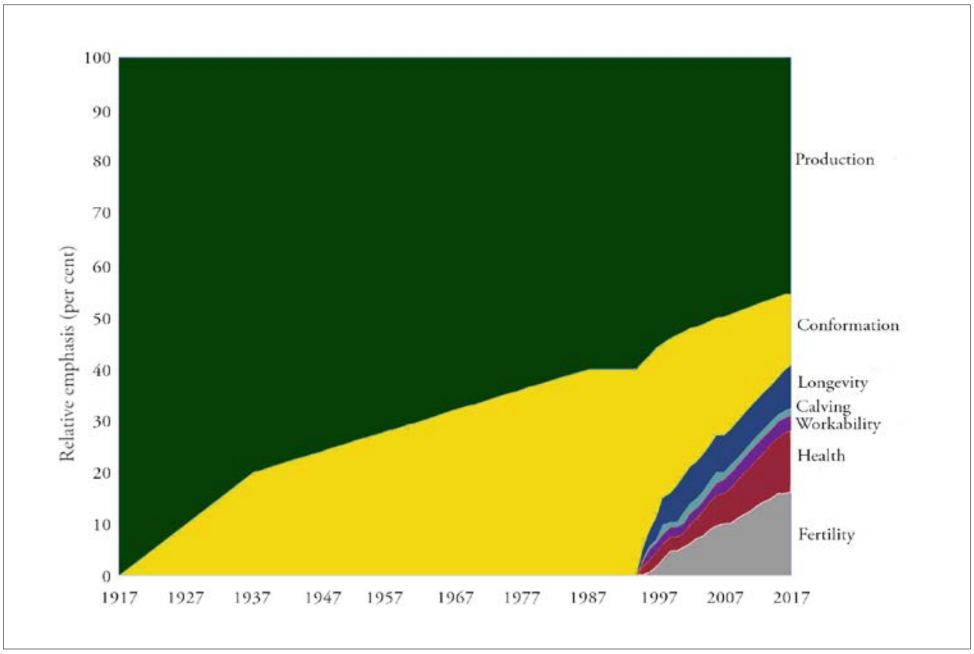
Two caveats to these conclusions must be noted. First, the evidence of trends in genetic diversity in modern varieties grown on large areas does not contradict the evidence of disappearance of landraces. In fact, while some crops have seen a broadening of their genetic base in recent decades because of development of cultivars using novel genetic material, disappearance of landraces from the fields has continued for many other crops and in regions where a significant amount of land continued to be planted with landraces. Second, disappearance of landraces does not necessarily imply allele-level erosion as many of the genes may be available in conserved varieties (FAO, 1997; Van de Wouw *et al.*, 2010).

The situation of diversity among livestock resources is very different from the trends for crops. Evidence on animal resources, mainly based on assessments of population of different breeds of livestock in different countries, suggests that genetic erosion among livestock breeds continues to take place at a significant pace. Data from DAD-IS show that among local breeds (i.e. the SDG Indicator 2.5.2) 27 percent are at risk.[22] In the case of livestock, modern breeding technologies, in particular artificial insemination, are used for indiscriminate cross-breeding of local with exotic breeds. The example of displacement of indigenous breeds of cattle in many parts of the world by Holstein-Friesian cattle through indiscriminate cross-breeding using modern reproductive

[22] Domestic Animal Diversity Information System, accessed January 2019.

techniques is well known (Rege and Gibson, 2003). Indiscriminate cross-breeding and displacement of indigenous breeds by exotic breeds are considered to be the most important causes of genetic erosion among various species of livestock (FAO, 2015a).

Figure 16. Schematic representation of relative emphasis on traits included in an average dairy cattle selection index over time



Source: Based on Miglior *et al.* (2017).

Contrary to plant genetic resources, there is no introgression of landrace genes into commercial breeds. However, within commercial breeding programmes, breeding goals have diversified and more attention is paid to the reduction of inbreeding.[23] Miglior *et al.* (2017) show that, over the years, priorities for cattle breeding have changed from a singular focus on increasing yields to include longevity, calving, workability, health and fertility. In addition, they point out that traits such as feed efficiency, methane emissions, adaptation to heat stress, hoof health, disease resistance, quality of milk and suitability for use of modern reproductive technologies are being considered for adoption into breeding priorities in breeding programmes in various countries (Figure 16). Similar trends of including robustness and animal welfare breeding goals are ongoing in pig and poultry breeding (Merks, Mathur and Knol, 2012).

3.2.4 Impact of agricultural intensification on associated biodiversity

Associated biodiversity refers to the range of living organisms other than the main plants and animals grown for food that exist in agro-ecosystems. In the context of crop production, this refers to subsoil organisms as well as organisms above the ground such as birds, bees, pests and weeds. Associated biodiversity encompasses organisms that are helpful to agriculture as well as organisms that are harmful to agriculture.[16]

The process of increases in food availability may also involve technological changes that have implications for associated biodiversity. A large number of studies have examined, primarily based on micro-level experiments, the impact of changes in agricultural practices on associated biodiversity in varied crop environments. For example, many studies have discussed the adverse impact of intensive tillage on abundance of some earthworm species, nesting birds, rodents and microbial activity in soil (see, for example, Chan, 2001; Crittenden *et al.*, 2014; Ernst and Emmerling, 2009; Kladivko, 2001; McLaughlin and Mineau, 1995; Rovira, Smettem and Lee,

[23] See Notter (1999) for a discussion of long-term impact of intensive selection for breeding on genetic drift due to inbreeding.
[16] http://www.fao.org/agriculture/crops/thematic-sitemap/theme/biodiversity/cab/en/

1987). Many insecticides and herbicides are known to adversely impact the populations of non-target organisms including pollinators (Geiger *et al.*, 2010; Goulson, 2013; McLaughlin and Mineau, 1995; Whitehorn *et al.*, 2012). The use of insecticides in rice paddies results in destruction of aquatic life, including edible fishes and other freshwater species in the rice fields (Cagauan 1995; Simpson and Roger 1995). Cagauan (1995) documents the evidence to show that the increased use of pesticides resulted in a decline in the practice of rice–fish culture in Thailand, Indonesia, Malaysia, Viet Nam and Philippines. Excessive use of these chemicals also tends to exacerbate the destruction of associated biodiversity. Excess doses of pesticide not only adversely affect the on-farm associated biodiversity but also affect fish populations in streams (Beketov *et al.*, 2013). More information on associated biodiversity is available in FAO (2019).

3.2.5 Agricultural expansion as a driver of deforestation

From emergence of agriculture around 10 000 years ago until the onset of industrial revolution, growth of agriculture across the world was based on expansion of land under agriculture obtained by clearing forests. There have been different phases, varied historically as well as regionally, in the pathways of land-use changes and reduction of forest cover. The period between the sixteenth and the nineteenth century saw an acceleration of deforestation in many parts of the world with increasing demands of land not only for expansion of agriculture but also for other human activities (Williams, 2003). Over the twentieth century, the greatest deforestation took place in the tropics, during the period in which many tropical areas were colonized by European countries as well as in the period after the Second World War (FAO, 2016d). Expansion of agriculture was one of the most important drivers of this change. It is only in the late twentieth century that the increasing deforestation was halted, and in some cases reversed in temperate countries, and the locus of large-scale deforestation for agricultural expansion shifted to tropical areas.

While the drivers of deforestation are complex and interrelated, it has been estimated that about 80 percent of deforestation has been on account of expansion of agriculture (Kissinger, Herold and De Sy, 2012, cited in FAO, 2016d). Hosonuma *et al*. (2012) analysed data from 46 tropical and subtropical countries to show that expansion of commercial agriculture was a more important cause of deforestation than subsistence agricultural production. FAO (2016d) summarized the evidence in respect of the role of expansion of agriculture in accelerating deforestation in different parts of the world. It points out that over 70 percent of deforestation in Latin America was related to expansion of commercial agriculture and pastures after 2000. In Southeast Asia, expansion of oil palm plantations since the 1990s resulted in large-scale clearing of forests. In sub-Saharan Africa, on the other hand, commercial agriculture was associated with only 30 percent of deforestation, while considerable deforestation was caused by low-productivity subsistence agriculture.

Expansion of agriculture has historically been a major proximate cause of destruction of forest biodiversity. Over the recent period, however, areas such as East Asia, Western and Central Asia, Europe and North America have seen a reversal of these trends and an increase in forest cover. This has been attributed in part to an increase in agricultural productivity in these regions (FAO, 2016d).

IV. BIODIVERSITY FOR FOOD AND AGRICULTURE AND ACCESS TO FOOD

Food access: Access by individuals to adequate resources (or entitlements) for acquiring appropriate foods for a nutritious diet.[17]

The second pillar of food security – access to food – refers to the physical and economic ability of people to access food. While physical access depends on factors such as distance to markets and availability of means of transport, economic access depends on factors such as prices of food, incomes and access to means of production and credit. Food insecurity is primarily caused by a lack of physical and economic access to the resources needed to secure enough food and provide a nutritionally adequate diet both in terms of quantity (energy) and quality (variety, diversity, nutrient content and food safety). This includes insufficient income or lack of access to productive assets and other resources that would otherwise allow the poor, vulnerable and marginalized to purchase food or produce it.

BFA improves the access of households to food in different ways. First, BFA contributes to raising agricultural production (see Section 3.1). Increased agricultural production results in greater access of farm households to food, directly through subsistence production of food as well as by way of giving higher cash incomes that can be used for buying food. Although many factors affect consumer prices, and there are considerable market imperfections in local food value chains in countries, greater availability of food puts a downward pressure on food prices, and thus contributes to improving access of non-farm households to food. Second, BFA from natural ecosystems can be a direct source of food for households, particularly for those living inside or on the fringes of such ecosystems. Third, BFA from natural ecosystems can be a source of cash incomes for households, which can, in turn, improve their access to food.

Food production at household level generally requires the use of genetic resources that are well adapted to the local environment, particularly in areas where the environment is harsh and other inputs (e.g. pesticides, veterinary medicines and supplementary feed) are difficult to access. The conservation and sustainable use of genetic resources and access to genetic material allows farmers, including livestock keepers and fisherfolk, to improve and diversify food production and thus access to enough food. However, where access to other essential productive assets, such as land and water, is lacking, access to improved genetic resources alone will not improve access to food. Genetic resources that provide a range of different products (e.g. natural fibres from plants and animals) and services (e.g. transport services provided by animals) also contribute to the diversification of income to buy foods.

While much attention has been paid to increased production on the farm to meet demands, equally critical are the supply chains that connect farmers to urban consumers and provide affordable access to nutritious, diverse and safe food. Cities contain the largest demand for high-value products such as fruits, vegetables and dairy, where small-scale and family farmers can have an advantage because the products are labour-intensive, and local/ regional product markets or markets honouring genetic diversity can be developed.

Since the possible ways in which BFA can help increase agricultural production and food availability have already been discussed in Section 3.1, in this section we focus on two ways in which BFA from natural ecosystems can improve access of households to food.

4.1 Consumption of directly collected food

As discussed in Section 3.1.1, people living in (or on the fringes of) natural habitats such as forests, grasslands, mangroves and seas have a significant reliance on naturally-occurring foods (fruits, nuts, meat, insects, etc.) gathered from their natural habitats (Vinceti, Eyzaguirre and Johns, 2008). Various kinds of fruits, insects, rodents and fish also grow naturally in agricultural fields and are collected by farm workers. A substantial share of these is consumed directly by the

[17] FAO (2006).

collectors. These foods can be an important source of dietary energy, proteins, minerals and other essential micronutrients.

The most detailed evidence of the contribution of wild foods to diets of forest-dwellers comes from the Poverty and Environment Network (PEN) surveys. The study, based on forest-dwellers in 25 countries, concluded that a majority of forest-dwellers included wild foods in their diets (see Box 1).

Box 1. PEN Surveys on Consumption of Forest Foods

The Poverty and Environment Network (PEN) conducted surveys of over 8 000 forest-dweller households in 58 sites in 25 countries between 2004 and 2010. Rowland *et al.* (2016) used these data to quantify the dietary contribution of forest foods.

In the PEN sample, about 53.5 percent of the households consumed at least one forest food. Although consumption of collected forest foods was widespread in this sample of forest-dweller households, the median quantity of collected forest food consumed was only 10.4 kg/capita/year. There was a considerable variation in the quantity of collected forest food consumed by forest-dweller households; the median for the top quartile of consumers was about four times (38.8 kg/capita/year) the overall median consumption. There was also a considerable variation in the prevalence and extent of consumption of collected forest foods across various sample sites. The sample included sites in Nepal, Bangladesh, Brazil and Bolivia in which over 90 percent of the households consumed collected forest foods. There were sample sites from Mozambique, Cameroon, Brazil, Bolivia (Plurinational State of), Belize and Bangladesh in which median consumption of forest foods was over 50 kg/capita/day. Across the entire sample of forest-dweller households, forests accounted for about 14 percent of total supply of fruits and vegetables. On average, people in the sample consumed about 105 g/capita/week of forest meat and fish. The study concluded that, although food collected from forests is not the main source of food for most forest-dweller households today, a majority of forest dweller households consume such foods and the contribution of such foods to their food consumption is not insignificant.

Associated biodiversity in agricultural farms is also an important source of wild food for farmers and agricultural labour households in many developing countries. In a study in the United Republic of Tanzania, Powell *et al.* (2013) found that 62 percent of wild food was sourced from agricultural farms and only 12 percent from forests. Since most wild foods were sourced from agricultural lands, there was a positive relationship between time spent on farm work and consumption of wild foods. Similarly, a study for Thailand showed that 35 percent of wild food consumed by households came from agricultural fields, 23 percent from forests, 14 percent from within habitations, and 12 percent from water bodies (Price 1997, cited by Powell *et al.* 2015). Farm rodents and pests are consumed in many African countries (Scoones, Melnyk and Pretty, 1992). In traditional rice production systems, farm households collect edible aquatic animals such as snails, crabs, crayfish, frogs and fish for their consumption (Balzer *et al.*, 2006; Halwart, 2006, 2008; Pingali and Roger, eds.,1995).

The evidence on use of edible weed species shows that while, on the one hand, there is a considerable unutilized potential of edible species that are not consumed, on the other, availability of many widely consumed species has declined with the use of herbicides and mechanized tilling (Clough *et al.*, 2007; Geiger *et al.*, 2010; Varshney *et al.*, 2012). More information on wild foods can be found in FAO (2019).

4.2 Supplementary income generation

Common property resources (trees, wood, non-timber forest produce, agro-forestry tree products, aquatic products captured from freshwater and marine resources), wild products gathered/captured from their natural habitats and BFA-dependent ecosystem services can be sold in the market, and the cash income thus obtained can be used for buying food.

This is particularly important for the rural poor, who tend to have a disproportionately high dependence on common property resources (Beck and Nesmith, 2001; Billé, Lapeyre and Pirard, 2012; Jodha, 1986; MEA, 2005; Sunderlin *et al.*, 2005). In a survey of forest-dweller communities in Latin America, Asia and Africa, 18.8 percent of households were found to collect wild foods for selling (Hickey *et al.*, 2016). In Africa, about 24 percent of sample households were engaged in the collection of wild foods for sale (*op. cit.*). Several studies in India have shown that the share of incomes from common property resources is higher for rural poor households than for non-poor households (Jodha, 1986; Pasha, 1992). In a study based on a national survey in India, Chopra (2008) found that collection of NTFPs was a significant source of subsistence income for the rural poor. In a study for Zimbabwe, Cavendish (2000) found that 40 percent of income of poor households came from environmental resources. In a study from Botswana, Kerapeletswe and Lovett (2001) found that poorer households had a greater reliance on common property resources. Their data showed that “sub marginal and marginal rural households receive 18 to 51 percent of their income from common property resources produce.”

Small-scale fisheries account for about two-thirds of global fish catches destined for human consumption. It is estimated that 90 percent of the world’s capture fishers are employed in small-scale fisheries (FAO, 2015b). In addition, a considerable amount of employment is generated in marketing and other occupations related to fishing. There are many micro-level studies that estimate the share of fishing in cash incomes of fishing communities in different parts of the world. Hori *et al.* (2006) showed that small-scale fishing in lakes, marshes, flooded forests, rice fields and ponds was an important source of cash income for households in rural Cambodia, as 66–90 percent of fish catch was sold in the market by households in their sample. In a study of fishing communities in Kenya, Geheb and Binns (1997) found that fishing in Lake Victoria was a source of income and a considerable amount of employment. Different types of fish were sold in the local markets, urban markets and to exporters. Fisherfolk owning boats earned an average of USD 729 per annum while casual workers involved in fishing had an average income of USD 394 per annum. In a study of incomes of households along riverbanks in the Congo Basin, Béné (2009) found that fishing accounted for 61 percent of average cash income of households. In data collected from villages on Lake Chilwa in Malawi, Ellis, Kutengule and Nyasulu (2003) found that 30 percent of income of households came from fishing. Purcell *et al.* (2018) estimated that 60 percent of fishers’ income in Fiji’s artisanal sea cucumber fisheries came from selling sea cucumbers. Barnes-Mauthe, Oleson and Zafindrasilivonona (2010) found that 83 percent of fish and invertebrates captured by small-scale fishers in Madagascar was sold commercially and estimated that fishing accounted for 82 percent of all household income of small-scale fishers in Madagascar. It has been estimated that about 73 percent of households in Bangladesh are involved in fishing as professional, part-time or subsistence fishers. In addition, about 2 million people in Bangladesh are estimated to be involved in fishing trade-related activities (Craig *et al.* 2004). In a study of fishing villages along the Old Brahmaputra River in Bangladesh, Rahman, Haque and Akhteruzzaman (2002) found that catching and selling fish was the main economic activity; fishing-related activities accounted for 76 percent of income of households owning fishing gear and 74 percent of income of households that did not own fishing gear.

There are only a few studies that have quantified the impact of wildlife-related services on the incomes of rural households (Spenceley and Goodwin, 2007). In a study of the impact of tourism development under the Community-based Natural Resource Management Programme in Botswana, Mbaiwa and Stronza (2010) found that development of tourism in these biodiversity-rich regions resulted in significant increase in incomes of households as they gave up traditional occupations and found employment in various tourism-related jobs. Parid *et al.* (2015) estimated that 47 percent of the income of households living near Kuala Tahan National Park in Malaysia came from various services related to ecotourism. Snyman (2014) studied the impact of development of ecotourism using data from a survey of rural households in 30 communities living near ecotourism camps in six southern African countries. They found that 59 percent of households in the sample obtained all their income from ecotourism-related activities while 93 percent of households obtained more than 50 percent of their income from ecotourism-related activities.

These studies show that BFA in natural ecosystems can be a source of considerable cash income. A part of this cash income is used, in turn, to buy food.

V. CONTRIBUTION OF BIODIVERSITY FOR FOOD AND AGRICULTURE TO DIET DIVERSITY

Utilization: Utilization of food through adequate diet, clean water, sanitation and health care to reach a state of nutritional well-being where all where all physiological needs are met.[18]

The third pillar of food security, utilization, rests on availability of a diverse and nutritious diet to individuals. Diet diversity is a critical requirement for adequate human nutrition since no single item in the diet can provide an adequate quantity of all nutrients required by a person. Even items that contain a substantial quantity of a particular category of nutrients, for example protein, may not provide all the amino acids that a human body requires. The problem is even more complex for micronutrients, as a wide variety of these are required in small quantities. Studies have shown that dietary diversity is a good predictor of diet quality, particularly in the case of children's diets (Kennedy *et al.*, 2007; Moursi *et al.*, 2008; Parlesak, Geelhoed and Robertson, 2014; Rah *et al.*, 2010).

Diversity of food is also needed to meet diverse requirements of individuals depending on their sex, age, body mass, metabolism and state of health, and activity status. Nutrient requirements of men and women are different. Pregnant and lactating women have different requirements from other women, as do children and the elderly. An athlete has different nutrient requirements from a person who lives a sedentary life. Nutrient requirements of a person who regularly does manual labour are very different from a white-collar worker.

Household food selection, preparation and allocation practices as well as child-care practices have an impact on food utilization. Appropriate utilization also requires knowledge of foods and how to process, store and prepare them. Food preparation and storage equally require access to various non-food inputs, such as clean water and fuel and, for traditional foods, depend on traditional knowledge.

Agricultural growth, if focused on large-scale farming and on a few species or commodities, does not necessarily have a positive impact on utilization if it does not benefit the nutritionally insecure. Similarly, while increased household income tends to improve caloric intake, it does not necessarily improve nutrition, especially not that of women and children. Food- and water-borne diseases, such as parasitic and other infections, hamper food utilization. The lengthening of food chains is creating new challenges and concerns regarding incidences of food safety, plant and animal health issues and emerging zoonotic diseases, contamination and antimicrobial resistance, all of which may influence health and food utilization.

5.1 Inter- and intraspecies nutrient diversity

Diet diversity is critically dependent on BFA. Nutrient composition of food items varies not only across items obtained from different plants and animal species but also across different varieties and breeds.[19] Over the last two decades, a considerable amount of work has been done to analyse variations in food composition of different items across species and varieties/breeds from which they originate (Burlingame, Charrondiere and Mouille, 2009; Kennedy and Burlingame, 2003). Data on food composition for many different food items sourced from a large number of studies have been compiled in the FAO/INFOODS database, a database prepared by FAO and the International Network of Food Data Systems.

Table 5 based on FAO/INFOODS data shows the range of selected nutrients in food items sourced from different species, subspecies, varieties and breeds. For example, in case of 100 grams of rice of various varieties included in the database, the protein content varies from 4.5 to 20.4 grams, dietary fibre varies from 0.3 to 17.4 grams and iron varies from 0.2 to 10.5 grams. In 100 grams of different types of common bean (*Phaseolus vulgaris*), protein content varies from 12.5 to 30.2 grams and dietary fibre varies from 18.4 to 33.8 grams. Across various types of

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[18] FAO (2006).

[19] Nutrient composition also varies across different parts of plants and animals that go into food, and with the nature and level of processing before it is consumed.

legumes, of different species, the range is even wider. In the case of potatoes, which comprise several species and varieties/cultivars, the protein content varies from 0.3 to 11.6 grams per 100 grams, iron content varies from 0.1 to 35.5 mg per 100 grams, and vitamin C content varies from 0.3 to 33.8 mg per 100 grams. Similar variations can be seen for other food items as well. Vitamin A varies between 0.4 and 11.7 µg per 100 grams for different types of dates, and between 10.6 and 74 µg per 100 grams for different varieties of papaya. Vitamin C varies from 2.5 to 192.2 mg per 100 grams in different varieties of banana, and from 41.3 to 112.4 mg per 100 grams in papaya. Protein content in milk of different breeds of goats varies from 2.5 to 5.3 grams per 100 grams of milk. Protein content in cuts of pork from different breeds of pigs ranges from 16.8 to 24.4 grams per 100 grams, while the same in cuts of beef from different breeds of cows ranges between 18.6 and 25.7 grams per 1 000 grams.

Table 5. Range of protein, dietary fibre, iron, vitamin C and vitamin A in 100 grams of selected food items (raw, fresh weight basis) sourced from different species/subspecies/ varieties/breeds of plants and animals

Food item (raw)	Protein (g)	Dietary fibre (g)	Iron (mg)	Vitamin C (mg)	Vitamin A (µg)
Rice	4.5–20.4	0.3–17.4	0.2–10.5	–	–
Quinoa	9.1–15.7	8.9–14.1	6.3–6.8	–	–
Cassava	0.3–1.6	–	–	–	0.3–55.7
Potato	0.3–11.6	1.3–1.7	0.1–35.5	0.3–33.8	45–53.3
Common bean	12.5–30.2	18.4–33.8	–	–	–
All legumes[a]	3.2–51.8	3.3–38.1	0.5–16	0.8–39	0.8–35.8
Leafy vegetables[b]	0.2–8.8	1.4–10.8	0.1–37.4	0.1–295	22.8–809
Banana	0.5–2.9	2.3–2.5	0.2–1	2.5–192.2	6.1–389
Apple	0.1–0.7	–	0.1–1	–	–
Date	0.4–3	5.1–12.3	0.1–4.2	–	0.4–11.7
Baobab	1.8–3.2	43–43	0.1–13.4	125.5–635	–
Papaya	–	–	0.3–0.7	41.3–112.4	10.6–74
Red raspberry	–	–	–	21–36	–
Goat milk	2.5–5.3	–	0.1–0.2	5.5	–
All types of milk	1.5–9.9	–	0–1	2.5–5.5	–
Pork	16.8–24.4	–	0.2–0.7	–	–
Beef (*Bos taurus*)	18.6–25.7	–	1.4–4.8	–	–

Notes: Variations in composition may also be due to differences in parts of plant/animal used, stage and time of harvest/lactation/slaughter, farm management practices and level of dryness.

a. Includes various legumes, with different types of processing.

b. Includes fresh leaves of various plant species that are used as food in different countries.

Source: Based on FAO/INFOODS Food Composition Database for Biodiversity – Version 4.0 (BioFoodComp4.0) (http://www.fao.org/fileadmin/templates/food_composition/documents/BioFoodComp4.0.xlsx).

Medhammar *et al.* (2012) reviewed breed- and species-level data on composition of milk of different dairy animals from a large number of sources. A selection of statistics on protein, calcium and iron content in different types of milk compiled in the study is provided in Table 6. These data show considerable variations between and within species. Beyond breed differences, the variations in composition of milk within species are also influenced by stages of lactation, number of calvings, seasonal variations, age and health of animals, and livestock management practices. As shown in these data, protein content in 100 grams of milk varies from 3.1 to 3.3 grams in cow milk, 2.7 to 4.6 grams in buffalo milk and 2.4 to 4.2 grams in milk of dromedary camels, and is as high as 7.5 to 13 grams in reindeer milk. In different kinds of milk, calcium content can vary from 68 to 358 mg per 100 grams of milk, while iron can vary from only trace amounts to as much as 0.98 mg per 100 grams of milk.

Differences between species and varieties also exist in disease/pest resistance, processing and storage traits, some of which can be modified by selection. Knowledge systems, including traditional knowledge systems, related to food production and food processing influence food utilization, for example as indicated by gender-specific trait prioritization in participatory plant breeding.

For smallholder subsistence producers, diet diversity crucially depends on diversity of food production. In this context, production in home gardens and backyard ponds has been found to be an important contributor to diet diversity. Home gardens – comprising seasonal crops, trees and animals – are repositories of considerable diversity. Often maintained by idle household labour, they are an important source of nutritious food such as vegetables and fruits to many households (Sundaram, Rawal and Clark, 2015).

Table 6. Range of protein, calcium and iron content in milk from different dairy animals (per 100 grams of milk)

Animal species	Protein (g)	Calcium (mg)	Iron (mg)
Cattle	3.1–3.3	112–116	0–0.07
Buffalo	2.7–4.6	147–220	0.17
Yak	4.2-5.9	119–134	0.15–0.98
Mithun	6.1–6.8	88	–
Reindeer	1.4–3.2	76–124	0.03–0.15
Donkey	1.4–1.8	68–115	–
Dromedary camel	2.4–4.2	105–120	0.17–0.26
Bactrian camel	3.6–4.3	152.3–155	–
Llama	3.4–4.3	170–220	–
Reindeer	7.5–13.0	320	–
Moose	7.8–14.4	156–358	0.31

Source: Based on data compiled in Medhammar *et al.* (2012).

5.2 Wild foods

In addition to agricultural produce, wild foods obtained both from natural ecosystems and from farmlands are also a rich source of food (see Section 3.1.1). Wild foods are a particularly important component of the diet of households that live near natural habitats (forest-dwellers, coastal communities, pastoralists, etc.) (Blaney, Beaudry and Latham, 2009; Powell *et al.*, 2013). Some of these wild foods – fruits, nuts, edible leaves, barks and stems, mushrooms, honey, insects, meat and fish – are very rich in nutrients. Wild leaves and weeds are rich sources of protein, vitamin A, iron and lysine. Many wild plants have a higher content of protein, fat, minerals and vitamins than crops (Scoones, Melnyk and Pretty, 1992; Ogle, Hung and Tuyet, 2001). Insects are often a cheap source of protein and fat, and in some cases, of micronutrients as well (Van Huis *et al.*, 2013). Table 7 lists a number of forest products that are rich in specific micronutrients.

Box 2. Enhancing local food security and nutrition through promoting the use of baobab (*Adansonia digitata L.*) in rural communities in Eastern Africa

The project aims at: (i) identifying and mapping baobab populations and recording the full range of morphological diversity and population vitality, identifying most valuable populations for conservation and propagation, and developing techniques for sustainable tree management and protocols for vegetative propagation of baobab; (ii) analysing nutrients and bioactive compounds of baobab raw products along different environmental gradients, reviewing local uses and processing technologies of baobab in different regions, nutrient analyses of processed baobab products and development of nutrient maintaining processing technologies and new products, as well as analysing the impact of supply chain organization on nutrient and physical properties of baobab products; (iii) assessing the nutritional status and role of baobab in daily diets, assessing the effect of baobab diet on nutritional and health status of school children, and describing the impact of commercial baobab utilization on nutritional and health status; (iv) assessing consumer preferences, current market demand and analysing market chains; (v) initiating the formation of community organizations for sustainable baobab management, developing an area-specific extension approach and initiating its implementation, and establishing a fully operational processing unit and supplying products to target groups; and (vi) informing relevant stakeholders about sustainable baobab management and its role in improved nutrition, and the results and technologies developed by the project.

Source: Submission by Germany.

There are also other ways in which BFA plays a part in human nutrition. Plant foods such as most fruits and vegetables, which are some of the richest sources of micronutrients including vitamins A and C, calcium and folic acid, come from pollinator-dependent crops (Potts et al., 2016). Various kinds of micro-organisms are also used for processing of food – for example, in fermentation – that improve digestibility of nutrients available in food.

Table 7. Common nutritional deficiencies and the potential role of forest foods

Nutrient-related problems	Forest food with potential for combating deficiencies
Protein and energy malnutrition due to inadequate food consumption: reduced growth, susceptibility to infection, and changes in skin, hair and mental facility	Energy-rich food available during seasonal or emergency food shortages, especially nuts, seeds, oil-rich fruit and tubers; e.g. the seeds of *Geoffroea decorticans*, *Ricinodendron rautanenil* and *Parkia* sp.; oil of *Elaeus guineensis*, babassu, palmyra and coconut palms; protein-rich leaves such as baobab (*Adansonia digitata*) and wild animals, including snails, insects and larvae
Vitamin A deficiency: impaired vision and immune function, and in extreme cases blindness and death; responsible for blindness of 250 000 children per year	Forest leaves and fruit are often good sources of vitamin A: e.g. leaves of *Pterocarpus sp.*, *Moringa oleifera*, *Adansonia digitata*, the gum of *Sterculia* sp., palm oil of *Elaeus guineensis*, bee larvae and other animal food
Zinc deficiency: retarded growth and development, increased incidence of pregnancy complications, suppressed immunity and impairments in neuro-psychological functions	Animal-source foods, particularly red meat, are excellent sources of zinc, although many nuts (e.g. pine nuts, coconut meat, pecans, brazil nuts) have comparable values on a per-weight basis, and mushrooms can make significant contributions

Iron deficiency: anaemia, weakness and increased susceptibility to disease (especially in women and children), impaired cognitive development	Wild animals (including insects such as tree ants), mushrooms (often consumed as meat substitutes) and forest leaves (e.g. *Leptadenia hastata*, *Adansonia digitata*); baobab fruit pulp is also an important source of iron
Folate deficiency: anaemia, neural tube defects	Leafy and other vegetables, and many fruits
Niacin deficiency: dementia, diarrhoea and dermatitis; common in areas with maize as staple diet	Forest fruit and leaves rich in niacin, such as *Adansonia digitata*, fruit of *Boscia senegalensis* and *Momordica balsamina*, seeds of *Parkia* sp., *Irvingia gabonensis* and *Acacia albida*

Source: Vinceti, Eyzaguirre, and Johns (2008).

Box 3. Improving community health–nutrition linkages through solar energy-based fish and crop integrated value chains

The project focuses on research and linking of several aspects along the value chain of sustainable aquaculture of *Oreochromis karongae*, a favoured and high-quality source of protein for human nutrition. In the context of these measures, an innovative linkage of fish and crop production in integrated aquatic systems (classical integrated agriculture–aquaculture systems [IAA] and aquaponics) will allow enhanced productivity and thus an optimized nutritional and socio-economic status of smallholder farmers in rural areas of Malawi adopting these techniques.

Source: Submission by Germany.

To sum, interspecies and intraspecies diversity is critical for human nutrition. There are two obvious implications of this.

First, information about variation in nutrient content can help consumers make choices to improve nutrition. For this, information about variations in nutrient content of food originating from different species, cultivars and breeds should receive greater focus in nutrition education. The Commission endorsed the *Voluntary Guidelines for Mainstreaming Biodiversity into Policies, Programmes and National and Regional Plans of Action on Nutrition* in 2015 in its Fifteenth Session. Element C of the Guidelines (Box 4) provides suggestions about kinds of awareness-raising activities that could be undertaken to mainstream the importance of biodiversity in nutrition education. In some cases, for example for promotion of consumption of nutritious insects, awareness programmes also need to address cultural barriers and the disgust factor in addition to disseminating information about the benefits of including edible insects in diets (Van Huis *et al.,* 2013).

Second, the variations in nutrient composition across varieties and species can be utilized to breed new varieties and hybrids that combine better nutrient composition with other desirable properties (such as high yield). Crop breeding for improved nutrient composition, popularly known as biofortification, has emerged as a major area of work in recent years in breeding programmes across the world. In particular, much work on biofortification of crops has been done under HarvestPlus, a CGIAR programme.[20] Figure 17 shows various biofortified crops that have been released or are being tested in different countries. As shown in the figure, banana, cassava, maize and sweet potato have been enriched with vitamin A, and introduced in many countries in sub-Saharan Africa, Latin America and the Caribbean. Iron-enriched bean has been

20 For further details, see Bouis (1999, 2000), Bouis and Saltzman (2017), Carvalho and Vasconcelos (2013), HarvestPlus (2014), Mayer, Pfeiffer and Beyer (2008), Meenakshi *et al.* (2010), Saltzman *et al.* (2013), Smith (2013), Stein *et al.* (2008) and www.harvestplus.org

released in many countries in Latin America and the Caribbean. In India, micronutrient-rich cultivars have been released for sorghum, cowpea, lentil, pearl millet, wheat and rice. In Bangladesh, iron- and zinc-enriched lentil, and zinc-enriched rice and wheat have been released. In Brazil, iron-enriched bean, vitamin A-enriched cassava, iron- and zinc-enriched cowpea, vitamin A-enriched sweet potato, and zinc-enriched maize have been released.

Box 4. Voluntary Guidelines for Mainstreaming Biodiversity into Policies, Programmes and National and Regional Plans of Action on Nutrition

Element C. AWARENESS

i. Support the development of national awareness campaigns that include elements such as the establishment of “know your foods” radio talk shows and television programmes that present the nutrition and health attributes of using foods from different varieties, cultivars and breeds of plants and animals, as well as wild, neglected and underutilized species, and their possible uses in everyday meals.

ii. Support the organization, at regular intervals, of initiatives such as policy advocacy workshops, round-table discussions and stakeholder meetings to increase the awareness of the public sector and of decision-makers of the importance of food from different varieties, cultivars and breeds of plants and animals, as well as wild, neglected and underutilized species, and of its role in ensuring good nutrition and food security. Sectors related to agriculture, health, education, rural development, environment and finance are also important targets for these awareness initiatives.

iii. In collaboration with partners such as FAO, universities, research institutes and farmers groups and associations, organize national and regional workshops that target the promotion of biodiversity for food and agriculture.

iv. Extend the existing FAO curriculum guide for nutrition education in primary schools to include a curriculum for teaching about biodiversity for food and agriculture from local/traditional food systems, including aquatic and animal food resources, their uses in diets and their nutrition and health protecting and promoting attributes.

v. As an educational tool for young children and the population at large, promote and encourage the display, on the cover of school textbooks, workbooks and exercise books, of pictures of local plant and animal breeds and varieties, with short and easy to comprehend messages on their nutrition and health attributes, and arrange practical cooking and tasting sessions for children and their parents to promote their integration into food preparation and eating patterns.

vi. Disseminate research results within the scientific communities of nutrition, agriculture, health and environment through, for example, conferences, websites, scientific articles and guidance documents.

vii. Organize special events related to biodiversity for food and agriculture, such as fairs, festivals or a national “Traditional Biodiversity Food Day”. Often there are many organizations working on similar activities and initiatives, and synergies can be developed by facilitating collaboration and networking.

Source: FAO (2016c)

Figure 17. Status of release and testing of biofortified crops in different countries

Source: HarvestPlus (http://www.harvestplus.org/file/2426/download?token=X7xFOr53)The Framework for Action endorsed at the Second International Conference on Nutrition (ICN2) identified the important role of awareness campaigns for improving diet diversity (Box 5).

Box 5. ICN2: Framework for Action

Recommendation 21: Conduct appropriate social marketing campaigns and lifestyle change communication programmes to promote physical activity, dietary diversification, consumption of micronutrient-rich foods such as fruits and vegetables, including traditional local foods and taking into consideration cultural aspects, better child and maternal nutrition, appropriate care practices and adequate breastfeeding and complementary feeding, targeted and adapted for different audiences and stakeholders in the food system.

Source: ICN2 Framework for Action.

VI. BIODIVERSITY FOR FOOD AND AGRICULTURE AND STABILITY

Stability: Stability of food systems implies that food is available to individuals and households at all times including under conditions of economic or environmental stress.[21]

To be food secure, a population, household or individual must have access to adequate food at all times. In other words, availability and access to food should not be at risk as a consequence of sudden shocks (e.g. economic or climatic crisis) or cyclical events (e.g. seasonal food insecurity). Globally, stability of food systems has become increasingly important because of greater market integration of food production, increased relevance of international trade and susceptibility of agriculture to vagaries of weather (increased in many regions due to climate change). In this context, building resilience in food production systems has emerged as an important goal of development of food systems. A diverse agricultural system is more resilient to various types of shocks including weather-related stress, pests and diseases, and price fluctuations (FAO, 2001, 2010, 2019; Vandermeer *et al*., 1998).

6.1 Resilience of food production

Polyculture, crop rotations and mixed farming have historically been integral to risk-management strategies in peasant production systems in many parts of the world. For example, Swinton and Dueson (1988) found that when crops of cowpea were destroyed by drought in Niger, farmers who planted sorghum or millets along with cowpea were able to harvest at least those crops. Pigeonpea is commonly intercropped with other short-duration crops such as sorghum, maize, millet, cotton, groundnut and even other pulses such as mung bean and urd bean (Ben Belhassan, Rawal and Navarro, eds., *forthcoming*.). Rao and Willey (1980) carried out detailed experiments on sorghum and pigeonpea intercropping. In their experiments, while sole pigeonpea failed once in five times and sole sorghum once in eight, intercropped sorghum–pigeonpea failed only once in thirty-six.

Polyculture helps spread the risk of crop losses due to climatic stresses. Polyculture typically involves simultaneous sowing of multiple crops of different duration, height, canopy structure, root structure and nutrient requirements. Crops of different duration are exposed to climatic stresses differently. Crops with different root structure and water requirements are able to withstand water stress differently in the event of droughts, excess rains and floods. Different canopy structure, leaf geometry and crop durations also allow for better utilization of solar radiation (Perrin, 1976). Studies on adaptation of food systems to climate change identify diversity as one of the most critical elements of adaptation strategy (Lin, 2011). Trees planted on field boundaries help reduce soil erosion, reduce solar radiation, act as windbreaks, help control pests, and provide habitat for pollinator populations. Trees planted along with crops can also provide food, forage for farm animals, fuelwood and timber, and income for farm households (Jamnadass *et al.* 2013).

Livestock holdings have been used as a buffer against shocks such as droughts in many parts of Africa and Asia (Binswanger, McIntire and Udry, 1989; Swaminathan and Rawal, eds., 2015). In a study of mixed farming in Lesotho, Dejene *et al*. (2011) found that farmers who combined crop production with livestock farming were more resilient in dealing with crisis and risks than farmers who were only engaged in crop production. Little *et al.* (2001) pointed out that herd diversification has been used historically as a strategy by East African pastoralists to cope with climatic risk. Rosenzweig and Wolpin (1993) found that farmers in India buy bullocks in years of good rainfall and sell them to meet income shortfalls in years of drought. Studies in eastern Africa have found that herders who combine crop production with livestock keeping are more resilient in being able to maintain their livestock holdings (Hogg, 1980; Little, 1992). In semi-arid regions in India, combining crop production with goat rearing has been reported to be an effective strategy for insurance against drought (Kumar and Upadhyay, 2009; Shrivastava, 2010; Sivakumar and Kerbart, 2004; Swaminathan and Rawal, eds., 2015).

[21] FAO (2006).

6.2 Protection from pests and diseases

Field-level diversity also acts as a buffer against pests and diseases. With multiple crops on the field, a particular disease or pest is less likely to affect all the crops. Not only does mixed cropping help spread the risk because of differential impact on different crops, the evidence suggests that mixed cropping can also result in a reduction in pest infestation and severity of diseases (Altieri, Glaser and Schmidt, 1990; FAO, 2010; Perrin, 1976; Risch, 1983). These effects, however, are specific to crop combinations and pests, and cannot be easily generalized (Smith and McSorley, 2000). Crop rotations are also useful in breaking insect and disease cycles and reducing weed density (Liebman and Dyck, 1993; Oerke, 2006). Mixing disease-susceptible high-yielding cultivars with disease-resistant cultivars of the same species can be a valuable strategy for disease control (Wolfe, 1985). Zhu *et al.* (2000) report on an experiment in which disease-susceptible high-yielding rice varieties planted with disease-resistant rice varieties gave high yield with much lower severity of rice blast, a major disease of rice. Intercrops and border crops can help in pest control by working as visual, olfactory or physical barriers to pests (Perrin, 1976). For example, intercropping onion and garlic, which have a strong odour, with some crops can help reduce the population of insects (Uvah and Coaker, 1984). Some intercrops may help impede the dispersal of eggs, larvae and adult insects (see Box 6). Less valuable crops can be mixed with the main crop if they can attract and divert insects from the more valuable crop (Aiyer, 1950; Hokkanen, 1991).

Box *6*. Push-pull strategy for insect pest management in maize

In the early 1990s, scientists at the International Centre of Insect Physiology and Ecology and its partner institutions in eastern Africa discovered that by intercropping maize with Desmodium, a leguminous plant, and Napier grass helped control Striga, a parasitic weed, and stem borer moth infestation. Desmodium acted as a false host for Striga, attracted predators of pests and pushed the stem borer to seek other habitats. On the other hand, Napier grass attracts stem borer but exudes a sticky substance that traps the larvae, preventing them from surviving to adulthood. An assessment in 2014 found that about 70 000 farmers in Ethiopia, Kenya, the United Republic of Tanzania and Uganda were using Desmodium intercropping to control striga and stemp borer (Reeves, Thomas and Ramsay, eds., 2016).

6.3 Diversity and seasonality of food supply

Diversity is critical to ensuring stability of food supply across different seasons. Plants of different species grow and mature in different climatic conditions. There are also important subspecies variations in crop duration. Given the different climatic conditions in which plants grow, multiple crops are produced in a year in many tropical and subtropical regions. Similarly, animals belonging to different species have different reproductive and growth cycles. These variations are important to ensure regularity of food supply over different seasons. This is particularly the case in countries with poor storage and transport infrastructure.

Food gathered from natural habitats of plants and animals also plays an important role in stabilizing access of households to food. Scoones, Melnyk and Pretty (1992) called wild foods “famine foods” as they help in coping when there are shortages in supply of staple food crops. Rural smallholder agriculturists depend on food gathered from natural habitats to smoothen seasonality of food produced on the farm (Dawson, Guarino and Jaenicke, 2007; Scoones, Melnyk and Pretty, 1992). Food collected from natural habitats can also be an important complement to food supply during emergencies (Vinceti, Eyzaguirre and Johns, 2008). Scoones, Melnyk and Pretty (1992) reviews evidence from Malawi, Zimbabwe, Sudan, Nigeria, Ethiopia and India on foods that are primarily consumed during periods of drought. Studies on famines from across the world report consumption of tree barks, wild fruits, seeds, grasses, fruits, leaves and berries by people to beat hunger (Scoones, Melnyk and Pretty, 1992).

Fishes and other organisms captured from water-bodies can also be important for stabilizing the food supply across seasons. In comparison with crop and livestock production, aquaculture and capture fisheries in many parts of the world have a lower seasonality of supply. Although fishes also have seasonal reproductive and growth cycles, different types of fishes can be cultured/captured in different seasons in perennial freshwater reservoirs in many regions and in many marine-fishing areas.

Growing different crops, growing different varieties of a crop, maintaining large and small livestock, and maintaining different breeds of livestock are all methods used by peasants to reduce risks on account of environmental stresses, diseases and pests. Diverse food systems also help smooth risks related to price fluctuations. The historical evidence clearly shows that the consumption of wild foods is an important strategy of rural households to tidy over seasonal shortages and shortages during emergencies.

6.4 Conservation for future stability

Conservation of BFA, in particular *ex situ* and *in vitro* conservation, provides an important buffer against potential loss of agricultural biodiversity in the event of natural disasters and other emergencies. This, in turn, is crucial for the stability of future food availability.

Plant genebanks globally hold nearly 5 million accessions of landraces (traditional varieties), wild species, breeding lines and cultivars.[22] Development of *ex situ* conservation has advanced hand-in-hand with the advance of scientific knowledge of phenotypical and genetic diversity among crops and animals. Identification of distinct varieties and breeds, cataloguing their phenotypical characteristics and, with the availability of modern techniques, identifying their genetic makeup and genome sequencing have been integral to the efforts for expanding the *ex situ* collections. It would not be an exaggeration to say that much of this crop diversity would have been lost without the efforts to collect the genetic resources and preserve them in public repositories over the last century.

Box 7. Genome-wide studies to improve drought stress tolerance of Ethiopian barley and durum wheat varieties

The project aims at identifying drought-tolerant durum wheat and barley genotypes from Ethiopian landrace collections and the identification of genomic regions or genes involved in drought stress response in barley and durum wheat using genome-wide association genetics studies. Based on these results, easy-to-handle molecular markers will be developed for combining positive alleles for drought stress, which will be used to introgress drought stress tolerance in adapted Ethiopian barley and durum wheat cultivars.

Source: Submission by Germany.

Ex situ, *in vitro* conservation is important because: (i) storage of plant and animal genetic material (seeds, semen, embryos and other forms of isolated genetic material) is considerably less expensive than maintaining live plants and animals (Koo, Pardey and Wright, 2003; Li and Pritchard, 2009); (ii) since it is practically impossible to maintain complete registries of *in situ* biodiversity, there is a risk of losing varieties and breeds unless they are also conserved in *ex situ* collections where they are fully enumerated and catalogued; (iii) important genetic resources in the form of varieties that do not display desirable phenotypical characteristics may be lost because of lack of demand. As agriculture becomes more market-oriented, growing less productive/profitable varieties and breeds becomes less attractive, resulting in their disappearance from *in situ* production. With mechanization, draught animals are displaced, and breeds that are especially good for draught power cease to be maintained by farmers.

[22] World Information and Early Warning System on Plant Genetic Resources for Food and Agriculture, accessed January 2019.

There is a growing recognition of the importance of combining *in vitro* and *in vivo*, and *ex situ* and *in situ*, conservation to prevent the loss of genetic resources (FAO, 2013; CBD, 2005; United Nations, 1972; Vaughan and Chang, 1992). In comparison with plants, *in vitro* cryopreservation of animal genetic resources is feasible only for a few livestock species (FAO, 2012). Systems of *ex situ in vitro* conservation of animal genetic resources are present in about one-third of the countries, though these mostly hold only a small proportion of all the livestock breeds that are actually in existence (FAO, 2015a).

Box 8. Canadian investment to increase the contribution of plant genetic resources to stability

Canada contributed CAD 15 million (2009–2015) to the Pan-Africa Bean Research Alliance (PABRA), which works towards supporting improved nutrition, health, gender equality and food security in several African countries through the development and dissemination of bean varieties that are resistant to drought, disease and pests. Since 1996, PABRA has released over 550 new bean varieties.

Global Affairs Canada contributed CAD 14.9 million (2015–2020) to scale up USC Canada’s “Seeds of Survival” programme in Central America and Africa. The programme works with smallholder farmers (women, men and youth) in Africa, Central America, Asia and Canada, to strengthen their knowledge and their food and seed systems through participatory plant breeding, community seed banks and agro-ecological practices. This project reached an estimated 293 communities and over 44 000 beneficiaries, improving their food security and climate resilience, with particularly strong results in Ethiopia.

Source: Submission by Canada.

VII.CONCLUDING REMARKS

The main focus of this study is to identify ways in which BFA, at the genetic, species and ecosystem levels, plays a role in supporting the four different pillars of food security.

Availability

The paper identifies three main ways in which BFA helps to improve availability of food.

First, genetic diversity provides the raw material for breeding new varieties and hybrids. Yield increases in all sectors (crop, livestock, aquatic and forests) have contributed to lifting millions out of poverty. Systematic efforts have been made since the twentieth century to discover and conserve germplasm from as many crop varieties as possible. These collections have been the most important sources of crop yield increases in agriculture globally. Equally, selection in livestock breeds, and increasingly in fish strains, has resulted in impressive yield gains.

Second, wild foods of plants and animals gathered/captured from natural habitats augment food supply. Captured fish account for about half of the global supply of fish. Although the overall contribution of wild foods to food supply is small, their contribution is significant for some commodities and in food supplies in locations situated in/on the fringes of these natural habitats.

Third, BFA contributes to food availability through various kinds of ecosystem services. These include provision of feed for domesticated animals, soil formation and restoration, and insect pollination.

However, data at subspecies level are hardly available. The analyses of statistical data at species or commodity level indicate a trend of declining dominance of the most important three commodities. The results suggest that supply and production of food has tended to become more species diverse at national level in recent decades. This is particularly true of crop production and aquaculture. In comparison, diversity of food production and supply based on terrestrial animals continues to be based on just a few species. Increasing diversity within countries can lead to increasing homogeneity across countries. The increasing diversity of supply of major food species or commodities, through production and trade, appears to go along with a declining diversity of supply of food from neglected and underutilized species, across all sectors.

Data gaps do not allow to draw a clear picture about a reduction in production system diversity in the process of agricultural intensification, but there is evidence that local genetic diversity is being lost in this process as they are replaced by modern varieties, breeds or strains. Base broadening through the introgression of specific traits sourced from genebanks occurs in major crops, but not in minor crops or livestock. However, breeding goals of commercial livestock breeding programmes for the major species have diversified.

Access

There are several ways in which BFA improves access of households (and individuals) to food. Most importantly, by contributing to increasing production BFA improves access of subsistence farmers to food and helps raise cash incomes from market-oriented agriculture. Increased production also puts downward pressure on food prices to the advantage of urban consumers.

At local level, biodiversity in natural ecosystems is a direct source of food, particularly for households living near these ecosystems. Common property resources and various ecosystem-based services are also an important source of cash income for such households.

Utilization

Diet diversity, and in turn diversity in food systems, is a critical requirement for adequate human nutrition. Data from the FAO/INFOODS database and various studies on food composition show that there are considerable species and sub-species level variations in nutrient composition. In recent years, there has been a significant refocusing of breeding goals as breeding programmes are increasingly incorporating improvement of nutrient composition of food as one of the goals. Biofortification has emerged as an important strategy to deal with micronutrient deficiencies. Apart from using for breeding, more nutritious cultivars, traditional varieties, neglected and underutilized species, and wild foods can themselves be used as a means for improved nutrition.

Many kinds of tree barks, gums and resins, roots, fruits, galls, stems, mushrooms, honey, animals and fish are rich sources of protein, fats, vitamins, minerals and other micronutrients.

Stability

A diverse agricultural system is more resilient to various types of shocks, including weather-related stress, pests and diseases, and price fluctuations. Practices such as polyculture, sequential crop rotation and mixed farming help spread the risk of crop failure, including through pests and diseases. Historically, in many parts of the world, wild foods have been used to smooth seasonality in agricultural production, and to deal with food shortages in emergencies. Stability is probably the pillar of food security where associated biodiversity plays the strongest role in supporting the domesticated genetic resources, and where data are still particularly scarce. There should be greater focus in breeding programmes on utilizing diverse genetic resources for improving resilience of food production and nutritional composition of food.

In situ and *ex situ* conservation of BFA are important elements of stability as they maintain these resources for future use. Efforts at improving *in situ* conservation have had limited success and genetic erosion of plant and animal genetic resource continues to be a serious problem. While considerable international resources have been deployed for *ex situ* conservation of genetic resources for major crops, much more needs to be done to preserve genetic resources of minor and neglected crops, animal, aquatic, forest and associated biodiversity genetic resources.

Knowledge management and awareness raising

The study also identifies huge knowledge gaps in the area of BFA. These require urgent policy attention, including in the way agricultural censuses address subspecies diversity and diverse production systems. There are large gaps in subspecies-level data on number and area planted with different crop varieties, on population of different breeds of livestock, on productivity differentials across varieties and breeds, and on subspecies variations in nutrient composition. Most countries do not regularly collect data on collection and consumption of wild foods. There are no systematic data on the extent of practices such as mixed farming, intercropping and polyculture, and production in home gardens. It is important that the international framework for collection of data is strengthened and countries establish data collection systems for better data on BFA.

The study also identifies gaps in the area of awareness raising about the importance of BFA for food security and improvements in nutritional outcomes. Messages about these should be mainstreamed in nutrition programmes and awareness programmes for consumers. The promotion of sustainable use of BFA should be mainstreamed in agricultural development policies and in extension activities for farmers.

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