Food and Agriculture Organization of the United Nations

COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

THEMATIC STUDY

BIODIVERSITY FOR FOOD AND AGRICULTURE AND ECOSYSTEM SERVICES

Thematic Study for *The State of the World's Biodiversity for Food and Agriculture*

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Executive summary

This study provides a short overview of the contributions that biodiversity for food and agriculture (BFA) makes to the delivery of ecosystem services. It is intended to complement material provided in the country reports submitted as inputs to the report on *The State of the World's Biodiversity for Food and Agriculture* (SoW-BFA). BFA is a subcategory of biodiversity taken for the purposes of the SoW-BFA (and in this thematic study) to correspond to "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 non-food agricultural products." The study considers a range of ecosystem services across the "provisioning", "regulating", "supporting", "habitat" and "cultural" categories.

The examples presented in the various sections of the document illustrate the wide range of ecosystem services provided by BFA. They also show that the benefits that a given food and agricultural production unit (i.e. farm, fish farm, forest stand, fishery or livestock holding) gains from biodiversity generally come both from within and from outside the production unit. These services are supplied, and made more resilient, by a diverse range of interacting components of biodiversity, often including those that are used in or associated with other production units (including those in other sectors of food and agriculture) and those found on land or in waters not used for food and agriculture. It follows, similarly, that flows of benefits to one production unit can be disrupted by events, including the effects of human management or mismanagement, in others and in the wider landscape or seascape. These interactions point to the need for a more integrated management of production units and their surroundings, at least at landscape (or seascape) scale. The examples also show that the biodiversity present in and around food and agricultural production systems often provides ecosystem services whose benefits are felt far beyond the food and agriculture sector (and in some cases far away in geographical terms). While there are potential "win–win" scenarios in the management of BFA for ecosystem services, there will inevitably be cases where there are trade-offs in terms of who benefits or loses out. Efforts need to be made to develop equitable ways of addressing such issues, as well as to facilitate cooperation in the implementation of mutually beneficial actions.

Assessing the significance of diversity *per se* to the capacity of BFA to supply ecosystem services is often difficult. However, experimental evidence and theoretical considerations suggest that biological communities that are more diverse at species or within-species level will often be more effective or more resilient suppliers of ecosystem services. Diversity also provides the basis for adapting production systems to future challenges to the supply of ecosystem services.

1. Introduction

This study provides a short overview of the contributions that biodiversity for food and agriculture (BFA) makes to the delivery of ecosystem services. It is intended to complement material provided in the country reports submitted as inputs to the report on *The State of the World's Biodiversity for Food and Agriculture* (SoW-BFA).[1]

1.1 Key concept

BFA is a subcategory of biodiversity taken for the purposes of the SoW-BFA (and in this thematic study) to correspond to "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 non-food agricultural products." Production systems are here taken to include those in the crop, livestock, forest, fisheries and aquaculture sectors. BFA includes plant, animal and aquatic genetic resources for food and agriculture, forest genetic resources, associated biodiversity[2] and wild foods.

The concept of ecosystems as suppliers of "services" that contribute to human well-being has gained widespread currency in recent decades. Obtaining information on the role of BFA in the supply of such services was a major objective of the country-reporting process for the SoW-BFA, which followed the Millennium Ecosystem Assessment (MEA, 2005a) in defining ecosystem services as the "the benefits humans derive from ecosystems." Such services have been categorized in various ways by different authors. For example, the Millennium Ecosystem Assessment identified the following four categories: provisioning services – "the products obtained from ecosystems"; regulating services – "benefits obtained from the regulation of ecosystem processes"; cultural services – the "nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences"; and supporting services – services "that are necessary for the production of all other ecosystem services" (ibid.). In contrast, the framework used by the Economics of Ecosystems and Biodiversity (TEEB) initiative does not treat supporting services as a separate category, but rather as a subset of the ecological processes that underlie the delivery of other services (TEEB, 2010). TEEB, however, distinguishes a separate category, habitat services, defined as services that "provide living space for resident and migratory species." In their reports for the SoW-BFA countries were invited to focus particularly on regulating and supporting services. The present study aims to cover all categories of ecosystem services. For the sake of simplicity of presentation, services are grouped into three main groups: provisioning; regulating, supporting and habitat; and cultural. Lower-level categories are based largely on those used by TEEB (TEEB, 2010).

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[1] The study was first drafted in 2016 in connection with the preparation of a draft version of the SoW-BFA that was presented to the Sixteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture. It was revised in 2018 and early 2019 in connection with the finalization of the SoW-BFA. It therefore does not cite literature published after February 2019 (other than its companion thematic studies – Dawson *et al.* [2019] and DuVal, Mijatovic and Hodgkin [2019] – and *The State of the World's Aquatic Genetic Resources for food and agiculture* [FAO, 2019], all of which were available in advanced draft form at the end of 2018). Production figures from FAO sources were updated prior to publication to reflect the latest available data as of May 2020.

[2] Associated biodiversity is described in the country-reporting guidelines for the SOW-BFA (FAO, 2013a) as "those species of importance to ecosystem function, for example, through pollination, control of plant, animal and aquatic pests, soil formation and health, water provision and quality, etc."

1.2 Links between biodiversity and the supply of ecosystem services

The capacity of ecosystems to deliver ecosystem services is inextricably linked to biodiversity. In some cases, there is a clear and direct link between a particular species and a given service, for example the provision of a particular type of food by a particular fish, crop or livestock species or the control of a particular crop pest by a particular predator species. However, the presence of any such individual species will depend on ecosystem structures and processes involving vast numbers of other species, linked in numerous ways (e.g. via food webs or habitat creation) and over a variety of time and spatial scales. Many ecosystem services need to be thought of as products of the ecosystem as a whole, for example carbon sequestration or control of water flow and quality by a forest, grassland or coastal ecosystem.

Food and agricultural production systems benefit from a range of ecosystem services generated locally (i.e. in and around the respective systems) and at a greater distance. For example, a crop production system may benefit from the services provided by insect pollinators that live in and around the fields, from the effects of a nearby woodland on the local climate and water supply, and from global climate-regulating services provided by the world's forests, grasslands, oceans and other ecosystems.

As well as benefiting from ecosystem services, food and agricultural production systems also supply them. Production systems are largely defined by their roles in the delivery of provisioning services – most notably in the production of food, but also in the supply of fibres, fuel, timber and a range of other products – and their management typically focuses mainly on these roles. However, the significance of other ecosystem services generated in and around production systems is increasingly being recognized. On the one hand, the supply of provisioning services is underpinned by regulating and supporting services (pollination, nutrient cycling, protection against disasters, etc.). On the other, production systems generate a range of non-provisioning ecosystem services, whose significance often extends far beyond the food and agriculture sector.

Given the scale and diversity involved – cropland, grasslands used for livestock grazing, marine and freshwater ecosystems used for fishing or aquaculture, and managed or harvested forests – it is clear that ecosystems used for food and agriculture (and the biodiversity in and around them) account for a substantial share of the ecosystem services generated on the planet. By the same token, the potential of crop and livestock production, forestry, fisheries and aquaculture to disrupt the delivery of ecosystem services is also enormous. Ensuring that BFA is well managed – used responsibly and sustainably and protected by conservation measures where needed – is vital to the supply of ecosystem services, both to the food and agriculture sector and beyond.

1.3 Scope and objectives of the study

The general significance of ecosystem services to human well-being – including via their contributions to food and agriculture – has been extensively reviewed in other publications, as has the significance of biodiversity in general in the supply of ecosystem services (e.g. MEA, 2005a; TEEB, 2010). This thematic study focuses more specifically on the biodiversity found in and around production systems – in particular on associated biodiversity and wild foods, but also on crops, livestock, forest trees and aquatic species used in aquaculture and targeted by fishers. It aims to provide an overview of the range of ecosystem services to which BFA contributes, the mechanisms involved, the roles played (or potentially played) by particular components of BFA and the significance of diversity *per se* at species or within-species level.

While the focus of the study is on the services provided by BFA, it clearly has to be recognized that production systems and their surroundings harbour species that can have damaging effects on food and agriculture, other socio-economic activities and/or human health. Although some effects of this kind are noted in the text, the study does not attempt to systematically explore all the ways in which plants, animals and micro-organisms can harm humans and disrupt their activities. It is also clear that the use of components of biodiversity to deliver one kind of ecosystem service can disrupt the supply of others (or directly cause "disservices" to human wellbeing and the environment). Negative environmental effects associated with crop and livestock production, forestry, fisheries and aquaculture systems have been extensively reviewed elsewhere (e.g. Steinfeld *et al*., 2006; Gerber *et al*., 2013; Smith *et al*., 2014; Edwards, 2015; Herrero *et al*., 2015; Robb *et al*., 2017; Mateo-Sagasta, Marjani Zadeh and Turral, 2018) and are not revisited in any depth in this study. While some effects of this kind are again noted (and in some cases also the potential role of BFA in reducing them), the study does not provide a detailed analysis of possible trade-offs. It thus does not provide a basis for strategic recommendations about how the components of BFA should be deployed (e.g. the expansion or contraction of particular sectors of production) to maximize overall benefits in terms of the supply of ecosystem services. Discussion of methods for increasing or maintaining flows of ecosystem services from BFA can be found in the companion thematic studies Dawson *et al*. (2019) and DuVal, Mijatovic and Hodgkin (2019).

2. Provisioning services

2.1 Food

The world's food production depends on its terrestrial and aquatic ecosystems. Figures from FAO's statistical database FAOSTAT indicate that as of 2017 approximately 82 percent of the calories in the global human food supply were provided by terrestrial plants, 17 percent by terrestrial animals and 1 percent by aquatic animals and plants.[3] The figures for protein supply were 60 percent from terrestrial plants, 33 percent from terrestrial animals and 7 percent from aquatic animals and plants. Within each of these broad categories, a range of different species – and varieties and breeds within species – are used in food production. A far wider range of species contribute to the functioning of the ecosystems upon which food production depends.

When considering the food-supply figures quoted above, it is important to recall that global averages mask the fact that certain sectors may be extremely important in specific geographical areas or to particular sections of the population: for example, fish in small island developing states and livestock in pastoral communities. Moreover, in addition to calories and protein, food security and good nutrition require adequate access to micronutrients, essential fatty acids and minerals. These are found in varying levels in the various species and populations of plants, animals and micro-organisms used as sources of food and in the products obtained from them.

2.1.1 Terrestrial domesticated animals

The vast majority of animal-source food obtained from terrestrial ecosystems comes from domesticated mammals and birds. According to FAOSTAT figures,[4] game (meat from wild animals) accounted for only 0.6 percent of global terrestrial meat production as of 2018 (although it should be noted that wild foods are generally underreported by countries).

Food production from domesticated animals is dominated by a relatively small number of species. Cattle, sheep, goats, pigs and chickens are sometimes referred to as the "big five" species on account of their major role in food production and their widespread distribution (FAO, 2015a). Viewed purely in terms of production, the "big five" could reasonably be reduced to a "big three". In 2018, Cattle, chickens and pigs together accounted for 88 percent of meat production, cattle for 81 percent of milk production and chickens for 93 percent of egg production. Beyond these three species, the biggest contributions to meat production came from sheep (3 percent), goats (2 percent), turkeys (2 percent), ducks (1 percent) and buffaloes (1 percent). Buffaloes (15 percent), goats (2 percent) and sheep (1 percent) were also relatively major contributors to the global supply of milk. Non-chicken eggs came mainly from ducks and geese.

Again, global figures mask a good deal of regional variation in the importance of particular species. For example, buffaloes rather than cattle are the leading milk producers in South Asia. "Minor" species, such as dromedaries, Bactrian camels, yaks, llamas, alpacas and reindeer play a significant role in various harsh production environments around the world.

Other bird and mammalian species that provide relatively small amounts of food in global terms include those such as horses and donkeys that are used primarily for other purposes, small mammals such as rabbits and (on a more local scale) guinea pigs, and those such as ostriches that are relatively newly domesticated or cater to niche markets. Products

[3] FAOSTAT (http://www.fao.org/faostat/en/#home) accessed May 2020.

[4] Unless otherwise indicated, all figures presented in this subsection are based on FAOSTAT data (http://www.fao.org/faostat/en/#home) accessed May 2020.

from domesticated or captive-raised terrestrial animals from taxonomic groups other than birds and mammals represent only a small fraction of global food production. In 2018, global honey production exceeded 1.85 million tonnes and production of land snails was almost 20 000 tonnes. In 2017, honey contributed 2 kcal per person per day to global food supplies.

Below the species level, domesticated animal populations are often subdivided into distinct breeds. Some of these have been developed as single-purpose breeds specialized in producing a specific food product. Others are multipurpose breeds that are good at supplying more than one type of food (e.g. both milk and meat) or can combine food production with other roles such as providing draught power. The other main significance of breed diversity is that it allows production to take place across a wide range of environments. Widely distributed livestock species generally include populations that have become adapted to extremes of climate, terrain, disease exposure and other environmental variables. They also include populations that have been developed to provide maximum output in favourable conditions. As humans' capacity to control production environments has increased, breeds of the latter type have become increasingly widespread.

Food production statistics are generally not broken down beyond the species level and it is therefore difficult to determine the contributions that different breeds or breed categories make to global production. However, some conclusions can be drawn from estimates of the contributions of different production systems.

Pig and poultry production, in particular, is increasingly dominated by specialized "industrial" production systems. MacLeod *et al*. (2013) estimated that, as of 2010, 61 percent of global pig production came from industrial systems, 20 percent from "intermediate" systems and 19 percent from "backyard" systems. The same authors concluded that only 14 percent of egg production and 4 percent of poultry meat production came from backyard production. Specialized layer systems accounted for an estimated 86 percent of egg production and 6 percent of poultry-meat production and specialized broiler systems for 81 percent of poultry-meat production (ibid.). These figures imply that a large proportion of monogastric[5] livestock production comes from the narrow range of high-output breeds that are raised in specialized industrial systems. These breeds have been intensively bred for meat or egg production and tend to be widely distributed internationally. Small-scale, backyard pig and poultry production based largely on locally adapted breeds (a wide and diverse range of breeds, reflecting diverse local conditions) is nonetheless still significant. For example, according to the above-cited study, half the pig population in developing countries was being raised in "backyard, small-scale and low-input systems in which pigs represent an important source of nutrition and income."

Food production from ruminants still comes largely from grazing or mixed crop–livestock production systems (ibid.). Animals in these systems are relatively dependent on locally available feed resources and exposed to the vagaries of the local environment. Particularly where conditions are harsh, adaptedness to specific local conditions remains important and hence a wide range of locally adapted breeds continue to be raised. Nonetheless, certain high-output breeds, such as Holstein-Friesian dairy cattle, have become very widespread and provide a disproportionately large share of the global supply of animal products from ruminants.

Finally, in addition to its significance to current food production, the diversity of animal genetic resources at species, breed and within-breed levels provides options for the future development of food production systems, whether through the introduction of species and breeds into new production systems or through breeding (genetic improvement) (FAO, 2015a).

[5] Monogastric animals are those that do not have a rumen.

2.1.2 *Terrestrial crop plants*

As noted above, terrestrial plants are the main sources of calories and protein in the human diet globally. While wild plants make important contributions to many people's diets (see Section 2.1.4 for further discussion), the bulk of the world's plant-sourced food comes from domesticated crop plants. Among the world's approximately 391 000 species of vascular plants (RBG Kew, 2016), it has been estimated that a little over 6 000 have been cultivated for food (IPK, 2018). Fewer than 200 of these species are currently produced in sufficient quantities to be listed in global production statistics (FAOSTAT), with only nine (sugar cane, maize, rice, wheat, potatoes, soybeans, oil palm, sugar beet and cassava) accounting for 67 percent of all crop production by weight in 2018. Where energy is concerned, these nine crops accounted for 70 percent of crop calories in the human food supply as of 2017.[6] In the case of protein supply, wheat, rice, maize, potatoes and soybean are the dominant individual crops globally, together accounting for 67 percent of protein supply from crops in 2017.

As is the case in other sectors, global food-supply figures for crops mask variation from region to region, country to country and locality to locality associated with differences in agroclimatic conditions, culinary traditions, levels of prosperity, etc. Moreover, figures for calorie and protein supply do not account for the significance of crop diversity to the availability of micronutrients, many of which tend to be deficient in diets based heavily on a few staple crops (e.g. Welch, 2002). It is often also the case that varieties within a given species differ significantly in their micronutrient content (e.g. Burlingame, Charrondiere and Mouille, 2009). Dietary diversity is regarded as a good predictor of dietary 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). The availability of a range of diversely adapted species and varieties also means that production can occur in a range of production environments and can help reduce the levels of inputs required (e.g. irrigation water for water-demanding crops in dry areas). Growing a range of crop species and varieties at the scale of the field, farm or landscape can give rise to a range of complementarities and synergies that increase and/or stabilize output, reduce input use and reduce risks (Dawson *et al*., 2019; DuVal, Mijatovic and Hodgkin, 2019).

Traditionally, many crop (and mixed) food production systems have been highly diverse in terms of the species and varieties grown. The overall status of within-species crop diversity on farms around the world and its precise significance in terms of food production are difficult to estimate. Relatively homogeneous, often large-scale, farms have become more widespread, and there are concerns about genetic vulnerability[7] and the loss of crop genetic diversity in many countries (FAO, 2010a). However, studies have found that many traditional varieties continue to be maintained on farm (ibid.). A large proportion of global food production comes from small farms (FAO, 2014a), many of which are relatively diverse in terms of the genetic resources they utilize. As noted above for livestock, the significance of crop diversity lies not only in its current role in production but also in the options it provides for future use in breeding programmes and in adapting farm management strategies.

[6] Unless otherwise indicated, all figures presented in this subsection are based on FAOSTAT data (http://www.fao.org/faostat/en/#home) accessed May 2020.

[7] "The condition that results when a widely planted crop is uniformly susceptible to a pest, pathogen or environmental hazard as a result of its genetic constitution, thereby creating a potential for widespread crop losses" (FAO, 1997). as a result of its ger

2.1.3 Aquatic species

A very diverse range of aquatic species are raised in aquaculture. As of 2016, production data for about 598 "species items"[8] had been recorded by FAO: 369 of finfish; 109 of molluscs; 64 of crustaceans; 9 of other aquatic invertebrates; 7 of amphibians and reptiles; and 40 of aquatic algae (FAO, 2018a). Moreover, many of the country reports submitted as a basis for the preparation of the report on *The State of the World's Aquatic Genetic Resources for Food and Agriculture* (FAO, 2019) indicated that more species were being farmed than had been reported via the regular FAO statistical survey. Countries also reported a number of species considered to have potential for future use in aquaculture. Despite the large total number of species items farmed, production at national, regional and global levels is dominated by a relatively small number of "staple" species (FAO, 2018a). For example, in 2016, 27 species items supplied more than 90 percent of farmed finfish production.[9]

Among[10] freshwater and diadromous fish,[11] farmed types range from low trophic-level species, such as carps, barbs, tilapia and pacu, to highly carnivorous species such as salmon, eel and snakehead. The majority of production volume comes from lower trophic-level species – relatively efficient producers of high-quality protein and thus of major significance to global food security. The salmonids are very significant in value terms, and improvements to their production systems mean that these carnivorous fishes are becoming more efficient users of feed resources. Although marine finfish represent a low proportion of total finfish aquaculture production, 33 different families are farmed. Farmed marine finfish tend to be carnivorous (e.g. snappers, groupers, pompano and tuna), but also include a few species that are omnivorous or herbivorous (e.g. mullet, scats and rabbitfish). Among crustaceans, marine/brackishwater production is dominated by the penaeid shrimp, with minor contributions from other families such as lobsters and metapenaeids. Freshwater crustacean aquaculture production comes from Chinese mitten crab, various crayfish/crawfish species and Macrobrachium freshwater prawns. Farmed molluscs are mainly bivalves and gastropods. Cephalopod aquaculture production is very limited. Other species contributing to aquaculture production include sea cucumbers, sea urchins, frogs and turtles. Crocodile production is growing quickly in Asia. Aquatic plant production is dominated by seaweeds.

Table 1 shows the contributions of different taxonomic groups to world food production from aquaculture in 2016. In the case of inland aquaculture, finfish production is very dominant, although the proportion of production accounted for by this taxonomic group declined from 97.2 percent to 92.5 percent between 2000 and 2016, because of relatively faster growth in other categories, particularly an increase in the production of crustaceans (including shrimps, crayfish and crabs) in Asia (FAO, 2018a). In marine and coastal aquaculture, in contrast, mollusc production dominates in terms of volume produced. Crustaceans account for a relatively small percentage of production volume, but are disproportionally significant in value terms. Aquatic animals belonging to other taxonomic groups are still quite marginal in terms of production volume, although some, such as Japanese sea cucumber (*Apostichopus japonicas*), are of high value. Global farmed aquatic plant production amounted to 30 million tonnes in 2016, up from 13.5 million tonnes in 1995 (ibid.).

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[8] A species item is a single species, a group of species (where identification to the species level is not possible) or an interspecific hybrid.

[9] Detailed production statistics can be found in FAO's Fishery and Aquaculture Statistics Yearbooks: http://www.fao.org//fishery/publications/yearbooks/en

[10] This paragraph is based on FAO (2019).

[11] Fish species that migrate between freshwater and the sea.

Table 1. World food production from animal aquaculture in 2016, by taxonomic group

	Inland aquaculture	Marine and coastal aquaculture	Quantity total		Value total	
	(tonnes)	(tonnes)	(tonnes)	(Percentage by volume)	(USD billion)	(Percentage by value)
Finfish	47 516	6 575	54 091	68	138.5	60
Crustaceans	3 033	4 829	7862	10	57.1	25
Molluscs	286	16 853	17 139	21	29.2	13
Other animals	531	407	938	1	6.8	3
Total	51 367	28 664	80031	100	231.6	100

Source: Data from FAO, 2018a.

Marine capture fishery production amounted to 79.3 million tonnes in 2016, 41.9 percent of which came from 25 major species and genera (FAO, 2018a). Most of these were finfish – largest contributors were the Alaska pollock (*Theragra chalcogramma*), anchoveta (*Engraulis ringens*), skipjack tuna (*Katsuwonus pelamis*) and sardinellas (*Sardinella* spp.) – but they also included the jumbo flying squid (*Dosidicus gigas*), the Gazami crab (*Portunus trituberculatus*) and the Akiami paste shrimp (*Acetes japonicas*). Inland capture fishery production amounted to 11.6 million tonnes in 2016. A large number of species contribute to this production. However, much of the reported output is not broken down by species, i.e. production is only noted as coming from freshwater fish, molluscs or crustaceans (FAO, 2018a). Among production for which species is recorded, the predominant species are the carps and other cyprinids, tilapia, Nile perch and freshwater prawns.

In addition to their contributions to the supply of calories and protein, aquatic species are also important sources of vitamins and pigments (e.g. spirulina and artemia) and omega-3 lipids (oily fish and marine phytoplankton) and are widely used in the production of food (and animal-feed) supplements (Coutteau *et al.*, 1997; Sargent, 1997; Habib *et al.*, 2008; de Deckere, 2001; Simopoulos, 1991; Adarme-Vega *et al.*, 2012).

Production data at the level of stocks and strains within species are limited in the aquatic sector. However, within-species diversity enables production in a range of different environments and provides the basis for adaptation to future changes through natural or human-controlled selection (FAO, 2008a).

2.1.4 Wild foods

Wild foods, as defined for the purposes of the SoW-BFA, are food products obtained from non-domesticated species. However, the distinction between wild and domesticated sources is not clear cut: wild foods have been described as lying “along a continuum ranging from the entirely wild to the semidomesticated, or from no noticeable human intervention to selective harvesting, transplanting, and propagation by seed and graft” (Harris, 1989). They may be harvested, gathered or hunted in natural or semi-natural ecosystems or in and around cultivated/intensively managed production systems (crop fields, plantations, gardens, fishponds, etc.). Wild foods include a diverse variety of products, ranging from mushrooms, fruits, leafy vegetables, woody foliage, bulbs and tubers, cereals and grains, nuts and kernels, and saps and gums to honey, birds’ eggs, fish and shellfish, terrestrial invertebrates such as insects and snails and meat from small and large vertebrates (Bharucha and Pretty, 2010; Shackleton *et al.*, 2010; CBD and WHO, 2015). Within each of these groups, up to several hundred different species may be eaten.

The most important category of wild food in terms of volume and protein supply globally is wild-caught fish and aquatic invertebrates (see Section 2.13). Capture fisheries are particularly significant to food security in certain regions of the world, including notably Oceania, where average national annual consumption of fish (including shellfish) per person in 2013 was 27 kg, relative to a global average of 19 kg. Figures for Melanesia (34 kg), Polynesia (46 kg) and Micronesia (72 kg) were even higher.[12] Bell *et al.* (2013) report figures of 146 kg per person per year for coastal fishing communities in Tuvalu. Freshwater capture fisheries are extremely important in many developing countries, particularly in landlocked areas such as the interiors of Southeast Asia, Africa and South America.America.

Wild foods are a major non-wood forest product (NWFP). Recent global figures for the value of NWFPs have not been published. However, in 2005, the value of recorded food products from forests (mostly fruit, berries, mushrooms and nuts) amounted to more than USD 8.6 billion globally, with wild honey and beeswax accounting for a further USD 1.8 billion, wild meat for USD 577 million and "other edible animal products" for USD 1 million (FAO, 2010b). Given that most NWFPs do not enter the commercial market and that there are many gaps in reporting and in the availability of data and relevant assessment tools at country level (FAO, 2014b; Sorrenti, 2017; FAO, 2016a), these figures are likely to be considerable underestimates of the actual value of wild foods from forests. More recent figures for the value of NWFPs, including wild foods, in Europe are given in Section 2.2.3.

Wild foods contribute significantly to the food security of very large numbers of people (Bharucha and Pretty, 2010; Rowland *et al.*, 2017; Sunderland, 2011). However, the site-specific nature of the data available on frequency of consumption, species consumed and contributions to protein, energy and micronutrient dietary intakes means that global estimates of the importance of wild foods to nutrition are difficult to establish. A lack of information on the nutritional composition of wild foods (Bharucha and Pretty, 2010; Colfer, Sheil and Kishi, 2006; Grivetti and Ogle, 2000; Powell *et al.*, 2015) and on the variability of nutritional composition within species (Stadlmayr *et al.*, 2013; Toledo and Burlingame, 2006) is another constraint. Powell *et al.* (2015) note that although the contribution of wild foods to total energy and protein intake is generally low, several studies have identified cases in which a high proportion of the dietary intake of micronutrients is obtained from wild foods. A survey of nearly 8 000 rural households in 24 countries across Africa, Latin America and Asia found that 39 percent of households harvested wild meat, most of which was used for subsistence, indicating that wild meat is a major source of protein and other nutrients for many millions of rural people in the tropics and subtropics (Nielsen *et al.,* 2018).

Wild foods are consumed for a wide range of reasons and in a variety of circumstances, including both year-round and seasonal use, the latter occurring for example when other foods are in short supply or when people have time to harvest them because of lulls in other activities. They make a range of contributions to livelihoods, food security and nutrition, including by increasing dietary diversity, increasing resilience against shocks such as crop failure and providing a source of income via sales (Bharucha and Pretty, 2010; Hickey *et al.*, 2016; Johns and Sthapit, 2004; Schulp, Thuiller and Verburg, 2014; Vinceti *et al*., 2013; Wunder, Angelsen and Belcher, 2014).

2.2 Raw materials

Crop, livestock, forest and aquatic production systems and the biodiversity used in and associated with them supply a wide range of non-food products, including materials used as fuels, in construction and in the manufacture of textiles, clothing, cosmetics and many

[12] Figures from FAOSTAT (http://www.fao.org/faostat/en/#home) accessed May 2020.

other goods. Ornamental products and materials used for medical and other biochemical purposes are discussed separately in Sections 2.4 and 2.5.

2.2.1 Terrestrial domesticated animals

In terms of the value of marketed products, the most significant non-food materials produced by the livestock sector are fibres, hides and skins. Global sheep-wool production in 2018 amounted to almost 2 million tonnes.[13] Fibres from other animals are produced in much lower quantities, but include high-quality products such as alpaca wool, cashmere and mohair. Within-species breed diversity adds to the diversity of fibres available. A range of species and breeds also provides diversity in the supply of hides and skins (global production of cattle, buffalo, sheep and goat hides and skins was almost 12.3 million tonnes in 2018). Animal dung, as well as being a major source of manure for use in agriculture, is widely used as a fuel, either in the form of dung cakes or as a source of biogas.

As well as providing material products, livestock are also a source of motive power. Species such as horses, donkeys, cattle and dromedaries provide transport for goods and people and traction in agriculture. At the end of the twentieth century, 30 percent of cropland in developing countries was being cultivated using draught animals (the remaining 70 percent was equally divided between hand and mechanized cultivation) (FAO, 2003). The share of animal power was predicted to fall to 20 percent overall by 2030, but to increase in sub-Saharan Africa (ibid.). Again, the availability of a range of breeds – including specialized draught, pack and riding animals – underpins the supply of these services.

2.2.2 Terrestrial crop plants

Major non-food products obtained from crop plants include biofuels and fibres. The former include liquids (e.g. ethanol and biodiesel), biogas and solid biomass. Ethanol is obtained from plant materials that contain large amounts of sugar or substances that can be converted into sugar (FAO, 2008b). Production is largely based on sugar crops (sugar cane and sugar beet) and starchy crops, such as cereals, i.e. on materials that could potentially be eaten by humans. Only a small fraction comes from lignocellulosic materials, such as wood and straw (OECD/FAO, 2016). Biodiesel is produced using oil extracted from crops such as rapeseed, oil palm, soybean, sunflower, peanut and jatropha (FAO, 2008b). Sources of biomass for heat and power include various agro-industrial and post-harvest residues and dedicated energy crops such as short-rotation perennials (eucalyptus, poplar, willow) and grasses (miscanthus and switchgrass) (ibid).

Where fibres are concerned, cotton is by far the most significant crop in terms of production volume; other major natural fibres derived from plants include jute, sisal, flax and hemp (van Dam, 2008). As with food crops, genetic diversity within fibre-producing species is vital to efforts to increase productivity and address threats such as pests and diseases (FAO, 2010a). Many fibre crops supply important by-products such as oilseeds (van Dam, 2008). Some provide materials used for an extremely wide range of purposes. The global market for hemp, for example, reportedly encompasses more than 25 000 products across the agriculture, textile, recycling, automotive, furniture, food and beverage, paper, construction and personal-care sectors (Johnson, 2018).

Crop plants provide vital raw materials for livestock production. An estimated 19 percent of dry matter fed to livestock globally consists of crop residues (straws, stovers, sugar-cane tops and banana stems), 13 percent of human-edible grains and 8 percent of "fodder crops" (grain and legume silage and fodder beets), with oil-seed cakes and other agro-industrial by-products accounting for another 10 percent each (Mottet *et al.*, 2017).

[13] All figures in this paragraph taken from FAOSTAT (http://www.fao.org/faostat/en/#home) accessed May 2020.

Part of the 46 percent accounted for by "grass and leaves" (ibid.) comes from sown grasses, legumes and other forages. A wide range species and varieties are grown as forage crops around the world, with the particular types and combinations grown varying depending on the climate and the nutritional needs of the animals fed (Capstaff and Miller, 2018). Genetic improvement of forage species is a relatively recently established activity as compared to that of cereals, fruits and vegetables, and has focused mainly on increasing yields and tolerance of harsh climatic conditions (ibid).

2.2.3 Forests and trees outside forests

Forests and trees outside forests supply a vast range of wood products and NWFPs. The former include wood used in construction, for pulp, in the manufacturing of a wide variety of wooden items, including furniture and tools, and as fuel. Global roundwood[14] production in 2018 amounted to 4 billion m^3, 1.9 billion m^3 of which was used for wood fuel.[15] NWFPs, in addition to food, ornamental and medicinal products (see Sections 2.1, 2.4 and 2.5), include a range of other plant- and animal-sourced materials such as bamboo (e.g. for use in construction and the manufacture of household items, tools and textiles), rattan (e.g. for use in producing furniture, canes, clothes and decorative items), cork (e.g. for use in wine bottling and in construction), bark, latexes, gums, resins (e.g. for use in producing turpentine), hides, skins and beeswax.[16] While synthetic alternatives to many NWFPs have been developed, in places there is now a resurgence of interest in natural products that are less polluting or higher in quality or that embody aspects of local culture, including in the context of hobby interest in traditional crafts and "survival skills" (Wong and Wiersum, 2019).

As noted in Section 2.14, no recent global figures for the value of NWFPs have been published and older published figures are recognized as being considerable underestimates. Regional figures for Europe (not including the Russian Federation) put the value of marketed NWFPs at EUR 1.6 billion for plant products (of which 47.2 percent came from ornamental plants, 29.0 percent from food, 20.9 percent from other plant products, 1.5 percent from raw material for medicine and aromatic products, 0.7 percent from exudates and 0.7 percent from raw materials for utensils handicrafts and construction) and EUR 0.62 billion for animal products (of which 51.10 percent came from wild meat, 45.68 percent from wild honey and beeswax, 2.90 percent from hides skins and trophies, 0.21 percent from other edible and non-edible animal products, 0.08 percent from living animals and 0.02 from raw materials for medicine) (Forest Europe, 2015). Thus, raw materials for uses other than food, ornament and medicines account for a relatively small proportion of the recorded value of NWFPs. Global figures for 2005 (FAO, 2010b) also show food and ornamental plants accounting for most of the recorded value of NWFPs.

Material obtained from forests and trees are crucial to the livelihoods of many people around the world. For example, as of 2011 an estimated 2.4 billion people (34 percent of the global population) relied on wood fuel (wood or charcoal) for cooking, including 63

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[14] Roundwood comprises "all wood obtained from removals, i.e. the quantities removed from forests and from trees outside the forest, including wood recovered from natural, felling and logging losses during the period, calendar year or forest year. It includes all wood removed with or without bark, including wood removed in its round form, or split, roughly squared or in other form (e.g. branches, roots, stumps and burls (where these are harvested) and wood that is roughly shaped or pointed. It is an aggregate comprising wood fuel, including wood for charcoal and industrial roundwood (wood in the rough). It is reported in cubic metres solid volume underbark (i.e. excluding bark)." (Eurostat *et al*., 2018).

[15] FAOSTAT data accessed May 2020.

[16] According to FAO (1999), "non-wood forest products consist of goods of biological origin other than wood derived from forests, other wooded land and trees outside forests." However, a range of range of different terms and definitions are used to describe products of this kind (Sorrentini, 2017). In the case of the Global Forest Resources Assessment, countries are invited to report on "goods derived from forests that are tangible and physical objects of biological origin other than wood" (FAO, 2018b).

percent of the population of Africa, 38 percent of the population of Asia and Oceania and 15 percent of the population of Latin America and the Caribbean (FAO, 2014c). As of the period 2000 to 2010, at least 1.3 billion people were living in homes where the walls, roofs or floors were constructed mainly from forest products, including 1 billion in Asia and Oceania and 150 million in Africa (ibid.).

Natural rubber,[17] which is mainly produced from the latex of the rubber tree (*Hevea brasiliensis*), is a major industrial raw material that is used for a variety of purposes, including in the production of tyres. Rubber trees are grown exclusively in the developing regions of the world: FAOSTAT data for 2018 indicate that 90 percent of the 14.3 million tonnes produced globally came from Asia.[18]

The total number of tree species in the world is estimated to be about 60 000 (Beech *et al*., 2017). Country reports submitted to FAO as inputs to the preparation of *The State of the World's Forest Genetic Resources* (FAO, 2014a) refer to more than 1 000 species "actively managed" for timber, a similar number for non-wood forest products (including foods) and about 500 for fuel. Many more are used in one way or another as sources of raw materials of various kinds. However, planted forests, which make up about 7 percent of the global forest area and account for more than 50 percent of the world's industrial roundwood production, are largely based on about 30 tree species belonging to four genera (*Acacia, Eucalyptus, Pinus* and *Populus*) (ibid).

Genetic diversity within tree species enables them to grow across a range of environmental conditions and to provide products with a variety of specific characteristics. Genetic diversity also provides the basis for evolution in response to changes in environmental conditions and for genetic improvement programmes aimed at increasing yield or resistance to diseases or other stressors. Globally, more than 700 tree species are subject to genetic improvement activities of some kind (FAO, 2014b).

2.2.4 Aquatic species

Non-food products provided by aquatic plants and animals include natural sponges, fish-skin leathers, hides from alligators and other reptiles, jewellery (e.g. pearls and abalone and trochus shells) and cosmetic compounds. A number of aquatic plant species provide products that are essential for food processing and other industrial purposes. For instance, phyco-colloids derived from seaweeds (e.g. alginates and carrageenans) have a wide range of uses as binders and gelling agents in processed foods (Hurtado, 2017). Marine algae, especially seaweeds, are also harvested for use in biofuel production (Mata, Martins and Caetano, 2010; Milledge *et al*., 2014).

2.3 Freshwater

Ecosystems contribute in many ways to the supply of freshwater that can be used domestically, in food and agricultural production systems and in industry. For example, vegetation, particularly forest vegetation, is thought to influence rainfall levels.[19] Vegetation, as well as dead plant material that provides soil cover, also affects the balance between water infiltration into the soil and run-off into downstream areas. Infiltration and run-off rates are also affected by soil structure, soil texture and soil organic matter content, which are in turn affected by the actions of (among other components of biodiversity) soil micro-organisms and invertebrates (see Section 3.3 for further discussion). Increasing

[17] The explanatory notes to the terms and definitions used for the Global Forest Resources Assessment indicate that non-wood forest products specifically include rubber/latex whether from natural forests or plantations (FAO, 2018b).
[18] FAOSTAT data (http://www.fao.org/faostat/en/#home), accessed May 2020.
[19] For further discussion, see Section 3.1.2.

infiltration rates means that water is released more slowly and over a longer period, which may help to keep streams and rivers flowing during dry periods of the year (TEEB, 2010).

Ecosystems also contribute to water purification. A range of different physical, chemical and biological processes contribute to removing contaminants (harmful organic and inorganic substances, pathogenic microbes, etc.) from water supplies as they pass through soils or through water bodies such as rivers and lakes. Many different organisms contribute to the process of filtering pollutants before they can enter waterbodies, "pumping" them from the water (e.g. into bottom sediments or the atmosphere) or degrading them into benign or less harmful components (Ostroumov, 2010).

The precise relationships between the levels of biodiversity within ecosystems and their capacity to deliver services related to the regulation and purification of water flows are not well understood. Structural diversity within a stand of vegetation increases the range of mechanisms through which runoff can be reduced. There is also some evidence that greater species diversity within a particular type of plant community is associated with a greater capacity to prevent excess run-off (see Section 3.3.1). Invertebrate and micro-organism diversity plays a vital role in the formation and maintenance of healthy soils (see Section 3.3.2) and hence to the water-holding and water-purifying services provided by soil ecosystems. The significance of algal species diversity in water purification has been investigated experimentally using artificial streams. For example, Cardinale (2011) showed that a mixture of eight algal species could remove nitrate from the water 4.5 times faster than one species could, the effect arising because of the abilities of the different species to occupy different niches within the stream. Overall, however, there is limited evidence that, in practice, more-diverse ecosystems are more effective than less-diverse ones as providers of water-purification services. Cardinale *et al*. (2012) concluded that more studies had found no relationship between diversity and water-purification capacity than had found a positive relationship.

Many rivers, streams and lakes are bordered by crop, livestock, aquaculture or forest production systems. Riparian forest and grassland vegetation can play a significant role in reducing the flow of sediment, excess nutrients and other pollutants into waterbodies, and "buffer" strips are sometimes planted specifically to deliver this service (Klapproth and Johnson, 2000). The other side of the coin, however, is that crop, livestock, forest and aquaculture production systems are often major sources of pollutant flows into water bodies and thus, where water quality is concerned, are providers of ecosystem disservices rather than services. Various components of BFA can, however, contribute to reducing these disservices. For example, the use of inputs such as pesticides, fertilizers and veterinary drugs that may end up as pollutants of aquatic ecosystems can be reduced by using more disease-resistant or pest-resistant varieties or breeds of domesticated plants, fish or terrestrial livestock, or by taking advantage of the pest-control and soil fertility-enhancing services provided by associated biodiversity.

2.4 Medicinal and other biochemical resources

Many components of BFA are valued for their medicinal properties or as sources of biochemical substances that can be used in the manufacture of pharmaceuticals, cosmetics, crop protection agents and other biochemical products. For example, domesticated plant species contain a wide range of chemical compounds that can be used for such purposes (Harborne, Baxter and Moss, eds, 1999; Ranalli, ed, 2007). Many agricultural by-products can be used as substrates for microbial processes that generate substances such as organic acids, enzymes, surfactants and pigments (Chatzipavlidis *et al.*, 2013). Various marine species are sources of bio-active compounds that can be used as pharmaceuticals (e.g. haemocyanin from the keyhole limpet) (Donia and Hamann, 2003; Harnedy and FitzGerald, 2012; Harris and Markl, 1999; Kim and Mendis, 2006; Rocha *et al.*, 2011;

Sipkema *et al.*, 2005). Terrestrial livestock species are also sources of various pharmaceutical substances, including insulin, antibodies and hormones (Redwan, 2009).

Numerous medicinal plant species, especially aromatic herbs, are grown in home gardens around the world and some are cultivated as field crops (Schippmann, Cunningham and Leaman, 2002). Many people in developing countries rely heavily on medicinal species collected from the wild, for example from forest ecosystems. A range of different industries engage in bioprospecting for substances with valuable properties or for species with characteristics that can provide models or inspiration for new innovations (Beattie *et al.,* 2011). Many commercially traded medicinal plants are collected from the wild rather than being cultivated (Schippmann, Cunningham and Leaman, 2002; Chen *et al.*, 2016).

2.5 Ornamental resources

Ornamental products are a significant component of the provisioning services provided by BFA. For example, domesticated ornamental plants are of major cultural[20] and economic importance (Ciesla, 2002; van Tuyl *et al.*, 2014). Aesthetic objectives are often important in breeding strategies for pet or companion animals. Among many domesticated species raised for food and agricultural purposes, some breeds or varieties are valued primarily for their aesthetic characteristics. There are, for example, many "fancy" breeds of chicken, pigeon, rabbit and other species. Among crops and forages, there are ornamental varieties of species such as cabbage, capsicum, tall grass and pumpkin. Many tree species have long been used for ornamental purposes. Their aesthetic features (e.g. foliage colour and density, form, size and shape), their fragrances and the shade they provide help to create serene settings in gardens, city parks, along streets, etc., and natural and planted woodlands and trees are often key elements of visually appealing rural landscapes (Ciesla, 2002). Ornamental tree species are embedded in many rituals, celebrations and customs (Crews, 2003). Ornamental fish include species specifically bred for their appearance as well as species that are taken from the wild. It has been estimated that the freshwater aquarium trade relies on cultured animals for around 98 percent of its products and that only 2 percent are captured (Sugiyama, Staples and Funge-Smith, 2004). The reverse is true for the marine aquarium trade, which relies on capture for 98 percent of its production (ibid.). The global marine aquarium trade regularly transports large numbers of species. Wabnitz *et al.* (2003) provide a figure of 1 471 species of fish traded worldwide. Rhyne *et al.* (2012) report that over marine 1 800 aquarium species were imported into the United States of America alone in 2005.

[20] The cultural significance of BFA and the products it supplies is further discussed in Section 4.