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联合国粮食及农业组织 Food and Agriculture Organization of the United Nations Organisation des Nations Unies pour l'alimentation et l'agriculture Продовольственная и сельскохозяйственная организация Объединенных Наций Organización de las Naciones Unidas para la Alimentación y la Agricultura منظمة الأغذية والزراعة للأمم المتحدة

COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

Item 2.1 of the Provisional Agenda
Sixteenth Regular Session
Rome, 30 January - 03 February 2017
THE STATE OF THE WORLD'S BIODIVERSITY FOR FOOD AND AGRICULTURE (DRAFT)

Status of preparation

Several parts of the draft *State of the World's Biodiversity for Food and Agriculture* have been drafted. It is however incomplete, with some sections at an early stage of drafting. While a number of sections of the draft Report have been reviewed by FAO and external experts, these sections still need to be revised and completed. Review of the remaining sections remains to be arranged. The whole Report needs to be further edited to ensure internal consistency and improve readability. The acknowledgements, preface, executive summary and list of abbreviations and acronyms still need to be prepared and will be included in the final report.

This document has been revised on 23 February 2017.

DRAFT REPORT

THE STATE OF THE WORLD'S BIODIVERSITY FOR FOOD AND AGRICULTURE

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COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2016

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The source for names of administrative units is the Food and Agriculture Organization Names of Countries and Territories (NOCS). The primary source of boundaries and administrative units is the Food and Agriculture Organization Global Administrative Unit Layers (GAUL). Disputed boundaries and undetermined regions have been added based on the United Nations Cartographic Section, Department of Field Support maps. More information can be found using the following resources:

Names of Countries and Territories (NOCS)
Food and Agriculture Organization of the United Nations (UNFAO)
http://termportal.fao.org/faonocs/appl/

Global Administrative Unit Layers (GAUL)
Food and Agriculture Organization of the United Nations (UNFAO)
http://www.fao.org/geonetwork/srv/en/main.home?uuid=f7e7adb0-88fd-11da-a88f-000d939bc5d8

United Nations Cartographic Section, Department of Field Support.
http://www.un.org/Depts/Cartographic/english/htmain.htm

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ABOUT THIS PUBLICATION

Background

This report presents the first global assessment of biodiversity for food and agriculture. It complements other global assessments prepared under the auspices of the Commission on Genetic Resources for Food and Agriculture (see Box 1), which have focused on the state of genetic resources within particular sectors of food and agriculture.

Box 1. The Commission on Genetic Resources for Food and Agriculture

With its 178 member countries, the Commission on Genetic Resources for Food and Agriculture offers an intergovernmental forum where global consensus can be reached on policies relevant to biodiversity for food and agriculture. The main objective of the Commission is to ensure the conservation and sustainable use of genetic resources for food and agriculture and the fair and equitable sharing of benefits derived from their use, for present and future generations. Its work focuses on developing and overseeing the implementation of policies and supporting initiatives that raise awareness and seek to solve emerging problems. It guides the preparation of periodic global assessments of the status and trends of genetic diversity, the threats facing genetic diversity and the measures being taken to promote its conservation and sustainable use. The Commission also negotiates global action plans, codes of conduct and other instruments relevant to the conservation and sustainable use of genetic resources for food and agriculture.

Scope and contents of the report

The State of the World's Biodiversity for Food and Agriculture (SoW-BFA) addresses the sustainable use, development and conservation of biodiversity for food and agriculture worldwide. Biodiversity for food and agriculture is taken to include the variety and variability of animals, plants and micro-organisms at the genetic, species and ecosystem levels that sustain the structures, functions and processes in and around production systems, and that provide food and non-food agricultural products.

The reporting and preparatory process

At its Eleventh Regular Session, in 2007, the Commission on Genetic Resources for Food and Agriculture adopted a number of major outputs and milestones to be addressed in its Multi-year Programme of Work,[1] including the presentation, at its Sixteenth Regular Session, of the SoW-BFA. At its Fourteenth Regular Session, in 2013, the Commission requested FAO to prepare the SoW-BFA, for consideration at its Sixteenth Regular Session.[2] It stressed that the process for preparing report should be based on information from country reports and should also draw on thematic studies, reports from international organizations and inputs from other relevant stakeholders, including centres of excellence from developing countries. It stressed that the report should focus on interactions between sectors and on cross-sectoral matters, taking full advantage of existing information sources, including sectoral assessments. It also suggested that priority be given to information not available in existing sources.

Inputs to the report

The main sources used to prepare the SoW-BFA were as follows:

Country reports

[1] CGRFA-11/07/Report, para. 90.
[2] CGRFA-14/13/Report, para. 14.

In June 2013, FAO invited countries to officially nominate national focal points to lead the preparation of country report s to be submitted to FAO to support the preparation of the SoW-BFA. FAO prepared guidelines to support the development of country reports. The guidelines outlined the suggested content of the report and provided questions to assist countries with their strategic analysis and with the development of each section of the reports. The guidelines were made available in all six official FAO languages (Arabic, Chinese, English, French, Russian and Spanish) and both in read-only form and as a dynamic version into which countries could enter their responses and thereby generate a preformatted country report.[3]

In April and May 2016, in response to a request by the Commission at its preceding session, FAO organized a series informal regional consultations at which countries and other stakeholders could share knowledge and information on the state of biodiversity for food and agriculture and discuss needs and priorities for the conservation and sustainable use of biodiversity for food and agriculture. The informal regional consultations also served to support national focal points in the finalization of their country reports. As supporting documentation for each informal regional consultation, FAO prepared a draft regional synthesis report based on the country reports that had so far been submitted. The regional synthesis reports were subsequently finalized based on feedback received from the participants of the informal regional consultations and on additional country reports received.

By 30 September 2016, 71 country reports had been received (see Table 1).

Table 1. Overview of country reports and their regional distribution

Region	Countries
Africa (12)	Burkina Faso, Cameroon, Chad, Ethiopia, Gabon, Gambia, Guinea, Kenya, Mali, Senegal, United Republic of Tanzania, Zambia
Asia (7)	Afghanistan, Bangladesh, Bhutan, India, Nepal, Sri Lanka, Viet Nam
Europe and Central Asia (19)	Belgium, Bulgaria, Croatia, Estonia, Finland, France[4], Germany, Hungary, Ireland, Netherlands, Norway, Poland, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom
Latin America and the Caribbean (14)	Argentina[5], Bahamas, Costa Rica, Ecuador, El Salvador, Grenada, Guyana, Jamaica, Mexico, Nicaragua, Panama, Peru, Saint Lucia, Suriname
Near East and North Africa (8)	Egypt, Iraq, Jordan, Lebanon, Oman, Sudan, United Arab Emirates, Yemen
North America (1)	United States of America
Pacific (10)	Cook Islands, Fiji, Kiribati, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga

Reports from international organizations

In April 2016, FAO invited 55 international organizations to report on their activities related to the management of biodiversity for food and agriculture using a standardized questionnaire. Responses were received from the following organizations: Africa Rice Center (AfricaRice); African Union – Interafrican Bureau for Animal Resources (AU-IBAR); African Union Commission, Department of Rural Economy and Agriculture; Bioversity International; Centre for Agriculture and Biosciences International (CABI); Global Crop Diversity Trust; IFOAM Organics International; Inter-American Institute for Cooperation on Agriculture (IICA); International Atomic Energy Agency (IAEA); International Center for Agricultural Research in the Dry Areas (ICARDA); International Center for Tropical Agriculture (CIAT); International Centre of Insect Physiology and Ecology (ICIPE); International Food Policy Research Institute (IFPRI); International Fund for Agricultural Development (IFAD); International Institute of Tropical Agriculture (IITA); International Maize and Wheat Improvement Center (CIMMYT); International Union for Conservation of Nature (IUCN); Pacific Organic and Ethical Trade Community (POETCom); Secretariat of the Convention on Biological Diversity; Slow Food; Tropical Agricultural Research and Higher Education Center (CATIE); United Nations Environment Programme – World Conservation Monitoring Centre (UNEP-WCMC); World Agroforestry Centre (ICRAF); World Bank. In addition, Oxfam voluntarily provided a report entitled

[3] The dynamic questionnaire was made available in Chinese, English, French, Russian and Spanish.
[4] Information on the state of France's biodiversity for food and agriculture is taken from a preliminary draft report.
[5] Information on the state of Argentina's biodiversity for food and agriculture is taken from a preliminary draft report.

Women's roles in biodiversity management from lessons to practice and impact: scaling up pathways in people's biodiversity management, containing case studies from Peru, Viet Nam and Zimbabwe.

Thematic studies

The following three thematic studies providing in-depth analysis of specific topics relevant to biodiversity for food and agriculture were prepared for the SoW-BFA:

- Biodiversity for food and agriculture: the perspectives of small-scale food providers
- The contribution of biodiversity for food and agriculture to resilience of production systems to environmental change and uncertainty
- The contributions of biodiversity to the sustainable intensification of food production

Regional synthesis reports

As described above, the series of informal regional consultations held in 2016 involved the preparation of a regional synthesis report for each region where consultations were held. The contents of these synthesis reports served as source material for the global analysis presented in the draft SoW-BFA.

State of the world reports

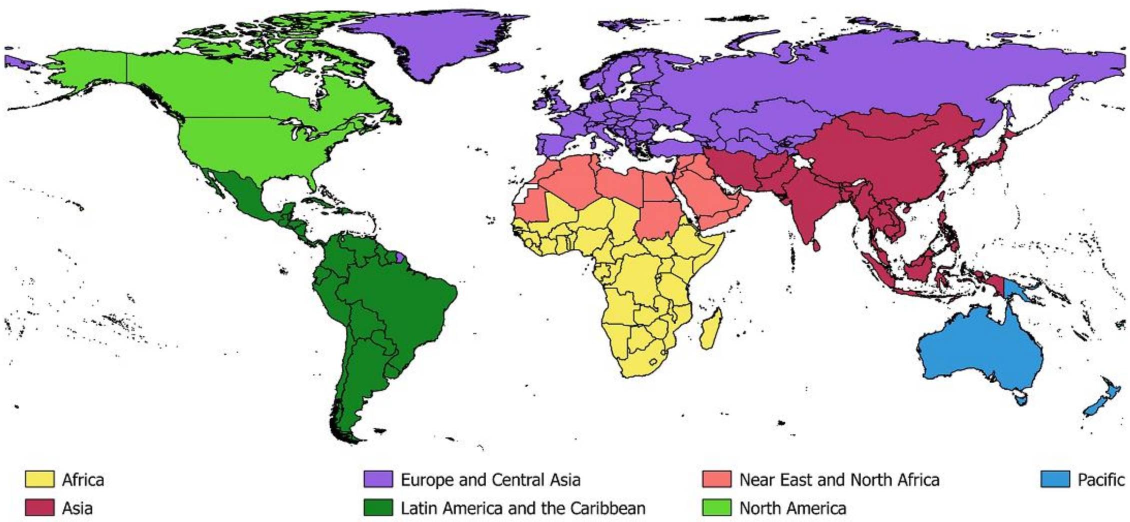
The subsections of the draft SoW-BFA that address plant (crop), animal (livestock), forest and aquatic biodiversity draw heavily on the respective global assessments (state of the world reports) published or in preparation under the auspices of the Commission on Genetic Resources for Food and Agriculture.

Regional classification of countries

The assignment of countries to regions follow the regional groupings used in FAO statistics and for election purposes (Figure 1). Seven regions are distinguished:

- Africa
- Asia
- Europe and Central Asia
- Latin America and the Caribbean
- Near East and North Africa
- Pacific

Figure 1. Assignment of countries to regions in this report



CONCEPTS AND DEFINITIONS

Biological diversity (often referred to as biodiversity) is defined in Article 2 of the CBD as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems" (CBD, 1992).

Biodiversity for food and agriculture (BFA) is a category of biodiversity taken for the purposes of this report 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." BFA comprises all biodiversity of relevance to food and agriculture, including genetic resources, associated biodiversity and the ecosystem services they support, and wild foods. Production systems (see below for further discussion of this term) are here taken to include those in the crop, livestock, forest, fishery and aquaculture sectors.

Associated biodiversity is a subcategory of biodiversity for food and agriculture. The concept is perhaps most familiar in the crop sector, where the biodiversity of harvested domesticated crop plants is distinguished from crop-associated biodiversity, the range of other species present in and around the production system that sustain ecosystem structures, functions and processes (e.g. Waliyar *et al.*, 2002; Lenné and Wood, 2011). Important examples include pollinators, predators of crop pests, the vegetation found in hedgerows and at field margins, the invertebrates and micro-organisms that create and maintain the soil and its fertility; in addition to beneficial species such as pollinators, crop associated biodiversity includes the various species that inhibit crop production by acting as weeds or pests. Equivalent categories of biodiversity can be distinguished in other sectors of food and agriculture. In a livestock production system, the domesticated animals can be distinguished from associated biodiversity such as rangeland plants, the micro-organism and invertebrate communities associated with these plants and with the soil, and the micro-organisms found in the animals' digestive systems. In a forest ecosystem, trees are surrounded by a multitude of plants, animals and micro-organisms that contribute in various ways to the functioning of the ecosystem. Likewise in the aquatic sector, capture fisheries are supported by their prey and regulated by predator species; some aquatic species rely on other species as hosts; kelp beds, seagrasses corals and other aquatic plants provide food, oxygen and habitat. Farmed aquatic species also rely on this associated biodiversity in extensive farming systems and in culture-based fisheries. The micro-flora and fauna of fish ponds provides a variety of ecosystem services to farmed aquatic species ranging from direct nutrition to the regulation of water quality.

Associated biodiversity consists largely of non-domesticated species. Exceptions include the domestic honey bee and some other pollinator species and prey (bait) species used to support recreational fisheries. Various biological control agents (natural enemies used to control pest species) are bred in captivity.

Management of associated biodiversity encompasses a wide range of different intensities. Much associated biodiversity is not, in any deliberate way, managed to promote its role in supplying ecosystem services to food and agriculture (or subject only to broad management measures that target the respective ecosystems). In other cases, habitats in and around production systems are deliberately managed in order to promote the presence of associated biodiversity species and thereby increase the supply of the ecosystem services they provide to the respective system. In yet other cases, associated biodiversity species are deliberately introduced into a production system to take advantage of the services they provide.

Where ecosystem services (see below) are concerned, associated biodiversity species are particularly associated with the supply of supporting and regulating services. However, they may also be sources of food and other products (provisioning ecosystem services) and have cultural significance (supply cultural ecosystem services). It should be noted that domesticated species may also provide ecosystem services other than provisioning ones and affect crop, animal, fish and forest production in different ways.

Genetic resources are defined under Article 2 of the CBD as "genetic material of actual or potential value". "Genetic material" is in turn defined as "any material of plant, animal, microbial or other origin containing functional units of heredity." Genetic resources can be embodied in living plants, animals or micro-organisms or in stored seeds, semen, oocytes, embryos, somatic cells or isolated DNA (deoxyribonucleic acid). In the context of food and agriculture, the term is often used to refer to the species managed or harvested within a given sector (e.g. animal or plant genetic resources for food and agriculture – see below).

Plant genetic resources for food and agriculture (PGRFA) are genetic material of plant origin of actual or potential value for food and agriculture (FAO, 2010).

Diversity within crop species is often huge. A "variety" is a plant grouping within a single botanical taxon of the lowest known rank that is distinguished from any other plant grouping by the expression of certain heritable characteristics that remain unchanged by propagation.[6] Cultivated varieties, or cultivars, can be broadly classified as "modern varieties" or "farmers' varieties" (FAO, 1996).[7] Modern varieties are the products of plant breeding in the formal system (sometimes called "scientific breeding") by professional plant breeders working in private companies or publicly-funded research institutes. They typically have a high degree of genetic uniformity and breed true (i.e. produce offspring with the same phenotypic traits as the parents). Farmers' varieties, otherwise known as landraces or traditional varieties, are the product of breeding or selection carried out by farmers, either deliberately or otherwise, continuously over many generations. Farmers' varieties tend not to be genetically uniform and contain high levels of genetic diversity.

Wild relatives of domesticated crop species, known as crop wild relatives, are sources of heritable traits for use in crop breeding. Traits conferring tolerance to abiotic and biotic stresses and improved nutritional qualities have been incorporated into elite crop varieties from crop wild relatives. Modern biotechnologies (e.g. embryo rescue and protoplast fusion) are increasingly being used to circumvent the crossing barriers that have prevented the introduction of novel alleles from crop wild relatives into cultivars.

Animal genetic resources for food and agriculture (AnGR) are genetic resources of animal origin used or potentially used for food and agriculture (FAO, 2007a,b; 2015). In line with the scope of previous global assessments carried out under the auspices of the CGRFA (see above), the term is used in this report to refer to the genetic resources of domesticated avian and mammalian species used in food and agriculture. The Global Databank for Animal Genetic Resources, hosted by FAO, records data on 38 species[8] (FAO, 2015).

Livestock species generally include a number of different subspecific populations referred to as "breeds". According to the definition used by FAO, a breed is "either a subspecific group of domestic livestock with definable and identifiable external characteristics that enable it to be separated by visual appraisal from other similarly defined groups within the same species or a group for which geographical and/or cultural separation from phenotypically similar groups has led to acceptance of its separate identity" (FAO, 1999). As of 2014, 8 774 breeds were recorded in the Global Databank (FAO, 2015).

Individual breeds, in turn, harbour varying quantities of genetic diversity, i.e. in some breeds the individuals are more genetically similar to each other than in others. Likewise, some breeds are more genetically distinct from the population at large than others. Breeds that have been present in a particular production environment for sufficient time for the effects of natural selection and managed breeding to adapt them to local conditions are referred to as "locally adapted" breeds.[9] Breeds can be

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[6] Adapted from the 1991 Act of the UPOV Convention. http://www.upov.int/upovlex/en/conventions/1991/w_up910_.html#_1

[7] It should be noted that "farmers' variety" is an imprecise term and that "varieties" referred to in this way may not meet the requirement that a variety breed true.

[8] Some of these are in fact groups of species (e.g. deer) or fertile interspecies crosses (e.g. dromedary × Bactrian camel crosses).

[9] The definition agreed upon by the CGRFA for use in national reporting states that "locally adapted breeds" are "breeds that have been in the country for a sufficient time to be genetically adapted to one or more of the traditional production systems or environments in the country" and that "exotic breeds" are "breeds that are not locally adapted".

subject to breeding programmes to improve their productivity or promote other desirable characteristics. They can be mated with each other to produce cross-bred animals that embody desirable characteristics from the parent breeds.

The wild relatives of domesticated livestock are generally not used in any systematic way in contemporary animal breeding. Some of the wild ancestral species of major domesticated species are now extinct, for example the aurochs (*Bos primigenius*) – ancestor of domestic cattle.

Forest genetic resources (FGR) are the heritable materials maintained within and among tree and other woody plant species that are of actual or potential economic, environmental, scientific or societal value (FAO, 2014a). Published estimates for the number of tree species range from 50 000 to 100 000. The country reports submitted for the *State of the World's Forest Genetic Resources* list nearly 8 000 species of trees, scrubs, palms and bamboo and of these about 2 400 are actively managed for their products and/or services (FAO, 2014a).

The distribution of genetic diversity within tree species is shaped by the evolutionary history of the species, introgression and hybridization with related species, as well as by forest degradation and fragmentation.

Although humans have long utilized tree species, tree improvement efforts were only initiated in the 1930s. Globally, more than 700 species are included in tree breeding programmes. Tree breeding is a slow process, as one cycle of testing and selection typically takes decades. Most advanced tree breeding programmes are only in their third cycle of testing and selection. This means that the gene pools of trees in breeding programmes are mostly still semi-wild. Only a few tree species have been domesticated to a level similar to that of agricultural crops.

Aquatic genetic resources for food and agriculture (AqGR) are the genetic resources of aquatic animal and plant species used or potentially used in fisheries or aquaculture and the biodiversity of the associated ecosystems that support them. The scope of the global assessment undertaken for the report on *The State of the World's Aquatic Genetic Resources for Food and Aquaculture* is farmed aquatic species and their wild relatives within national jurisdiction. Globally, there are more than 31 000 species of finfish, 85 000 species of aquatic molluscs, 47 000 species of aquatic crustaceans and 13 000 species of seaweed. Global capture fisheries harvest over 2 000 species, including finfish, crustaceans, molluscs, echinoderms, coelenterates and aquatic plants (FAO, 2014c). Within these thousands of species there are numerous genetically distinct stocks and phenotypes.

There are about 580 species used in aquaculture reported to FAO: 362 finfish species (including hybrids); 104 mollusc species; 62 crustacean species; 9 other aquatic invertebrate species; 6 species of frogs and reptiles; and 37 species of aquatic plants (FAO, 2016b).

Unlike domesticated crop and livestock species, which generally include many breeds, varieties or cultivars, there are few recognized within-species strains among the species used in aquaculture. Subspecific stocks of aquatic species in the wild are recognized. Although some stocks are genetically characterized, it is more usual for the stock to be characterized by their geographic location (e.g. North Atlantic cod).

Wild foods are food products obtained from non-domesticated species. They may be harvested (gathered or hunted) from within food and agricultural production systems or from natural or semi-natural ecosystems. The group of species that supplies wild foods overlaps to some extent with those in the above-described "sectoral" categories of genetic resources. For example, food can be obtained from various wild relatives of domesticated plants and animals and from forest trees. In the aquatic sector, the majority of production comes from wild foods and many aquaculture facilities use wild caught biodiversity for broodstock or larval grow-out. Wild capture fisheries are probably the largest single example of the human use of wild foods, although they may not be categorized as such in much of the literature.

Ecosystem services are the "the benefits humans derive from ecosystems" (MEA, 2005). The Millennium Ecosystem Assessment identified four categories of ecosystem service: provisioning, regulating, supporting and cultural (*ibid*.). Provisioning services are "the products obtained from ecosystems", i.e. food and raw materials of various kinds. Regulating services are "benefits obtained from the regulation of ecosystem processes", for example regulation of the climate, air and water quality, or the incidence of diseases and natural disasters. Cultural services are the "nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences". Supporting services are services "that are necessary for the production of all other ecosystem services." Examples include photosynthesis and nutrient cycling. The distinguishing feature of supporting services is that they have a less direct effect on human welfare. 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 preparing their country reports for *The State of the World's Biodiversity for Food and Agriculture*, countries were invited to focus primarily on regulating and supporting services. A number of questions in the country-reporting guidelines referred specifically to these two categories of ecosystem service.

Conservation of biodiversity for food and agriculture is taken in this report to include all actions implemented with the aim of preventing the loss of diversity in the populations, species and ecosystems that constitute biodiversity for food and agriculture.

In situ conservation is defined under the CBD as "conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties."

In the context of biodiversity for food and agriculture, *in situ* conservation comprises measures that promote the maintenance of biodiversity (including domesticated biodiversity) in and around crop, livestock, forest, aquatic and mixed production systems.

Ex situ conservation, as defined under the CBD, is "the conservation of components of biological diversity outside their natural habitats."

In the context of biodiversity for food and agriculture, *ex situ* conservation comprises the conservation of components of biodiversity for food and agriculture outside their normal habitats in and around production systems. This may involve the maintenance of live organisms at sites such as botanical gardens, aquaria, field gene banks, zoos or rare-breed farms or storage of seeds, pollen or cryoconserved materials such as semen or embryos.

Sustainable use of the components of biodiversity is one of the three objectives of the CBD, which defines the term as follows: "the use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining its potential to meet the needs and aspirations of present and future generations."

In the case of biodiversity for food and agriculture, use includes the various practical activities involved in cultivating or raising domesticated species, the implementation of breeding programmes for domesticated species and the domestication of additional wild species, the introduction of domesticated or wild species into new production systems, the management of wild species and their habitats in and around production systems to promote the delivery of ecosystem services, and the harvesting of food and other products from the wild.

Sustainable use and conservation are inter-related in various ways. From one perspective, sustainable use can be seen as an element of conservation. In the case of wild biodiversity, enabling people to use a wild species or ecosystem in a sustainable way may lead to its being protected from more destructive activities. Domesticated biodiversity is to a large degree dependent on use. Individual varieties and breeds of crops, aquatic species and livestock are products of human-controlled breeding and would cease to exist without ongoing management. *In situ* conservation of domesticated biodiversity therefore inevitably involves use (unless the targets are feral populations).

From another perspective, conservation of biodiversity for food and agriculture can be viewed as a prerequisite for sustainable use (i.e. for the sustainability of crop, livestock, forest and aquatic production). For example, the ongoing supply of products from a food and agricultural system may depend on the conservation of neighbouring (or more distant) habitats that provide essential ecosystems services. Among domesticated species, there is an inevitable tendency for some individual varieties and breeds to fall out of use as production systems evolve and demands for particular products and services increase or decrease. Without conservation measures these breeds and varieties, which add to the range of options available for future use, risk being lost.

A **production system** for the purpose of this report is a category of management unit (farm, livestock holding, forest, fishery in a natural or man-made water body, aquaculture holding or mixed management unit) that shares common characteristics with respect to the climatic zone in which it is located and the type of management practised. The following climatic zones are distinguished: tropical; subtropical; temperate; and boreal. The following types of system are distinguished: grassland based livestock systems; landless livestock systems; naturally regenerated forests; planted forests; self-recruiting capture fisheries; culture-based fisheries; fed aquaculture; non-fed aquaculture; irrigated crops (rice); irrigated crops (other); rainfed crops; mixed production systems (involving resources from two or more subsectors of food and agriculture, i.e. the livestock, crop, forest, fisheries and aquaculture sectors). For further details of this classification system, see Table 2.

Table 2. Classification of production system used in this report

Name of production system	Description
Livestock grassland-based systems	Systems in which the animals obtain a large proportion of their forage intake by grazing natural or sown pastures, includes: • Ranching: grassland-based systems in which livestock is kept on privately owned rangeland • Pastoralist: grassland-based systems in which the livestock keepers move with their herds or flocks in an opportunistic way on communal land to find feed and water for their animals (either from or not from a fixed home base)
Livestock landless systems	Systems in which livestock production is separated from the land where the feed given to the animals is produced.
Naturally regenerated forests	Includes: • Primary: Forests of native species, where there are no clearly visible indications of human activities and the ecological processes are not directly disturbed by humans • Modified natural: Forests of naturally regenerated native species where there are clearly visible indications of significant human activities • Semi-natural (assisted natural regeneration): Silvicultural practices in natural forest by intensive management (weeding, fertilizing, thinning, selective logging)
Planted forests	Includes : • Semi-natural (planted component) : Forests of native species, established through planting or seeding, intensively managed • Plantations (productive) : Forests of introduced and/or native species established through planting or seeding mainly for production of wood or non-wood goods • Plantations (protective) : Forests of introduced and/or native species, established through planting or seeding mainly for provision of services
Self-recruiting capture fisheries	Includes capture fisheries in marine, coastal and inland areas that can involve • Natural ecosystems • Modified ecosystems e.g. reservoirs and rice paddies;
Culture-based fisheries	Fisheries on resources, the recruitment of which originates or is supplemented from cultured stocks (i.e., populations chosen for culture and not stocks in the same sense as that term is used for capture fisheries) raising total production beyond the level sustainable through natural processes.
Fed aquaculture	The farming of aquatic organisms including fish, molluscs, crustaceans, aquatic plants, crocodiles, alligators, turtles and amphibians. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators etc. Farming also implies individual or corporate ownership of the stock being cultivated; i.e., the population chosen for culture and not a stock in the same sense as that term is used for capture fisheries. Fed aquaculture production utilizes or has the potential to utilize aquafeeds of any type in contrast with the farming of filter-feeding invertebrates and aquatic plants that relies exclusively on natural productivity. Also defined as “farming of aquatic organisms utilizing aquafeeds in contrast to that deriving nutrition directly from nature”.
Non-Fed aquaculture	The farming of aquatic organisms including fish, molluscs, crustaceans, aquatic plants that do not need supplemental feeding. Farming implies some sort of intervention in the rearing

	process to enhance production, such as regular stocking, feeding, protection from predators etc. Farming also implies individual or corporate ownership of the stock being cultivated; i.e., the population chosen for culture and not a stock in the same sense as that term is used for capture fisheries. In non-fed aquaculture systems culture is predominately dependent on the natural environment for food, e.g. aquatic plants and molluscs.
Irrigated crops (rice)	Irrigated rice refers to areas where rice is cultivated purposely provided with water, including land irrigated by controlled flooding.
Irrigated crops (other)	Irrigated crops other than rice refers to agricultural areas purposely provided with water, including land irrigated by controlled flooding
Rainfed crops	Agricultural practice relying exclusively on rainfall as its source of water.
Mixed production systems (livestock, crop, forest and /or aquatic and fisheries mixed)	Production systems with multiple components. They include: • Crop-livestock: mixed systems in which livestock production is integrated with crop production. • Agro-pastoralist: livestock-oriented systems that involve some crop production in addition to keeping grazing livestock on rangelands; they may involve migration with the livestock away from the cropland for part of the year; in some areas, agropastoral systems emerged from pastoral systems • Agroforestry-livestock: mixed system in which livestock production is integrated with the production of trees and shrubs38 • Integrated aquaculture: mixed systems in which aquaculture is integrated with crop and livestock production. May involve ponds on farms, flooded fields, enrichment of ponds with organic waste, etc. • Other combinations

Source: FAO, 2013.

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CHAPTER 1 – INTRODUCTION

1.1 Introduction

Delivering safe and nutritious food to a growing world population poses a number of challenges. Among the most serious is the need to make crop and livestock systems, forests, fisheries and aquaculture more productive while preserving the ability of agricultural landscapes to deliver other ecosystem services that are essential for life on earth. In spite of repeated warnings about the rapid loss of biodiversity for food and agriculture (e.g. MEA, 2005; FAO and PAR, 2011), and of the mounting evidence about its key role in food security and nutrition (FAO and PAR, 2011; Sutherland, 2011; Tscharntke *et al.*, 2012), agricultural systems worldwide are becoming ever simpler, more structurally uniform and less diverse in terms of species, varieties and breeds. These trends have serious implications for human nutrition, for biodiversity and ecosystem services and for the resilience and adaptability of agricultural systems.

The importance of biodiversity to food security and nutrition, to the livelihoods of many millions of farmers, livestock keepers, forest dwellers, fishers and aquaculture practitioners, and to efforts to promote sustainable development more generally, has gradually been acquiring greater recognition on international agendas.

The Sustainable Development Goals include a halt to biodiversity loss, significant action to reduce the degradation of natural habitats, sustainable management of all types of forests and the integration of ecosystem and biodiversity values into national and local planning, development processes and poverty reduction strategies (Goal 15); sustainable management and protection of marine and coastal ecosystems, action to promote their restoration in the interest of healthy and productive oceans and effective regulation of harvesting and overfishing (Goal 14); and sound management of the genetic diversity of cultivated plants, domesticated animals, and their related wild species, as part of efforts to end hunger, achieve food security and improved nutrition and promote sustainable agriculture (Goal 2).

The adoption of the Convention on Biological Diversity (CBD) in 1992 established an international legal framework for the conservation and sustainable use of biodiversity, including domesticated and non-domesticated species used in food and agriculture, along with the fair and equitable sharing of the benefits arising from the use of genetic resources. The CBD's programmes of work on agricultural biodiversity, forest biodiversity, inland water ecosystems and marine and coastal biodiversity aim to promote these objectives in the respective ecosystems. The Aichi Biodiversity Targets, adopted in 2010, address, inter alia, the need to integrate biodiversity into national and local development and poverty reduction strategies (Target 2), to reduce the loss, degradation of all natural habitats including forests (Target 5), to ensure sustainable management and harvesting of aquatic species, recovery of depleted stocks and protection of aquatic ecosystems (Target 6), to ensure sustainable management of areas under agriculture, aquaculture and forestry (Target 7), to increase the area of land and water covered by protected areas (Target 11) and to safeguard the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives (Target 13). On 3 December 2016, the high-level ministerial segment of the thirteenth meeting of the Conference of the Parties to the CBD adopted the Cancún Declaration on mainstreaming the conservation and sustainable use of biodiversity for well-being.[10] By adopting this Declaration, more than 190 countries have committed themselves to stepping up efforts to integrate biodiversity into their agriculture, forestry, fisheries and tourism policies.

The Millennium Ecosystem Assessment, published in 2005, described the many contributions that ecosystems and the biodiversity within them make to human well-being, highlighting the ways in which crop, livestock, forest and aquatic production systems rely on biodiversity both directly as a source of products and indirectly via its role in creating and maintaining conditions in which production can occur (MEA, 2005).

On 3 December 2016, the high-level ministerial segment of the thirteenth meeting of the Conference of the Parties to the CBD adopted the Cancún Declaration on Mainstreaming the Conservation and

[10] https://www.cbd.int/doc/c/edd1/7e90/76ccae323fc6c2286ceba9a2/cop-13-24-en.pdf.

Sustainable Use of Biodiversity for Well-being (CBD, 2016). By adopting this Declaration, more than 190 countries have committed themselves to stepping up efforts to integrate biodiversity into their agriculture, forestry, fisheries and tourism policies.

Over the past 20 years, a significant number of approaches and frameworks have been developed under the auspices of FAO to enhance agricultural productivity and sustainability across all subsectors of food and agriculture (FAO, 2014a). These include the Ecosystem Approach to Fisheries and Aquaculture (FAO, 2002; Staples and Funge-Smith, 2009), the “Save and Grow” framework for sustainable crop production intensification (FAO, 2011a), Sustainable Forest Management (FAO, 2014b), the Global Soil Partnership (FAO, 2012) and Climate-Smart Agriculture (FAO, 2013), all of which explicitly acknowledge the importance of biodiversity for food and agriculture and its contributions to the delivery of ecosystem services.

A paradigm shift towards a focus on sustainable and diversified production systems has steadily been taking place. Rather than being viewed simply as suppliers of products (e.g. food or timber), the crop, livestock, forest, fisheries and aquaculture sectors are now increasingly recognized for their potential significance in climate change mitigation, flood control, the conservation and sustainable use of biodiversity and the delivery of other ecosystem services such as pollination, soil formation and water cycling. The development of an integrated approach to sustainability across agriculture, forestry and fisheries is also increasingly being discussed (FAO, 2014a).

The Commission on Genetic Resources for Food and Agriculture (CGRFA) has overseen global assessments of the state of genetic resources in the plant (crop), animal (livestock), forest and aquatic sectors (FAO, 1996, 2007a, 2010, 2014c, 2015, 2016a), which have led to the adoption of internationally agreed global plans of action for plant, animal and forest genetic resources (FAO, 2007b, 2011b, 2014d). These global assessments have focused largely on the contributions that genetic resources within a given sector make to that sector, for example the contribution of plant genetic resources to productivity in the crop sector, the livelihoods of crop producers and the long-term sustainability of crop production. Less attention has been paid to interactions between the biodiversity of the different sectors, for example to the significance of synergies within mixed systems (e.g. crop–livestock, crop–aquaculture, silvi-aquaculture or agroforestry) or to the potential benefits of more integrated approaches to the management of biodiversity at ecosystem or landscape/seascape scales or at the level of policy and institutional development.

To date, the CGRFA’s global assessments have also not focused on the various categories of biodiversity that are generally not the main targets of management or harvesting in the crop, livestock, forest, fishery or aquaculture sectors but nonetheless contribute to the productivity and the sustainability of production systems - pollinators, soil-dwelling organisms, corals, seagrasses, etc. Moreover, at least in the plant and animal sectors (the distinction is less relevant in the forest and aquatic sectors), wild species gathered or hunted for food or other purposes have also not been among the main targets of the global assessments.[11] *The State of the World’s Biodiversity for Food and Agriculture* addresses biodiversity in all sectors of food and agriculture (crop, livestock, forest, fisheries and aquaculture), including the components addressed in the sectoral global assessments. The main emphasis is, however, on interactions between the sectors and on components of biodiversity not covered in the sectoral assessments.

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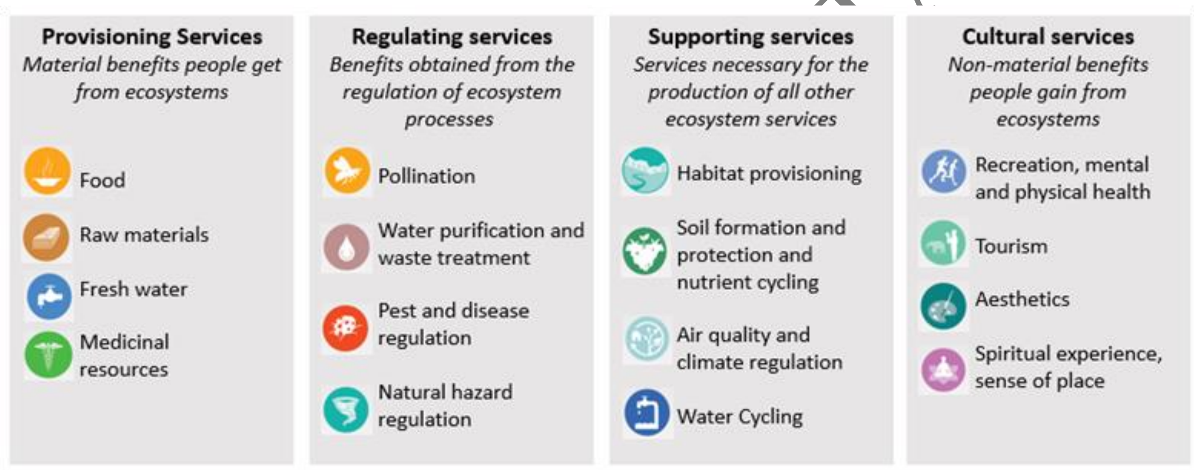
1.2 Biodiversity for food and agriculture and the delivery of ecosystem services

Introduction

Much of the analysis presented in this report draws on the concept of ecosystems services (see Figure 2). Drivers of change affecting biodiversity for food and agriculture (BFA) (Chapter 2), the status and trends of BFA (Chapter 3) and efforts to manage BFA (Chapter 4) are all discussed within an ecosystem services framework. This subsection presents an introductory overview of the roles of BFA in the supply of ecosystem services.

Ecosystem services can be defined as “the benefits humans derive from ecosystems” (MEA, 2005). As noted in the Concepts and definitions section, the ecosystem services concept is applied to the supply of a wide range of different benefits, ranging from the multitude of products supplied by “provisioning services” to the various aspects of wellbeing directly or indirectly enhanced by “regulating” and “supporting” services and the intangible benefits provided by cultural services.

Figure 2. Ecosystem service categories



Sources: FAO, 2013a and TEEB, 2016.

The capacity of ecosystems to supply 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 processes involving vast numbers of other species, linked in numerous ways (e.g. through 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 the control of water quality and flow by a forest or floodplain ecosystem or the sequestration of carbon by a grassland ecosystem.

Food and agricultural production systems (including crop and livestock, forest, fishery and aquaculture 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 an 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.

Food and agricultural production systems also supply ecosystem services. Production systems are 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 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 other ecosystem services whose benefits extend far beyond the food and agriculture sector. Just from the scale and diversity of the production systems 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 they (and the biodiversity in and around them) account for a substantial share of the regulating, supporting, cultural and habitat 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 biodiversity for food and agriculture 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.

The significance of ecosystem services to human wellbeing – including via their contributions to food and agriculture – have been extensively reviewed in other publications, as has the significance of biodiversity in the supply of ecosystem services (e.g. MEA, 2005; TEEB, 2009). As described in the Section 1.1 the main focus of the present report is on the biodiversity found in and around production systems – in particular on associated biodiversity (see Concepts and definitions section) and wild foods, but also on the diversity of crops, livestock, forest trees and aquatic species used in aquaculture and targeted by fishers. The introductory overview presented below aims to describe the significance of this biodiversity in the supply of the main categories of ecosystem services (see Concepts and definitions section). The services are described linearly, one by one. However, it should be recalled that, as noted above, that the supply of one service is often dependent on a range of others – and hence ultimately on all the biodiversity involved in the delivery of these services. It should also be recalled that while the contributions of BFA to supply of ecosystem services are to a degree independent of human control, they are heavily affected by human actions, both in terms of management practices at production system level and in terms of the wider management of the economy and the environment. These factors are discussed in greater detail, respectively in Chapter 4. The practical significance of BFA to food security, livelihoods and the resilience of food and agricultural systems is discussed in greater detail in Chapter 4.

Provisioning services

Food

The world's food production depends on its terrestrial and aquatic ecosystems. Approximately 82 percent of the supply of food calories comes from terrestrial plants, 16 percent from terrestrial animals and 1 percent from aquatic animals and plants. The figures for protein supply are 60 percent from terrestrial plants, 33 percent from terrestrial animals and 7 percent from aquatic animals and plants.[12] 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.

The above-quoted global averages mask the fact that certain sectors may be extremely important in specific areas, for example fish in small island developing states and livestock in pastoral communities. Moreover, in addition to calories and protein, nutritional food security requires adequate access to micronutrients, essential fatty acids and minerals. These are found in varying levels in the wide range of species, varieties and breeds of plants and animals that are used as sources of food.

Terrestrial domesticated animals

The majority of animal-source food obtained from terrestrial ecosystems comes from domesticated mammals and birds. According to FAO's FAOSTAT database, game (meat and offal from wild animals) accounts for only 0.65 percent of global meat production.

[12] All figures in this paragraph are based on FAOSTAT data for 2011

As noted in the Concepts and definitions section, 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" can in fact probably be reduced to a "big three". Cattle, chickens and pigs together account for 88 percent of meat production, cattle for 83 percent of milk production and chickens for 92 percent of egg production. Beyond these three species, the biggest contributions to meat production come from sheep (2.8 percent), turkeys (1.8 percent), goats (1.7 percent), ducks (1.4 percent) and buffaloes (1.2 percent). Buffaloes (13 percent), goats (2 percent) and sheep (1 percent) are also relatively major contributors to the global supply of milk. Non-chicken eggs come mainly from ducks and geese.

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. It is also important to recall the significant roles played by "minor" species, such as dromedaries, Bactrian camels, yaks, llamas, alpacas and reindeer, 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 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 2013, global honey production exceeded 1.6 million tonnes and production of land snails exceeded 16 thousand tonnes. In 2011, honey contributed 2 kcal per person per day to global food supplies (FAOSTAT).

Below the species level, domesticated animal populations are often subdivided into distinct breeds (See Part 1). Some of these breeds have been developed as single-purpose animals specialized in producing a specific food product. Others are multipurpose animals 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 role of breed diversity is in enabling production across a wide range of production environments. Widely distributed livestock species tend to include populations that have become adapted to various extremes of climate, terrain, disease exposure and so on. Other breeds have been bred 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, are increasingly dominated by specialized "industrial" production systems. MacLeod *et al.* (2013) estimated that 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 livestock production comes from the narrow range of high-output breeds that are raised in these 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 developed 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. 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 cattle, have become very widespread and provide a disproportionately large share of global food output.

Terrestrial crop plants

[EDITOR'S NOTE: This subsection on terrestrial crop plants is incomplete.]

About 7 000 species of plants have been cultivated or collected by humans for food at one time or another (FAO, 1996). Thirty of these species account for 95 percent of human dietary energy obtained from plants (*ibid*). Three species – wheat, rice and maize –provide more than half of global plant-derived energy intake. A further six crops or commodities – sorghum, millet, potatoes, sweet potatoes, soybean and sugar (cane/beet) – bring the total to 75 percent (*ibid*.). About 120 crops are considered to be significant at national level in one or more countries and many more at local level (*ibid*.).

Aquatic species

A very diverse range of aquatic species are used in aquaculture. As of 2014, production data for about 580 species and/or species groups were being reported to FAO: 362 species of finfish; 104 species of molluscs; 62 species of crustaceans; 15 other animal species; and 37 plant species (FAO, 2016). Moreover, many of the country reports submitted as a basis for the preparation of the forthcoming report on *The State of the World's Aquatic Genetic Resources for Food and Agriculture* 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.

Table 3 shows the contributions of different taxonomic groups to world aquaculture production in volume and value terms in 2014. Finfish accounted for over two-thirds of production in volume terms, with 59 percent of the total coming from inland finfish aquaculture alone (FAO, 2016). Marine finfish aquaculture accounted for a disproportionately large share in value terms, owing to the large percentage of production coming from high value fishes such as salmon, trout and groupers. Farmed mollusc production amounted to more than twice the figure for crustaceans in volume terms, but only a little over half in value terms. Farmed crustaceans, primarily marine shrimp, are an extremely valuable aquaculture product. Many of the molluscs produced in freshwater aquaculture were used for freshwater pearl production in Asia. Other aquatic animals are still quite marginal in terms of production volume, although some, such as Japanese sea cucumber, are of high value. Almost all aquatic animals produced from aquaculture are destined for human consumption. However, there is some production of bait fish for recreational fisheries, mosquito fish for pest control, and culture of marine and freshwater molluscs for jewellery. The farming of ornamental fish is an important sector that can be extremely profitable at a local level. Global farmed aquatic plant production amounted to 27.3 million tonnes in 2014, a quarter of aquaculture production by volume but less than 5 percent by value (*ibid*.).

Table 3. World animal aquaculture production in 2014

	Inland aquaculture	Marine and coastal aquaculture	Quantity subtotal		Value subtotal	
	(tonnes)	(tonnes)	(tonnes)	(Percentage by volume)	(US$ billion)	(Percentage by value)
Finfish	43 559 260	6 302 631	49 861 891	68	99.2	63
Crustaceans	2 744 537	4 170 536	6 915 073	9	36.2	23
Molluscs	277 744	15 835 450	16 113 194	22	19.0	12
Other animals	520 850	372 718	893 568	1	3.7	2
Total	47 102 391	26 681 334	73 783 725	100	160.2	100

Source: FAO, 2016.

Each of the taxonomic groups listed in Table 3 includes a diverse range of farmed species. Among freshwater and diadromous fish,[13] 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 highly 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, 35 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 production is very limited.

A range of other species contributes to aquaculture production, including sea cucumbers and sea urchins, frogs and turtles. Crocodile production is growing quickly in Asia. Aquatic plant production is dominated by seaweeds.

Marine capture fishery production amounted to 81.5 million tonnes in 2014, 40.9 percent of which came from 25 major species and genera (FAO, 2016). Most of these are finfish – largest contributors are the Alaska pollock (*Theragra chalcogramma*), anchoveta (*Engraulis ringens*), skipjack tuna (*Katsuwonus pelamis*) and sardinellas (*Sardinella* spp.) – but they also include two species of squid (*Dosidicus gigas, Illex argentines*), one of crab (*Portunus trituberculatus*) and one of shrimp (*Acetes japonicas*).

Inland capture fishery production amounted to 11.9 million tonnes in 2014. 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 freshwater fish, molluscs or crustaceans (FishStatJ, 2016). Among production for which species is recorded, the main species are the carps and other cyprinids, tilapia, Nile perch and freshwater prawns.

In addition to the volume of food provided from aquatic systems, it should also be noted that a number of aquatic species are used as food supplements (or animal feed supplements), because of their high levels of vitamins and pigments (e.g. spirulina [Habib *et al.*, 2008] and artemia]Coutteau *et al.*, 1997]) or omega-3 lipids (oily fish [Sargent, 1997] and marine phytoplankton [Simopoulos,1991; de Deckere,2001; Adarme-Vega *et al.*, 2012]).

Data on the use of diversity at the level of stocks and strains within species are limited in the aquatic sector (see Section 3.2). However, within-species diversity enables production in a range of different environments and provides the basis for adaptations to future changes through natural or human-controlled selection (FAO, 2008; see Section 4.9).

Wild foods

Wild foods, as defined in the Concepts and definitions section, are food products obtained from non-domesticated species. They may be harvested, gathered or hunted from within food and agricultural production systems or from natural or semi-natural ecosystems. As described by Bharucha and Pretty (2010) and Shackleton *et al.* (2010), wild foods include varied forms of (terrestrial and aquatic) plant and animal products, ranging from fruits, leafy vegetables, woody foliage, bulbs and tubers, cereals and grains, nuts and kernels, saps and gums (which are eaten or used to make drinks) and mushrooms to invertebrates such as insects and snails, honey, bird eggs, bushmeat from small and large vertebrates, reptiles, birds, fish and shellfish (WHO/CBD, 2015). Within each of these groups, up to several hundred different species and varieties can be counted. It is probably fair to say that wild capture fisheries are the largest use of wild resources for food in terms of volume and protein supply,

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

and this is particularly true in specific regions such as the Pacific, where fisheries are a cornerstone of food security, with average annual consumption of fish (including shellfish) among coastal rural populations ranging from 30 to 146 kg per person, greatly exceeding the global average of 16–18 kg per person per year (Bell *et al.*, 2011). Wild capture fisheries are also extremely important in many developing countries, particularly in landlocked areas such as the interiors of Southeast Asia, Africa and the Amazonian region.

Wild foods help to ensure food security and nutrition for an estimated 1 billion people (Burlingame, 2000). Given the site-specific nature of the data available on the frequency of consumption, species consumed and contributions to protein, energy and micronutrient dietary intakes, global estimates of the importance of wild foods to nutrition are difficult to establish. A recent review of the literature by Powell *et al.* (2015) notes that although the contribution of wild foods to total energy and protein intake is generally low, several studies have demonstrated cases in which a high proportion of the dietary intake of micronutrients is obtained from the consumption of wild foods. In addition, wild foods increase dietary diversity, increase resilience – for example during short seasonal food shortages – and can be important sources of income (Barucha and Pretty, 2010; Hickey *et al.* 2016; Johns and Sthapit, 2004; Vinceti *et al.*, 2013; Schulp *et al.*, 2016; Wunder *et al.*, 2014). A more detailed discussion of the importance of wild foods to food security and nutrition, resilience and livelihoods is discussed in sections 4.7, 4.9 and 4.10.

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 fuels and materials for use in construction, in the manufacture of textiles and clothing, cosmetics and in a variety of other products (materials for medical and other biochemical uses are discussed briefly in a separate subsection below).

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 2013, for example, amounted to more than 2 million tonnes and was worth approximately US$7.9 billion (FAOSTAT). Fibres from other animals are produced in much lower quantities, but include high-quality fibres such as alpaca wool, cashmere and mohair. Within-species breed diversity adds to the diversity of fibres available. A range of species and breeds likewise provide diversity in the supply of hides and skins (global production of cattle, buffalo, sheep and goat hides and skins was approximately 20 million tonnes in 2013 – FAOSTAT). 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, a range of breeds – including specialized draught, pack and riding animals – underpin provision.

Aquatic plants and animals

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, from molluscs) and cosmetic compounds. A number of aquatic plant species provide products that are essential for food processing and other industrial purposes. For example, phyco-colloids such as alginates and carrageenans derived from seaweeds have a wide range of uses as binders and gelling agents in processed foods (Hurtado, 2016). Marine algae, especially seaweeds, are also harvested for biofuel production (Mata *et al.*, 2010; Milledge *et al.*, 2014).

Fresh water

Ecosystems contribute in various ways to the supply of freshwater that can be used domestically and in agriculture, including fisheries and forestry, and industry. For example, as discussed below in the subsection on regulating services, vegetation, particularly forest vegetation, is thought to influence rainfall levels. Vegetation, as well as dead plant material (which 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 organic matter content, which are in turn affected by the actions of (among other components of biodiversity) soil micro-organisms and invertebrates (see below for further discussion). In addition to reducing flood risks, increasing infiltration rates means that water is released more slowly and over a longer period, which may keep streams and rivers flowing (completely or partially) during dry periods of the year (TEEB, 2009).

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 water bodies, "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. As discussed below, there is some evidence that species diversity in plant communities can contribute to preventing excess run-off, and it is well recognized that invertebrate and micro-organism diversity plays a vital role in the formation and maintenance of healthy soils. The role of aquatic-plant diversity in water purification has been investigated experimentally using artificial streams with different levels of algal species diversity. 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.

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 biodiversity for food and agriculture can contribute to reducing these disservices. For example, the use of inputs such as pesticides, fertilizers and veterinary drugs that may eventually end up as pollutants of aquatic ecosystems can be reduced by using more disease- or pest-resistant varieties and breeds of domesticated plants, fish and terrestrial livestock, or by taking advantage of the pest-control and soil fertility-enhancing services provided by associated biodiversity.

Medicinal and other biochemical resources

Many components of biodiversity for food and agriculture are valued for their medicinal properties or as sources of biochemical substances that can be used in pharmaceuticals, cosmetics, crop protection and various industrial processes. Many marine species are sources of bio-active compounds that can be used as pharmaceuticals (e.g. haemocyanin from the marine mollusc keyhole limpet: bio-active peptide extracts) (Harris and Markl, 1999; Donia and Hamann, 2003; Sipkema *et al.*, 2005; Kim and Mendis, 2006; Rocha *et al.*, 2011; Hamedy and Fitzgerald, 2012). Terrestrial livestock species are a source of various pharmaceutical substances including insulin, antibodies and hormones (Redwan *et al.*, 2009).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). The roles of micro-organisms in food and in agro-industrial processing are discussed in more detail in Sections 4.4 and 4.5.

Ornamental resources

Ornamental products are an economically significant component of the provisioning services provided by biodiversity.[14] Domesticated ornamental plants are of major cultural and economic importance (Ciesla, 2002; van Tuyl *et al.*, 2014). Aesthetic objectives are often important elements of breeding strategies for pet or companion animals (including fish). 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 fish, chicken, pigeon, rabbit and other species. Ornamental fish include species specifically bred for their appearance as well as wild caught species. It is roughly estimated that the freshwater aquarium trade relies on cultured animals for 98 percent of its products and only 2 percent are captured. The reverse is true for the marine aquarium trade, which relies on capture for 98 percent of its production (Sugiyama *et al.*, 2004). 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 1 800 aquarium species were imported into the United States America alone in 2005.

Regulating, supporting and habitat services

It is increasingly recognized that crop, livestock, forest and aquatic production systems benefit directly or indirectly from a wide range of different regulating, supporting and habitat services, whether generated internally within the system or provided by other ecosystems. However, in the following descriptions the field is explored from the opposite perspective, i.e. the role of food and agricultural systems in the supply of ecosystem services, and particularly the significance of biodiversity for food and agriculture, both domesticated and non-domesticated.

Air-quality and climate regulation

Air quality

Gaseous and particulate air pollutants cause serious problems for human health and for ecosystem functions. Particulate matter can be removed from the air when it becomes attached to the surface of trees and other plants and gaseous pollutants can be absorbed through leaf stomata. It has been estimated that trees and forests in the (conterminous) United States of America removed 17.4 million tonnes of air pollution in 2010, a service valued at US$6.8 billion (Nowak *et al.*, 2014). Although most of the pollution removal occurred in rural areas, most of the impact on human health and most of the value generated was provided by trees in urban areas. Thus a major share of the value of this service comes from trees growing in parks, cemeteries, gardens and streets rather than in forests *per se*. Different tree species have different capacities to remove pollutants from the air, for example because of their size or because of the characteristics of their leaves, and this needs to be taken into account if trees are being planted to deliver air-quality regulation services (Smith, 2012). It also needs to be borne in mind that biogenic volatile organic compounds emitted by trees can cause an increase in ozone pollution,[15] and that different types of tree will produce different quantities of these compounds (Donovan *et al.*, 2005: Karlik and Pittenger, 2012). The ability of the species to thrive in local conditions also needs to be taken into account (Smith, 2012).

Climate

Ecosystems and their constituent biodiversity can affect the climate at both local and global scales. Local-scale effects on temperature have been demonstrated, for example by Alkama and Cescatti (2016) who found that, in all climatic zones except at the most northern latitudes, forest clearance increased temperatures, particularly mean annual maximum air surface temperatures, with the most marked effect being observed in arid zones. Shading provided by trees can have a significant effect on the temperatures of rivers and streams and hence on river biodiversity and the ecosystem services it provides, including the supply of food from river fisheries (Bowler *et al.*, 2012; Lenane, 2012). Forests can also affect rainfall patterns. For example, Spracklen *et al.* (2012) concluded, based on

[14] The cultural significance of BFA and the products it supplies is discussed below in the subsection on cultural ecosystem services

[15] The biogenic volatile organic compounds react with oxides of nitrogen (e.g. those emitted by motor vehicles) in the presence of sunlight to produce ozone, a pollutant harmful to plants and to human health.

models of atmospheric transport and satellite observations of rainfall and vegetation cover, that over more than 60 percent of the tropical land surface air that had passed over extensive vegetation in the preceding few days produces at least twice as much rain as air that has passed over little vegetation.

Globally, the climate is affected by the absorption and release of greenhouse gases such as carbon dioxide and methane. In a world struggling to address climate change, the sequestration of carbon has become an increasingly significant ecosystem service. Forests, grasslands and marine ecosystems – many of which serve as forestry, livestock or fishery production systems – are key players in global carbon cycles.

Soils hold the largest terrestrial carbon pool (Scharlemann *et al.*, 2014) and play a crucial role in the global carbon balance by regulating dynamic biochemical processes and the exchange of greenhouse gases with the atmosphere. Within agricultural systems, soils have been a net source of greenhouse gases (Lal, 2013b). The roles of biodiversity in preventing erosion and maintaining healthy soils are discussed below. It is clear that biodiversity, both above and below ground, is vital to soil health and hence to soil's contribution to carbon sequestration. However, much remains to be learned about the roles of different species and groups of species in the processes that lead to the accumulation and/or release of carbon from the soil and how these processes are influenced by environmental variables (Cock *et al.*, 2011; Beed *et al.*, 2011). The significance of diversity *per se*, for example whether and how the number of species present in the community or in a particular functional group influences the provision of carbon sequestration services, also need to be better understood. Some studies have shown that higher levels of diversity in grassland plant communities leads to more carbon sequestration in the soil (Fornara and Tilman, 2008; Steinbass *et al.*, 2008). Lange *et al.* (2015) found that the positive effect of plant diversity operated via its influence on soil microbial communities. It is also known that micro-organisms contribute significantly to ecosystem carbon budgets by influencing carbon turnover and retention in soil through their roles as detritivores, plant symbionts or pathogens (Trivedi *et al.*, 2013).

In the case of forests, the carbon stored in plant biomass exceeds that present in the soil. The capacity of forests to sequestrate and store carbon benefits from the presence of species and within-species populations that are well adapted to local conditions (Loo *et al.*, 2011). Where smallholder tree plantings in agroforestry systems are concerned, the provision of carbon sequestration services is also dependent on the trees' capacity to provide livelihood benefits to local people, as otherwise they are unlikely to be planted and maintained (*ibid.*). Globally, higher levels of biodiversity are associated with higher levels of carbon storage in forest ecosystems: tropical moist forests are both diverse and rich in carbon (Midgley *et al.*, 2010). However, no clear association between biodiversity levels and levels of carbon storage has been demonstrated within and among tropical forests, although some studies indicate such a link, and studies in other ecosystems have shown that high diversity is often associated with higher levels of primary production and stability and hence with higher carbon stocks (Hicks *et al.*, 2014).

The ongoing role of forests, whether managed or unmanaged, as carbon stores is dependent on their ability to withstand the various shocks that they have to contend with, droughts, storms, fires, disease outbreaks, etc, many of which are being exacerbated by climate change, changes to land use and other drivers (FAO, 2014). Resilience in the face of such shocks is therefore an important characteristic. It is relatively difficult to investigate links between biodiversity and resilience in forests (as compared to ecosystems such as grasslands) because they are more difficult to observe and manipulate (Miles *et al.*, 2010). However, theoretical considerations and findings from other ecosystems suggest that resilience may be promoted by higher levels of biodiversity. Various mechanisms can contribute to such effects, including those related to functional redundancy and response diversity (see above) (Hicks *et al.*, 2014). Likewise, diversity at different levels, from genetic (within species) to landscape plays an important role in recovery from various kinds of shock (*ibid*).

Grasslands have always been home to grazing animals and many have long been used to raise cattle, sheep and other domesticated species. These animals affect plant and soil communities via their grazing, trampling and dunging and via the dispersal of seeds. The effects that grazing livestock have on carbon sequestration depend on a range of factors including stocking rates, how grazing is managed, the climate and the characteristics of the local soils and plant communities. For example, McSherry and Ritchie (2013) found that the negative effect of grassland grazing on soil organic carbon density was decreased by an increase in precipitation on finer textured soils. On sandy soils, however, the same increase in precipitation caused an increase in the effect of grazing on soil organic carbon. In grasslands dominated by C4 grass species, increasing grazing intensity increases soil organic carbon, while it decreases soil organic carbon in C3-dominated grasslands (*ibid*). Choosing appropriate management strategies for grassland/grazing systems is therefore a complex matter, even more so given that the methane and other greenhouse gas emissions associated with the animal-production process and the various livelihood and environmental benefits and costs of livestock keeping also need to be taken into account. Different species and breeds of livestock have different grazing behaviours and thus potentially have different effects on carbon sequestration or emission in/from grassland soils. Likewise, the impacts of mixed herds/flocks are potentially different from those of single species or breeds. However, it remains unclear whether attempting to promote carbon sequestration by optimizing the choice of grazing animals could be a practical strategy or how widely it could be applied.

The soil organic carbon pool in many cropland soils has been strongly depleted (Lal, 2013a), especially in soils that are managed using extractive farming practices (Lal, 2013b). However, carbon sequestration in crop production systems can potentially be improved through changes in management practices, some of which involve utilizing the diversity of domesticated BFA and/or promoting the activity of associated biodiversity. Options include no-till farming with crop residue mulch, integrated nutrient management, complex crop rotations, cover cropping and agroforestry (Corsi *et al.*, 2012; FAO, 2013b; Lal, 2013b). The application of biofertilizers (fertilizers containing living micro-organisms) may contribute to maintaining or increasing soil organic matter, especially when such fertilizers increase the formation of permanent humus compounds. However, more research is needed to provide evidence of their true potential to increase carbon sequestration (Dębska *et al.*, 2016). More generally, soil-dwelling invertebrates and micro-organisms are vital to efforts to maintain and improve the health and carbon-sequestering capacity of the soil (Gougoulias, *et al.*, 2014). For further information on soil and crop management practices that utilize and enhance biodiversity for food and agriculture, see Section 4.3.

Aquatic ecosystems and their biota account for the largest carbon and nitrogen fluxes on the planet and serve as its largest carbon sinks (Pullin and White, 2011). Oceans are the world's largest long-term carbon sinks – capturing about 30 percent of the carbon dioxide released annually, most of which is then stored for millennia – and account for 55 percent of all so-called green carbon (carbon stored in plants and soils) (Nelleman *et al.*, 2009). Carbon dioxide is removed from the atmosphere both by being dissolved in water and by being used by phytoplankton and other aquatic plants, including those in coastal ecosystems such as mangrove forests, salt marshes and seagrass meadows. Coastal ecosystems make a particularly large contribution to carbon sequestration. Some aquatic micro-organisms such as foraminiferans and coccolithophores incorporate carbon into their bodies the form of calcium carbonate. When they die and sink to the floor of the ocean, much of this carbon is buried in sediments, where it remains locked up indefinitely (Pullin and White, 2015). Calcium carbonate in the skeletal structures of marine invertebrates – particularly echinoderms (starfish, sea urchins, etc.) – and the carbonates precipitated in the intestines of marine fish also make huge contributions to global carbon storage. The world's oceans absorb 2 gigatonnes more carbon per year than they release into the atmosphere (*ibid*). All these services are underpinned by the biodiversity of the ecosystems that supply them (Laffoley and Grimsditch, 2009; Pullin and White, 2011).

Natural hazard regulation

Natural hazards include events such as droughts, floods, cyclones and hurricanes, earthquakes, volcanic eruptions, avalanches, wild fires and landslides (TEEB, 2010; FAO, 2015b). The frequency and severity of many types of extreme events are affected by ecosystem properties. As described above, various ecosystems contribute to climate change mitigation. One benefit of this is likely to be a diminution of the rise in the frequency of several kinds of extreme weather events predicted to occur under climate change. However, ecosystems also contribute in more immediate ways to the moderation of extreme events. For example, a number of coastal ecosystems (mangroves, coral reefs, seagrass meadows, kelp forests, etc.) provide protection against coastal storms and flooding. Forests and other vegetation regulate water flows and diminish the risk of flooding in downstream areas. Forests and other trees can provide protection against the effects of storms.

Agriculture and food production may affect the capacities of ecosystems to deliver services related to the moderation of extreme events. These effects can be harmful, for example if poorly managed livestock grazing removes vegetation that regulates water flows and reduces the risk of flooding or if crop production practices diminish the water-holding capacity of farmland soils. However, it may be possible to adopt more favourable management methods that reduce such problems or to adapt production systems to strengthen their capacity to moderate extreme events, both internally and in the wider environment. For example, trees can be planted to provide shelter for crops and livestock in the immediate vicinity against the effects of extreme winds, heat waves, snowfalls, etc. (Gregory, 1995) or to help reduce flooding on a wider scale. Grazing livestock can be used in fire or avalanche prevention (Fabre *et al.*, 2010; Lovreglio *et al.*, 2014; Pecora *et al.*, 2015). Services of this kind can often be best delivered by locally adapted genetic resources that can withstand harsh local environments. They may be enhanced by the use of a diverse range of species, varieties or breeds. For example, a shelterbelt consisting of a combination of trees, shrubs and grasses is likely to be more effective than a single-species block of trees, as the latter may create an impermeable barrier that generates turbulence or create a wind-tunnel effect at ground level (CPP, 1999).

Soil formation and protection and nutrient cycling

Erosion prevention

Soil erosion has severe negative effects on a range of ecosystem services, including food production, carbon sequestration and the regulation of water flows (Pimentel, 2006). Soils are formed and maintained through the actions of a wide variety of species, including plants, micro-organisms and invertebrates (see below). The main factor in reducing soil erosion is vegetation cover, which protects the soil from rainfall and wind, acts as a barrier to run-off and – through the actions of plant roots – helps to bind the soil in place (Pimentel, 2006; Zuazo and Pleguezuelo, 2008). Some plants are more effective than others in preventing erosion. In crop systems, the choice of crops and production methods can influence the amount of erosion that occurs (e.g. terracing of rice paddy can impede erosion and help maintain production). The same is true for numbers and types of animals kept and the grazing strategies practised in grassland production systems. Diverse plant cover does not necessarily provide better erosion control than monospecies cover. However, there is some evidence that increasing diversity can create beneficial effects through positive effects on root length and number of root tips (Allen *et al.*, 2016). More generally, the maintenance of plant cover is dependent on a range of ecosystem processes, nutrient cycling, pollination, seed dispersal, etc., which involve a wide variety of species within the local ecosystem. The risk of losing plant cover may be reduced through the delivery of ecosystem services related to the prevention of disastrous events such as fires. Diversity within the vegetation itself is likely to promote its resilience to shocks such as droughts that can have a negative effect on plant cover.

Maintenance of soil quality

Healthy soils are vital to food production and to the delivery of a range of other ecosystem services. Soil formation and maintenance are inextricably linked to biodiversity. Micro-organisms, for example, contribute to soil formation by promoting the breakdown of the parent mineral material, establishing nutrient-cycling pathways and creating habitats for other organisms (Beed *et al.*, 2009; Schulz *et al.*, 2013). They are key players in the carbon cycle, breaking down dead plant and animal matter and releasing carbon back into the atmosphere in the form of carbon dioxide or accumulating it within their bodies, some of the latter ending up in long-term storage in soil organic matter (Gougoulias *et al.*, 2014). Micro-organisms secrete substances that act as binding agents and promote the aggregation of soil particles, in turn affecting the carbon- and water-holding properties of the soil (Beed *et al.*, 2011). Micro-organisms are also vital to the nitrogen cycle. Different groups of bacteria fix nitrogen from the atmosphere in the form of ammonia, break down proteins in dead plant and animal material, convert ammonia via nitrites into nitrates that can be taken up by plants, and return nitrogen to the atmosphere via denitrification. Certain types of bacteria and fungi enter into mutually beneficial symbiosis with plant roots: nodulating bacteria associated with the roots of legumes fix nitrogen from the atmosphere and mycorrhizal fungi increase the uptake of phosphorus and other nutrients by plants (Barrios, 2007).

Soil invertebrates include species such as earthworms and ants that act as so-called ecosystem engineers and modify the physical properties of the soil. Structures created by these organisms influence soil processes such as the infiltration, storage and release of water and the sequestration of organic matter. They provide habitats for communities of smaller invertebrates and micro-organisms (Cock *et al.*, 2011). A wide range of invertebrates, including those that live in the leaf litter, contribute to the decomposition of plant material and the release of nutrients (*ibid*.).

Soil micro-organisms and invertebrates are bound together in complex food webs and via their various effects on each other's habitats. The diversity of these communities is important to the effective functioning of the soil ecosystem. By experimentally manipulating soil communities, studies have shown that reducing diversity can impair various functions including decomposition, nutrient retention and nutrient cycling (Wagg *et al.*, 2014) and reduce resilience in the face of shocks (Griffiths *et al.*, 2000).

Plants play an important role in physically protecting the soil from erosion (see above). They also contribute organic matter to the soil and their roots affect soil structure through their physical actions and by releasing substances that bind soil particles (Angers and Caron, 1998). In crop production systems, a range of strategies can be used to maintain and improve soil quality, including composting, use of cover crops/green manure crops, crop rotation, zero or reduced tillage and agroforestry (FAO, 2005) (see Section 4.3 for further information on these methods and the significance of biodiversity in their application). Above-ground animals, including domesticated livestock, drop dung and urine onto the ground, trample the soil with their feet and may spread plant seeds across the landscape. In this context, animals can have both positive and negative effects on soil quality. Excessive trampling can damage the soil structure and large doses of nutrients from dunging can harm vegetation, disrupt nutrient cycling and result in the loss of nutrients into water courses where they act as pollutants. On the other hand, animal manure can serve as an important source of nutrients and be used to increase the organic matter content of depleted soils. It is widely used as a fertilizer in crop production. Use of animal manure can increase the abundance and diversity of soil micro-organisms and invertebrates and promote their contributions to soil quality (Graham *et al.*, 2009; Sradnick *et al.*, 2013).

Pollination

An estimated 87.5 percent of all flowering plant species are pollinated by animals (Ollerton *et al.*, 2011). Crop plants pollinated by animals account for 35 percent of global food production (Klein *et al.*, 2007). Animal-pollinated plants are particularly significant in the supply of micronutrients for human consumption, accounting for 98 percent of the available vitamin C, 55 percent of available folate and 70 percent of vitamin A (Rose *et al.*, 2016). Bees are generally the main providers of pollination services. These include both managed honeybees and wild bee species. Other insects, as well as birds, bats and some other species, also contribute. The value of pollination services has been estimated to be approximately €153 billion per year globally (Gallai *et al.*, 2009).

While farmers in intensive systems often rent managed honeybees to pollinate their crops, many farmers are reliant on wild pollinators. Moreover, it has been shown that pollination services are enhanced by the presence of wild insects even where honeybees are abundant (Garibaldi *et al.*, 2013). Both higher density and higher species diversity of pollinator visits to flowers have been shown to be associated with higher crop yields (Garibaldi *et al.*, 2016). Species diversity among pollinators can be important in buffering the supply of pollination services against the effects of fluctuations in the populations of individual species (Kremen *et al.*, 2002).

Pollinator density and diversity in turn depend on the characteristics of the local environment and management practices, with declines in bee populations associated, for example, with the effects of parasites, pesticide use and a lack of floral diversity in the local area (Goulson *et al.*, 2015). Pollination services can potentially be promoted by appropriate management of crop fields and the surrounding ecosystem. For example, pollinator habitats at field edges and other uncultivated areas can be conserved or enhanced so that they provide sufficient resources such as food and water and nesting sites and materials (Sheffield *et al.*, 2016). Weed management can be adapted so as to increase benefits to pollinators while avoiding excessive production losses due to weed interference (Altieri *et al.*, 2015). Pollination services can also potentially be promoted by intercropping with crop species that are attractive to pollinators or through agroforestry (Frimpong *et al.*, 2011; Varah *et al.*, 2103; Perreira *et al.*, 2015).

Pest and disease regulation

Pest and disease control services are provided by a range of species, including predators, parasitoids and herbivores, often referred to biological control agents. These can include species that occur naturally in the local area (so-called natural biological control agents) and those that are deliberately introduced in order to control a problem species. The latter may involve the permanent introduction of a new species into the local ecosystem or the repeated application of a control agent directly onto a specific target (Cock *et al.*, 2011). Permanent introduction of a natural enemy is referred to as "classical biological control" and is typically used against exotic pests that cannot be effectively controlled by locally occurring natural enemies. The practice of introducing biological control agents directly onto a target crop during a specific cropping cycle is known as "augmentative biological control" (*ibid*.).

Biological control services can be provided by domesticated crops and livestock and by species used in forestry, aquaculture and fisheries. Examples involving livestock include the use of ducks to control pests in rice fields (Teo, 2001; Men *et al.*, 2002) and chickens to control ticks (Dryer *et al.*, 1997). Various kinds of grazing livestock are used to control invasive plant species (FAO, 2015a; Silliman *et al.*, 2014). Livestock grazing can also contribute to the control of some crop pests (Hatfield *et al.*, 2007; Umberger, 2009). Farmed and wild fish can contribute to the control of crop pests, for example in rice–fish productions systems (Halwart and Gupta, 2004). For example, grass carp has been introduced to control invasive aquatic vegetation; gold fish, tilapia and mosquito fish have been introduced to control mosquitoes through predation on eggs and larvae (Bartley and Casal 1998 and Gozlan 2008). Cover crops can be used to control weeds via the effects of shading, competition for space and nutrients or the release of chemicals (allelopathic substances) that are harmful to the weeds (Teasdale, 2003; Lemessa and Wakijira, 2015). In some instances, sterile biological control agents are used in order to prevent the species from reproducing and thus allow the process to be better controlled (e.g. the use of sterile grass carp in the United States of America – Mitchelle and Kelly 2006).

Advantages of biological control over other pest-control methods include the absence of toxic effects on humans and other species. Natural biological control agents and classical biological control agents (once they have become established) often provide services at little or no direct cost to producers. However, the effectiveness of these services depends on the capacity of the local ecosystem to maintain the respective natural-enemy species in sufficient numbers. This capacity can be diminished by human actions, for example by habitat destruction (Letourneau, 1998) or inappropriate use of pesticides (Ruberson *et al.*, 1998), but it is also possible to manage habitats so as to increase their suitability for natural enemies (Ferro and McNeil, 1998; Gurr *et al.*, 1998).

Diversity among biological control agents can contribute to the effectiveness of service provision. For example, different natural enemies of a given pest may have complementary effects and thus provide more effective control if they are present together. Moreover, the presence of a number of different natural enemy species increases the likelihood that biological control services will be able to continue if individual species are lost or their populations decline. The diversity of natural enemies is in turn dependent on the presence of a range of other species within the local ecosystem – plants that provide shelter, prey species that provide alternative sources of food and so on. In addition to providing ongoing biological control services, diverse ecosystems that support a range of natural enemy species also provide a potential source of new species for use in future biological control strategies (Cock *et al.*, 2011).

Water purification and waste-water treatment

The role of biodiversity in the supply of freshwater is discussed above in the subsection on provisioning services. Many of the same processes contribute to the decontamination of water after it has been used. To a large extent, these services can be regarded as two sides of the same coin: waste water treatment often delivers freshwater that can potentially be used again by downstream users. However, water-treatment services can also benefit salt and brackish water ecosystems and waters flowing into them and some are delivered by these ecosystems and the biodiversity associated with them. The purifying service provided by natural beds of oysters and other molluscs, such as mussels, that filter water is well established and efforts are being made to to restore oyster beds to supply food and other ecosystem services (Lindahl *et al.*, 2005; Coen et al,. 2007; Grabowski and Peteron, 2007; Zu Ermgassen *et al.*, 2013; NOAA, 2016), Species raised in aquaculture may be able to play a role in delivering services of this kind. Farmed shellfish can, for example, remove excess carbon, nitrogen and other nutrients from the water and incorporate them into their bodies or deposit them in sediments through production of pseudofaeces (Rice, 2001; Higgins *et al.*, 2011). Both natural and farmed marine seaweed systems provide water purification services in coastal waters through cycling and nutrient stripping (Chopin *et al.*, 2001; Neori et al, 2007; Smale *et al.*, 2013). Integrated multi-trophic level aquaculture (see Section 4.3) takes advantage of the absorptive capacities of shellfish and/or aquatic plants to remove waste from one part of the production cycle (e.g. the production of fish or shrimp) and utilize it to produce additional product (e.g. seaweed) (Troell *et al.*, 2009).

Habitat provisioning

A habitat is a location that can serve as the home of a particular species. It provides the species with conditions in which it can survive and reproduce, for example temperatures within a given range and access to appropriate feed resources in sufficient quantities. Without suitable habitat, a species cannot survive and can play no role in the supply of ecosystem services.

TEEB (2010), which as noted in the Concepts and definitions section treats habitat services as a distinct category of ecosystem service, highlights two aspects of habitat creation and maintenance that can be regarded as particularly significant. The first of these is the provision of habitats that enable migratory species to maintain their life cycles, for example feeding and roosting sites for migratory birds and free flowing rivers for migratory fishes. Providing services of this kind means that an ecosystem helps to support the beneficial roles played by the respective species at distant locations. The second aspect is the maintenance of genetic diversity (including the diversity of domesticated species) and in particular the maintenance of habitats that serve as "hotspots" of biodiversity. Habitat services both underpin the ongoing delivery of other ecosystem services and help to maintain diversity that may be vital in allowing ecosystems to adapt to future changes.

Biodiversity is both a contributor to and a product of habitat services. All species rely on others, some directly as sources of food, shelter, pollination, etc. and others indirectly via ecosystem functions that help to make the environment habitable, for example preventing soil erosion or regulating water flow and quality (see above).

The habitat impacts of food and agricultural production systems are very diverse. In some cases, industrial livestock units for example, production environments are almost totally human-controlled and whatever natural or semi-natural habitats may previously have been present are obliterated. In others, habitats are transformed to create favourable conditions for particular species (crops, livestock, forest trees, etc.) but still retain semi-natural elements – in the soil, at field margins, etc. In yet others, production takes place largely in semi-natural habitats – grazed rangelands or managed forests, for example – altered to varying degrees by the introduction of domesticated species or other management interventions. Finally, there are systems in which products are extracted from essentially "wild" ecosystems such as oceans and unmanaged forests.

None of these production activities leave natural habitats in their pristine forms, although well managed fisheries often have negligible impact on aquatic ecosystems. Land- and water-use changes associated with agriculture and food production are recognized as major drivers of habitat loss (CBD, 2010). For example, livestock over-grazing has been shown to negatively effect riparian communities and has resulted in the loss of important aquatic species in some areas (Armour *et al.*, 1991). It is therefore tempting to regard food and agricultural systems purely as purveyors of habitat "disservices" rather than habitat services. There are, however, several factors that suggest that this is not the whole story. For example, some wild species are now heavily dependent on particular agricultural habitats, and can be threatened not only by the intensification of production systems but also by their abandonment (e.g. Zakkak *et al.*, 2014; Dyulgerova *et al.*, 2015). Moreover, domesticated species raised in semi-natural ecosystems sometimes provide particular habitat-maintenance services that are difficult to replace.

The link between agriculture and habitat services is illustrated, for example, by the fact that out of 231 habitat types listed in Annex 1 of the European Union's Habitats Directive (EU, 1992), 63 are considered either to be fully or partly dependent on agricultural practices (Halada *et al.*, 2011). In most cases, the habitat-benefiting effects are a result of grazing or mowing (*ibid.*) and are therefore mainly associated with livestock production, although some wild species can be affected by the loss of arable fields (Brambilla *et al.*, 2009; Nikolov *et al.*, 2011). In many places, the abandonment of agriculture leads to the spread of scrub and woodland – habitats that have their own value for wildlife and may contribute to other ecosystem services. However, at a landscape scale, scrub and woodland may be less biodiverse than a mosaic landscape created by traditional agriculture, and their spread may threaten species that rely on more open habitats such as meadows.

So-called conservation grazing – the intentional use of grazing animals such as cattle sheep and horses to maintain vegetation in a state that provides suitable habitat for particular kinds of wildlife has become a widespread practice, particularly in Europe (Woodland Trust, 2012;). Positive impacts on targeted biodiversity have been observed, for example, in sand-dune habitats (Plassman *et al.*, 2010), marshlands (Mérő *et al.*, 2015) and grasslands (Faria *et al.*, 2012). Care must, however, be taken to avoid a one-size-fits-all approach, as grazing can be harmful to some habitats and conservation objectives (e.g. Jofré and Reading, 2012; Sharps *et al.*, 2015).

In some cases, habitat services only come to light after livestock are removed from a site. For example, when cattle and water buffalo were banned from the Keoladeo National Park in India, a wintering site for the rare Siberian crane (*Leucogeranus leucogeranus*), an aquatic grass species no longer fed upon by the animals became more abundant, making it difficult for the cranes to dig up plant tubers they used for feed and leading to a decline in their population (Pirot *et al.*, 2000). The disappearance of the large blue butterfly from the United Kingdom provides another example. The large blue is a brood parasite, i.e. it operates a cuckoo-like strategy of tricking other species into raising its young. The hosts in this case are certain types of ants, the most suitable being *Murmica sabuleti*, a species that thrives on closely grazed pastures. A decline in sheep numbers led to a decline in the *M. sabuleti* population and in turn to the local extinction of the large blue (Thomas, 1980).

Some food and agricultural production systems are in themselves very diverse floristically, which in turn contributes to their roles as habitats for other species. For example, in many parts of the tropics people maintain highly diverse home gardens that serve as sources of food, medicines, ornamentally and culturally important plants, fuel, fodder and other products. In places, these gardens serve as refuges for native wild plants that are threatened by habitat loss in the wider landscape (Hemp, 2004; Webb and Kabir, 2008; Larios *et al.*, 2013). Home gardens can be important for the survival of crop wild relatives (Salako *et al.*, 2014) and for the maintenance of within-species genetic diversity in wild species (Gao *et al.*, 2012). Domesticated plant species contribute to the habitat services provided by such production systems. For example, coffee plants in home gardens in Ethiopia have been found to be important habitats for a range of rainforest epiphytic species (Hylander and Nemomissa, 2008). Many forests are highly diverse habitats; a number of forest zones recognized among the world's biodiversity hotspots (CEPF, 2016). In the marine environment, kelp beds, although usually dominated by a few major keystone species, support a range of species that depend on the seaweeds for shelter, food and substrate (Graham, 2004).

The diversity of domesticated species present in a production system can add to the diversity of the habitats created. Crop rotation or intercropping can contribute to a more wildlife-friendly agriculture (Mineau and McLaughlin, 1996; Sokos *et al.*, 2013; Vignesh *et al.*, 2014). Likewise mixed-species forest plantations tend to provide greater habitat diversity than monocultures (e.g. Hartley, 2002; Felton *et al.*, 2016). Sometimes a mixed herd or flock of animals will provide better habitat management services than a single species or breed (e.g. Loucougaray *et al.*, 2004). Although fish farmers do not appreciate it, waterfowl numbers have in some cases increased around fish ponds due to the extra supply of easily accessible food (Fleury and Sherry, 1995).

At a larger scale, the availability of a range of domesticated plants and animals (terrestrial and aquatic) enables habitat services to be provided in a diverse range of environments (although it can also facilitate the provision of disservices if deployed inappropriately). For example, the above-described conservation grazing services provided by livestock depend on the availability of animals that are well adapted to local climates, terrains and forage resources. Different species – and to some extent different breeds – have different feeding habits that can be used to achieve different objectives in habitat management (GAP, 2009). The overall diversity of wild species used in food and agriculture (e.g. wild aquatic species and forest trees) clearly also contributes to the capacity of ecosystems to provide habitat services.

Associated biodiversity species are essential to the supply of habitat services in food and agricultural systems. In the soil, for example, earthworms, ants, termites and small mammals create habitats for smaller organisms by building resistant soil aggregates and pores (Turbé, *et al.*, 2010). These structures can become hotspots for microbial activities that in turn underpin habitat services (and other ecosystem services) on a larger scale.

Cultural and amenity services

Cultural and amenity services are the aesthetic, recreational, inspirational, spiritual and educational benefits that people obtain from direct or indirect contact with ecosystems (TEEB, 2010). Biodiversity has a major influence on the aesthetic appearance of many ecosystems, their capacity to inspire, their suitability for various recreational activities and their educational significance. Some cultural activities depend directly on the presence of particular species or a significant level of species diversity, for example various wildlife-watching activities or recreational fishing. In other cases, characteristic species or biological communities add to the particular aesthetic and inspirational qualities of a local landscape. Many traditions, crafts and culinary specialties are linked to some aspect of local biodiversity. Biodiversity increases an ecosystem's potential as an educational resource – more species and more ecological interactions to learn about.

Many cultural ecosystem services are associated with wild ecosystems. However, food and agricultural production systems and their domesticated and associated biodiversity also greatly contribute to the supply of these services. This is the case, for example, for many culinary traditions, which are often linked to local products and may depend on particular local species, breeds or varieties crops, livestock or fish. The same is true for a variety of non-food products made from wood, plant and animal fibres, and animal skins, feathers, bones and horns.

Farming, livestock-keeping, forest and fishing communities are often guardians of a range of traditional knowledge related to the characteristics and management of local biodiversity for food and agriculture. In addition to its practical value, this knowledge is part of the cultural heritage of the local area (and of society more broadly). Many myths, legends and folktales, songs, dances, poems and artistic traditions (drawing, sculpture, etc.) are likewise linked to local food and agricultural biodiversity. The survival of such artistic traditions is not necessarily dependent on the ongoing presence of respective elements of biodiversity. However, if the biodiversity is lost, the traditions may lose much of their imaginative power, as well as sources of ongoing inspiration. Particular plants and animals (terrestrial and aquatic) or products obtained from them are important elements in many cultural and religious events and festivals. Livestock are used in various sports and pastimes. Gardening and raising small livestock such as pigeons and rabbits are widely pursued as leisure activities, and in some places somewhat larger scale hobby farming is popular. Pets and companion animals of various kinds, including aquarium species, are also widely popular.

Agricultural, pastoral, wetland and managed-forest landscapes are often valued for their aesthetic qualities, their cultural significance or as sites for recreational activities. Particular crops, fish, trees or types of livestock may be vital to the "sense of place" associated with a given location. Grazing livestock can play a major role in shaping the local vegetation and hence the character of semi-natural landscapes. There is clearly a degree of subjectivity in judgements about what kind of landscape is preferable. Arguments can be put forward in support of more naturalistic or “rewilded” landscapes. However, in many places landscapes shaped by agriculture and livestock keeping are highly valued by both local people and tourists (Ciaian and Gomez y Paloma, 2011; Zander *et al.*, 2013). Landscape-related ecosystem services are often best provided by locally adapted animals and plants, both because of their ability to cope with local conditions and because of their links to local culture.

In addition to the intangible benefits that they provide in terms of recreation, aesthetic appreciation, inspiration and so forth, cultural ecosystem services can also have measurable positive effects on human health. Studies have shown that access to green spaces can produce benefits in terms of, inter alia, cardiovascular, reproductive and mental health (Mitchell and Popham, 2008; Dadvand *et al.*, 2012; Tamosiunas *et al.*, 2014; WHO/CBD, 2015). The significance of biodiversity in these effects, and the mechanisms involved remain quite poorly understood (WHO/CBD, 2015). In addition to possible direct effects on psychological well-being, interaction with “nature” may promote a more physically active lifestyle and also bring people into contact with diverse environmental microbiota, a factor increasingly considered to have a significant influence on health (*ibid*).[16] In some countries, there is a growing interest in “care farming”, the use of commercial farms, agricultural landscapes and normal farming activities for therapeutic or health-promoting purposes, as well as in approaches such as animal and horticultural therapy (Hassink, 2003; Hine *et al.*, 2008; Elings, 2012).

Cultural ecosystem services also create significant economic opportunities in fields such as tourism (including, in the context food and agriculture, farm holidays and visits to areas with historical or scenic farming or forest landscapes) and recreational fishing and hunting. For example, recreational fishing is a multibillion dollar industry largely practised in developed countries but gaining popularity in developing countries as well (Arlinghause and Cook, 2009). Guidelines have been developed to help ensure that it is done in a responsible manner (FAO, 2012).

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[16] Links between human microbiota and health are beyond the scope of this report. However, it is interesting to note that there is some evidence that exposure to farms and farmland, as well as to farm animals and dogs, can help people acquire microbial diversity that can protect against allergic disorders (WHO/CBD, 2015).

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[CHAPTER 2 – DRIVERS OF CHANGE]

CHAPTER 3 – THE STATE AND TRENDS OF BIODIVERSITY FOR FOOD AND AGRICULTURE

3.1 Introduction

[Editor's note: The main objective of this chapter is to describe the status of biodiversity for food and agriculture, including genetic resources for food and agriculture, associated biodiversity and the ecosystem services they support, and wild foods, and to identify trends. The status and trends of associated biodiversity species are presented following an ecosystem services classification.

The chapter provides information on the following topics:

- The state of knowledge on the status and trends of biodiversity for food and agriculture;
- The state of diversity of genetic resources for food and agriculture, associated biodiversity and wild foods;
- The trends that can be identified in the diversity of genetic resources for food and agriculture, associated biodiversity and wild foods, and the species under threat;
- The trends in ecosystem services; and
- Major gaps in the information available, and needs and priorities for improving knowledge of state and trends of biodiversity for food and agriculture.

The final version will include additional subsections, and an introduction to replace this note.]

3.2 Plant, animal, forest and aquatic genetic resources for food and agriculture

Introduction

Approaches to monitoring the status and trends of genetic resources for food and agriculture vary from sector to sector. A range of different aspects of diversity can potentially be monitored. Biodiversity is generally considered to encompass diversity at ecosystem, species and within-species levels. Within species, in addition to genetic diversity at the allelic level, there may be distinct groupings such as varieties and breeds. Units of diversity such as species, varieties or breeds can arise or become extinct. They can embody different amounts of genetic diversity and exist at different levels of extinction risk. They can be distributed in different ways geographically and in relation to each other. They can also be grouped in different ways, for example based on their ecological function or their potential roles in food and agriculture. Individual organisms within a population can be distributed in different ways across these categories or across the units of diversity. For example, in addition to species (or breed or variety) "richness", i.e. the number of those units present, it is possible to measure the "evenness" with which individual organisms are distributed across these units (and various indices combining these measures can be calculated). The immediate relevance of these various aspects of status and trends to the management of genetic resources varies from sector to sector, as does the magnitude of the task of monitoring them. The current state of knowledge and the state of capacity to expand it and keep it up to date also varies from sector to sector and country to country.

Plant genetic resources for food and agriculture

Generally accepted indicators of the diversity of plant genetic resources have yet to be developed. Interest focuses particularly on developing indicators for genetic erosion and genetic vulnerability at within-species level. The former can be defined as "the loss of individual genes and the loss of particular combinations of genes (i.e. of gene complexes) such as those maintained in locally adapted landraces" (FAO, 1996). Genetic vulnerability is "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, 1996). Indicators of genetic erosion would ideally be sensitive to changes in the frequency of important alleles (and give them more weight than less important ones), provide a measure of the extent of potential loss (e.g. by estimating the fraction of genetic information at risk relative to the total diversity) and allow assessment of the likelihood of loss over a specific time period in the absence of intervention (FAO, 2010). Genetic vulnerability can be characterized by a number of different population-level attributes that might serve as useful indicators, for example the extent of genetic diversity of genes conferring resistance to, or tolerance of, actual and potential major pests and diseases or abiotic stresses (*ibid*.).

Although it is not possible to make definitive statements about global trends in the erosion of on-farm crop diversity, the evidence presented in the country reports prepared for the *The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture* (Second SoW-PGRFA) (FAO, 2010)[17] indicates that at least for some crops and in some areas the diversity present in farmers' fields has declined and that threats to diversity are getting stronger. There is considerable consensus that, overall, the shift from traditional production systems utilizing farmer varieties to "modern" production systems depending on released varieties is leading to genetic erosion. Numerous traditional crop varieties are reported to have disappeared or become rarer. However, the picture is complex. For example, it appears that many farmers who plant modern varieties also continue to maintain traditional varieties. Studies of trends in genetic diversity within released varieties also indicate a complex picture, with some reporting no reduction or even increases in diversity over time. It is likewise difficult to make definitive statements about trends in genetic vulnerability. More than

17 Unless otherwise indicated the material presented in this subsection are taken from this report.

half the country reports prepared for the Second SoW-PGRFA indicated that genetic vulnerability is significant.

The diversity of crop wild relatives has decreased in some areas and appears to be particularly threatened in marginal areas experiencing changes in climatic conditions, where migration is prevented by ecogeographical barriers. As a consequence, efforts to collect these resources and secure them under long-term conservation facilities are increasing.

Where the diversity of *ex situ* collections is concerned, the number of accessions stored as of 2010 was 7.4 million (an increase of 20 percent since 1996). However, fewer than 30 percent of these (between 1.9 and 2.2 million) were estimated to be distinct accessions. FAO has recently (2016) expressed concerns about possible losses in *ex situ* collections as a result of a lack of funds for regeneration (FAO, 2016a). Given that the reproductive behaviours and seed physiology of crop wild relatives and wild food species are, in general, not well known and that their regeneration is therefore more difficult and demanding, it can be expected that these species will increasingly be affected by these budgetary constraints.

Animal genetic resources for food and agriculture

At global level, the status and trends of animal genetic resources for food and agriculture are assessed largely on the basis of summary statistics on the risk status of individual breeds, i.e. the proportions of the world's breeds that are categorized as at risk, not at risk, extinct or of unknown risk status (according to the classification system used by FAO).[18] Since 1993, FAO has published global data of this kind in a number of reports, the most recent being *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture* (FAO, 2015a).[19] The approach has some limitations in that it does not take into account the state of genetic diversity within populations (e.g. the effects of inbreeding or of cross-breeding with other breeds) and treats all breeds equally regardless of their significance to the overall diversity of the species (or with respect to other possible conservation criteria). It also only registers changes when breeds move from one risk-status category to another.[20] Lack of regularly updated data on the size and structure of breed populations is a major practical constraint to the monitoring of risk status in many countries, particularly in the developing regions of the world, and globally.

As of July 2014, out of 8 774 reported breeds, 17 percent were classified as at risk of extinction, 18 percent as not at risk, 7 percent as extinct and 58 percent as being of unknown[21] risk status. A comparison of data from 2006 and 2014 and shows a slight increase (15 to 17 percent) in the proportion of breeds classified as being at risk of extinction[22] (it should be noted that given the above-mentioned weaknesses in the state of reporting this apparent change needs to be interpreted with some caution).

Among the extant species regarded as having been the wild ancestors of major livestock species, the most at risk according the IUCN Red List of Threatened Species[23] are the African wild ass (*Equus africanus*) and wild Bactrian camel (*Camelus ferus*), both of which are classified as critically

[18] Breeds are assigned to risk categories on the basis of the size, structure and trends of their populations. Data are drawn from the Global Databank for Animal Genetic Resources, the backbone of FAO's Domestic Animal Diversity Information System. Countries are responsible for entering data on their breed populations into the system.

[19] Unless otherwise indicated the material presented in this subsection are taken from this report.

[20] In 2013 the Commission on Genetic Resources for Food and Agriculture adopted the following set of indicators for AnGR diversity: the number of locally adapted breeds; the proportion of the total population accounted for by locally adapted and exotic breeds; and the number of breeds classified as at risk, not at risk and unknown. The indicators have not (as of 2016) been fully put into operation because the necessary classification of breeds as locally adapted or exotic has not been completed.

[21] Breeds are considered to be of unknown risk status if no population data have been reported to FAO during the preceding 10 years.

[22] Data for 2006 were analysed for the first report on *The State of the World's Animal Genetic Resources for Food and Agriculture* and from 2014 for the second report in the series. Trends were calculated using the data recorded in the Domestic Animal Diversity Information System as of June 2014.

[23] Data as of June 2016.

endangered. The wild water buffalo (*Bubalus arnee*) and banteng (*Bos javinicus*) are classified as endangered. The gaur (*Bos gaurus*), wild yak (*Bos mutus*), Asiatic mouflon (*Ovis orientalis*), bezoar (*Capra aegagrus*) and swan goose (*Anser cygnoides*) are classified as vulnerable. The wild rabbit (*Oryctolagus cuniculuse*) is classified as near threatened.[24]

Forest genetic resources

The status and trends of forest genetic resources are monitored, with varying degrees of coverage and precision, at ecosystem, species and intraspecific levels. In many parts of the world vast areas of land once covered by forests have been converted to other land uses, much of this change occurring during the twentieth century. Forests still cover 30.6 percent of the global land area and, while global forest area continues to shrink, the rate of annual net loss of forests has been significantly reduced during recent decades (FAO, 2016b).

About 13 percent of the world's forests (524 million hectares) have been designated primarily for biodiversity conservation, but forest degradation and the loss of primary forests are likely to continue, especially in the tropics (FAO, 2016b). Globally, forest genetic resources are being threatened and eroded by conversion of forests to agriculture, unsustainable harvesting of trees for wood and non-wood products, grazing and browsing, climate change, forest fires and invasive species (FAO, 2014a).

Monitoring of forest biodiversity at global level is hampered by methodological and other challenges. Most countries face difficulties in assessing their primary forest area (FAO, 2016b). Similarly, forest degradation, forest restoration and species composition are difficult to monitor precisely at global level. Monitoring of the risk status of trees species is also currently not comprehensive and the total number of extant tree species in the world remains uncertain. The Global Tree Assessment,[25] an initiative led by Botanic Gardens Conservation International and the IUCN/Species Survival Commission Global Tree Specialist Group, aims to provide conservation assessments of all the world's tree species by 2020 (Newton et al., 2016). While the global picture is incomplete, a number of countries are able to monitor the risk status of all their tree species.

There is no systematic global monitoring system in place for intraspecific diversity in tree species. Schemes for genetic monitoring of forest trees have been proposed at global (Namkoong et al., 1996; 2002) and regional levels (e.g. Aravanopoulos et al., 2015). However, they have not yet been implemented and only a very few countries have tested such schemes in practice (e.g. Konnert et al., 2011). Loss of intraspecific diversity in economically important tree species has been a major concern in forest management for decades. Forest management practices can have genetic impacts on tree populations. However, they need to be assessed on a case by case basis. The extent of the impact depends on the management system and the stand structure, as well as on the demography, biological characteristics and ecology of the species (Wickneswari et al., 2014). In temperate forests, for example, silvicultural interventions, such as the thinning of a stand, usually have limited genetic consequences (Lefèvre, 2004) and many silvicultural systems maintain genetic diversity in tree populations rather well (Geburek and Müller, 2005). However, if forest management practices change evolutionary processes within tree populations, this can have a more profound impact on genetic diversity of subsequent tree generations (Lefèvre et al. 2013).

Aquatic genetic resources for food and agriculture

Monitoring of the biodiversity of marine and inland fisheries, and the biodiversity of AqGR in aquaculture varies substantially within these subsectors and among countries. Monitoring of diversity at intraspecies level is relatively undeveloped in the aquatic sector as compared to the terrestrial livestock and crop sectors. Fisheries and aquaculture data submitted by Members to FAO provide valuable information on aspects of aquatic biodiversity for food and agriculture. However, information is not always reported at the species level. This is especially problematic for inland

[24] This refers to the status of the wild rabbit in its natural range. Outside its natural range, the species is widespread and often considered a pest.
[25] https://www.bgci.org/plant-conservation/globaltreeassessment/

fisheries, where over half the production is not designated by species (Bartley *et al.*, 2015). In aquaculture, reports indicate that more species are being farmed now than ever before, especially as more marine fishes are being bred in captivity (FishStat Plus; Duarte *et al.*, 2007).

The state of marine fisheries is assessed by FAO through analysis of over 400 stocks of fish throughout the world. Species targeted by marine fisheries are classified according to whether they are overfished (fished at biologically unsustainable levels), fully fished (fished at biologically sustainable levels) or underfished. Based on FAO's analysis in 2013, the share of fish stocks within biologically sustainable levels (fully fished or underfished) declined from 90 percent in 1974 to 68.6 percent in 2013; thus, 31.4 percent of fish stocks were estimated to be overfished (FAO, 2016c). Of the stocks assessed in 2013, 58.1 percent were fully fished and 10.5 percent underfished (*ibid*,).

FAO does not provide an equivalent analysis for freshwater fisheries. The state of inland capture fishery resources is more difficult to monitor for a number of reasons including the diffuse nature of the sector, the large number of people involved, the seasonal and subsistence nature of many small-scale inland fisheries, the fact that much of the catch is consumed locally or traded informally and the fact that the resources can be greatly affected by activities other than fishing, including stocking from aquaculture and diversion of water for other uses such as agriculture and hydro-electric development (FAO, 2012). While there is no dedicated FAO programme to assess the state of inland fisheries, the 32nd Session of the FAO Committee on Fisheries recommended "the development of an effective methodology to monitor and assess the status of inland fisheries, to underpin their value, to give them appropriate recognition and to support their management … [and] requested that FAO develop this assessment methodology, including broader ecosystem considerations that impact inland fisheries." (FAO, 2016d).

There has been a reported decline in top level carnivores in many marine and inland fisheries. This is referred to as "fishing down the food web" and can indicate overfishing (Pauly *et al.*, 1998). Often the productivity of a fishery remains high, especially in inland waters, as lower trophic level species increase in the absence of larger predators, but the value of the fish drops as the large, more valuable species disappear (Welcomme, 2001).

The status of many aquatic species is also assessed by conservation and trade organizations. IUCN maintains a list of threatened species (the Red List)[26] and their level of endangerment. Currently over 1 300 marine species including plants, fish, molluscs, crustaceans and other invertebrates, and over 16 000 wetland species are listed as endangered, threatened or vulnerable on the IUCN Red List. Among freshwater fish (not the full range of biodiversity mentioned above), out of 5 785 species that had been assessed for the IUCN Red List at the end of 2011, 60 were considered extinct, 8 extinct in the wild and 1 679 (29.3 percent) threatened (Carrizo et al, 2013). If it is assumed that half the 1 062 species classified as data deficient are under threat, the proportion of threatened species would amount to 36.1 percent of the total (*ibid*). However, not all of the fish assessed by IUCN are used for food and agriculture. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)[27] also maintains information on the status of aquatic biodiversity that is traded internationally. Several species used in fisheries and aquaculture are on the CITES appendices (e.g. sturgeons, tunas and sharks), and can only be traded internationally under certain conditions (e.g. with special permits) or not at all.

There is very little monitoring of the state of feed organisms cultured for use in aquaculture. Many of these micro-algae and micro-invertebrates are highly managed populations or essentially large-scale cell cultures (see the forthcoming FAO thematic background study on aquatic micro-organisms).

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[26] http://www.iucnredlist.org/
[27] https://www.cites.org/eng/app/appendices.php

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3.3 Pollination and pollinators

Introduction

Pollination is a key ecological process, whereby pollen is carried from the male to the female part of flowers for reproduction. This process is important in both human-managed and natural terrestrial ecosystems and is critical for food production and human livelihoods (FAO, 2009; FAO, 2016).

As noted in Section 1.2, nearly 90 percent[28] of all flowering plant species, including the vast majority of plants in tropical forests, savannah woodlands, mangroves and temperate deciduous forests, depend,[29] at least in part, on animal vectors to transfer pollen, although other means of pollen transfer, such as self-pollination or wind-pollination, are also significant (FAO, 2009; Ollerton *et al.*, 2011; IPBES, 2016). Some species of pollinators are specialists (i.e. visit only one or a few plant species). Others are generalists (i.e. visit a wide range of species). Similarly, specialist plants are pollinated by a small number of species, while generalist plants are pollinated by a broad range of species (IPBES, 2016).

Animal pollination is largely supplied by managed and wild bee species, although other insects, such as flies, butterflies, moths, wasps and beetles, as well as vertebrates such as rodents, bats and birds are also important pollinators (FAO, 2016; IPBES, 2016).[30] Bats contribute to the pollination of a substantial number of plant species (FAO, 2008). For example, it has been estimated that they play some part in the pollination of at least 500 Neotropical species from 96 genera (Vogel, 1969).

Thirty-five percent of the world's total crop[31] production comes from species that are at least in part pollinated by animals (Klein *et al.*, 2007). Levels of pollinator dependence vary significantly among crops, with the highest levels found mainly in fruits, vegetables and nuts (*ibid.*). Most of these crops are important dietary sources of vitamins and minerals, as well as providing, in many cases, an important source of income (IPBES, 2016). Among trees, some species are pollinated by wind and some by insects. Nearly all coniferous trees, including pine, spruce and firs, rely on wind pollination, as do many broadleaved trees, including asp, oak, ash, elm, plane and pecan. The most common form of pollination in tropical rain forests is insect pollination (Kozlowski *et al.*, 1991).

State of knowledge

Formal scientific studies, citizen science projects[32] and indigenous and local knowledge all contribute to improving understanding of wild and managed pollinators and of pollinator-dependent crops and wild plants. Together, they help to improve understanding of the economic, environmental and socio-cultural values of pollination (IPBES, 2016), to identify threats to pollinators and to determine how such threats are affecting pollinator populations.

The availability of data on the status and trends of pollinators varies significantly by region, country and type of pollinator. Data are more complete in Europe and North America than elsewhere in the world. Within these regions managed pollinator species are better documented than wild pollinators, because they are i) economically important; ii) easier to monitor (they are kept in a box) and 3) their taxonomy is well understood (NRC, 2007; IPBES, 2016; country reports). A report on the status of pollinators in North America (NRC 2007) notes that despite taxonomic impediments (there are almost certainly many insect pollinator species that have not yet been identified), quite a large amount of information is available on pollinator population trends. However, the quality of this information, and

[28] This ranges from 94 percent in tropical communities to 78 percent in temperate zone communities (IPBES, 2016).
[29] Pollinator dependency is a measure of the level of impact that animal pollination has on the productivity of particular plant species.
[30] More than 90 percent of the leading global crop types are visited by bees and around 30 percent by flies. Each of the other animal pollinator taxa visits less than 6 percent of the crop types.
[31] Crop species that are directly consumed by humans.
[32] For example, the country report from the United Kingdom notes that a large amount of data on associated biodiversity are collected by citizen scientists – public citizens (that are not professional scientists) who collect data following strict standardized protocols. In many cases, published outputs from these surveys undergo a peer-review process.

hence the state of knowledge on status and trends, varies from taxon to taxon. The International Union for Conservation of Nature (IUCN)[33] Red List assessment covers 58 out of the 130 common crop pollinating bees in Europe and North America (IPBES, 2016).

Most country reports mention that national Red Lists have been established to assess the status, trends and threats of native flora and fauna species. At present, however, using such lists as a knowledge base for trends in pollinators has its limitations. For example, while they provide data on the risk status and habitat of a range of animal pollinator species, these species cannot be searched for based on pollination-related key words. They are classified according to IUCN criteria such as rate of decline, population size, area of geographic distribution and degree of population and distribution fragmentation, rather than by their function (i.e. pollination).

It appears from the country reports from all regions that bees, in particular honey bees and to some extent bumble bees, stingless bees and wild bees, are the most frequently monitored groups of pollinator species. Relevant programmes include the bee monitoring framework that was developed in the United Kingdom as part of England's Pollinator Strategy (DEFRA, 2014). Many countries recognize gaps in their knowledge on the status and trends of pollinating bees. However, many gather data on trends in the numbers of beehives. The country report from Ethiopia, for example, notes that despite a general lack of information on managed associated biodiversity the annual inventory of beehives provides a form of "indirect" monitoring.

A number of countries mention that, as an alternative to gathering data on the animals themselves, monitoring plant reproductive success or pollen deposition deficits may be an effective means of measuring pollinator trends. However, this approach will only work if the effects of other influences, such as climate and floral herbivory, can be accounted for (FAO, 2008).

Butterfly monitoring is largely conducted voluntarily, by experts and enthusiasts. For example, the country report from Germany notes that volunteers conduct weekly walks along set routes (transects), recording all species of diurnal butterflies year after year.[34] The population data obtained are used to track trends in butterfly populations at local, subnational and national levels. Butterflies are also among the groups of species monitored by the Dutch Network Ecological Monitoring (NEM)[35] programme in the Netherlands.[36] Data are mostly collected by volunteers and provided to private data management organizations. The results are published by, among others, the Netherlands Environmental Assessment Agency and Statistics Netherlands. Around 16 000 volunteers are active in the programme's various monitoring networks (De Groot, 2014). Ireland has established butterfly and bumblebee monitoring programmes.[37]

Information on the status and trends of other pollinators is generally quite limited. The International Union for Conservation of Nature (IUCN) Red List provides information on the global status of many vertebrate pollinators such as humming birds and bats. The migratory habits species belonging to these groups often require that monitoring work is done on a multicountry scale (FAO, 2008). Several relevant initiatives are reported from Mexico and the United States of America (*ibid*.). Data on fly populations are limited (FAO, 2008). However, there are relevant case studies: for example, showing severe impacts of urbanization on fly populations in human-dominated landscapes (Kearns *et al.*, 1998). Overall, the risk status of most of the world's insect pollinator species has not been assessed (IBPES, 2016).

Status and trends of pollinators, pollinator-dependent crops and pollination

Status and trends of pollinators

[33] https://www.iucn.org/.
[34] See, for example, http://www.tagfaltermonitoring.de (in German).
[35] http://www.netwerkecologischemonitoring.nl/home.
[36] There are also networks for mammals, birds, reptiles, amphibians, fish, dragonflies, flora, and mushrooms.
[37] http://www.biodiversityireland.ie.

Data from FAO's statistical database, FAOSTAT, show that the number of managed western honey bee hives is increasing globally. In 1961, countries reported fewer than 50 million hives. In 2014, they reported more than 83 million hives, producing an estimated 1.5 million tonnes of honey annually.

The pollination assessment published by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) in 2016 notes that despite the overall upward trends globally important seasonal colony losses are known to occur in some European countries and in North America (data for other regions of the world are largely lacking) (IPBES, 2016). This is reflected in the country report of the United States of America, which notes that honey bees have been in serious decline for decades: there were approximately 5.7 million managed honey bee colonies in the country in the 1940s and approximately 2.74 million colonies in 2015. The country report further notes that sharp colony declines occurred following the introduction of the ectoparasitic mite *Varroa destructor* in 1987 and again around 2006 with the first reports of colony collapse disorder.[38] The number of managed honey bee colonies seems to have stabilized in recent years, but this has required increased efforts by the beekeeping industry.[39] Since 2006, the average seasonal loss of honey bees in the United States of America has averaged around 31 percent, far exceeding the 15–17 percent loss rate that commercial beekeepers have indicated as an economically sustainable average.[40] A few country reports from northwestern Europe mention that the state of insect colonies in general, and of bee colonies in particular, is currently below the optimal threshold for pollination of flowering plants in arable land and grassland.

In Europe, 9 percent of bee and butterfly species are threatened and populations are declining in 37 percent of bee and 31 percent of butterfly species (excluding data deficient species, which include 57 percent of bees) (IPBES, 2016).[41] Several country reports from Europe, including Ireland, Norway, Poland and Switzerland, refer specifically to a decline in bumble bees. Two cases of severe bumble bee declines, that of the great yellow bumble bee (*Bombus distinguendus*) in Europe and that of Franklin's bumble bee (*Bombus franklini*) in the western United States of America, are highlighted by IPBES (2016). In both cases, effects on food and agricultural production systems have not yet been examined (*ibid*.).

The country report from the United Kingdom refers to work showing that among 216 bee species monitored nationally, 70 percent showed a decline in distribution between 1980 and 2010. With regard to the country's butterfly populations, the report indicates that recent years (2008 to 2013) have seen no overall change, but that long-term figures (1976 to 2013) show that the populations of 50 percent of butterfly species have decreased. Some other countries mention anecdotal indications of trends. The report from Grenada for example states that farmers frequently comment on falling numbers of butterflies and other insects in their fields, but that no specific studies have been conducted to confirm this perceived change or to identify the possible reasons for it.

Where vertebrate pollinators are concerned, IPBES (2016) estimates, based on IUCN Red List data, that 16.5 percent of species are threatened with global extinction (increasing to 30 percent for island species), with a trend towards more extinctions.

Status and trends of pollinator-dependent crops

A study undertaken by Aizen *et al.* (2009) using FAO data concluded that the importance of pollinator-dependent crops relative to pollinator-independent crops increased significantly at global scale between 1961 and 2006. The spread of pollinator-dependent crops occurred at the expense of natural and semi-natural habitats, pastures and land previously cultivated with non-dependent crops (*ibid*.). Yield growth and stability in pollinator-dependent crops have, however, been lower than in pollinator-independent crops (Aizen, 2009; IPBES, 2016). The reasons for this have not clearly been

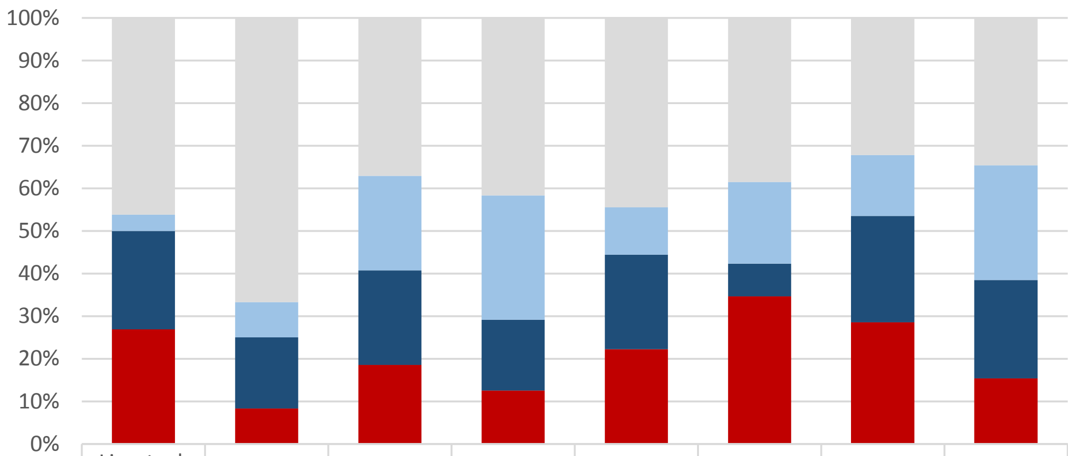
[38] The term colony collapse disorder describes a complex set of interacting stressors, including exposure to pesticides and other environmental toxins, poor nutrition (resulting in part from decreased availability of high-quality and diverse forage), exposure to pests (e.g. Varroa mites) and disease (viral, bacterial and fungal) that cause high colony losses (USDA, 2012).
[39] When overwintering colony losses are high, beekeepers compensate for these losses by "splitting" one colony into two, supplying the second colony with a new queen bee and supplemental food in order to quickly build up colony strength.
[40] The country report cites Steinhauer et al. (2015).
[41] Data for other regions are currently insufficient to draw general conclusions.

established. However, many studies at local scales show that crop production is higher in fields with diverse and abundant pollinator communities than in fields with less diverse pollinator communities (Garibaldi *et al.*, 2016). As noted in Section 1.2, pollinator density and diversity depend in turn on the characteristics of the local environment (e.g. the quality and quantity of food and nesting resources) and on management practices in agriculture.[42]

Status and trends of pollination

Some country reports provide information on trends in the state of pollination within their various production systems. Figure 3 summarizes the information provided.

Figure 3. Reported trends in the state of pollination within production systems



	Livestock grassland-based systems	Livestock landless systems	Naturally regenerated forests	Planted forests	Irrigated crops (rice)	Irrigated crops (other)	Rainfed crops	Mixed systems
Not known	12	8	10	10	4	10	9	9
Increasing	1	1	6	7	1	5	4	7
Stable	6	2	6	4	2	2	7	6
Decreasing	7	1	5	3	2	9	8	4

Note: The bars show the proportion of responding countries that provided each answer. Non-responding countries (among the total 71 that provided country reports) are not included in the figures.
Source: country reports.

In all cases, a large proportion of countries either provide no information or report that trends are not known. It is therefore difficult to draw clear conclusions about trends within particular production systems. Some countries report perceived declines (quantitative data are generally lacking) in the state of pollination services in agriculture without specifying which production systems are affected.

Needs and priorities

Numerous countries report having monitoring systems and programmes in place for pollinators relevant to food and agriculture. However, in many cases monitoring data are not linked to spatial data on the distribution of production systems. Better indications of where in production systems changes in pollinator populations are happening would help countries to assess the significance of such trends and plan strategies to address them. The country reports note a number of other priorities including the need to improve methodologies for documenting changes in the abundance and distribution of pollinators, to strengthen taxonomic capacity (needed to cope with the large number of

[42] For example, Klein et al. (2007) report case studies for nine crops on four continents that indicated that agricultural intensification jeopardizes wild bee communities and their stabilizing effect on pollination services at the landscape scale.

species involved) and to strengthen knowledge of the roles and economic significance of wild pollinator species (currently weak relative to knowledge of managed honey bees).

Several countries note that addressing knowledge gaps on the status and trends of pollinators and pollination will require systematic and long-term monitoring efforts. Citizen science project could contribute to monitoring several groups of wild pollinator species, including butterflies, birds and bats. As described above, this is already happening to some extent in a number of countries.

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3.4 Pest and disease regulation

[EDITOR'S NOTE: Review of this section has not been completed]

Introduction

Pest, disease and weed regulation is a crucial ecosystem service for food and agriculture. The direct providers of this service are a vast category of associated biodiversity known as biological control agents (BCA). Non-BCA biodiversity contributes indirectly to the creation of a pest-suppressive environment by, inter alia, providing alternative food sources and shelter for BCAs. BCAs can be deliberately introduced (augmentative and classical biological pest control – see Section 4.3.2) or managed indirectly by manipulating the environment to promote their presence (conservation biological control).

BCAs are taxonomically diverse and include many species of bacteria, fungi, invertebrates and vertebrates. To provide an overview of their roles it is useful to classify them into functional groups (de Bello *et al.*, 2010). The most significant are parasitoid insects, predators, entomopathogenic bacteria, fungi and nematodes, other fungi (antifungal) and herbivores (Box 2).

Box 2. Main functional groups of biological control agents

Parasitoids. Species belonging to this group spend part of their life cycles (usually the larval stage) inside or in the surface of a host, killing or consuming it in the process. Approximately 10 percent of known insect species are parasitoids (Godfray, 1994). Examples include wasps of the superfamily *Apocryta* and flies of the *Tachinidae* family.

Predators. This group includes many arthropod species – including members of the Acari (mites), Araneae (spiders), Opiliones (harvestmen), Odonata (dragonflies), Hemiptera (including assassin bugs), Neuroptera (lacewings), Coleoptera (beetles), Diptera (flies) and Hymenoptera (bees, wasps) (Cock et al., 2011) – as well as a number of vertebrates (amphibians, birds, fish, mammals and reptiles). Predators feed on a range of pest species in all sectors of food and agriculture, although generalists may feed on useful species as well. The group includes aerial, aquatic and ground predators (Holland *et al.*, 2012). The former have good dispersion ability and can predate on the higher parts of plants; they include flying insects (e.g. Coccineallidae and Diptera families) and insectivorous birds and bats. Aquatic predators specifically used as control agents include fish species in ricefield systems (e.g. the common carp, *Cyprinus carpio*, and the Nile tilapia, *Oreochromis niloticus*); wrasses (Labridae) employed as sea-lice parasite cleaners in salmon cages and a number of carnivorous species (e.g. the seven spot featherback, *Notopterus notopterus*) used to control tilapia breeding by predating their young. Ground predators are associated with the soil surface and the upper layer of the soil. Their ability to disperse is more limited. Examples include ground and rove beetles whose larvae overwinter in the soil. Predatory amphibians include toads (e.g. *Rhinella marina* and *Rhinella arenarum*) and frogs (e.g. *Leptodactylus chaquensis*, *Leptodactylus latinasu*s and *Physalaemus albonotatus*), although the importance of their role (as well as that of the reptiles) in biological control remains poorly understood (Hocking and Babbit, 2014).

Entomopathogenic fungi. This group comprises members of the Fungi kingdom that invade and reproduce in arthropod tissues, killing the host (e.g. *Beauveria bassiana* and *Metarhizium anisopliae*).

Antifungal fungi. This group comprises members of the Fungi kingdom that limit the development of fungal plant disease by competition, promoting plant resistance or killing the disease-causing fungi. Examples include *Trichoderma* spp.

Entomopathogenic nematodes (EPNs). These nematodes invade the tissues of many types of insects (including Lepidoptera, Coleoptera and Diptera). Important EPNs include *Steinernema* spp. and *Heterorhabditis* spp. (Cock *et al.*, 2011).

Entomopathogenic bacteria. A healthy soil contains wide range of micro-organisms that naturally suppress pests and diseases (Beed *et al.*, 2011). An important species in this in this category is the bacterium *Bacillus thuringiensis*, which synthesizes a compound (Bt) that is toxic to insects.

Weed and algae damaging herbivores. Herbivores such as weevils (Curculionidae) and leaf beetles (Chrysomelidae) help control weeds in croplands (Cock *et al.*, 2011). Fish such as the grass carp (*Ctenopharyngodon idella*) are used in irrigation systems to control aquatic weeds (Halwart and Gupta, 2004). Rabbitfish (*Siganus* spp.) and scats (*Scatophagus* spp.) help control fouling epiphytic algae in marine fish cages.

Despite the benefits they provide, an increase in the richness and abundance of BCAs can sometimes lead to antagonistic relations such as superpredation, hyperparasitoidism (parasitoidism of parasitoids) and predation among generalist predators (Griffin *et al.*, 2013; Holland *et al.*, 2012; Landis *et al.*, 2000; Martin *et al.*, 2013). Competition between BCAs for the same prey (functional redundancy) may not add to the effectiveness of pest regulation, i.e. one BCA species may perform as well as two (Martin *et al.*, 2013; Rafikov *et al.*, 2008; Straub *et al.*, 2008). However, functional redundancy tends to increase the resilience of pest control services by reducing the risk that all BCAs for a particular pest will be lost (e.g. because of climate change) (Beed *et al.*, 2011; Cock *et al.*, 2011). Interactions of this kind mean that creating pest suppressive landscapes requires a good understanding of the ecology of the respective locations. The success of pest control is determined not just by the sheer richness and abundance of BCAs, but also by the characteristics of the trophic relations that exist within the food web (Martin *et al.*, 2013).

Smallholders in developing countries have traditionally practised conservation biological control, in other word have manipulated the local ecosystem to promote the presence of BCAs. The strategy is becoming increasingly mainstream in large-scale agriculture (Beed *et al.*, 2011). Further information on integrated pest management is provided in Section 4.3.2.

Main biological control agent species reported to be under active management

Several reporting countries indicate that associated biodiversity is being actively managed to provide pest and disease regulating services, whether directly or indirectly (e.g. habitat provisioning for BCAs). Species reported to be under active management are listed in Table 4. The majority are predatory and parasitoid invertebrates associated with crop production.

Table 4. Species of associated biodiversity reported to be actively managed for the provision of pest and disease regulation services, and target pests when specified

Functional group	Species/Groups	Target
Allelopathic plants	Mexican marigold (*Tagetes erecta*) Wild cabbage (Brassica oleracea) Velvet bean (Mucuna pruriens)	Nematodes Weeds
Bacteria (entomopathogenic)	Bacillus subtili Bacillus thuringiensis Pseudomonas fluorescens *Xenorhabdus* spp. (in symbiosis with entomopathogenic nematodes)	
Bacteria (other)	Pseudomonas spp.	Pathogens
Fungi (antifungal)	Trichoderma asperellum Trichoderma atroviride Trichoderma harzianum Trichoderma viride	Fungal plant diseases
Fungi (entomopathogenic)	Beauveria bassiana Isaria spp. Metarhizium anisopliae	
Fungi (other)	Peanut rust disease (*Puccinia spegazzini*)	Mikania weed (Mikania micrantha)
Herbivores	Fish (e.g. Ctenopharyngodon idella) Salvinia weevil (Cyrtobagous salviniae) Sida-leaf feeding beetle (*Calligrapha pantherina*) Weevil (Neohydronomous affinis) Weevil (Neochetina bruchi) Weevil (Neochetina eichhorniae)	Aquatic weeds Watermoss (*Salvinia* spp.) Arroleaf sida (*Sida rhombifolia*) Water lettuce (Pistia stratiotes) Weeds, water hyacinth (*Eichhornia* spp.)

Nematodes (entomopathogenic)	Heterorhabditis spp. Steinernema spp.	
Parasitoids (flies)	Leucopis spp. Metagonistylum minense	
Parasitoids (wasps)	Cotesia flavipes	
	Telenomus remus	
	Acerophagus papayae	
	Amitus spinifera	
	Anagyrus dactylopii	Citrus mealybug (*Planococcus citri*)
	Anagyrus indicus	
	Anagyrus kamali	Pink mealybug (Maconellicoccus hirsutus)
	Anagyrus spp.	
	Aphelinus mali	
	Aphidius rhopalosiphi	
	Aphytis holoxanthus	
	Aphytis lepidosaphes	
	Aphytis melinus	Wooly apple aphid (*Eriosoma lanigerum*) Hemipteran pests
	Aphytis roseni	
	Asecodes hispinarum	Coconut leaf beetle (*Brontispa longissima*)
	Cales noacki	
	Chrysocharis spp.	
	Closterocerus spp.	
	Coccophagus spp.	
	Copidosoma koehleri	Potato tuber moth (Phthorimaea operculella)
	Diglyphus begini	
	Diglyphus websteri	
	Eretmocerus paulistus	
	Ganaspidium spp.	
	Goniozus nephantidis	
	Gyranusoidea indica	Pink mealybug (Maconellicoccus hirsutus)
	Habrobracon concolorans	Tomato leafminer (*Tuta absoluta*)
	Leptomastidea spp.	
	Metaphycus helvolus	
	Metaphycus lounsburyi	
	Metaphycus luteolus	
	Opius spp.	
	Prospaltella porteri	
	Psyllaephagus pilosus	Blue gum psyllid (Ctenarytaina eucalypti) in Eucalyptus spp.
	Scutellista cyanea	
	Trichogramma chilonis	
	Trichogramma spp.	
	Zagrammosoma spp.	
Predators	Bugs (Anthocoridae)	
	Bug (Nesidiocoris tenuis)	Tomato leafminer (*Tuta absoluta*)
	Groundbeetles (Carabidae)	
	Hoverflies (Syrphidae)	
	Lacewing (Chrysoperla carnea)	Tomato leafminer (*Tuta absoluta*)
	Lacewing (*Sympherobius* spp.)	
	Lacewings (C*hrysoperla* spp.)	
	Ladybird beetle (Clitostethus arcuatus)	
	Ladybird beetle (Coccinella septempunctata)	
	Ladybird beetle (Cryptolaemus montrouzieri)	Papaya mealy bug (Paracoccus marginatus)
	Ladybird beetle (*Rodolia cardinalis*)	
	Ladybird beetles (*Cryptolaemus* spp.)	Citrus mealybug (*Planococcus citri*)
	Mite (Amblyseius idaeus)	Red spider mite (Tetranychus urticae)
	Mite (Typhlodromus pyri)	
	Wrasses (Labridae)	Sea lice parasites in aquaculture
Others	Common sunflower (*Helianthus annuus*)	As a trap crop for thrips
	Neem (Azadirachta indica)	Fly repellent
	Stem gall fly (Cecidochares connexa)	Siam weed (Chromolaena odorata)

Source: country reports.

The state of knowledge

The country reports indicate varying levels of knowledge on the status and trends of associated biodiversity species related to pest and disease control. A number of countries report extensive monitoring of associated biodiversity in this category. Examples include Switzerland (agro-environment monitoring programmes by the Federal Office for Agriculture), the United Kingdom (Bees, Wasps and Ants Recording Society; Farmland Bird Indicator), the United States of America (National Invertebrate Genetic Resource Program) and Germany. Some countries report that monitoring activities take place on a less systematic basis. For example, Croatia mentions that natural enemies (spiders and mites) are monitored, although not consistently, as part of its Reporting and Early Warning System in Agriculture. Some countries report that some information on the status and trends of BCAs is derived from individual research projects. Guyana mentions that although it does not have monitoring activity for associated biodiversity in its rice production systems, some recording of natural enemies is done as part of pest monitoring activities. Monitoring programmes for pests and diseases themselves exist throughout the world.

Many country reports make no specific reference to the monitoring of BCAs or other components of biodiversity that contribute to pest and disease control, although some are probably covered by monitoring programmes reported to be undertaken for other purposes or for which the purpose is not specified. It is also likely that the status of managed BCAs (such as those listed in Table 4) is at least to some degree monitored, although this is often not stated explicitly in the country reports. Notwithstanding these various strands of reporting, many country reports acknowledge major weaknesses in monitoring programmes BCAs included.

Trends in major components of associated biodiversity contributing to pest and disease regulation

While, as described above, the state of knowledge remains very far from complete, the country reports provide a number of indications of the status of individual BCA species, groups of BCAs or species categories that include substantial numbers of BCAs. For example, Bangladesh reports a decline in insect predators and spiders in crop fields. Nepal mentions a general decline in the diversity of natural enemies. The United Kingdom reports that its indicator for farmland birds (many of which are insectivorous)[43] declined by 55 percent between 1970 and 2013. Similarly, the United States of America reports a decline of almost 40 percent in its grassland bird index between 1968 and 2014. India reports the decline of parasitoid wasps (Ichneumonidae, Braconidae families) and of parasitoid flies (Tachinidae).

Many countries mention drivers of change that are recognized as threats to BCAs, including use of agrochemicals (particularly pesticides), loss of natural areas due to deforestation, urbanization, monoculture expansion, overexploitation of production systems, invasive species and climate change-related hazards (droughts, floods, changing rainfall and temperature patterns). Several country reports explicitly link declines in BCA diversity to particular drivers of change. For example, Bangladesh, Nepal and the Netherlands attribute downward trends to the use of agrochemicals such as pesticides. Table 5 presents examples from the country reports of the reported risk status of components of associated biodiversity that contribute to pest and disease control, along with (where available) the main reported threats to these species.

Climate change is affecting both the population size and the geographical distribution of pests, weeds and diseases and of the associated biodiversity that regulate them, in some cases threatening the ongoing delivery of pest and disease control services (Cock *et al.*, 2011). For example, a large number of invertebrates have shifted poleward and into elevated areas in response to rising temperatures (Easterling, 2007; Hickling *et al.*, 2006; Musolin and Fujisaki, 2006; Parmesan and Yobe, 2003).

[43] 11 out of 19 species are predominantly insectivorous during the spring and summer and therefore have a potential role in controlling insect pests (DEFRA, 2016). However, little is known about the effectiveness of these species as pest control agents (*ibid*.).

Other species, however, are less mobile and have to adapt *in situ* through evolution (Cock *et al.*, 2011). This is a slower process than migration and so the risk of extinction is higher if changes to the environment happen quickly (Cock *et al.*, 2011; Coope, 2004).

Table 5. Examples of components of associated biodiversity that contribute to pest and disease regulation reported to be under threat

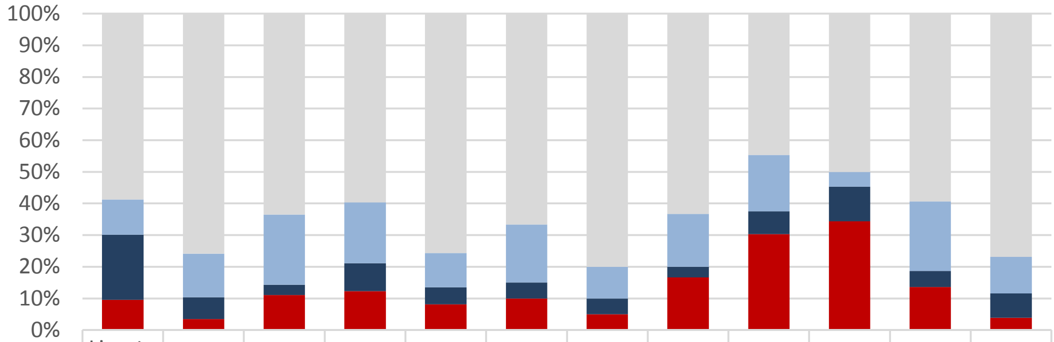
Country	Species/groups	Degree of threat	Main threat
Argentina	Insectivorous birds	Moderate	Use of agrochemicals, tillage without rotation, climate change
Belgium	Insectivorous birds (Alauda arvensis, Perdix perdix) Insectivorous birds (Emberiza citrinella, Miliaria calandra)	VU Threatened	Intensive agriculture
Burkina Faso	Bats	High	Poaching, habitat destruction, pesticide susceptibility, direct exploitation
Cook Islands	Atiu swiftlet (Collocalia sawtelli) Cook reed warbler (Acrocephalus kerearako) Rarotongan monarch (*Pomarea dimidiata*) Rarotonga starling (*Aplonis cinerascens*)	EN	
Estonia	European roller (*Coracias garrulus*) Flat bark beetle (Cucujus cinnaberinus) Lesser searcher beetle (*Calosoma inquisitor*)	CR	Changes in use of arable land (e. g. drainage, changes in mechanisation, crops), disappearance of dead, hollow and dry trees, pollution, acidification Forestry, disappearance of dead, hollow and dry trees, changes in tree species in forests, changes in age-structure of forests, disappearance of old forests and/or big trees, clear-cutting Forestry
Guyana	Hoary-throated spinetail (*Synallaxis kollari*)	EN	
Ireland	Damselflies and dragonflies (Odonata)	EN: 2 VU: 2 NE: 9	
Lebanon	European greenfinch (*Carduelis carduelis*)	EN	Loss of habitat (mainly caused by fires), climate change, illegal hunting, pollution.
Norway	Spider species in livestock grassland-based systems Spider species in rainfed crop systems Centipede species in semi-natural forests Spider species in in semi-natural forests	EN: 3 VU: 25 VU: 8 VU: 5 EN: 3 VU: 23	Habitat loss due to land-use change, pollution Habitat loss due to land use change
Panama	Great tinamou (*Tinamus major*) Little tinamou (*Crypturellus soui*) Great curassow (*Crax rubra*) Highland tinamou (Nothocercus bonapartei) Resplendent quetzal (*Pharomachrus mocinno*) Marbled wood quail (Odontophorus gujanensis) Chiriqui quail-dove (*Geotrygon chiriquensis*)	EN	

Switzerland	Bat species	NT: 7 (23%) Swiss Red List *: 15 (50%)	Renovation and reassignment of historic buildings, intensive agriculture and forestry practices, land use changes, use of pesticides. Habitat fragmentation due to the presence of infrastructure (e. g. communication routes, lights)
	Dragonfly species (Odonata)	EX: 2 (3%) CR: 12 (16%) EN: 7 (10%) VU: 5 (7%)	Habitat loss (e.g. fragmentation, drainage)
	Ground and tiger beetle species (Carabidae)	Swiss Red List *: 148 (29%)	Habitat loss (e.g. draining of moors), intensive agriculture
	Lacewings species (Chrysopidae)	Swiss Red List *: 21 (18%)	Loss of habitat for larvae
Slovenia	Eurasian skylark (*Alauda arvensis*) Corn crake (*Crex crex*) Eurasian scops owl (*Otus scops*) Eurasian wryneck (*Jynx torquilla*) Lesser grey shrike (*Lanius minor*) Red-backed shrike (*Lanius collurio*) Woodlark (Lullula arborea)	VU EN VU EN	Habitat loss
Sri Lanka	Spider species	Threatened: 100 EN: 40 CR: 21	Habitat loss, excessive use of pesticides

*Note: Countries followed the IUCN Red List categories and criteria (IUCN, 2012) (CR [Critically Endangered]; EN [endangered]; EX [Extinct]; NT [Near Threatened]; VU [Vulnerable]) except where stated otherwise. *Swiss Red List classification system − see Cordillot and Klaus (2011) for more information on this classification system.*
Source: country reports.

Countries' responses on trends in the supply of pest and disease regulation services in different production systems are summarized in Figure 4. In livestock, forest, aquatic and mixed systems, upward trends are more common than downward. However, in crop systems downward trends are equally or more common than upward. Downward trends are particularly dominant in rainfed and to a lesser extent in non-rice irrigated crops systems.

Figure 4. Reported trends in the state of pest and disease regulation in production systems



	Livestock grassland-based systems	Livestock landless systems	Naturally regenerated forests	Planted forests	Culture-based fisheries	Fed aquaculture	Non-fed aquaculture	Irrigated crops (rice)	Irrigated crops (other)	Rainfed crops	Mixed systems	Other
Not indicated	37	44	40	34	28	40	32	19	25	32	35	20
Increasing	7	8	14	11	4	11	4	5	10	3	13	3
Stable	13	4	2	5	2	3	2	1	4	7	3	2
Decreasing	6	2	7	7	3	6	2	5	17	22	8	1

Note: The bars show the proportion of responding countries that provided each answer. Non-responding countries (among the total 71 that provided country reports) are not included in the figures.
Source: country reports.

Needs and priorities

Although associated biodiversity provides pest and disease control services in virtually every production systems and integrated pest management practices are widely used and attracting increasing interest (see Section 4.3.2), the country reports indicate that there are many gaps in knowledge on the status and trends of these components of associated biodiversity. Efforts need to be made not only to monitor population trends in known BCA species, but also better to identify the components of associated biodiversity that contribute to these services, understand their roles, identify threats affecting them and track changes that may be occurring in their geographical distribution and that of the diseases and pests they control. Biogeographic redistribution of associated biodiversity, pests, weeds and diseases is an important, yet often overlooked, consequence of climate change. As species shift geographically, producers are facing new challenges (e.g. facing novel pests or loss of BCAs) and need to adjust their production systems. Improving the monitoring of trends in the distribution of these species will facilitate efforts to identify and address problems of this kind.

Some countries complement public-sector research and monitoring programmes with observations made by non-professional so-called citizen scientists (see examples in Section 6.3). Expanding programmes of this kind might be a means of improving knowledge of the status and trends of components of associated biodiversity that contribute to the supply of pest and disease regulating services.

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3.5 Building and maintaining healthy soils

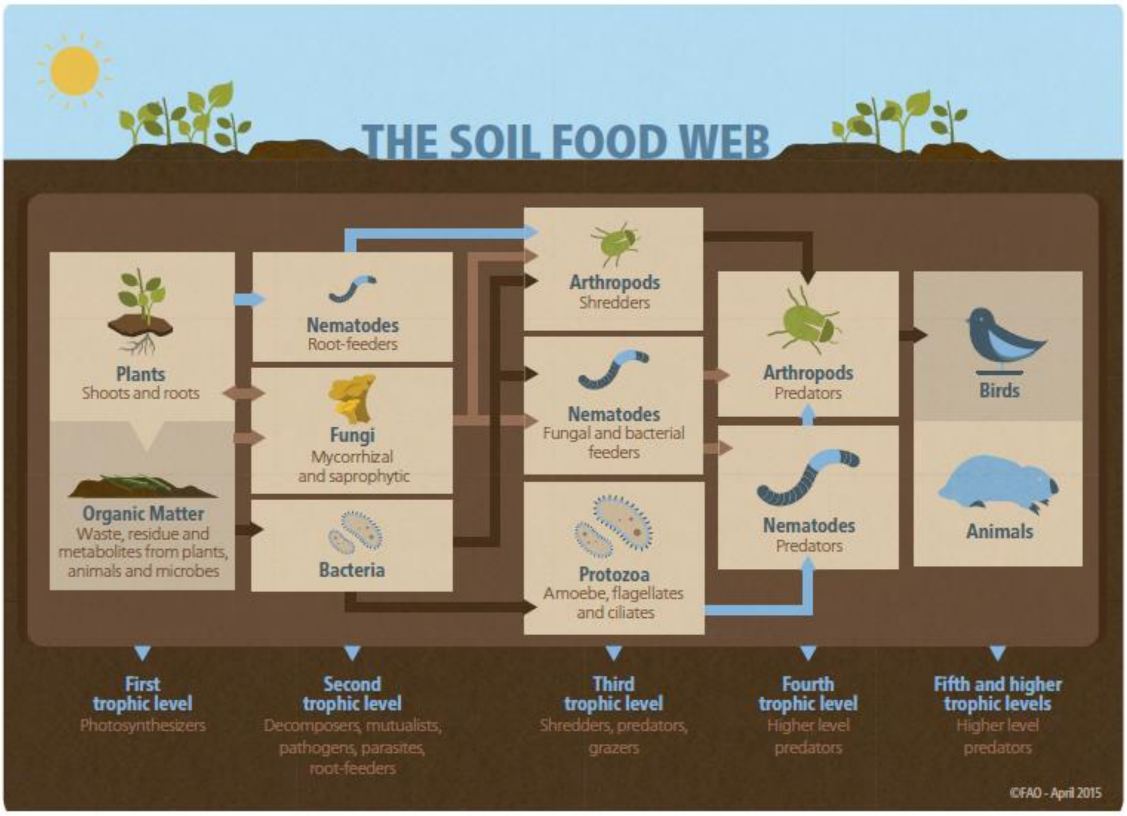
Introduction

This section addresses the status and trends of components of biodiversity for food and agriculture involved in soil formation and protection. Soil biota is highly diverse, and includes micro-organisms (e.g. fungi, bacteria, algae, protozoa), mesofauna (invertebrates of 0.1 to 2mm in length, that include nematodes, mites, springtails and molluscs), and macrofauna (e.g. earthworms, ants, beetles, termites, spiders and moles) (see Figure 5). Plants and above-ground animals also contribute to the building and maintaining healthy soils, for example by providing nutrient inputs or protection against erosion (Angers and Caron, 1998; Vanni, 2002; Graham *et al.*, 2009).

Soil-dwelling organisms are essential to nutrient cycling and influence the physical structure and chemical composition of soils, enabling and regulating crucial processes such as carbon sequestration and nutrient uptake by plants. Soil functions depend on a complex web of interactions between different groups of organisms (Beed *et al.*, 2011; Okoth *et al.*, 2013). For example, symbiosis between bacteria and fungi and plant roots is a key mechanism in nutrient cycling. Aquatic organisms are vital to the formation of pond sediments, to the accumulation of deposits in flood plains and river beds, and to nutrient cycling within these sediments and deposits and in the wider aquatic environment (Hauer *et al.*, 2016; Palmer *et al.*, 2000). Marine micro-organisms play a major role in global nutrient cycling, being responsible of about half of the Earth's primary production (Arrigo, 2005).

The roles of different groups of organisms in these and other ecosystem functions are summarized in Table 6. The soil food web is illustrated in Figure 5. Table 7 shows the typical numbers of various categories of organisms in healthy soils in different types of ecosystem.

Figure 5. The soil food web



Source: FAO, 2015.

Table 6. The functions of soil organisms

Type of soil organism		Major functions
Photosynthesizers	Plants Algae Bacteria	Capture energy Use solar energy to fix CO_2. Add organic matter to soil (biomass such as dead cells, plant litter, and secondary metabolites).
Decomposers	Bacteria Fungi	Break down residue Immobilize (retain) nutrients in their biomass. Create new organic compounds (cell constituents, waste products) that are sources of energy and nutrients for other organisms. Produce compounds that help bind soil into aggregates. Bind soil aggregates with fungal hyphae. Nitrifying and denitrifying bacteria convert forms of nitrogen. Compete with or inhibit disease-causing organisms.
Mutualists	Bacteria Fungi	Enhance plant growth Protect plant roots from disease-causing organisms Some bacteria fix N_2. Some fungi from mycorrhizal associations with roots and deliver nutrients (such as P) and water to the plant.
Pathogens Parasites	Bacteria Fungi Nematodes Micro-arthropods	Promote disease Consume roots and other plant parts, causing disease. Parasitize nematodes or insects, including disease-causing organisms.
Root-feeders	Nematodes Macro-arthropods (e.g. cutworm, weevil larvae and symphylans)	Consume plant roots Potentially cause significant crop yield losses.
Bacterial-feeders	Protozoa Nematodes	Graze Release plant available nitrogen (NH_4^+) and other nutrients when feeding on bacteria. Control many root-feeding or disease-causing pests. Stimulate and control the activity of bacterial populations.
Fungal-feeders	Nematodes Micro-arthropods	
Shredders	Earthworms Macro-arthropods	Break down residue an enhance soil structure Shred plant litter as they feed on bacteria and fungi. Provide habitat for bacteria in their guts and faecal pellets and burrow through soil. Enhance soil structure as they produce faecal pellets and burrow through soil.
Higher-level predators	Nematode-feeding nematodes Larger arthropods, mice, voles, shrews, birds, other above-ground animals	Control populations Control the populations of lower trophic-level predators. Larger organisms improve soil structure by burrowing and passing soil through their guts. Larger organisms carry smaller organisms long distances.

Source: Tugel et al., 2000.

Table 7. Typical numbers of soil organisms in healthy ecosystems

		Agricultural soils	Prairie soils	Forest soils
Bacteria	Per teaspoon of soil (one gram dry)	100 million to 1 billion.	100 million to 1 billion.	100 million to 1 billion.
Fungi		Several yards. (dominated by vesicular-arbuscular mycorrhizal fungi).	Tens to hundreds of yards. (dominated by vesicular-arbuscular mycorrhizal fungi).	Several hundreds of yards in deciduous forests. One to forty miles in coniferous forests (dominated by ectomycorrhizal fungi)
Protozoa		Several thousand flagellates and amoebae, one hundred to several hundred ciliates.	Several thousand flagellates and amoebae, one hundred to several hundred ciliates.	Several hundred thousand amoebae, fewer flagellates.
Nematodes		Ten to twenty bacterial-feeders. A few fungal-feeders. Few predatory nematodes.	Tens to several hundred.	Several hundred bacterial- and fungal-feeders. Many predatory nematodes.

Arthropods	Per square foot	Up to one hundred.	Five hundred to two thousand.	Ten to twenty-five thousand. Many more species than in agricultural soils.
Earthworms		Five to thirty. More in soils with high organic matter.	Ten to fifty. Arid or semi-arid areas may have none.	Ten to fifty in deciduous woodlands. Very few in coniferous forests.

Notes: 1 foot = 0.3048 m; 1 yard = 0.9144 m; 1 mile = 1.609344 km.
Source: The table is included in the country report of the United States of America (also published in Tugel et al., [2000] and online in the Soil biology primer of the National Resources Conservation Service: available at https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/biology/?cid=nrcs142p2_053860).

State of knowledge

The country reports generally indicate that knowledge of the biodiversity that contributes to soil formation and protection and to nutrient cycling in production systems is insufficient and that trends in the status of these resources are not monitored. Among the 71 reporting countries, eight indicated that they have a monitoring system in place explicitly for organisms that play a role in soil ecology. The level (sampling frequency and type of analysis) and coverage (number of species monitored) of these systems vary greatly from country to country.

Some countries describe monitoring efforts focused on a particular component of soil biodiversity. For example, the report from Kenya mentions that land snails are actively studied and monitored because of their important role as soil fertility enhancers. Estonia notes that its Agricultural Research Centre monitors the diversity and distribution of earthworms. Sri Lanka mentions monitoring activities for soil biodiversity in specific production systems: arthropod diversity in paddy fields and microbial diversity in various farming systems. Other countries report larger scale monitoring systems. The Netherlands, for example, has a nationwide monitoring programme for soil biodiversity (see Box 3). Information on monitoring activities conducted by France's Observatory of Agricultural Biodiversity is provide in Box 16. France's Agricultural Biodiversity Observatory (in Section 6.3).

Box 3. The Netherlands' soil biological monitoring programme

In the Netherlands, the nationwide soil biological monitoring programme BISQ (Biological Indicator of Soil Quality) was developed with the aim of collecting data that would enable policy-makers to assess the quality and resilience of soil ecosystem services. BISQ is considered to rank among the most advanced soil-monitoring systems in the world.

BISQ links soil functioning to soil biodiversity. First, the most important life-support functions of the soil were identified: decomposition of organic matter; nutrient cycling; soil structure formation; plant-soil interactions; and ecosystem stability. Next, ecological processes linked to these functions were described. Finally, the dominant soil-organism groups and ecological process parameters were determined and combined in an indicator system (see Table 8).

About 300 locations, with different combinations of land use and soil type, were selected, and since 1999 every year about 60 locations (farms, natural areas and urban sites) have been sampled, with the samples analysed for soil biological characteristics. Because of budget constraints, soil sampling was discontinued in 2014, but the data obtained so far continue to be used for policy formulation. Sampling may restart when budget becomes available again.

In general, the abundance of soil organisms was found to be higher in the soil of dairy farms than in arable land. Earthworms especially appeared to be scarce in arable land, and were virtually absent in mixed forests and heathlands. Nematode abundance was highest in dairy farms on peat and lowest in the mineral layer of mixed forest on sand.

Data from the BISQ have been used to develop benchmarks for ten relevant combinations of soil type and land use. For each of these combinations, a limited number of monitoring sites were selected that were considered to be well managed and to represent relatively good-quality soil ecosystems. The average of the BISQ parameters for these sites was taken as a benchmark for a good-quality soil ecosystem. In agriculture, these benchmarks can serve to help farmers to improve soil quality and

establish more sustainable farming practices. In nature conservation, the benchmarks can guide managers of protected areas in their efforts to restore nature values on former agricultural lands.
The main lesson learnt from the programme is that biological soil monitoring, with measurements carried out for more than 15 years on a semi-routine scale, is feasible.

Table 8. The BISQ indicator framework

Life support functions	Ecological processes	Dominant soil organism groups and ecological process parameters	Indicators
Decomposition of organic matter	Fragmentation	Earthworms, enchytraeids, mites, wood-related fungi	Taxonomic diversity per trophic level
	Transformation of organic substrate	Bacterial degradation routes Litter- and dung-related fungi Genetically diverse microflora	Taxonomic diversity per trophic level Bacterial DNA polymorphism
Nutrient cycling	C:N mineralization	Trophic interactions	Model-derived nitrogen production
	Microbial activity	Micro-organisms	Concentration, biomass, thymidine incorporation
	Predation microfauna	Protists Nematodes Springtails Mites	Active/inactive cysts Maturity index Functional diversity Maturity index
Soil structure formation	Bioturbation and formation of soil aggregates	Earthworms Enchytraeids Mycelium hyphae	Functional diversity Number of organisms Biomass
Plant-soil interactions	Uptake of N, P, H2O and heavy metals	Mycorrhizal macrofungi	Functional diversity
	Nitrification	Nitrifying bacteria	Nitrate production from NH4+
	Feeding on plant roots	Nematodes and fungal pathogens	Plant parasitic index
Ecosystem stability	Trophic links; loops and cascade effects	Structure of community	Food web structure; food web pyramid

After Rutgers et al., 2009.
Sources: British Ecological Society, 2016; CBS, PBL and Wageningen UR, 2016; Rutgers et al., 2009; Rutgers et al., 2014; Personal communication with Michiel Rutgers (RIVM), 24 November 2016.

Provided by Martin Brink.

Some countries indicate that while they have no systematic national monitoring programmes in place for soil biodiversity, relevant activities are sometimes conducted within the framework of individual projects. For example, Norway reports the “Living Topsoil” project, under which soil biodiversity and health are assessed and farmers are then encouraged to modify their management practices to improve soil health. The United Kingdom mentions a pilot project identifying and characterizing communities of soil organisms using genetic barcoding and metabarcoding approaches.

As evidenced by the lack of information in the country reports, knowledge of the roles of aquatic invertebrates, micro-organisms and other aquatic organisms higher in the food chain, in soil formation, and of the status and trends of these components of biodiversity, is very limited.

Even where soil biodiversity *per se* is not monitored comprehensively, it may be possible to make use of proxy indicators or indicator species. The country report from the United States of America mentions that using data from the National Resource Inventory, a survey conducted once every five years, and other studies, trends in soil management practices can be monitored as a proxy for soil health – with a focus on soil carbon, soil erosion, adoption of reduced tillage practices, adoption of crop rotations and adoption of cover crops.

Countries report a number of other initiatives that while not strictly focused on the monitoring of soil biodiversity nonetheless contribute to the accumulation of knowledge on their soil resources. For example, Norway reports a “soil mapping” initiative that involves surveys of soil properties in predetermined areas of the country (about 40 km2 are surveyed each year). The data collected provide a basis for identifying trends in soil texture and health.

No comprehensive global assessment of below-ground biodiversity has been conducted to date. Despite the development of the Global Soil Biodiversity Atlas (Orgiazzi *et al.*, 2016), no benchmark values exist on a global scale. Quantifying changes in soil biodiversity is therefore difficult and few monitoring programmes exist that quantify soil biodiversity across regions and at multiple trophic levels. The first major global assessment of soils was published in 2015. Details are presented in Box 4; a summary of the regional trends in soil biodiversity loss as identified in this global assessment is presented in Table 9.

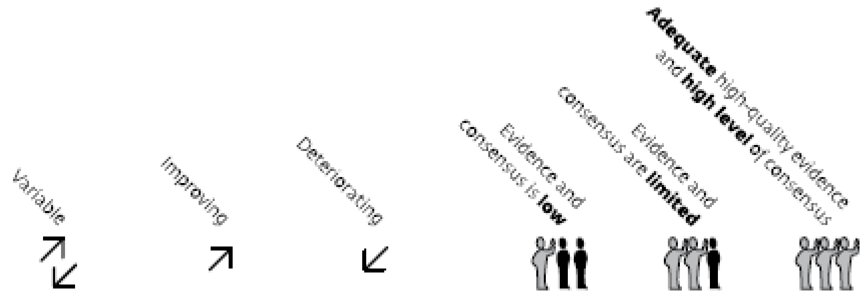
Box 4. The report on The Status of the World's Soil Resources

The Status of the World's Soil Resources, prepared by the Intergovernmental Technical Panel on Soils of the Global Soil Partnership, presents the first major global assessment of soils and soil change (FAO and ITPS, 2015).

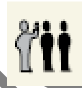
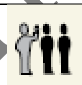
The report notes that the importance of soil biota to the supply of ecosystem services has become an important focus area for soil science research over the last few decades. Soil biodiversity contributes to soil functioning by regulating nutrient cycles, controlling the dynamics of soil organic matter, supporting soil carbon sequestration, regulating greenhouse gas emissions, modifying soil physical structure and soil water regimes, enhancing the amount and efficiency of nutrient acquisition by vegetation through symbiotic associations and nitrogen fixation by bacteria, and influencing plant and animal health through the interaction of pathogens and pests with their natural predators and parasites. However, understanding of the functional consequences of below-ground biodiversity loss is limited, at least compared to what is known about above-ground losses.

Among the ten factors identified as major threats to the continued provision of soil ecosystem services, the loss of soil biodiversity is listed as the fourth most important, after soil erosion, organic carbon change and nutrient imbalance. Although the biodiversity of the soil is immense (an estimated 360 000 species of animals live in soil, and 10 grams of soil contain about 10^{10} bacterial cells from more than 1 million species) it is vulnerable to human disturbances. Increasing land-use intensity and associated soil organic matter loss are exerting pressure on soil biodiversity. Many studies have reported that agricultural intensification and the conversion of natural lands to agriculture have led to declines in soil biodiversity. Larger bodied soil animals such as earthworms, mites and collembolans, as well as soil fungi, are particularly vulnerable to intensive land use.

Table 9. Summary of regional extent, trends and uncertainties of soil biodiversity loss



Region	Summary	Condition and trend					Confidence	
		Very poor	Poor	Fair	Good	Very good	In condition	In trend

Sub-Saharan Africa	Sub-Saharan Africa suffers the world's highest annual deforestation rate. The areas most affected are the in the moist areas of West Africa and the highland forests of the Horn of Africa. Cultivation, introduction of new species, oil exploration and pollution reduce the population of soil organisms thus reducing faunal and microbial activities.			↙				
Asia	Limited information is available for soil biodiversity in Asia. Some reports show high microbial biodiversity in the soils of organic farming lands.			↗↙				
Europe and Eurasia	Loss of biodiversity is expected in the most urbanized and contaminated areas of the region. However, there are almost no qualitative estimations of the biodiversity loss in soils.			↙				
Latin America and the Caribbean	Suspected to occur in deforested and overexploited agricultural areas.			↗↙				
Near East and North Africa	The extent of loss of soil biodiversity due to human impact is largely unknown in the Near East and North Africa region. More studies need to be undertaken to understand the scope of the problem.		↙					
North America	The extent of loss of soil biodiversity due to human impact is largely unknown in North America. The effects of increasing agricultural chemical use, especially pesticides, use on biodiversity is a major public concern. Known level of carbon loss suggests similar loss in biodiversity.			↗↙				
Southwest Pacific	Rates of loss were most likely highest during the expansion of agriculture, particularly over the last 100 years, and this may have slowed. However, information on baselines and trends is lacking in nearly all districts and countries.			↗↙				

Source: FAO and ITPS, 2015.

Status and trends

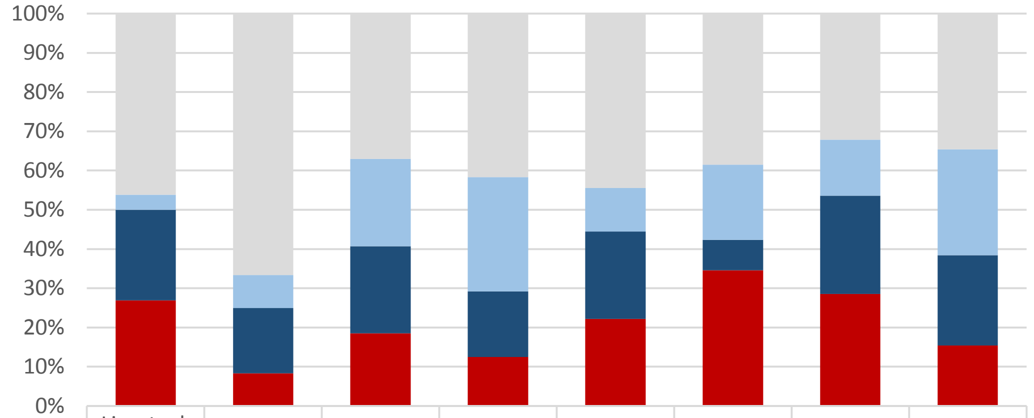
As noted above, the majority of reporting countries were unable to provide information on the status and trends of components of associated biodiversity involved in soil formation and protection and nutrient cycling. Some countries, however, provided partial or tentative statements in this regard. For example, the country report from the United States of America notes that the above-mentioned soil-related monitoring activities indicate positive trends in the implementation of some management practices that are potential proxies for the status of soil biodiversity. Other countries that indicate at least some positive trends include Ethiopia, which reports that planting of trees that symbiotically fix nitrogen has had a positive effect on soil micro-organism diversity in planted forest systems. Countries reporting unfavourable developments include El Salvador, which notes large-scale soil erosion associated with loss of forest cover and mentions that this has been accompanied by losses of soil invertebrates and micro-organisms. The report from Zambia mentions negative trends among grassland invertebrates and micro-organisms. These effects are attributed to a decline in livestock numbers (caused by disease outbreaks) that has disrupted soil-formation processes, although the report also mentions that overstocking and overgrazing in communal areas has negatively affected soils and their capacity to supply water-related ecosystem services. The report from Grenada notes reports from farmers of a decline in earthworm numbers.

Countries' responses on trends in the state of soil-related ecosystem services (i.e. nutrient cycling and soil formation and protection) are summarized in Figure 6 and Figure 7. On nutrient cycling, the country reports provide a mixed picture. In grassland and (to greater degree) mixed and forest systems, responses indicating positive trends were somewhat more common than those indicating negative trends. In the case of crops, both rainfed crop systems and irrigated rice systems received more negative than positive responses (no countries reported an upward trend in the latter system). Among the very few countries that provided information on trends in non-rice irrigated systems, one reported a positive trend. The picture for soil formation and protection services is likewise mixed. Positive trends are more commonly reported than negative for forest and mixed systems and negative trends more commonly reported than positive in crop and grassland systems.

A few country reports provide information relating trends in soil-related ecosystem services to management practices in specific production systems. For example, the report from Panama mentions that in grassland systems the use of herbicides and antiparasitic livestock drugs leads to contamination of the soil and affects soil invertebrates and inhibits soil-formation and nutrient-cycling services. Bangladesh reports that soil formation and protection is being hampered in areas where soil micro-organism diversity is affected by the use of pesticides and fertilizers. The report from Grenada mentions that burning waste materials after weeding has contributed to a reduction in nutrient cycling. On the more positive side, Estonia reports that changes to manure storage and handling practices in landless livestock and mixed systems have improved nutrient cycling.

It is clear from Figure 6 and Figure 7– and widely noted in the country reports – that many countries lack data on the state of soil-related ecosystem services. In the case of all the widely reported production system categories, a large majority of countries reporting the presence of the system provide no indication of trends. The large proportion of responding countries that indicate negative trends in major food-producing systems is a cause for concern. Globally, many indicators of soil health are in decline and ecosystem services provided by soils are under severe threat (FAO and ITPS, 2015). In the words of the report on the Status of the World's Soil Resources, "the critical situation of soils and the risk that the degradation of soils will strongly impact ecosystem services and in turn production if soil sustainable management practices are not adopted" (*ibid*).

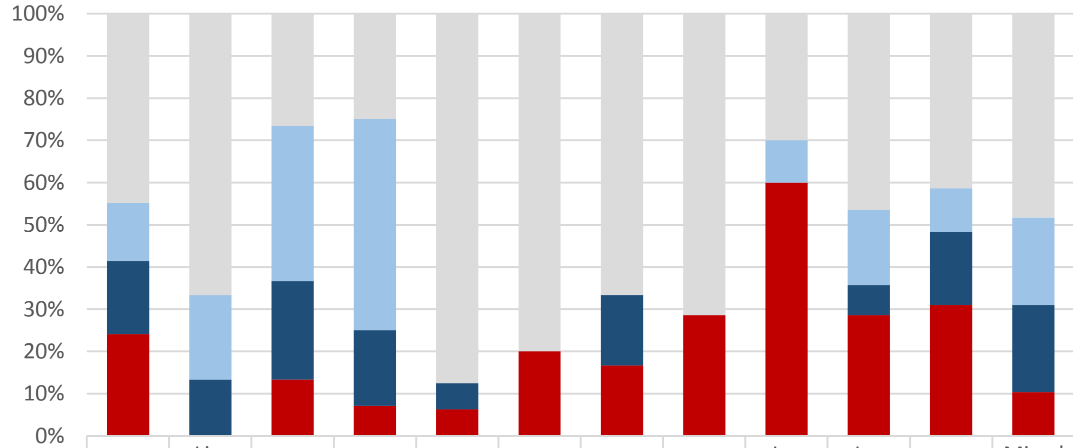
Figure 6. Reported trends in the state of nutrient cycling in production systems



	Livestock grassland-based systems	Livestock landless systems	Naturally regenerated forests	Planted forests	Irrigated crops (rice)	Irrigated crops (other)	Rainfed crops	Mixed systems
Not known	12	8	10	10	4	10	9	9
Increasing	1	1	6	7	1	5	4	7
Stable	6	2	6	4	2	2	7	6
Decreasing	7	1	5	3	2	9	8	4

Note: The bars show the proportion of responding countries that provided each answer. Non-responding countries (among the total 71 that provided country reports) are not included in the figures.
Source: country reports.

Figure 7. Reported trends in the state of soil formation and protection in production systems



	Liv. gr.-based	Liv. landless	NRF	Planted forests	SRCF	CBF	Fed aq.	Non-fed aq.	Irr. crops (rice)	Irr. crops (other)	Rainfed crops	Mixed systems
Not known	13	10	8	7	14	4	8	5	3	13	12	14
Increasing	4	3	11	14	0	0	0	0	1	5	3	6
Stable	5	2	7	5	1	0	2	0	0	2	5	6
Decreasing	7	0	4	2	1	1	2	2	6	8	9	3

Note: The bars show the proportion of responding countries that provided each answer. Non-responding countries (among the total 71 that provided country reports) are not included in the figures.
Liv. gr.-based = Livestock grassland-based systems; Liv. landless = Livestock landless systems ; NRF = Naturally regenerated forests; SRCF = Self-recruiting capture fisheries ; CBF = Culture-based fisheries; aq. = aquaculture; Irr. = Irrigated.
Source: country reports.

Needs and priorities

There are major gaps in knowledge of the components of biodiversity involved in nutrient cycling and soil formation and protection. Baseline population data that could serve as a starting point for monitoring programmes are generally lacking, especially for invertebrates and micro-organisms, and the specific roles of different species and taxa in the provision of ecosystem services are often not adequately understood. Trends in status of these components of biodiversity and the effects that changes in their status may be having on the supply of soil-related ecosystem services are thus difficult to quantify.

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3.6 Natural hazard regulation

[EDITOR'S NOTE: Review of this section has not been completed]

Introduction

Hazard regulation is defined in the guidelines for the preparation of country reports as the "capacity of ecosystems to ameliorate and reduce the damage caused by natural disasters." Natural hazards such as drought, floods, cyclones and hurricanes, earthquakes, tsunamis and volcanic eruptions have a large impact on all sectors of food and agriculture (FAO, 2015), as well as more broadly on human lives and livelihoods.

Biodiversity for food and agriculture (BFA) contributes in many ways to hazard regulation. Links between flash floods and forest degradation are evident in a many of countries, and in some places communities and governments are showing increasing interest in the value of forests not only as providers of timber and non-timber products but also for their roles in mitigating floods, avalanches, rock falls and soil erosion (UNEP, 2010). The roles of wetland and coastal ecosystems such as mangroves, coral reefs and saltmarshes – and their biodiversity – in flood control, shoreline stabilization and storm protection are also widely recognized, as are the importance of peatlands, grasslands and floodplains in flood protection (Bravo de Guenni *et al.*, 2005; Ramsar Convention on Wetlands, 2015, 2011a, 2011b; GEAS UNEP, 2013). Many of these ecosystems are used for food and agriculture or provide habitats for associated biodiversity and wild food species. The frequency of many types of natural disasters is expected to increase as a result of climate change (IPCC, 2013). The roles played by BFA in carbon sequestration, and hence in climate change mitigation, thus also make an important contribution to hazard regulation. The roles of BFA in disaster resilience are further discussed in Section 1.2.

It is difficult to definitively distinguish a subset of associated biodiversity that contributes to hazard regulation. As described above, hazard regulation services are often provided by whole ecosystems or landscapes, for example in watersheds or in coastal areas. However, within these systems some species or functional groups may play a particularly direct or significant role in hazard regulation and may be managed in order to promote these roles.

State of knowledge

A number of knowledge and monitoring systems for natural disasters are in operation at global level, including the Global Disaster Alert and Coordination System, the International Disaster Database (EM-DAT) and climate and weather related information systems operated by the World Meteorological Organization (GDACS, 2016; EM-DAT, 2016; WMO, 2014, 2016;). Many countries have national monitoring and assessment programmes for various kinds of natural hazards. Generally, however, these global and national initiatives do not involve any particular focus on components of BFA (or biodiversity in general) that provide hazard regulating services.

There are also a number of global and national information systems devoted to ecosystems associated with food and agriculture (including the forest and aquatic sectors) that are recognized as playing an important role in hazard regulation. In the case of forests, for example, FAO's CountryStat system makes available data from Global Forest Resource Assessment (GFRA) (at the time of writing for the years 1990, 2000, 2005 and 2010 – the latest GFRA was conducted in 2015). The GFRA "examines the current status and recent trends for about 90 variables covering the extent, condition, uses and values of forests and other wooded land, with the aim of assessing all benefits from forest resources" (FAO, 2016). Global Forest Change (Hansen *et al.*, 2103) hosted by the University of Maryland (United States of America) makes available Earth observation satellite data and maps illustrating annual changes in global forest cover for the years 2000 to 2012. Global Forest Watch, a partnership convened by the World Resources Institute, provides high resolution maps of changes in forest cover and near real-time alerts showing locations of suspected recent forest loss (Global Forest Watch, 2016). Global Forest Watch data have been used, inter alia, to monitor changes in the state of the world's mangroves (Strong and Minnemeyer, 2015).

In the case of wetland ecosystems, the GlobWetland I project, which was launched by the European Space Agency in collaboration with the Secretariat of the Ramsar Convention in 2003 and ran until 2008, used satellite Earth observation applications to support inventorying, monitoring, and assessment of 52 different wetlands across 21 countries on four continents. A follow-up project, GlobWetland II, focuses on Mediterranean countries (GlobWetland, 2016). GlobWetland II is one of a number of projects and initiatives contributing to the development of a Global Wetlands Observing System under the GEO-Wetlands Initiative 2017–2019, a global partnership coordinated by the University of Bonn (Germany), Wetlands International and the Ramsar Convention Secretariat (GEO BON, 2016).

The Global Ocean Acidification Observing Network monitors and makes data available on variables related to ocean acidification and the responses of ecosystems to this effect (Newton *et al.*, 2015; GOA-ON, 2016). Data on various categories of biodiversity are targeted, including data specifically on the state of coral-reef biodiversity, including on changes in biomass of corals, coralline algae and other photosynthesizers in coral reefs, changes in the population structure of corals and other components of reef biodiversity and changes in reef ecosystem processes and habitat quality (*ibid*).

Relevant national information systems include the Coral Reef Information System (CoRIS), the information portal of the Coral Reef Conservation Program of the National Oceanic and Atmospheric Administration (NOAA) in the United States of America provides access NOAA's coral reef information and data products (NOAA, 2016). NOAA's coral reef-related activities include mapping, monitoring and assessment, along with natural and socio-economic research and modelling (*ibid*).

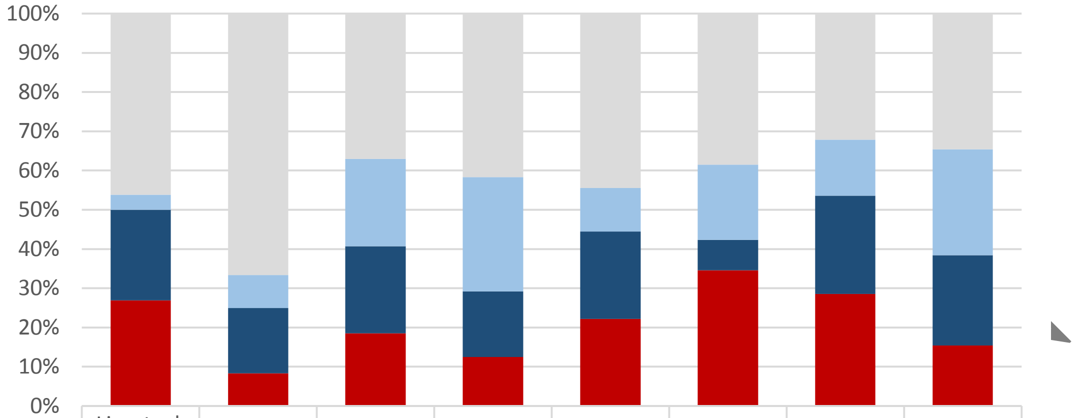
Status and trends

A number of country reports identify components of BFA that play a particularly significant role in hazard regulation. In all cases, references are to plants. For example, several reports note the crucial role of mangrove species in coastal protection. The importance of vegetation bordering rivers and in paddy fields and wetlands is noted. Some countries mention the particular importance of trees and bushes in binding the soil or as windbreaks to reduce the impact of storms. The report Bhutan notes that fodder species play a role in landslide regulation. Countries list a number of other species that are managed to promote hazard regulation (see Section 1.2). For example, Jordan mentions that the trees *Cupressus sempervirens* and *Ceratonia siliqua* are planted as part of fire control efforts. However, little information is provided in the country reports on the status and trends of these individual species or on categories of species regarded as being particularly significant to hazard regulation services.

As noted above, the role of BFA in the supply of natural hazard regulation depends largely on the state of relevant ecosystems rather than on the state of individual species. As described in Section [cross ref], agricultural ecosystems that show the highest resilience to natural hazards tend to be diversified production systems. Examples include systems that combine trees and shrubs with crops, livestock and or aquaculture. Trees and shrubs often provide protection against extreme weather events. Country report data show upward trends in the use of agroforestry across all crop production system categories, in grassland-based livestock systems and in mixed systems.

Countries' responses on trends in the delivery of hazard regulation services in different production systems are shown in Figure 8. For all production system categories, a large majority of countries either provided no response or stated that trends are unknown. In most production systems, answers indicating stable trends are more common than those indicating upward or downward trends. Fishery and aquaculture systems are exceptions in that upward trends are the most frequently reported. Few countries provided further details on their reported trends. It may be that reported upward trends indicate an increase in the importance of natural hazard regulation rather than an improvement in the capacity of ecosystems to deliver this service.

Figure 8. Reported trends in the state of natural hazard regulation in production systems



	Livestock grassland-based systems	Livestock landless systems	Naturally regenerated forests	Planted forests	Irrigated crops (rice)	Irrigated crops (other)	Rainfed crops	Mixed systems
Not known	12	8	10	10	4	10	9	9
Increasing	1	1	6	7	1	5	4	7
Stable	6	2	6	4	2	2	7	6
Decreasing	7	1	5	3	2	9	8	4

Note: The bars show the proportion of responding countries that provided each answer. Non-responding countries (among the total 71 that provided country reports) are not included in the figures.
Source: country reports.

The limited extent to which countries were able to provide information on the status and trends of hazard regulation services in food and agricultural systems reflects a general lack of information on trends in this ecosystem service. For example, trends in natural hazard regulation in most of the ecosystems in Europe reportedly remain unknown (European Environment Agency, 2010). Delivery of this service in Europe is reported to be in a mixed state, with a stable trend, in wetlands and in a degraded state, with a stable trend, in lakes and rivers (*ibid*.).

Trends in state of ecosystems that provide natural hazard regulation services can to some extent serve as proxies for trends in the services themselves. Substantial losses or degradation of ecosystems that are crucial to the delivery of hazard regulating services are clearly grounds for concern. For example, the global extent of wetlands is estimated to have declined by between 64 and 71 percent during the twentieth century and losses and degradation continue worldwide (Ramsar Convention on Wetlands, 2015). Trends in status of many wetland species are also negative (*ibid*.) Many mangrove habitats are degraded and mangrove cover is declining dramatically (Giri *et al.*, 2011; GEAS UNEP, 2013; Webber *et al.*, 2015). It is estimated that between 20 and 35 percent of global mangrove area has been lost since 1980 (FAO, 2007; Webber *et al.*, 2015).

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[3.7 Water related ecosystem services]

[EDITOR'S NOTE: This subsection will cover associated biodiversity that contributes to water purification and waste treatment, water cycling, nutrient cycling]

[3.8 Habitat provisioning]

3.9 Wild foods

Introduction

Wild foods, as defined in the Concepts and definitions section, are food products obtained from non-domesticated species. They include products from a variety of sources including plants, bacteria, animals and fungi. They may be harvested (gathered or hunted) from within food and agricultural production systems or from natural or semi-natural ecosystems. The distinction between wild and domesticated foods is not clearly defined: wild foods lie “along a continuum ranging from the entirely wild to the semi-domesticated, or from no noticeable human intervention to selective harvesting, transplanting, and propagation by seed and graft” (Harris 1989). In marine and freshwater systems, where the boundary between capture fisheries and wild-food gathering is not clear cut, a distinction is usually made between commercial and subsistence harvesting. Capture fisheries are probably the largest single example of the human use of wild foods, and probably constitute the largest wild food industry, providing a total of 94.6 million tonnes of aquatic animals and plants in 2014 (FAO FishStatJ, 2016).

Wild edible species are found in and around production systems in all sectors: forest, fisheries and aquaculture, crop and livestock (and in mixed systems). In forests, wild foods are often referred to as a category of non-timber forest products, and include plants, mushrooms, game meat, and insects and other invertebrates. Contrary to what is often assumed, evidence demonstrates that a significant proportion of wild foods come from agricultural areas or from around the home (Powell, 2015). In agricultural and mixed systems, a large variety of wild herbs, insects, fish (e.g. in rice fields), weeds and unmanaged plants are harvested (see Barucha and Pretty [2010] and Halwart [2008] for example). Garden hunting (or farm bush hunting) occurs when wild animals enter swiddens and fallows. Because of the relative abundance of food sources, several game species thrive in habitat mosaics of swiddens and forest (Parry *et al.*, 2009).

Wild foods make an important contribution to the global food basket and help ensure the food security and nutrition of an estimated 1 billion people (Burlingame, 2000), although it is not clear whether capture fisheries are included in these estimates. The contribution of wild foods to food security and nutrition, resilience and livelihoods is discussed in Section 4.7. This section presents the state of monitoring and assessment, diversity and trends of wild foods.

State of knowledge

Comprehensive information regarding the use, state and conservation of wild foods remains limited, as few assessments of wild foods are conducted at national, regional or global levels. Commercial fisheries are an important exception, although they may not be monitored closely when they are conducted as artisanal, subsistence or recreational activities.

The inclusion of wild foods in national statistics is limited to non-existent (Roe and Elliott, 2004), even though these foods represent an important part of the global food basket (Bharucha and Pretty, 2010). As wild foods are often collected informally, they are usually overlooked in inventories and economic assessments (Schulp *et al.*, 2014). In some countries, the United States of America for example, indications of the diversity and use of wild foods can be obtained from data such on participation in hunting and fishing, the value of capture fisheries, and the value of various other commercial wild foods such as mushrooms, maple syrup, blueberries, ginseng, herbs, kelp and seaweed. Such data are included in national statistics in some countries, data on the hunting of small game and cervids and on catches of wild fish in Norway for example. They may be kept by organizations such as angling associations (as reported by Poland) or be included in fishing and hunting license records. Where the quantity of wild mushrooms is monitored, official statistics may be available. Official data for wild mushrooms are recorded in countries such as Slovenia, which allows the trends to be monitored. However, as Slovenia’s country report indicates, these data do not significantly reflect changes in the environment but rather indicate changes in market prices and general interest in trading fungi; yearly changes may reflect specific conditions for fructification.

Information on wild foods often comes from ethnobiological/ethnobotanical inventories, usually carried by universities and research institutes. Such assessments are numerous; however, they tend to be localized and one-off studies. Other sources of information include scientific literature, game-bag statistics from national organizations, and local cookbooks (which can be used to identify wild food species and their uses).

Compared to other regions, Europe and Central Asia and North America have a particularly high level of information on the status and trends of associated biodiversity and wild food resources. Where wild foods are concerned, fish and game species seem to be quite systematically monitored in most of the reporting countries in these regions. Monitoring levels for fungi, wild berries, medicinal plants and herbs vary from country to country.

At global level, inventories and assessments have been undertaken for wild edible fungi (Boa, 2004) and edible insects (van Huis *et al.* 2013). Regular assessments are conducted for key commercial marine fish stocks (FAO's biennial assessment The State of World Fisheries and Aquaculture). Capture fishery production is reported by FAO member countries (FishStatJ database). However, no equivalents exist from the many smaller scale fisheries and minor stocks in both marine and freshwaters. Global overviews of the status, trends and use of wild foods featured in the Millennium Ecosystem Assessment (MA, 2005) and in a recent WHO/CBD report (WHO/CBD, 2015). IUCN provides a useful assessment of the risk status of various individual wild foods species. However, species used for food are not identified as such in IUCN's database.

Status and trends

Wild food diversity

Providing definitive figures on the number of wild species used for food worldwide is difficult for several reasons, including challenges in the identification of species and in the application of Linnaean nomenclature. In many cultures, and even from one village to the next, more than one vernacular name is used for the same species (Powell *et al.*, 2014). Nonetheless, thousands of wild species have been documented and recorded. For example, in Asia and the Near East, between 20 and 600 wild foods have been recorded at various locations, with an average of 90 to 100 species per community (Bharucha and Pretty, 2010). Selected key references presenting global figures on the number of species by wild food type are listed in Table 10.

Table 10. Number of wild food species, by type

Wild food type	Number of species	Reference	Notes
Wild plant species	Over 7 000 species have been used for human consumption at one stage or another in human history	Grivetti and Ogle (2000)	
Wild mushrooms for food	A total of 1 154 food species and genera recorded from 85 countries	Boa (2004)	Two categories of wild edible fungi can be distinguished: genera containing species that are widely consumed and often exported in significant quantities (e.g. Boletus and Cantharellus) and genera with species that are eaten usually in small amounts, and rarely if ever traded beyond national boundaries.
Wild aquatic foods	Globally, wild capture fisheries harvest over 2 000 aquatic species from marine and freshwater	FAO (2014)	2 033 species items feature in FAO capture fisheries data, including fish, crustaceans, molluscs, echinoderms, coelenterates and aquatic plants, most of them are used for food or feeds. Because of a lack of detailed assessments of artisanal uses, the numbers are likely to be very much higher, as evidenced by numerous assessments of aquatic foods from reef gleaning, rice fields and wetlands.
Edible insects	2 037 edible insect species worldwide according to an inventory of the literature conducted	Yde Jongema (2015)	By using only Latin names and correcting for synonyms, Yde Jongema of Wageningen University, the Netherlands, conducted a worldwide inventory using the literature and listed 2 037 edible insect

	in June 2015		species worldwide as of June 2015. As reported by van Huis (2013), lower estimates have also been published: DeFoliart (1997) counted 1 000 species; Ramos Elorduy (2005) noted “at least” 1 681 species.

In their reports prepared for The Second State of the World’s Plant Genetic Resources for Food and Agriculture (FAO, 2010) and The State of the World’s Forest Genetic Resources (FAO, 2014), several countries included lists of species used for food and other purposes. In the former case, at least 800 unique species (from 55 countries) were explicitly mentioned as being used for food; in the latter, more than 1 000 unique species (72 countries).

Country reporting for The State of the World’s Biodiversity for Food and Agriculture

Countries were invited to provide information on wild foods known to be harvested, hunted, captured or gathered. From a total of 3 597 entries, over 2 440 distinct wild species used for food (from 53 countries) were reported.[44] The number of wild foods reported in each region is presented by type in Figure 9. Several countries reported on wild foods without indicating individual species by their scientific names. For example, the report from the United States of America mentions that Native Americans utilize 55 different types of wild foods from forests, including blueberries, cranberries, chives, fiddlehead ferns, young dandelion leaves and beaked hazelnuts. Bulgaria mentions having inventoried over 5 000 species of crop wild relatives, some of which are used for food. Spain reports 138 crop wild relatives identified as being used for food.

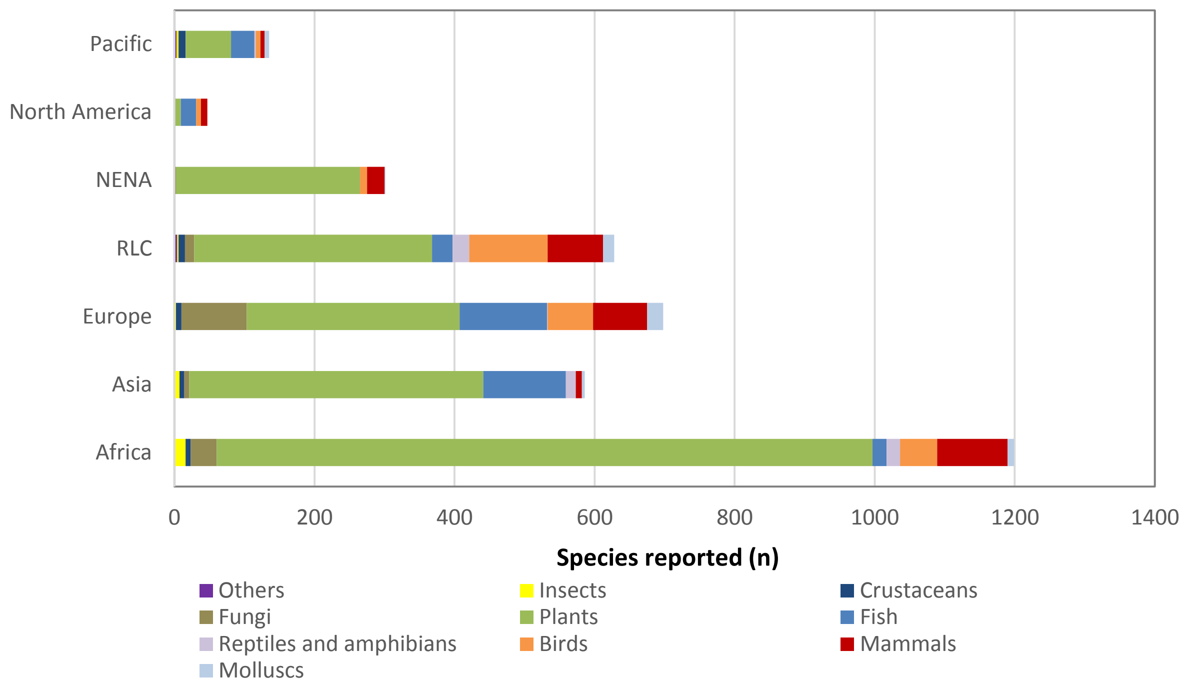
The number of wild foods reported by countries does not reflect the global picture. For example, more than 2 000 species of insects are known to be used as food worldwide (Table 10), while only 19 species were reported by countries. Reasons for this include the limited number of countries that reported wild foods (53), the fact that several countries where wild foods are not seen as contributing significantly to food security and nutrition did not provide an extensive inventory (if they reported species at all) and a bias in the distribution of reporting countries across the regions of the world. For example, many more countries from Europe and Central Asia contributed country reports than countries from Asia or the Near East and North Africa. The reported figures therefore clearly need to be interpreted with caution.

Several countries report very high numbers of wild food species. For example, in Latin America and the Caribbean, Peru alone reports 523 species of edible fruits, of which only 66 are domesticated. Nicaragua’s report mentions a series of studies that provide information on some 150 wild and domesticated plant species, found mostly in well-conserved forests and used mainly by indigenous communities and by communities of African origin living on the Caribbean coast of the country.

With the exception of Anas (a genus of ducks), the 10 genera most frequently reported by countries are all plants – *Ficus* (55 mentions), *Dioscorea* (44 mentions), *Rubus* (41 mentions), *Amaranthus* (31 mentions), *Grewia* (31 mentions), *Prunus* (28 mentions), *Solanum* (27 mentions), *Vaccinium* (26), *Sorbus* (25 mentions) and *Anas* (25 mentions). The species most commonly reported are listed in Table 11.

[44] Additionally, 209 distinct genera were reported without the species being indicated.

Figure 9. Number of reports of wild foods, by type and region



Note: NENA = Near East and North Africa; RLC = Latin America and the Caribbean.
Source: country reports.

Table 11. Examples of wild food species, genus and families commonly reported, by type

Type (number of species reported)	Examples of species, genus and families commonly reported
Plants (1641)	Species: Adansonia digitata, Tamarindus indica, Dioscorea bulbifera, Portulaca oleracea, Ziziphus mauritiana, Colocasia esculenta, Morus alba, Vaccinium myrtillus, Vitellaria paradoxa, Allium ursinum, Annona senegalensis, Borassus aethiopum, Crataegus monogyna, Diospyros mespiliformis, Grewia villosa, Moringa oleifera, Syzygium cumini, Urtica dioica
	Genus: Ficus, Dioscorea, Rubus, Amaranthus, Grewia, Prunus, Solanum, Vaccinium, Sorbus, Ziziphus, Garcinia, Vachellia, Rosa, Diospyros, Syzygium, Capparis, Landolphia, Morus, Rumex, Cordia, Crataegus, Ribes, Annona, Cola, Lannea, Prosopis, Vitex, Allium, Asparagus, Artocarpus, Boscia, Commiphora, Pyrus, Aframomum, Oryza, Adansonia, Corchorus, Ipomoea, Portulaca, Senna, Tamarindus
	Families: Rosaceae, Fabaceae, Malvaceae, Moraceae, Apocynaceae, Anacardiaceae, Lamiaceae, Poaceae, Asteraceae, Arecaceae, Rubiaceae, Solanaceae, Sapotaceae, Amaranthaceae, Dioscoreaceae, Capparaceae, Sapindaceae, Phyllanthaceae, Rutaceae, Myrtaceae, Rhamnaceae, Annonaceae, Araceae, Ericaceae, Cucurbitaceae, Clusiaceae, Burseraceae, Cactaceae, Polygonaceae, Ebenaceae, Asparagaceae, Brassicaceae, Euphorbiaceae, Acanthaceae, Apiaceae, Urticaceae, Vitaceae, Zingiberaceae, Chenopodiaceae, Cordiaceae
Fungi (107)	Species: Cantharellus cibarius, Boletus edulis, Hydnum repandum, Craterellus cornucopioides, Lactarius deliciosus, Morchella esculenta
	Genus: Tuber, Boletus, Cantharellus, Lactarius, Termitomyces, Morchella, Armillaria, Craterellus, Hydnum, Russula, Tricholoma, Leccinum, Lentinus, Macrolepiota, Suillus, Agaricus, Amanita, Coprinus, Cortinarius, Kuehneromyces, Marasmius, Pleurotus
	Families: Agaricaceae, Albatrellaceae, Amanitaceae, Auriculariaceae, Boletaceae, Cantharellaceae, Coriolaceae, Cortinariaceae, Fistulinaceae, Gomphidiaceae, Hericiaceae, Hydnaceae, Hygrophoraceae, Lentinaceae, Lyophyllaceae, Marasmiaceae, Phallaceae, Physalacriaceae, Pleurotaceae, Pluteaceae, Polyporaceae, Russulaceae, Schizophyllaceae, Strophariaceae, Suillaceae, Tricholomataceae, Parmeliaceae, Morchellaceae, Sarcoscyphaceae, Tuberaceae
Mammals (175)	Species: Sus scrofa, Capreolus capreolus, Cervus elaphus, Oryctolagus cuniculus, Alces alces, Cuniculus paca, Dama dama, Odocoileus virginianus, Pecari tajacu, Ammotragus lervia, Capra ibex, Dasypus novemcinctus

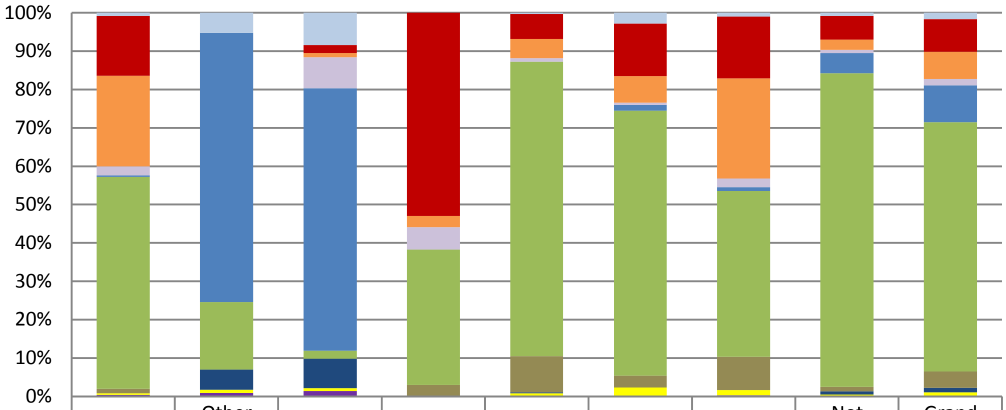
	Genus: Lepus, Sus, Cervus, Tragelaphus, Mazama, Capreolus, Gazella, Odocoileus, Ovis, Capra, Oryctolagus, Sylvilagus, Alces, Cuniculus, Dama, Dasyprocta, Pecari, Ammotragus, Cercopithecus, Colobus, Dasypus, Heliosciurus, Hystrix, Panthera, Rupicapra, Hippotragus, Kobus, Loxodonta, Manis, Mustela, Oryx, Rangifer
	Families: Bovidae, Cervidae, Leporidae, Suidae, Sciuridae, Cercopithecidae, Mustelidae, Felidae, Tayassuidae, Canidae, Cuniculidae, Dasyproctidae, Hystricidae, Dasypodidae, Elephantidae, Herpestidae, Manidae, Procyonidae, Viverridae, Anomaluridae, Antilocapridae, Didelphidae, Hippopotamidae, Nesomyidae, Orycteropodidae, Procaviidae, Pteropodidae, Thryonomyidae
Birds (143)	Species: Anas platyrhynchos, Phasianus colchicus, Lagopus muta, Meleagris gallopavo, Scolopax rusticola, Tetrao urogallus, Anas crecca, Branta canadensis
	Genus: Anas, Anser, Aythya, Callipepla, Columba, Lagopus, Mareca, Meleagris, Patagioenas, Phasianus, Alectoris, Ortalis, Scolopax, Streptopelia, Tetrao, Zenaida, Branta, Corvus, Coturnix, Dendrortyx, Perdix, Colinus, Dendrocygna, Francolinus, Leptotila, Lyrurus, Numida, Struthio, Tockus, Turtur
	Families: Anatidae, Phasianidae, Columbidae, Odontophoridae, Cracidae, Scolopacidae, Bucerotidae, Numididae, Accipitridae, Corvidae, Ardeidae, Rallidae, Struthionidae, Tinamidae, Charadriidae, Otididae, Strigidae, Sturnidae
Insects (19)	Species: Apis mellifera, Atta laevigata, Caleta caleta, Cirina forda
	Genus: Apis, Atta, Caleta, Cirina, Enantia, Gryllus, Imbrasia, Locusta, Odontotermes, Oecophylla, Olethrius, Parides, Paulinia, Raphia, Rhuda, Rhynchophorus, Ruspolia, Samia, Tetrix, Trigona, Vespa, Zonocerus
	Families: Acrididae, Apidae, Cerambycidae, Curculionidae, Formicidae, Gryllidae, Lycaenidae, Noctuidae, Notodontidae, Papilionidae, Pieridae, Pyrgomorphidae, Saturniidae, Tachinidae, Termitidae, Tetrigidae, Tettigoniidae, Vespidae
Crustacea (29)	Species: Birgus latro, Cardisoma carnifex, Macrobrachium rosenbergii, Nephrops norvegicus, Scylla serrata
	Genus: Macrobrachium, Birgus, Cardisoma, Panulirus, Nephrops, Palinurus, Scylla
	Families: Astacidae, Atyidae, Cambaridae, Coenobitidae, Crangonidae, Gecarcinidae, Grapsidae, Nephropidae, Ocypodidae, Palaemonidae, Palinuridae, Pandalidae, Penaeidae, Portunidae, Ucididae
Molluscs (37)	Species: Anadara tuberculosa, Helix pomatia, Anadara similis, Mytilus galloprovincialis, Octopus vulgaris, Sepia officinalis
	Genus: Helix, Anadara, Octopus, Sepia, Mytilus, Eledone, Archachatina, Potadoma
	Families: Arcidae, Mycetopodidae, Mytilidae, Ostreidae, Pectinidae, Spondylidae, Tridacnidae, Unionidae, Veneridae, Loliginidae, Octopodidae, Sepiidae, Achatinidae, Ampullariidae, Aplysiidae, Helicidae, Muricidae, Pleuroceridae, Trochidae, Turbinidae, Volutidae, Patellidae
Fish (240)	Species: Salmo trutta, Anguilla anguilla, Gadus morhua, Salmo salar, Sander lucioperca, Thymallus thymallus, Abramis brama, Anabas testudineus, Aspius aspius, Esox lucius, Heteropneustes fossilis, Leuciscus idus, Ompok bimaculatus, Perca fluviatilis, Pleuronectes platessa, Rutilus rutilus, Solea solea, Thunnus albacares, Tinca tinca
	Genus: Salmo, Anguilla, Coptodon, Labeo, Clarias, Thunnus, Coregonus, Epinephelus, Gadus, Leuciscus, Tor, Channa, Ompok, Sander, Scophthalmus, Thymallus, Abramis, Anabas, Aspius, Cirrhinus, Clupea, Esox, Heteropneustes, Mystus, Perca, Pleuronectes, Rutilus, Siganus, Solea, Sperata, Tenualosa, Tilapia, Tinca
	Families: Cyprinidae, Salmonidae, Cichlidae, Scombridae, Clupeidae, Pleuronectidae, Bagridae, Anguillidae, Clariidae, Gadidae, Percidae, Serranidae, Siluridae, Sparidae, Channidae, Schilbeidae, Sciaenidae, Scophthalmidae
Reptiles and amphibians (44)	Species: Iguana iguana, Ctenosaura similis, Chelonia mydas, Crocodylus acutus, Ctenosaura pectinate, Eretmochelys imbricate, Varanus niloticus
	Genus: Ctenosaura, Iguana, Crocodylus, Varanus, Conraua, Pangshura, Chelonia, Eretmochelys, Kinixys, Melanochelys, Nilssonia, Python, Trichobatrachus
	Families: Arthroleptidae, Boidae, Bufonidae, Cheloniidae, Crocodylidae, Dermochelyidae, Elapidae, Geoemydidae, Iguanidae, Megophryidae, Petropedetidae, Pythonidae, Ranidae, Testudinidae, Trionychidae, Varanidae, Viperidae
Others (5)	Species: Spirulina platensis, Isostichopus fuscus, Loxechinus albus, Holothuria atra, Eunice gigantea

Source: country reports.

The production systems and other environments in which the reported wild food species are present and harvested are not specified in 33 percent of cases. Of the remaining 2 400 entries, the largest numbers of species are reported to be extracted from forest production systems (including planted and naturally regenerated forests) (42 percent), capture fisheries and aquaculture (12 percent), mixed production systems (17 percent), crop production systems (10 percent), other environments (roadsides, home gardens, etc.) (13 percent) or other aquatic environments (rivers, canals, ponds, etc.)

(5 percent) (Figure 10). Overall, 82 percent of wild foods for which information on the source is provided are explicitly reported to be extracted from production systems.

Figure 10. Production systems and other environments in which wild species are present and harvested



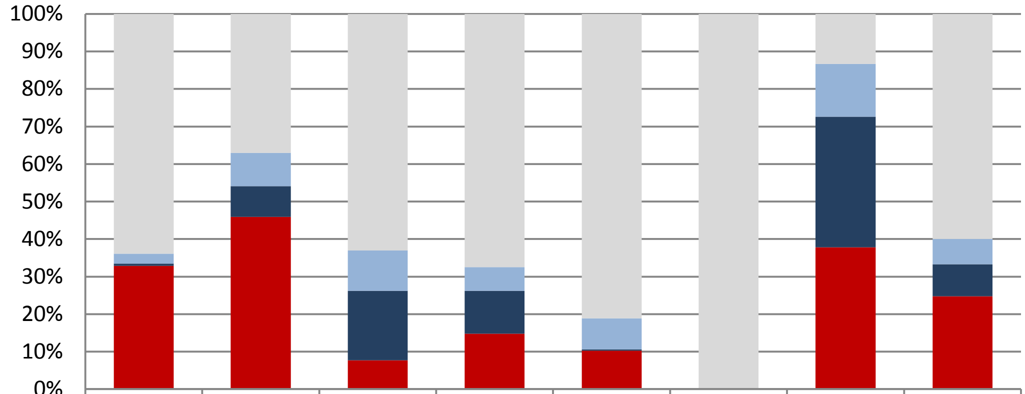
	Crop PS	Other aquatic	CF and Aq	Livestock	Forest PS	Mixed PS	Other	Not specified	Grand Total
Molluscs	2	6	24	0	3	11	3	10	59
Mammals	39	0	6	18	66	53	50	74	306
Birds	59	0	3	1	51	27	81	32	254
Reptiles and amphibians	6	0	23	2	10	2	7	10	60
Fish	1	80	195	0	0	6	3	62	347
Plants	138	20	6	12	780	268	134	979	2337
Fungi	3	0	0	1	96	12	27	14	153
Crustacea	0	6	22	0	3	0	0	10	41
Insects	1	1	2	0	8	9	4	4	29
Others	1	1	4	0	0	0	1	2	9

Note: PS = production systems; CF = capture fisheries; Aq = aquaculture.
Source: country reports.

Wild food trends

Countries were invited to report on the trends of wild foods. Figure 11shows that among the 3 597 records, trends are not reported or not known in 60 percent of cases; 25 percent are reported to be decreasing in abundance, 8 percent to be stable and 7 percent to be increasing. Africa is the region where the highest proportion of wild foods (44 percent) are reported to be decreasing in abundance, followed by Asia (30 percent) and Latin America and the Caribbean (33 percent). The taxonomic groups with the highest number of wild foods reported to be decreasing in abundance are plants (628), followed by fish (125). The highest proportions of declining wild foods are reported among crustaceans, fish and molluscs. In terms of production systems and environments, the majority of wild foods reported to be decreasing are found in forests (56 percent) (Figure 12).

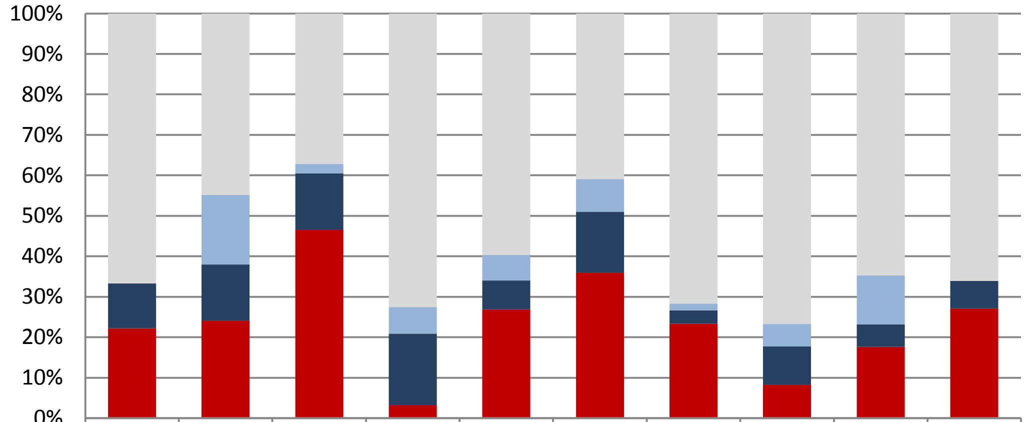
Figure 11. Reported wild food trends (by region)



	Africa	Asia	Europe	RLC	NENA	North America	Pacific	Grand Total
Not known/reported	766	217	440	425	245	47	18	2158
Increasing	32	52	75	40	25	0	19	243
Stable	7	48	129	72	1	0	47	304
Decreasing	394	269	54	93	31	0	51	892

Note: NENA = Near East and North Africa; RLC = Latin America and the Caribbean.
Source: country reports.

Figure 12. Reported wild food trends (by type)



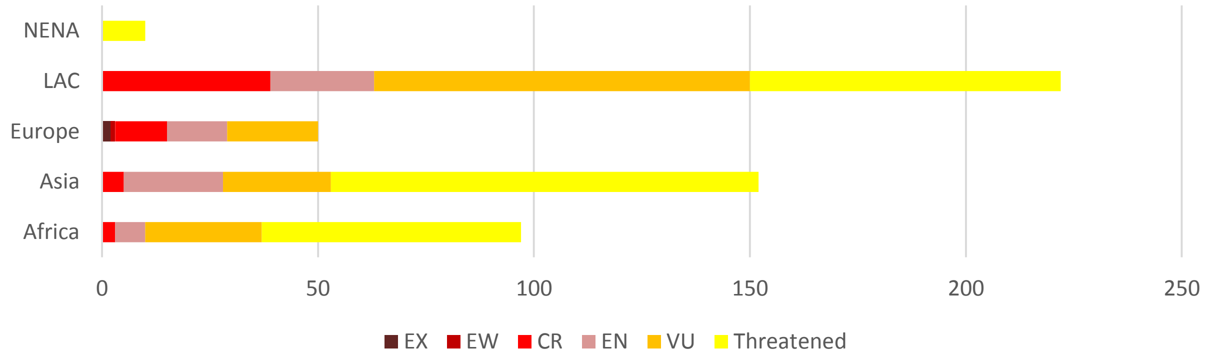
	Others	Insects	Crust.	Fungi	Plants	Fish	R&A	Birds	Mamm.	Moll.
Not known/reported	6	13	16	111	1395	142	43	195	198	39
Increasing	0	5	1	10	147	28	1	14	37	0
Stable	1	4	6	27	167	52	2	24	17	4
Decreasing	2	7	20	5	628	125	14	21	54	16

Note: Crust. = Crustaceans; R&A = Reptiles and amphibians; Mamm. = Mammals; Moll. = Molluscs.
Source: country reports.

Countries were asked to report on wild food species for which there is a significant threat of extinction or the loss of important populations in the country, using the IUCN Red List categories and criteria as reference. Overall, 528 distinct wild foods were reported by 28 countries to be critically endangered (59), endangered (68) or vulnerable (160). Several species (241) were reported to be "threatened" without further specification of the IUCN category. Two species were reported to be extinct in the wild and one to be extinct. The responses are summarized in Figure 13. The largest numbers of threatened wild foods are found in Latin America and the Caribbean, followed by Asia and Africa.

Several countries that list wild foods do not explicitly report any of them as threatened. At the other end of the spectrum, Cameroon reports that most wild foods are threatened with extinction. It indicates that this applies mostly to species that are found in locations that do not have protected area status and that are affected by agriculture, hunting, grazing and other human activities. In Bangladesh, a number of wild animals such as the swamp dear (*Cervus duvauali*), the one-horned rhinoceros (*Rhinoceros unicornis*) and the wild water buffalo (*Bubalus arnee*) that were once abundant and used as food have become extinct.

Figure 13. Risk categories of wild foods for which a significant threat of extinction or loss is reported



Note: Countries reported according to the IUCN Red list categories: EX (Extinct); EW (Extinct in the wild); CR (Critically endangered); EN (Endangered); and VU (Vulnerable). In addition, several species were reported to be to be "threatened", without further specification of the IUCN category. Not represented in the figure are data from the country reports of the United States of America, which noted five populations of salmon that have been listed as endangered under the Endangered Species Act and 23 populations listed as threatened, and the countries of the Pacific region, which reported a total of 12 species, all of unknown risk status.
Source: country reports.

As noted above, capture fisheries are a major commercial industry, and as such are subject to monitoring. Figures for 2013 indicate that among fish stocks commercially used and assessed 68.6 percent were being fished within biologically sustainable levels and that 31.4 percent were overfished (FAO, 2016). Compared to the situation in the 1970s this is a clear deterioration, although there have been some improvements on a regional scale (*ibid*.).

For other types of wild foods, there is generally little recorded and published information on trends. There are some anecdotal indications of trends and there may also be evidence available from indirect indicators such as trends in drivers of change that affect the status of wild foods. Influences of this kind are numerous and complex. However, frequently mentioned drivers include land-use change, climate change, natural disasters, invasive alien species and overexploitation. Trends may also become apparent in cases where overabundance of wild food species leads to negative consequences, for example if they become invasive species. Relevant examples from the country reports are provided below.

Countries indicated that in recent decades there had been a decline in the availability and diversity of certain wild food species. For example, the status of wild edible plant species in Nepal is believed to have deteriorated as a result of the (often cumulative) effects of land-use changes (e.g. expansion of agricultural lands, infrastructure development, habitat destruction, timber harvesting, fuelwood collection and forest fires), overharvesting, overgrazing and invasive species. At the same time, land-use changes, such as infrastructure development, have contributed to increasing the availability of wild foods by improving physical access to remote areas.

In Yemen, wild foods constitute a basic food resource for the rural population. Although it is reported to be difficult to assess losses accurately, wild food resources are believed to be declining as a result of overharvesting, overcollecting, overgrazing, deforestation and woodland degradation. Oman indicates that many forest trees are recognized as sources of wild foods such as figs and berries, but that production has declined over time, mainly because of significant reductions in pollinator populations, believed in turn to have been caused by climate change.

Invasive species are another driver reported to be affecting wild food stocks. For example, the report from the United States of America notes that data from the 1990s and 2000s show 44 native species of fish threatened or endangered by alien invasive species. It also refers to a further 27 native fish species negatively affected by introductions.[45] Invasive mussels, such as zebra mussels, are also reported to compete with native mussels, clams and snails and to reduce oxygen for fish and other aquatic species.

Saint Lucia reports that it does not depend greatly on wild foods or hunting, but mentions that anecdotal information indicates that the supply of wild meats from animals such as agoutis, opossums and wild pigs declined as a result of the ravaging effects of hurricane Tomas. However, it further notes that the populations of wild pigs (*Sus scrofa*) and the red-rumped agouti (*Dasyprocta antillensis*) have recovered to such extent that they are disrupting production on farms. Efforts are being made to domesticate the agouti and control the pigs. Another example from Saint Lucia of how overabundance of a wild food species can be problematic is the case of the lionfish (*Pterois volitans*), an invasive alien species that grows and reproduces quickly and feeds predominantly on reef species such as snappers, parrotfish and grunts. Its only known natural predator is the grouper fish. The lionfish has become common in local waters and the country's Fisheries Department is now promoting its consumption.

Some countries, Switzerland for example, indicate that in recent decades there have been no recorded declines in the availability of wild foods that have affected the livelihoods of those that depend on them. Other countries, however, report that declines in the availability of wild foods have had significant impacts. The Gambia, for example, mentions that massive losses of wild foods have obliged communities to turn to new items (often industrially produced foods) to supplement their diets. In Finland, the collapse of freshwater populations of native salmonids has meant that food from these sources has been replaced by imported farmed salmon. Similarly, wild berries harvested from farmed and forested land have been replaced by commercially produced cultivars and imports. In Cameroon, the impacts of the loss of wild foods are reported to be numerous: 1) local communities lose income from the sale of wild food products, as well as valuable nutritional benefits; 2) migration increases among these populations as they can no longer make a livelihood from the wild food products; 3) population movements may lead to problems with land acquisition and co-existence with local communities and may cause intertribal conflicts; 4) loss of income sources may lead to poverty, misery and crime; 5) people may have difficulty adapting their diets and lifestyles to the loss of traditional products.

Needs and priorities

With the exception of capture fisheries, the state of wild food resources is not well recorded in most regions. Some countries mention that this is largely because the conservation and use of wild food resources are not considered priorities at policy level. In Europe, for example, many countries explained that this was the case because their food security does not depend on these resources. Countries expressed the need for an inventory of wild food species and for the development of plans and strategies that ensure these species are conserved and used in a sustainable manner. This will require technical skills and equipment, as well as financial resources, all of which are currently in short supply.

Bangladesh mentions that, while wild food species have been used by rural communities across the region for centuries, there are still no organized programmes/projects that highlight, for example, the value of crop wild relatives and edible wild plants to food and nutrition, both in daily life and in times of food crisis. It reports that, with a large number of wild edible plant species disappearing as a result of the expansion of agricultural lands, development projects and other factors, there is a need to develop breeding programmes and activities to maintain and sustainably use these species.

[45] The country report cites Pimentel *et al*. (2005).

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[3.10 Needs and priorities]

CHAPTER 4 – THE STATE OF USE OF BIODIVERSITY FOR FOOD AND AGRICULTURE

4.1 Introduction

For the purpose of this chapter, use is taken to include (see definition of “sustainable use” as in the Concepts and definitions section) the various practical activities involved in cultivating or raising domesticated species, the introduction of domesticated or wild species into new production systems, the management of wild species and their habitats in and around production systems to promote the delivery of ecosystem services, and the implementation of breeding programmes for domesticated species and the domestication of additional wild species. These elements of use are addressed in the first part of the chapter. The first part also includes a discussion of the various ways in which micro-organisms are used in food processing and in agro-industrial processes.

The first part contains the following sections:

- Associated biodiversity species actively managed for the provision of ecosystem services;
- The state of use of management practices that are considered to promote the conservation and sustainable use of BFA;
- The use and management of micro-organisms for food processing and agro-industrial processes;
- The state of breeding of BFA.

The second part of the chapter contains sections on the use, roles or contributions of BFA, actively managed or otherwise, to food security and nutrition, the sustainable intensification of food production and agriculture, the resilience of production systems, and the improvement of livelihoods. It should be noted that the contribution of BFA to ecosystem services is described in detail in Section 1.2, Chapter 3, and in most sections of Chapter 4, therefore a specific section dedicated to the contribution of BFA to ecosystem services is not presented.

The second part contains the following sections:

- The role of BFA in food security and nutrition, with a subsection dedicated to the importance of wild foods for food security and nutrition;
- The contribution of BFA to the sustainable intensification of food production and agriculture;
- The contribution of BFA to the multiple dimensions of resilience;
- The importance of BFA for improving livelihoods.

[4.2 Associated biodiversity species managed for the provision of ecosystem services]

4.3 Management practices promoting the conservation and sustainable use of biodiversity for food and agriculture

4.3.1 Organic agriculture

Organic agriculture is one of the most well known and scrupulously defined "ecological" approaches to farming. In the country reporting guidelines, it is described as "a production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity. It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological and mechanical methods, as opposed to using synthetic materials, to fulfil any specific function within the system."[46] While some production systems managed in this way are certified as organic by official bodies, others – especially in non-OECD countries – are not. Many farms that practice *de facto* organic agriculture are not certified. This may mean that reported figures for the amount of organic agriculture (in sense defined above) practised are underestimates. Organic standards can be applied to any type of production system, including crop, livestock, aquaculture, bee keeping, forestry and mixed systems (e.g. agroforestry or aquaponics).

Examples of methods used in organic agriculture include maximized use of natural alternatives to synthetic (artificial pesticides, artificial fertilizers, seeds, veterinary products, etc.), a focus on soil health (use of compost, reduced or no tillage, cover crops, green manure, etc.), diversification of species, breeds or varieties (polyculture, rotations, companion crops, animal–plant integration, etc.), establishment of semi-natural habitats (grass strips, flower strips, hedges, etc.) and livestock management that privileges animal welfare (cage-free management, access to open fields, etc.), sustainable pasture management and use of local feed sources. Additionally, the production of genetically-modified crops and their use in animal feed is not allowed. Because of the environmental benefits it provides, organic agriculture is considered as an (agri)environmental indicator by institutions such as the Organisation for Economic Co-operation and Development, FAO, the European Environmental Agency and Eurostat (OECD, 2013; FAOSTAT, 2016; European Environmental Agency, 2015; Eurostat, 2011, 2015).

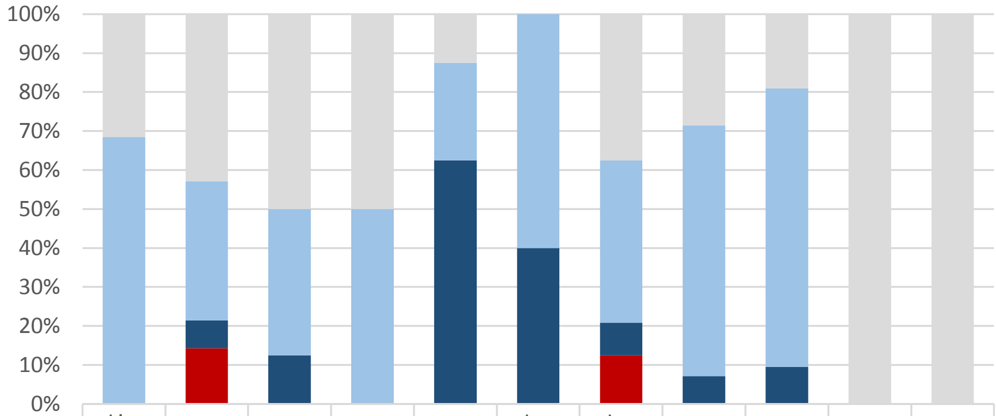
Production systems managed under organic standards are tightly linked to the surrounding ecosystem (except for those in high containment greenhouses). In organic crop production, for example, management involves harnessing ecosystem services such as biological pest control, pollination, nutrient cycling and water retention as direct or indirect substitutes for off-farm inputs such as artificial pesticides and fertilizers (Alcamo *et al.*, 2003). Ecosystem services are delivered by associated biodiversity communities and several studies have shown a positive relation between such communities and organic production systems (Costanzo and Bàrberi, 2013; Bengtsson *et al.*, 2005; Gaston and Spicer, 2004). The categories of associated biodiversity that benefit most from organic management in terms of abundance and diversity are birds, predatory and parasitoid insects, spiders, pollinators, soil-dwelling organisms and field flora (FiBL, 2016a; Reganold and Wachter, 2016). For example, establishing permanent strips of flowering plants at crop field margins attracts pollinators and biological pest control arthropods by providing them with vegetation cover and alternative food sources (Landis *et al.*, 2000). For more information on associated biodiversity and of its role in the supply of ecosystem services, see Chapters [Crossref].

The country report questionnaire invited countries to provide information on the extent of use of organic agriculture in different productions systems.[47] The production systems where organic

[46] This definition is adapted from FAO/WHO Codex Alimentarius Commission (1999).
[47] The questionnaire did not draw a distinction between certified and uncertified organic production.

agriculture was most frequently reported were rainfed crop production, irrigated (non-rice) crop production and mixed systems (Figure 14). Organic production was less frequently reported in livestock and forestry systems. Only a few countries reported organic aquaculture systems. According to the Research Institute of Organic Agriculture (FiBL, 2016b), at least 11.9 million hectares of cropland and 27.5 million hectares of grassland were under organic production 2014.[48] Major commodities produced under organic standards include bananas, cocoa, coffee, cotton, forest products, palm oil, soybeans, cane sugar and tea (*ibid*.), although most commodities are now available in certified organic form (FiBL Statistics).[49] Certification of organic aquaculture (43 222 ha globally as of 2014) is still incipient and some aspects such as nutrient recirculation, use of power for water pumping and aeration, feeding sources, use of hormones, breeding techniques and conversion periods remain under discussion (*ibid*.). Although aquaculture is the fastest growing sector of food and agriculture, the certified organic products remain a small percentage of the total volume of aquaculture production. In 2009, there were 240 certified organic aquaculture farms in 29 countries, producing a total of 53 500 tonnes of organic aquaculture products; this accounted for about 0.1 percent of global certified aquaculture production (IFOAM EU Group, 2010). Although only three countries provided information on organic beekeeping this practice is found in 55 countries and accounts for 1 million beehives (1.3 percent of total world's beehives according to FAO data in 20132), of which more than 70 percent is located in Europe (FiBL, 2016b).

Figure 14. Reported presence, and trend in the adoption, of organic agriculture by production system



	Liv. grassland-based	Liv. landless	NRG	Planted forests	Fed aquaculture	Irr. crops (rice only)	Irr. crops (rice excl.)	Rainfed crops	Mixed systems	Other PS	PS not specified
Not indicated	6	6	8	6	1	0	9	8	4	5	6
Increasing	13	5	6	6	2	3	10	18	15	0	0
Stable	0	1	2	0	5	2	2	2	2	0	0
Decreasing	0	2	0	0	0	0	3	0	0	0	0

Note: Liv.=Livestock; NRG= Naturally regenerated forests; Irr.=Irrigated; PS=Production system
The bars show the proportion of responding countries that provided each answer. Non-responding countries (among the total 71 that provided country reports) are not included in the figures.
Source: country reports.

Forty-five out of 71 country reports indicate that organic agriculture is practised in at least one production system category. Among the reporting countries, 85 percent of OECD members and 53 percent of non-OECD members indicate that organic management is practised. Twenty-three countries provided information on the area under organic management.

[48] The figures for cropland are considered to be underestimates, as data are not available from some countries with large areas of organic agriculture.
[49] Statistics on organic production can be found in Organic World website (implemented by FiBL) > Statistics > Data tables and map > Crop area > at http://www.organic-world.net/statistics/statistics-data-tables/ow-statistics-data-crops.html

According to FiBL (2016b) certified organic agriculture is practised in at least 172 countries, 87 of which have put in place a legal framework to regulate it (Table 12). Globally, organic agriculture extends over 43.7 million ha (including areas that are under conversion into certified organic) (almost 1 percent of agricultural land) and encompasses 2.3 million producers[50] (*ibid*.). Oceania accounts for 17.3 million ha (40 percent), Europe for 11.6 million ha (27 percent) and Latin America for 6.8 million ha (16 percent); 75 percent of organic producers are located in Asia, Africa and Latin America (*ibid*.). Worldwide, the share of organic agricultural land has increase by 300 percent and the number of producers by 1 000 percent since 1999 (IFOAM, 2015). During the last decade, there has been an expansion of organic farmland in all regions. Between 2006 and 2014, the fastest growth was in North America (an increase of72 percent), Europe (60 percent) and Oceania (40 percent, albeit with some years of stagnation); the world average was 45 percent (FiBL, 2016b). The information provided by the countries that participated in the SOW-BFA process also indicates positive trends (Figure 14). Where retail sales are concerned, 80 percent of the market share of organic produce is concentrated in the United States of America and Europe, accounting for more than US$50 billion (FiBL, 2016b). However, markets in developing and emerging countries are rapidly growing.

Table 12. Indicators of the status of organic agriculture worldwide

Indicator	World	Top regions
Countries with organic production systems	172	
Organic agricultural land	43.7 million ha	Oceania: 17.3 million ha Europe: 11.6 million ha Latin America: 6.8 million ha
Organic share of total agricultural land	0.99%	Oceania: 40% Europe: 27% Latin America: 16%
Organic farmland expansion (2006 to 2014)	45%	North America: 72% Europe: 60% Oceania: 40%
Number of producers*	2.3 million (+1 000% since 1999)	Asia: 920 000 Africa: 600 000 Latin America: 390 000
Number of countries with organic regulations (2015)	87	Europe: 39 The Americas and the Caribbean: 21 Asia: 20
Size of organic market	US$80 billion	North America: 27.1 billion euros European Union: 23.9 billion euros

*Note: data are for 2014 unless stated otherwise. *The number of producers may be an underestimate as some countries that contributed data reported numbers of companies, projects or grower groups that may involve a number of individual producers.*
Source: FiBL, 2016.

Non-profit bodies such as IFOAM – Organics International and FiBL, and several governments are increasing support for organic agriculture through a range of programmes and policies, including targeted subsidies, market development, capacity building, monitoring and research. Many country reports refer to policies that address organic agriculture. For example Bhutan notes its objective of become 100 percent organic by 2020. Nepal emphasizes the development of organic agriculture in its Tenth Five-Year Plan (2002–2007). Costa Rica mentions that its National Development Plan 2014–2018 projects a 20 percent increase in the area of organic farmland. Jordan mentions that expansion of organic agriculture is targeted in its National Programme for Organic Farming (2009) and that it has established a section in the Ministry of Agriculture dedicated to this organic production. Other countries have long-standing schemes supporting and monitoring organic agriculture, for example the Federal Programme for Organic Farming and Other Forms of Sustainable Agriculture in Germany and the National Organic Program in the United States of America. In the EU, numerous projects related to organic food and farming are supported under the EU's framework programmes and include

[50] This figure may be underrepresented as some countries that contributed to FiBL (2016) provided the number of companies, projects or grower groups that may involve a number of individual producers.

partners from several EU countries. Examples of such projects under the current framework programme (Horizon 2020) include Coordination of European Transnational Research in Organic Food and Farming Systems (CORE Organic) and the Diversifood project.

The difficulty involved in monitoring non-official organic production systems is an important factor contributing to gaps in information on the status and trends of organic agriculture. Many smallholder farms (e.g. low-input or traditional systems) may produce according to organic standards but not be recognized as such by official bodies, for example because of a lack of regulatory frameworks, difficulties regulatory bodies may have in reaching and assessing sites, or farmers' inability to pay certification fees or to access the international organic market. Participatory guarantee schemes (PGS) and internal control systems (ICS) are legal alternative certification frameworks recognized by some governments (e.g. India and Brazil) for internal markets; such frameworks allow groups of smallholders to assert that their production follows organic standards (or other rules such as fair trade) in a self-organized way, enabling them to access premium markets and to be reported by official bodies at relatively low costs (Gould, 2007).

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WHO/FAO. 1999. *Codex Alimentarius*. Rome: Food and Agriculture Organization.

4.3.2 Integrated pest management

[EDITOR'S NOTE: Review of this section has not been completed]

Introduction

Integrated pest management (IPM) has been defined in many different ways over the years. For example, more than 65 definitions of the term are listed by Bajwa and Kogan (2002). FAO uses the following definition: "the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms" (FAO and WHO, 2014). The guidelines for the preparation of country reports note that relevant pest control mechanisms include: "crop rotation; inter-cropping; seedbed sanitation, appropriate sowing dates and densities, under-sowing, conservation tillage, pruning an direct sowing; where appropriate, use of pest resistant/tolerant cultivars, push-pull strategies and standard/certified seed and planting material, balanced soil fertility and water management, making optimum use of organic matter; prevention of spread of harmful organisms by field sanitation and hygiene measures and protection and enhancement of important beneficial organisms." IPM practices are thus more knowledge intensive than the calendar-based application of pesticides and therefore farmers need to become experts in the ecology of their production systems, maintain healthy soils, regularly monitor the environment and ensure the maintenance of healthy populations of biological control agents (BCAs) (organisms that are harmful to pests − see Section 3.4 for further details).

The mechanism that underlies most IPM programmes is biological control (FAO, 2009; FAO, 2011), particularly conservation biological control (modification of the agroecosystem and/or its immediate surroundings so as to increase the impact of local BCAs − Orr, 2009). However, other types biological control, such as augmentative (mass culture and periodic release of specific natural enemy species) and classical biological control (introduction of a BCA into an area where it does not naturally occur) may also be used (see Table 13) (Orr, 2009; Waage, 2007). Cultural control (modifying the environment to reduce its suitability for pests) and physical control (use of physical barriers to keep pests away) are also important components of IPM strategies. Chemical control measures are only used when an outbreak occurs. Both pest and BCA populations have to be constantly monitored so that levels of yield damage can be predicted and decisions taken as to whether pesticides need to be applied.

Table 13. Examples of IPM practices and tactics

IPM practices	Tactic	Example	Source
Biological control	Augmentation	Release of *Trichogramma* parasitoid wasps against lepidopteran pests	Knutson, 1998
	Classical	Importation of cactus moth (*Cactoblastis cactorum*) to control *Opuntia* cacti	Zimmermann et al., 2000
	Conservation	Attract natural enemies to the field	Sengonca et al., 2002
Cultural control	Permanent vegetation in field margins	Attract natural enemies to the field	Kremen and Miles, 2012
	Crop rotation	Disruption of life cycle of pests	Zehnder et al., 2007
	Resitant crop varieties	Locally adapted varieties	Teetes, 1994
	"Push-pull" systems	Napier grass (*Pennisetum purpureum*) and *Desmodium* integrated in the field against sorghum stemborers	ICIPE, 2015
Physical control	Soil sterilization	Solarization	Stapleton et al., 1986
	Barriers	Nets against birds	Briassoulis et al., 2007
Chemical control	Pesticides	Only if pest suprasses economic threshold	Alston, 2011

IPM prioritizes prevention over intervention. This requires a good understanding of the local biodiversity and the trophic relations within the local ecosystem. IPM promotes BCA abundance and a reduction in damaging herbivore populations, along with an increase in the diversity of both groups (Heong *et al.*, 2007; FAO, 2011; FAO, 2012). Increasing the diversity of damaging herbivores may lead to interspecific competition for plant resources and hence reduce the chance that a few species become dominant and begin to act as pests.

Associated biodiversity also contributes to cultural control. For example, so-called pull–push systems (originally developed in East-Africa to control sorghum and maize stemborers) involve the use of a repellent plant (e.g. Desmodium spp.) in the field and an attractant plant (e.g. Pennisetum purpureum) at the field edges (ICIPE, 2015). Other cultural control tactics include intercropping, cover crops and the establishment of permanent wild-flower strips. Complex vegetation cover and presence of alternative food sources (e.g. nectar and pollen) attract natural enemies and may make it easier for them to survive the winter (Langellotto and Denno, 2004). Examples of the roles of different components of associated biodiversity in IPM in various production systems are shown in Table 14. Additional examples of associated biodiversity species that countries report by countries to be managed for pest and disease regulation are provided in Section 3.4 (Table 4 in particular).

Table 14. Examples of the roles of associated biodiversity in biological control-based IPM

IPM practice	Component of associated biodiversity	Control agents	Pests controlled	Species protected	Source
Biological control	Aquatic species	Fish, amphibians,	Rice field pests	Rice (Oryza sativa)	Halwart and Gupta, 2004; Hocking and Babbit 2014
	Arthropods	Ladybirds (Coccinellidae: Coleoptera)	Aphids (Aphidoidea superfamily)	*Citrus* spp., apple orchards and several annual crops	Roy and Migeon, 2010
		Parasitoid wasps (several Hymenoptera families, see Gurr et al., 2012)	Rice leaffolder (Cnaphalocrocis medinalis)	Rice (Oryza sativa)	Gurr et al., 2011
	Bacteria*	Bt formulations (Bacillus thuringiensis)	Helicoperva spp.	Tomato (Solanum lycopersicum)	Zhang et al., 2013
	Birds	European pied flycatcher (*Ficedula hypoleuca*)	Lepidopteran damaging larvae	Forest vegetation	Unwin, 2011
	Fish	Wrasse	Sea Lice (Lepeophtheirus salmonis)	Atlantic Salmon (*Salmo salar*)	Ottesen et al., 2011
	Fungi*	Muscardine fungus (*Beauveria bassiana*)	Colorado potato beetle (*Leptinotarsa decemlineata*)	Potato (Solanum tuberosum)	Wraight and Ramos, 2002
		Metarhizium anisopliae	Common click beetle (*Agriotes sputator*)	Maize (*Zea mays*)	Eckard et al., 2014
	Nematodes*	Steinernema carpocapsae	Carpenter moth (Prionoxystus robiniae)	Chestnut (*Castanea* spp)	Hannon and Beers, 2007
Cultural control: "Push–pull" system	Plants	Napier grass (*Pennisetum purpureum*) and Desmodium	Spotted stalk borer (*Chilo partellus*)	Sorghum spp.	ICIPE, 2015

*Note: *Usually applied as biopesticides.*

Livestock, aquaculture, orchard and rice–fish systems can also be protected using IPM tactics, mainly through biological control. For example, the stable fly Stomoxys calcitrans, which causes skin lesions and stress in mammalian livestock and can transmit pathogens, can be controlled using the parasitoid wasp Spalangia endius (FAO/IAEA, 2016). Some fungal species show promise as means of controlling parasitic nematodes in small ruminants (FAO, 2016).

Salmon (*Salmo* and *Oncorhynchus* spp.) are susceptible to a parasitic copepod known as the salmon louse (*Lepeophtheirus salmonis*), which can be controlled by fallowing growing sites to disrupt its life cycle, farming resistant varieties, such as the coho salmon (*Oncorhynchus kisutch*) instead of the Atlantic salmon (*Salmo salar*) or using wrasses (small fish that predate on the lice) (Salmon Health Consortium and PMRA, 2003; Ottesen *et al.*, 2011). The use of fish as BCAs is widespread in Asian rice–fish systems. Grass carp (*Ctenopharyngodon idella*), common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*) are actively introduced into ricefield systems, where they feed on planthoppers and leafhoppers (Halwart and Gupta, 2004). In traditional rice cultivation, water management regimes promote aquatic species such as fish and amphibians that predate on rice pests.

Many insect pests (e.g. *Adoxophyes honmai, Tuta absoluta*) can be regulated by releasing artificial sexual pheromones that disrupt or delay their mating (Witzgall *et al.*, 2010). In several citrus and apple orchards in Australia and New Zealand the light brown apple moth (*Epiphyas postvittana*) is successfully controlled using this technique (Brockerhoff *et al.*, 2012).

IPM measures to control weeds and plant diseases (bacterial, viral, fungal and nematode-related) involve crop, soil and, in some cases, water management. For example, reduced tillage, mulching and use of allelopathic cover crops hamper weed growth in soil-based systems. Application of organic amendments helps reducing soil-borne diseases by increasing the complexity of soil ecosystems and improving soil structure. In rice−fish systems, aquatic weeds and algae are eaten by the fish and can also be controlled by sound water-management practices (Halwart and Gupta, 2004). Rabbitfish (*Siganus* spp.) and scats (*Scatophagus* spp.) can be introduced into marine fish cages to reduce fouling by epiphytic algae.

IPM can be fostered via regulation of the pesticide market. For example, the country report from Bhutan notes that the Pesticides Act of Bhutan, 2000,[51] which enables tight centralized regulation of the import, sale and use of pesticides, promotes the use of IPM. Measures of this kind can lead to economic benefits and help to reduce countries’ dependence on pesticide imports. The Government of Indonesia, for example, has introduced strong regulation of pesticide use, which has reduced the country' imports by two-thirds (Bottrell and Schoenly, 2012; FAO, 2012). Under legislation introduced in 2009 (Directive 2009/128/EC),[52] the European Union requires its Member States to reduce pesticide application and implement the principles of IPM. By 2013, insecticide use in the European Union had been reduced by 25 percent compared to 2009, a trend that seems to be being maintained.[53]

Several country reports from Latin America mention policies that, directly or indirectly, facilitate the adoption of IPM. For example, Panama aims to stimulate IPM practices through Executive Decree No. 121 of 2015,54 which promotes organic production and the use of biological pest control measures. The National Forestry Commission of Mexico monitors about 50 000 hectares of pest-affected systems every year and recommends the adoption of IPM. Argentina has established IPM partnerships (Consorcios de Manejo Integrado de Plagas) at regional level through the National Agricultural Technology Institute’s Programa Nacional de Protección Vegetal (National Programme on Crop Protection). These partnerships bring stakeholders together to find common ground on IPM approaches.

[51] Available (in English) at http://faolex.fao.org/cgi-bin/faolex.exe?rec_id=028426&database=faolex&search_type=link&table=result&lang=eng&format_name=@ERALL
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[53] FAOSTAT (available at http://faostat.fao.org/beta/en/#data/RP_).
[54] Decreto Ejecutivo N° 121 (De martes 08 de septiembre de 2015) Aprueba el Nuevo Reglamento Para la Producción, Transformación y Comercialización de Productos Agropecuarios Orgánicos de Panamá y Deroga el Decreto Ejecutivo No. 146 de 11 de agosto de 2004, Que Reglamenta la Ley 8 del 24 de enero de 2002 (available in Spanish at https://www.gacetaoficial.gob.pa/pdfTemp/27876_A/GacetaNo_27876a_20150925.pdf).

Trends in the use of integrated pest management

Out of 71 reporting countries, 42 indicate that IPM is practised in at least one production-system category. IPM is reported in 85 percent of reporting OECD members and in 50 percent of reporting non-OECD members. The production systems for which IPM is mostly frequently reported are non-rice crop systems (rainfed and irrigated) and mixed systems (Table 15). A few countries, predominantly in Europe, reported IPM in aquaculture systems.

Table 15. Reported presence, and trends in the adoption, of integrated pest management

Production system	Number of countries reporting the presence of the production system	Number of countries reporting integrated pest management	Trends in the use of integrated pest management (number of countries)			
			Decreasing	Stable	Increasing	Not indicated
Livestock grassland-based systems	63	20	2	3	4	11
Livestock landless systems	58	9	1	1	3	4
Naturally regenerated forests	63	18	0	3	6	9
Planted forests	57	21	0	4	6	11
Fed aquaculture	60	7	1	1	3	2
Non-fed aquaculture	40	5	1	0	1	3
Irrigated crops (rice)	30	8	0	0	6	2
Irrigated crops (other)	56	24	0	1	13	10
Rainfed crops	64	27	1	5	14	7
Mixed systems	59	24	2	2	12	8
Other production systems	26	5	0	0	0	5
All countries (n = 71)	NA	42	NA	NA	NA	NA
OECD (n = 20)	NA	17	NA	NA	NA	NA
Non-OECD (n=51)	NA	25	NA	NA	NA	NA

Source: country reports.

In almost every production system for which trends are reported, increases in the use of IPM are indicated more frequently than decreases. These findings reflect long-term upward trends in the use of the technology. The following paragraphs provide a historical overview.

IPM (then termed Integrated Pest Control) was first introduced in the Cañete Valley, Peru, in 1956 to address the negative effects of excessive pesticide use in the control of cotton pests such as the moth Heliothis virescens and the weevil Anthonomus vestitus. A series of measures were put introduced: importation of Trichogramma parasitoid wasps and Hippodamia ladybird beetles from the United States of America; importation of predatory insects (*Calosoma* spp., *Zelus* sp., *Rasahus hamatus*, *Megacephala carolina chilensis*) and parasitoid wasps (*Microbracon vestiticida*, *Heterolaccus townsendi*) from other regions of Peru; mass rearing of the parasitoid fly *Euphorocera peruviana*; promotion of the native parasitoid wasp *Trichogramma exiguum* through maize intercropping within cotton fields and major reductions in pesticide use (Herrera, 2010). IPM programmes in the Cañete Valley were interrupted in 1972 following agrarian reform measures.

IPM was further fostered after the first international conference on the brown planthopper (*Nilaparvata lugens*), a major pest of rice, held at the International Rice Research Institute in 1979 (FAO, 2012). With technical assistance from FAO, IPM programmes were launched in several Asian countries in the 1980s to control rice pests whose natural enemies had disappeared as a result of pesticide use (Gallagher *et al.*, 1994; Matteson *et al.*, 1994; Bottrell and Schoenly, 2012).

Rising demand for fish has driven the adoption of IPM in rice–fish systems in Asia. Fish are highly sensitive to insecticides and therefore farmers are discouraged from applying them in fish−rice systems (FAO, 2012). Alternatively, pesticide applications can be managed in conjunction with water level management to remove fish from the main field during spraying. In either case, the presence of the fish reduces the requirement for pesticides.

IPM has been widely adopted across Europe. The country report from the Netherlands, for example, indicates that, in 2010, 60 percent of growers of arable crops, fruit crops and vegetables used IPM, which was also applied in between 65 and 70 percent of tree nurseries and flower-bulb farms (the emphasizes the significance of the above-mentioned Directive 2009/128/EC in the promotion of IPM practices). Although not mentioned in its country report, Spain started IPM programmes in the horticulture sector in 2006-2007 (Pardo-Losilla, 2010). In the following years, these programmes expanded to cover most pepper and tomato production and significant proportions of other horticultural products (FAO, 2009) (see Box 5 for further information on IPM in Spain). The Government of the Andalusia region of Spain invested millions of euros in the adoption of IPM after traces of isosenphos methyl (an unauthorized insecticide in the European Union) were found in a shipment of sweet peppers exported to Germany (CVUA, 2007), an incident that led to a significant drop in imports of Spanish horticulture produce (Pérez-Mesa and García, 2010; Pérez-Mesa *et al.*, 2012).

Box 5. Integrated Pest Management in horticultural production in the Almeria region, Spain

The region of Almeria (Southeastern Spain) concentrates approximately 36 000 ha of horticultural production, making it one the largest areas dedicated to this sector in the world. Globally it is also the region where Integrated Management Practice (IPM) is most widely applied as, in 2013, pests were regulated under biological control in 27 000 ha (75 percent of total). Today, 10 000 ha of pepper (nearly 100 percent), 9 500 ha of tomato (more than 80 percent), 3 500 ha of cucumber and substantial areas of zucchini, eggplant, melon and green beans among others are managed under biological control practices. Citrus and grapes are also important sectors in which IPM are applied.

Spanish authorities have been actively promoting IPM programs to reduce the use of phytosanitary products through national and international legal frameworks. Exotic invasive species or pests are strictly monitored (*Law 42/2007 of 13 December of Natural Patrimony & Biodiver*sity; *Royal Decree 630/2013*) while the release of exotic biological control agents (BCAs) requires authorization and an assessment on their environmental and biodiversity impacts (*National Plant Health Law 43/2002 and Royal Decree 951/2014*). The use of non-exotic BCAs is also regulated under the latter law. The use of BCAs must comply with the Good Agricultural Practices, regulated by the European Parliament's *Directive 2009/128/EC* which promotes IPM. Additionally, the European Union enforces eco-toxicological assays before registering new phytosanitary products (*Regulation (EC) No 1107/2009*) and prevention and management measures of invasive alien species (*Regulation (EU) no 1143/2014*).

By January 2015, 64 different insect and mite species were used in 442 registered products for biological control, of which 5 species were of exotic origin (used in 8 products). Some examples are listed in the table below. As a consequence of reducing chemical control, the presence of some secondary pests (e. g. *Nezara viridula* bug in pepper) and the spread of viral diseases carried by pests like *Bemiscia tabaci* (whitefly) and *Frankliniella occidentalis* (western flower thrip) may increase. Yet biological control is considered by the authorities to be more efficient and sustainable than pesticides as resistance development and chemical residues are avoided.

Table 16. Examples of biological control agents used in Almeria, Spain, for horticultural production

Crop	Pest	Biological Control Agent
Chestnut trees	*Dryocosmus kuriphilus* (gall wasp, exotic from China)	*Torymus sinensis* (parasitoid wasp, exotic from China)
Citrus trees	Aonidiella aurantii (red scale)	*Aphytis melinus* (parasitoid wasp)
Cucumber, pepper	Aphids	*Aphidius colemani* (parasitoid wasp)

	Bemisia tabaci (whitefly)	Amblyseius swirskii (predatory mite)
Cucurbits	Tetranychus urticae (red spider mite)	Phytoseiulus persimilis (predatory mite)
Eucalyptus	*Gonipterus scutellatus* (eucalyptus weevil, exotic from Australia)	*Anaphes inexpectatus* (parasitoid wasp, under research)
		Anaphes nitens (parasitoid wasp, exotic from Australia)
		Anaphes tasmaniae (parasitoid wasp, under research)
Pepper	Frankliniella occidentalis (western flower thrip)	*Orius laevigatus* (predatory bug)
Table grape	Frankliniella occidentalis (western flower thrip)	Amblyseius cucumeris (predatory mite)
		Amblyseius swirskii (predatory mite)
	Planococcus citri (citrus mealybug)	Anagyrus pseudococci (parasitoid wasp)
		Cryptolaemus montroucieri (predatory beetle)
	Tetranychus urticae (red spider mite)	Amblyseius andersoni (predatory mite)
		Amblyseius californicus (predatory mite)
		Amblyseius swirskii (predatory mite)
Tomato	*Bemisia tabaci* (whitefly), *Tuta absoluta* (tomato leafminer)	Nesidiocoris tenuis (predatory bug)
Not specified	Nesidiocoris tenuis (predatory bug)	Macrolophus pygmaeus (predatory bug)

Provided by Gonzalo Eiriz.

In Africa, particularly in East Africa, small-scale farmers are increasingly adopting IPM as a consequence of international trade regulations (FAO and CBD, 2016). In Asia, IPM has featured in national policies in India, Indonesia, the Philippines and Viet Nam IPM since the 1980s. IPM farmer field schools were established as part of an FAO regional programme (Swanson and Rajalahti, 2010). This agroecosystem-literacy approach has proved very successful and has spread to over 90 countries and to address other production systems and other management practice (Figure 15) (FAO, 2016b).

Figure 15. Evolution of the farmer field school approach

Note: IPM = Integrated Pest Management; IPPM = Integrated Production and Pest management; FS = Farmers School. Source: FAO, 2016b.

Although awareness of the benefits of IPM among consumers, farmers, governments and international agencies is increasing and the use of IPM tactics is becoming more widespread, insecticide use is still at a high level. Reasons for this include aggressive marketing, insufficient legal regulation and the knowledge-intensive nature of IPM itself (Waage, 2007; FAO, 2012). Pesticides may seem attractive to growers because of their low costs and simplicity of use (FAO, 2012). IPM systems require training and monitoring (by trained farmers or extension workers), which can be costly (Waage, 2007). The frequent release of natural enemies in places with high pest pressures can be prohibitively expensive (FAO, 2009) and strategies are often based on single control measures rather than an ecosystem approach (FAO and CBD, 2016). The United States Department of Agriculture launched the National IPM Initiative in 1993 with the aim of implementing IPM on 75 percent of cropland by 2000 (Ehler, 2006). The practice is implemented on 70 percent of cropland, but full IPM programmes are reportedly implemented on only 10 percent, with the rest being managed under minimal forms of IPM (e.g. only pest monitoring to reduce pesticide application) (Baker *et al.*, 2015; US GAO, 2001; Waage, 2007).

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4.3.3 Pollination management[55]

[EDITOR'S NOTE: Additional information from the country reports will be added to this section. Review of this section has not been completed]

Introduction

With a growing population and growing demand for fruit, nut and vegetable crops, the dependence of agriculture on pollination is increasing (Aizen *et al.*, 2008, 2009), as is the challenge of ensuring that pollen limitation will not constrain production yields (Isaacs *et al.*, 2016). In various parts of the world, active research is being undertaken to improve understanding of the relative benefits of different pollination management strategies under various production scenarios, involving both wild and managed pollinators (Potts *et al.*, 2010). This is expected to lead to new insights that will allow farmers to select from a suite of pollination management tactics that can be economically integrated into their production practices (Isaacs *et al.*, 2016).

Bee management for pollination[56]

In many parts of the world, bees (mainly honey bees, and some species of bumble bees, solitary and stingless bees) are managed to provide pollination services to crops. In view of the limited amount of agricultural land available and the need to maximize production, demand for managed pollinator species for crop pollination, including bees, is expected to remain high (IPBES, 2016).

Honey bee management

The two major honey bee species managed around the world are the western honey bee, Apis mellifera, and the eastern honey bees Apis cerana and Apis indica (IPBES, 2016). These cavity-nesting bees can be managed in human-made containers, otherwise known as hives, that can be moved to follow honey flows or placed into crop fields for pollination (Crane, 1983).

The need to move hives for honey production, and more recently pollination, has made migratory beekeeping a standard practice in many parts of the world (Pettis *et al.*, 2014). Migratory beekeeping is advantageous to the beekeeper in that it enables movement to fulfil paid pollination contracts or to maximize honey production (IPBES, 2016). However, migratory beekeeping does affect local honey bee and native bee populations, as it facilitates the spread of bee diseases and pests and can cause pathogen spillover into native bee populations (Goulson, 2003; Moritz *et al.*, 2005; Fürst *et al.*, 2014; Smith *et al.*, 2014).

In regions with intensive production of fruit, vegetable, oilseed and nut crops, honey bee hives are commonly rented from beekeepers and placed directly in crop fields (Delaplane and Mayer, 2000; Isaacs *et al.*, 2016). In the United States of America, for example, 1.5 million or more colonies are moved across the country to California each year to pollinate almond trees in February and March (Sumner and Boris, 2006). In its country report, Norway notes that honey bee rental[57] is important to the production of rapeseed, cherries, apples, pears, plums, raspberries, strawberries and blackcurrants, particularly in areas where the density of honey bee colonies is low. It should be noted, however, that a significant proportion of global crop production takes place with limited access to honey bee hives for rental (Isaacs *et al.*, 2016).

While honey bee colonies provide large numbers of foraging bees, and movable hives allow for flexible use where and when needed, for many crops, honey bees may not always be the most efficient pollinators (Isaacs *et al.*, 2016). In exploring alternative approaches to meeting crop pollination requirements, researchers have found that the management of other bee species, such as bumble bees or solitary Osmia bees, could complement or in some cases even replace pollination by honey bees (James and Pitts-Singer 2008).

Bumble bee management

[55] This section heavily draws upon chapters 8 and 9 of Isaacs *et al*., 2016.
[56] This section heavily draws on IPBES, 2016.
[57] Honey bee colonies can be rented for about US$ 75 per colony by crop.

In the past few decades, bumble bees (the genus *Bombus)* have increasingly been traded commercially for use as pollinators. Five species of bumble bee are currently used for crop pollination, the major ones being the European species *Bombus terrestris* and the North American *Bombus impatiens* (Velthuis and van Doorn, 2006).

Massive introduction of colonies, within or outside the natural range of these species, has been identified as one of the main threats to native bumble bees and other bee species (Cameron *et al.*, 2011b). Factors involved include : i) competition for resources (including forage and nesting sites); ii) transmission of diseases and pathogens;[58] and iii) reproductive interference due to interspecific mating between introduced and native species (Kanbe *et al.*, 2008). The greatest risk associated with bumble bee management is probably the spread of diseases at local, national and international levels (Goka *et al.*, 2006). Commercially produced bumble bee colonies can pose a significant risk to native pollinators due to the introduction of parasites in populations that may have a low prevalence of pathogens (e.g. Szabo *et al.*, 2012). However, the movement of commercial colonies may also disrupt spatial patterns in local adaptation between hosts and parasites (Meeus *et al.*, 2011).

Stingless bee management

In South and Central America, Australia, Africa and Asia, stingless bees (Meliponini) are traditionally a source of honey, propolis[59] and wax (Cortopassi-Laurino *et al.*, 2006; Nates-Para, 2001, 2004; Heard and Dollin, 2000; Kwapong *et al.*, 2010). Recently, however, their role as possible managed pollinators of agricultural crops is also raising interest (Slaa *et al.*, 2006, Giannini *et al.*, 2015), as they could compensate for the local declines in honey bee populations (Brown and Paxton, 2009, Jaffé *et al.*, 2010, van Engelsdorp and Meixner, 2010) by ensuring enough pollinators are present (Aizen and Harder, 2009) and by pollinating crops more effectively (Garibaldi *et al.*, 2013).

Across developing countries, the potential of stingless beekeeping (also known as meliponiculture) remains underexploited (Jaffé *et al.*, 2015). This form of beekeeping is essentially informal. Technical knowledge is scarce and management practices lack standardization. Commercialized bee products, including honey, colonies and, in a few cases, crop pollination, are generally unregulated, and demand often exceeds supply (*ibid*.). While managing stingless bees for crop pollination purposes is less common, efforts are being made in several countries to promote them as crop pollinators. In Brazil, for example, *Melipona fasciculata* has been identified as a potential eggplant pollinator (Nunes-Silva *et al.*, 2013), and *M. punctata* and *M. scutellaris* have been identified as potential pollinators of guava, greenhouse strawberries (Castro, 2002) and apples (Vianna *et al.*, 2014). In Mexico, studies have shown that the stingless bee *Nannotrigona perilampoides* is a cost-effective pollinator for some locally-grown crops (González-Acereto *et al.*, 2006) and the species was also tested for tomato pollination (Cauich *et al.*, 2004). In Asia (India, Indonesia, Malaysia, Thailand and the Philippines) management of stingless bees for pollination is also beginning to take root (Cortopassi-Laurino *et al.*, 2006).

In Australia, already at the end of the last century, a survey found that stingless bees were being managed as honey bees for pollination purposes (Heard and Dollin, 2000). Stingless bees are used and promoted mostly for macadamia nut, orchards (*ibid*.), mango and watermelon pollination (Dollin, 2014). The most common species kept for pollination purposes in Australia are *Trigona carbonaria* (69 percent) and *T. hockingsi* (20 percent) (Heard and Dollin, 2000).

Growing interest in the production of honey from stingless bees has already generated some new practices, such as the developing trade in stingless-bee colonies (e.g. in Australia) and attempts to introduce species outside their natural ranges (e.g. in Japan – Amano, 2004). These developments pose potential new risks, such as the introduction of pathogens and the loss of genetic diversity. Optimization of stingless bee management should therefore be done with care and within the native ranges of the respective species.

[58] Commercial bumble bees have been noted to have a higher prevalence of several diseases than their wild counterparts (IPBES, 2016).

[59] Propolis is a mixture of beeswax, plant resins collected by bees from plants (particularly from flowers and leaf buds) and bee saliva (Krell, 1996). Bees use it as a sealant within the hive. It is harvested for use in (*inter alia*) the production of cosmetics and alternative medicines (*ibid*.).

Solitary bee management

Solitary bees have been used for crop pollination for almost a century. The longest-managed and described species are the alfalfa leafcutter bee (*Megachile rotunda*) (introduced into North and South America and Australia) (Pitts-Singer and Cane, 2011; Ruz, 2002), the alkali bee (*Nomia melanderi*) (Cane, 2008), the blue orchard bee (*Osmia lignaria*) (both used in North America) (Bosch and Kemp, 2001), the hornfaced bee (*O. cornifrons*) (used in Japan) (Maeta, 1990), the horned bee (*Osmia cornuta*) and the red mason bee (*Osmia bicornis*) (both used in Europe). The handling of these species is relatively simple, involving the use of standardized nesting boxes and simple cocoon collection and cleaning procedures for further breeding (Bosch and Kemp 2002; Sedivy and Dorn, 2013). Solitary bees significantly increase crop yield and often provide better crop quality than that obtained when crops are pollinated mostly by honey bees.

Because of their effectiveness as crop pollinators and their ease of handling, solitary bees are often introduced into new locations as managed pollinators. They are mostly used in open-field pollination, but also do well in greenhouse conditions (Bosch and Kemp, 2000, Wilkaniec and Radajewska, 1997).

Solitary bees that are transported or introduced into new localities can affect native pollinator species and the pollination services they provide (Bartomeus *et al.*, 2013). To date, however, environmental risks associated with managed solitary bees have been less studied than those associated with honey bees and bumble bees. Further studies are required on diseases spread by managed solitary bees, especially on their effects on native bees and on procedures for controlling pathogens and internal parasites.

Management practices promoting the abundance of wild bees in and around production systems[60]

In addition to the managed bees described above, a significant amount of crop pollination is delivered by some of the approximately 20 000 described species of wild bees. Their contribution can range from partial (Isaacs and Kirk, 2010; Rogers *et al.*, 2014) to complete supply of the pollination needs of the crop (Winfree *et al.*, 2008); they may also complement the pollination services provided by honey bees (Greenleaf and Kremen, 2006; Brittain *et al.*, 2013a).

The delivery of pollination services by wild bees is particularly important for producers in areas where there is no access to commercial honey bee suppliers. It can also provide insurance against pollination deficits in areas where honey bee populations are declining.

Ecological theory predicts that greater pollinator diversity should result in higher levels of crop pollination service delivered by wild bees, which could protect crop production from yield fluctuations caused by annual variation in the effectiveness of managed bees. A global analysis of the link between pollinator visitation to flowers and yield response found a stronger relationship for wild bees than for honey bees (Garibaldi *et al.*, 2013), indicating that yield increases could be achieved if wild bee populations were enhanced in crop-producing regions.

Supporting wild bees in production systems

The diversity and abundance of wild bees found on farms depend strongly on the quality of habitat and management on the farm itself, but are also influenced by the landscape context in which the farm is located (Kennedy *et al.*, 2013). Options for conserving bees and the pollination services they provide within agricultural mosaic landscapes therefore range from small-scale ‘‘farmscaping’’ that enhances habitat quality locally (e.g. some organic farms) to landscape-scale restoration and conservation of semi-natural habitats that provide off-site resources within the foraging ranges of bee species (Williams and Kremen, 2007). A growing number of studies have shown that interactions between local- and landscape-scale factors determine the on-farm abundance and richness of bee populations (e.g. Rundlöf *et al.*, 2008) and also influence the outcome of on-farm efforts to support pollinators, pollination and other ecosystem services (Batáry *et al.*, 2011; Heard *et al.*, 2007).

Landscape influence on wild bees on farms

[60] This section heavily draws upon Isaacs *et al*. (2016).

Various landscape components have the potential to affect the on-farm diversity and abundance of bees and other crop pollinators. It is, for example, likely that for many bee species found on farms the proportion of high-quality habitat in the landscape determines the size of the local source population and that species that cannot persist solely on farms are lost if the amount of habitat drops below a certain threshold (Tscharntke *et al.*, 2005). The configuration of habitat patches (e.g. their degree of fragmentation) may also affect bee populations by influencing their foraging movements and dispersal patterns, although a recent global analysis of local and landscape factors indicates that the amount of semi-natural habitat is more consistently important than the exact configuration (Kennedy *et al.*, 2013). The types of habitat (e.g. grassland or forest) comprising the landscape in general may also influence the diversity of pollinators on farms and the impact of mitigation efforts.

The effect of the surrounding habitat on pollinators has important implications for efforts to sustain and enhance pollinator populations within agricultural landscapes. Overall, efforts to promote pollinators through actions on the farm, whether via restoration or via the use of less intensive management practices (see Kleijn *et al.*, 2003), may be most effective in landscapes that still have at least moderate amounts of natural habitat. The supply of pollinators to colonize or recolonize farms depends on the presence of sufficient persistent forage and nesting habitat in the landscape (Tscharntke *et al.* 2012).

Landscapes with no remaining natural habitat (or less than 1 percent) may not be able to support certain pollinators and therefore on-farm habitat enhancement in the local area may have little added effect (Kremen *et al.*, 2002; Isaacs *et al.*, 2016). In such landscapes there may be a need for habitat restoration or enhancement efforts and subsequent reintroduction of pollinator species. However, landscape-level efforts to support pollinators tend to be challenging. Many aspects of a landscape are static, at least in the short term. Moreover, actions required are often beyond the capacity of individual producers and therefore require coordination and commitment across property boundaries and are likely to require the involvement of regulatory agencies.

Forage and nesting resources for wild bees on farms

Although most farmers cannot control the wider landscape surrounding their fields, they do have control of how those fields and their borders are managed. Many are making efforts to enhance their farms to support pollinators, sometimes with technical help from non-profit organizations or financial support from government programmes. Such efforts can also benefit the delivery of other ecosystem services (e.g. habitat enhancement to conserve native bee species on farms also tend to favour the natural enemies of pests).

Efforts to enhance wild bee pollinators on farms need to recognize that bees may be limited by the availability of foraging resources, nesting resources or both. With different species having different preferences with regard to nesting sites and the species of plants whose flowers they will visit, the presence of a diverse range of foraging and nesting resources can be expected to contribute to the maintenance of a diverse range of bee species.

Forage for bees: To date, most efforts to provide or restore habitat for wild bees on farms have focused on planting or altering the management of field borders to promote flowering species and hence augment forage resources (Pywell *et al.*, 2005). Efforts in Europe are well advanced (e.g. Carvell *et al.*, 2006, 2007) and development and testing are ongoing in other regions (e.g. Morandin and Kremen, 2013; Blaauw and Isaacs, 2014; Williams *et al.*, 2015). Successful planting requires an appropriate choice of species and good knowledge of how to establish and maintain them. Choice of plant species with particular bloom phenology or floral morphology can be tailored to fit specific goals such as supporting species with the greatest pollination potential, supporting species of greatest conservation concern or promoting the maximum species diversity. Some planting strategies are designed to achieve multiple goals. For example, plant species that promote the most effective crop pollinators can be combined with those that support rare pollinators. Mixes of species that bloom throughout the growing season will support a greater diversity of pollinators and benefit crops that bloom at different times of year. Plantings with long flowering periods provide stability of resources for social bees that are active through the season. For example, bumble bee queens and early workers pollinate spring crops, later season workers pollinate summer crops and the next generation of queens require late summer flowers before entering winter diapause. Plantings with long flowering periods may also support pollinator species whose flight periods extend beyond the cropping season. They may also provide nesting sites and may divert bees away from pesticide exposure in crop fields.

Nesting resources to support wild bees: Research indicates that abundance and composition of bee communities on farms may be as sensitive to the availability of nesting resources as to that of forage (Forrest *et al.*, 2015). However, knowledge of how best to enhance nesting resources remains limited. Where there is abundant perennial forage, nest site augmentation can produce dramatic responses in certain species (Steffan-Dewenter and Shiele, 2008). Surveys of ground-nesting bees indicate that habitat enhancements on farms can support higher bee-nest density and emergence through the season (Sardiñas and Kremen, 2014). However, studying bee nest distribution is challenging and to date there has been little research on nest augmentation on farms or the response of bee nesting to habitat enhancements. This has, however, recently become an active area of research.

Competition and synergies between pollinators

Competition among insects for forage resources and nesting sites is a potential concern when applying diversification practices involving pollinators. Such competition can reduce pollination efficiency and lower crop yields. There is, however, also evidence from multiple crop systems that honey bees and wild bees can be complementary or even synergistic. In the case of sunflowers, for example, deGrandi-Hoffmann and Watkins (2000) found that honey bee foraging activity was enhanced in the presence of non-Apis bees, a theory that was supported by Greenleaf and Kremen (2006). Similarly, combinations of honey bees and the solitary blue orchard bee (*Osmia lignaria*) were found to lead to greater nut set in almond orchards (Brittain *et al.* 2013a). Additional complementary pollination mechanisms were revealed in a related study, which showed that wild pollinator communities, including bumble bees and syrphids, complement honey bees by visiting flowers in more sectors of the tree canopy when windy weather conditions cause honey bees to forage only on the inside of the canopy (Brittain *et al.*, 2013b).

Status and trends in the application of pollination management across production systems

Table 17. Presence, and trends in the adoption, of pollination management per production system as reported by countries.

Production system	Number of countries reporting the production system	Number of countries reporting the practice	Trends of management practice			
			Decreasing	Stable	Increasing	Not indicated
Livestock grassland-based systems	63	19	1	2	3	13
Livestock landless systems	58	8	1	0	3	4
Naturally regenerated forests	63	18	0	2	5	11
Planted forests	57	18	2	1	3	12
Irrigated crops (rice only)	30	3	0	1	0	2
Irrigated crops (non-rice)	56	23	1	4	5	13
Rainfed crops	64	23	0	5	8	10
Mixed systems	59	20	1	3	7	9
Other production systems	26	6	0	0	0	6
Not specified prod system:	71	7	0	0	0	7
All countries (n=71)	NA	43	NA	NA	NA	NA
OECD (n=20)	NA	17	NA	NA	NA	NA
Non OECD (n=51)	NA	27	NA	NA	NA	NA

Source: country reports.

The country reports indicate that pollination management practices are most commonly applied in crop production systems, including rainfed and irrigated systems. Somewhat lower figures are reported for livestock grassland-based and mixed farming systems, as well as for naturally regenerated and planted forests. Most countries were not able to indicate the extent to which pollination enhancing practices are being applied in their various production systems or to report on trends in their use. A higher proportion of OECD countries than non-OECD countries reported pollination management practices.

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4.3.4 Diversification practices in aquaculture

Given its dynamic performance, and with fairly stable catches from capture fisheries, it is likely that aquaculture will be the main source of future growth in the fisheries sector (FAO, 2016). According to FAO's *The State of World Fisheries and Aquaculture* (2016), there has been a general upward trend in the share of aquaculture production in total fish production in all continents, with the exception of Oceania.[61] World aquaculture production of fish accounted for 44.1 percent of total production (including for non-food uses) from capture fisheries and aquaculture in 2014, up from 42.1 percent in 2012 and 31.1 percent in 2004 (*ibid*.).

Aquaculture is very diverse in terms of the range of species, environments and production systems utilized (the 567 aquaculture species reported to FAO include seaweeds, molluscs, crustaceans, fish and other groups).[62] It also includes a range of diversification practices that may involve integration of different aquatic species and/or integration with other sectors of food and agriculture such as crop or livestock production and forestry.

The country reporting guidelines invited countries to provide information on diversity-based practices in aquaculture, including specifically on polyculture and aquaponics (an integrated multi-trophic system). Countries were also invited to report on mixed systems, such as integrated aquaculture (mixed systems in which aquaculture is integrated with crop and livestock production) and any other systems in which aquaculture is integrated with other sectors of food and agriculture.

This section first provides an overview of diversification practices in aquaculture. It is possible to categorize these practices in various ways; however, for the purposes of presentation, they are here grouped according to whether they involve "mixed systems", i.e. cross-sectoral integration (including the specialized case of aquaponics) or based on the use of multiple aquatic species only. The final part of the section discusses trends in the use of diversification practices in aquaculture and presents findings from the country reports on the levels of (and trends in) the use of polyculture and aquaponics practices in different production systems.

Aquaculture within mixed production systems

Integrated aquaculture

Many modern aquaculture technologies are promoted in relative isolation from their agricultural surroundings. In contrast, traditional aquaculture is not a distinct operation but rather a component of local farming systems; as such, it is managed in accordance with farmers' overall strategies for the use of their labour capacity, land and other resources (Dabbadie and Mikolasek, 2015). Such systems are often referred to as "integrated aquaculture" (Edwards et al., 2002; FAO, 2003; Nhan et al., 2007; van der Zijpp et al. 2009). They have long been widely practised by rural households in freshwater environments, mainly in Asia.

A 2001 review on integrated agriculture-aquaculture (FAO/ICLARM/IIRR, 2001) identified a wider range of systems:

- grass–fish and embankment–fish systems – fish ponds integrated with vegetable crops and grass. The grass, plant wastes and vegetable cuttings are fed to grass carp or various other herbivorous fish species;
- seasonal ponds and ditches – components of other farming systems that become inundated for a period of the year allowing fish stocking and culture;
- livestock–fish integration systems featuring chickens, ducks or pigs-based systems – typically involving the placing of a livestock pen or cage over or next to a fish pond such that waste feed and manures drop into the pond, directly feeding the fish or fertilizing the water to increase primary productivity;

[61] In Oceania the share of aquaculture production in total fish production has declined in the last three years.
[62] FAO estimates that about 567 aquatic species are currently farmed all over the world, representing a wealth of genetic diversity both within and among species (FAO, 2016). This number is increasing very fast, as there were only 340 aquatic species reportedly farmed in 2008 and 210 in 2001.

- rice–fish systems – integration of fish and other aquatic species into rice paddies. This typically requires specific water-management activities to provide adequate water for the aquatic species, which may be wild, naturally recruited species or deliberately introduced (stocked) fish or shrimp species; and
- a few examples involving shrimp (in coastal areas) and prawn (in freshwater areas) –integration may involve rotational cropping, i.e. alternating with rice production. In more brackish water, shrimp may be integrated with fish, seaweeds or molluscs. The more traditional systems are tidal trap ponds that capture wild aquatic species that may or may not be fed.

Integrated systems have been advocated as a means of increasing land- and water-use efficiency and nutrient recycling (Nhan *et al*., 2006). Well known types include the Vietnamese VAC (Vuon, Ao & Chuong, meaning garden/pond/livestock pen in Vietnamese), which combines a pond containing several species of fish with a garden producing vegetables or fruit and livestock supplying organic fertilizers (Luu, 2003). Widespread promotion of this system started in the 1980s, and distinct upland and a lowland models have emerged: the upland model is generally larger (garden: 1 000–15 000 m^2) than the lowland model (garden: 200–300 m^2). Studies have, however, shown that integrated systems are complex to manage, as maximizing benefits to farmers while minimizing negative environmental impacts not only requires good management of the pond subsystem itself but also effective integration of the subsystem with other farming activities (Dabbadie and Milolasek, 2015).

Integrated irrigation-aquaculture (IIA) or integrated rice–fish farming (IRF) are other methods of integrating aquaculture with crops. Rice–fish farming is probably one of the oldest integrated fish–crop systems and developed through a kind of co-evolution between agriculture and aquaculture. Once found mostly in Asia, it has more recently spread to other regions of the world (Halwart and Gupta, 2004). In some countries such as Madagascar, it is the dominant fish production system and plays a major role in diversifying the diet and improving nutrition, particularly in remote rural areas. It has sometimes been introduced in response to external drivers. For example, in Senegal, after two decades of drought had led to the expansion of mangrove areas and a resulting salinization of surface and ground water, lowland rice farmers built fishponds along the foreshore to protect their fields against the inflow of salt water and began to produce fish (Diallo, 1998; cited by Halwart and Gupta, 2004).

Around the world, integrated aquaculture remains the main gateway into sustainable fish production (or sustainable intensification of fish production) for small or medium-scale farmers who lack access to inputs such as good-quality feeds. It is seen as an efficient way of recycling nutrients and organic matter (Edwards, 1980; Moriarty and Pullin, 1987; Billard, 1986; Ahmed and Saint, 2014) and can provide economic benefits at a level similar to (and frequently much higher than) those obtainable from alternative agricultural or other rural activities (Nhan *et al.*, 2007; Simon and Benhamou, 2009; Berg, 2002). Despite these benefits, the development of integrated aquaculture faces a number of challenges. The most significant are probably commercial, cultural and legal, as many consumers around the world regard the use of manures and similar organic matter as problematic. The use of wastes in animal production is forbidden by law in some countries and even modern technologies such as aquaponics (see below) sometimes have a dubious legal status in this regard. Regulatory issues of this kind, along with the complexity involved in the management of integrated systems and the increasing availability and affordability of fish-farming feeds in Asia in recent decades, may be responsible for the sharp decline observed in this practice in the region and elsewhere (Edwards, 2015).

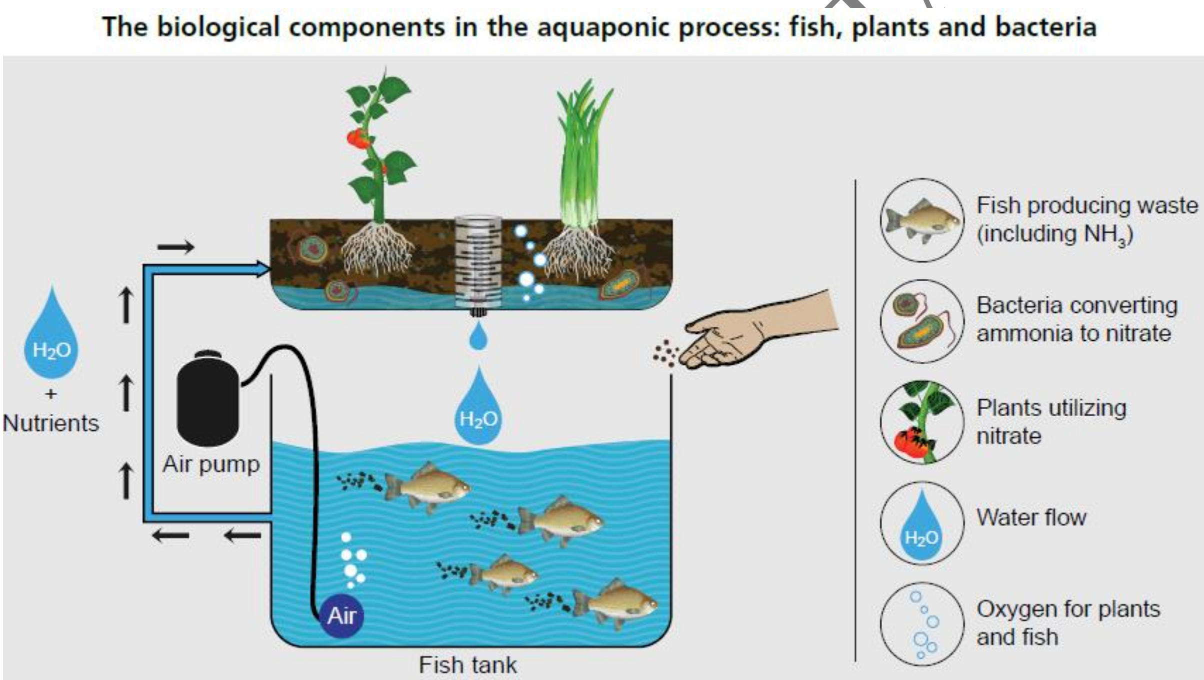
Another challenge is that because of internal limitations such as decreasing oxygenation when using organic matter and the possible accumulation of toxic compounds (ammonia, nitrite etc.), integrated systems have upper yield limits. While integrated aquaculture is an economically viable activity in many regions of the world, it is not expected to be able to meet predicted future levels of demand for fish. However, the current global imbalance in the production and use of organic waste and manures may be a challenge that creates opportunities for integrated aquaculture to reinvent itself through the development of technologies such as insect or plankton production.

Aquaponics

Aquaponics can be described as a symbiotic integration of two productive systems within a closed recirculating system: (i) aquaculture, the practice of fish farming; and (ii) hydroponics, the cultivation of plants in water without soil (Somerville *et al.*, 2014) (Figure 16). Nutrient-rich effluent from the aquatic component of the system is filtered through an inert substrate containing plants. Bacteria metabolize the waste, and the plants assimilate the resulting nutrients. The purified water then returns to the fish tanks (*ibid*). The system can supply high-value products, such as fish and vegetables, while lowering nutrient pollution of water bodies. Given that it combines crop and aquatic production, aquaponics can be regarded as a specialized kind of mixed production system. From the aquatic perspective, it can also be regarded as a specialized kind of integrated multitrophic aquaculture (IMTA) (see below).

Aquaponics is mostly practised in freshwater, but can also be applied in marine recirculated aquaculture systems. Martan (2008) notes that fish polyculture (i.e. use of multiple fish species) can be used to enhance aquaponics. Although it is traditionally based on a three compartment system (fish/biofilter/plants), some more complex designs have been tested (e.g. fish/filter-feeding molluscs/bottom-feeding organisms/biofilter/plant/plant-eating organisms), the main difficulty being to keep all the compartments in the system in balance.

Figure 16. An example of an aquaponic system



Source: Somerville et al., 2014.

Table 18. Major benefits and challenges of aquaponic food production

Benefits	Challenges
Sustainable and intensive food production Two products (fish and vegetables) produced from one nitrogen source (fish food) Extremely water efficient Does not require soil Does not use fertilizers or chemical pesticides High yields and high-quality products Organic-like management and production Higher levels of biosecurity and lower risks from external contaminants Higher control of production leading to lower losses Can be used on non-arable land such as deserts, degraded soil or salty, sandy islands.	High initial start-up costs compared with soil vegetable production or hydroponics. Knowledge of fish, bacteria and plant production needed Fish and plant requirements do not always match perfectly Not recommended in places where cultured fish and plants cannot meet their optimal temperature ranges Reduced management choices compared with stand-alone aquaculture or hydroponic systems Mistakes or accidents can cause collapse of the system Daily management mandatory Energy demanding

Creates little waste Daily tasks, harvesting and planting are labour-saving Economical production of either family food production or cash crops in many locations Construction materials and information base are widely available	Requires reliable access to electricity, fish seed and plant seeds Aquaponics alone will not provide a complete diet

Source: adapted from Somerville et al., 2014.

Recirculating aquaculture systems and hydroponics have both become widespread because of (among other benefits) the higher yields and quality products they supply, their efficient use of land and water and their easy management (including in terms of pollution control). However, combining these two systems (i.e. aquaponics) can be complicated and expensive, and requires consistent access to external inputs (Somerville *et al*., 2014). The main benefits and challenges of aquaponics are summarized in Table 18.

Aquaponics has the potential to provide higher yields with less labour, less land, less fertilizer and pesticide and a fraction of the water usage. It provides a high level of biosecurity and hence a low risk of disease and external contamination. It is a potentially useful tool in efforts to overcome some of the challenges confronting traditional agriculture in the face of freshwater shortages, climate change and soil degradation. Aquaponics works well in places where the soil is poor and water is scarce, for example in urban areas (aquaponics systems can be used in urban settings such as backyards, rooftops or balconies), arid zones and low-lying islands. However, commercial aquaponics is not appropriate in all locations, and many start-ups have failed. Before investing in large-scale systems, operators need to consider all aspects of the enterprise carefully, especially the availability and affordability of inputs (fish feed and building and plumbing supplies), the cost and reliability of electricity supplies and whether they have access to a significant market willing to pay premium prices for locally produced and pesticide-free vegetables (*ibid*.).[63]

Polyculture in the context of aquaculture

Polyculture in the context of aquaculture is the culture of more than one aquatic species in the same pond or farming system. The motivating principle behind this practice is that by raising a combination of fish species with complementary feeding habits and niches in the same culture system, the naturally available food and water resources are better utilized and animal production per unit area is maximized (Figure 17). Although the feeding niches of some polyculture species are reasonably well known, predicting synergisms or antagonisms between species remains difficult. The balance between complementarity and competition among the cultured species is therefore the key feature of polyculture (Azim and Little, 2006).

The concept of polyculture was originally applied to the practice of raising multiple fish species in pond culture systems. However, it has now expanded to include the raising of multiple aquatic species of different taxa in a range of different contexts. A culture unit may involve several components, for example a fish cage, seaweed and shellfish lines. Goals have shifted from a simple focus on maximizing production efficiency to encompass other objectives such as the capture of nutrients and improvement of water quality in order to meet environmental targets or to enable multiple re-use of the water. Systems that specifically target production at different trophic levels (such as the fish–seaweed–shellfish example mentioned above) are becoming more widespread.

The first subsection below discusses polyculture in its traditional sense in the context of fishponds. The next subsection addresses marine systems and expands on the concept of integrated multitrophic aquaculture.

Figure 17. A polyculture system

[EDITOR'S NOTE: Figure will be added.]

[63] To support aquaponic development, FAO has produced a technical manual (Somerville *et al*., 2014) on small-scale aquaponic food production.

Fish pond polyculture[64]

a) Types of fish pond polyculture

Fish pond polyculture involves a range of different practices. For example, Rahman *et al.* (1992) distinguished three main types (extensive, semi-intensive and intensive systems) based on their levels of management (i.e. fish stocking density and combination, nutritional inputs, etc.).

- Extensive polyculture involves no addition of nutritional inputs (i.e. manure or feed) to the system. The polycultured animals depend solely on the food that is naturally available in the environment. Extensive practices provide lower fish production yields than intensive systems, but they also require much less effort and are less costly.
- Semi-intensive practices involve the addition of manure (e.g. in the case of freshwater polyculture of carp species) to promote growth of phytoplankton, but do not involve adding feed supplements, or only in very limited amounts. Semi-intensive systems therefore require additional expenditure, but also provide higher outputs than extensive systems.
- Intensive systems provide the highest levels of production, but are also the most expensive to operate. They involve the use of high-quality pellet feed that covers all the nutritional requirements of the cultivated animals. They also involve water aeration and recirculation techniques to ensure that water quality remains high. Because of these feeding and management methods, intensive systems are able to maintain higher fish stocking densities than the other types of system.

Another way of classifying different types of polyculture is on the basis of spatial organization. In this respect, the three main types are direct, cage-cum-pond and sequential (Figure 18).

- Direct polyculture involves housing two or more species in the same pond or aquaculture unit, without partitioning. This means that there may be direct contact between the species, so extra aeration is often required (depending on stocking densities) to ensure there is sufficient oxygen in the system.
- Cage-cum-pond polyculture also involves housing more than one species in the same pond. However, at least one species is kept within a cage or net-like enclosure to separate it from the other(s).
- Sequential polyculture is an integrated aquaculture system in water flows through a series of units each of which houses a separate species. This system requires extra space and greater energetic inputs, and therefore has higher costs. However, it can be very useful *in situ*ations where there are antagonistic relationships or competition between the cultured species.

Figure 18. Types of fish pond polyculture

[EDITOR'S NOTE: Figure will be added.]

b) Fish pond polyculture around the world

Polyculture originated in Asia, but it is now practised in a range of different forms on all continents (Dabbadie and Lazard, 2003). In China, herbivorous carp species, such as the phytoplanktivorous silver and variegated carp (*Hypophthalmichthys molitrix*) and the macrophytophagous grass carp (*Ctenopharyngodon idella*), are the most commonly stocked species. Because of their growth performance and their short food chain feeding regime, these herbivorous Chinese carps are also frequently included in polyculture systems in other Asian countries, as well as in Africa, Europe and North and South America (Dabbadie and Lazard, 2003; Mikhailovich, year unknown). In its country report, Bangladesh mentions that carp polyculture is a popular and traditional practice and that the country's fish farmers produce about 3 to 4 tonnes of fish per hectare per year using this practice.

In central and eastern Europe, the Caucasus and Central Asia, carp[65] is also the dominant species in polyculture (Woynarovich *et al.*, 2010; Dabbadie and Lazard, 2003). The total area of fish ponds and

[64] The source information for this subsection is Tracey, 2013 unless stated otherwise.

water reservoirs smaller than 100 hectares available for carp polyculture across these subregions is almost 500 000 hectares[66] (Woynarovich *et al.*, 2010). In Eastern Europe, other fish species used in polyculture include tench (~6.5 percent), pike (~1.3 percent) and salmonids (~4.4 percent) (Dabbadie and Lazard, 2003). In its country report, Poland states that its aquaculture sector focuses mainly on freshwater fish, in particular carp and trout. Carp are often bred in semi-intensive polyculture systems with non-processed grain feeding. In these systems, the most important species raised with the dominant carp species (*Cyprinus carpio*) is the Chinese carp, followed by crucian, tench and sturgeons. Sturgeons are the most important group of species raised with trout. Hungary mentions using seven major fish species in polyculture, with carp being the dominant species.

In some African countries, the Nile tilapia (*Oreochromis niloticus*) is combined with catfish (*Heterobranchus isopterus*, *Clarias* sp.) or bonytongue fish (*Heterotis niloticus*). The secondary species (i.e. the catfish or bonytongue fish) can increase in the pond's total fish yield by more than 40 percent.

In South America, experiments have been conducted on the use of tambaqui (*Colossoma macropomum*), a freshwater species of serrasalmid, as the main species and Prochilodus sp., common carp (*Cyprinus carpio*) and tilapia as secondary species (*ibid*.).

Box 6. The potential of growing nutrient-rich small fish species with high-value carp species in polyculture – an example from Bangladesh

Studies in rural Bangladesh have shown that small fish make up 50 to 80 percent of the total fish intake of the local population in the peak fish-production season. Although they are consumed in small quantities, the frequency of small-fish intake is high. As many species are eaten whole – complete with head, viscera and bones – they are particularly rich in bioavailable calcium, and some are also rich in vitamin A, iron and zinc. In areas where relevant fish resources are available and fish is consumed on a regular basis, there is good scope for agricultural policies and programmes to promote the production of micronutrient-rich small fish and thereby increase fish intakes and improve nutrition and health.

The results of many studies and field trials conducted in Bangladesh with carps and small fish species in pond polyculture have shown that the presence of the small, native, vitamin A-rich mola fish (*Amblypharyngodon mola*) greatly improves the nutritional quality of the total fish production, without affecting the growth of the carps.

Mola breed in the pond, and the frequent harvesting of small quantities favours home consumption. Production of only 10 kg of mola/pond/year in the estimated 4 million small, seasonal ponds in Bangladesh could meet the annual recommended fish intake of 6 million children.

Successful trials with the polyculture of small and large fish species have also been conducted in rice fields and wetlands. The approach thus has the potential to be widely implemented. However, to fully realize its potential to improve nutrition, further data are needed on nutrient bioavailability, intrahousehold seasonal consumption, and cleaning, processing and cooking methods for small fish species.

Sources: FAO, 2016 and Thilsted, 2012.

c) The main benefits and challenges of fish pond polyculture

Fish pond polyculture practices provide numerous benefits. The presence of multiple species with different feeding habits promotes effective use of naturally available food resources. For example, partially digested excreta from the macrovegetation-feeding grass carp can be eaten by the bottom-

[65] There are about 30 to 35 strains of domesticated common carps in Europe. Many strains are maintained in China (FAO, 2004).

[66] The total is about 350 000 hectares in Central and Eastern European countries (Albania, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Montenegro, Poland, Romania, Republic of Moldova, Russian Federation, Serbia, Slovakia, Slovenia and Ukraine), about 100 000 hectares in the Russian Federation and approximately 50 000 hectares in the countries of the Caucasus (Armenia, Azerbaijan and Georgia) and Central Asia (Kazakhstan, Tajikistan, Kyrgyzstan, Uzbekistan and Turkmenistan).

dwelling coprofagous common carp (Rahman *et al.*, 1992). Multiple predator species can reduce the prevalence of trophic deadlocks (a trophic deadlock is a component of the food web that is not consumed by any other) (Dabbadie and Lazard, 2003). Polyculture also enhances the availability of natural foods. For example, when feeding, the common carp opens its relatively large mouth in an accordion-like fashion to dig in the mud. By doing so, it stirs the bottom of the pond and aerates the sediment. The aerated zone oxidizes organic matter and improves nutrient recycling (*ibid*). Similarly, the bottom-dwelling mrigal (*Cirrhinus mrigala*) contributes to resuspending nutrients in the water and aerating the bottom sediment while searching for food (Rahman *et al.*, 1992.). The excreta of herbivorous fish species act as natural fertilizers and help increase the yields of other species.

Polyculture can also contribute to improving water quality and the control of undesirable organisms. For example, stocking phytoplanktophagous silver carp helps to keep harmful algal blooms (a very common phenomenon in most tropical manure fed ponds) under control. The striped snakehead (*Channa striata*), the African catfish (*Clarias gariepinus*) and the cichlid Hemichromis fasciatus are used as predators of tilapia fry to control pond overpopulation in semi-intensive polyculture systems (Kaewpaitoon, 1992; El Nagar, 2007; Bogne Sadeu *et al.*, 2013; Dabbadie, 1996).

Challenges involved in the use of fish pond polyculture include the need to strike the right balance between complementarity and competition among the fish species used (Dabbadie and Lazard, 2003). Stocking density has to be carefully controlled. If it is too high, fish yields decrease, as there is less naturally available food per individual animal. Another complicating factor is the need to sort the different fish species at harvest time, which involves extra work and negatively affects the system's benefit–cost ratio (*ibid*).

Marine systems

Several types of marine aquaculture involve the integrated use of multiple species (Troell, 2009). Systems include those in which several species are raised in a pond/tank/cage, those involving sequential integration (in which a flow of wastes is directed sequentially between culture units containing different species), and those involving temporal integration (in which species are housed sequentially within the same holding site, with the later species in sequence benefiting from wastes generated by the preceding species). Sequential practices include systems that involve the use of mangroves as biofilters. These latter systems can be viewed as a kind of integrated aquaculture in the sense discussed above (i.e. to involve "cross-sectoral" integration of aquaculture and forestry).

Integrated multitrophic aquaculture

As noted above, the concept of polyculture in the sense of raising several species of fish together in the same unit is being subsumed within broader concepts of integration within aquatic systems. Although integrated approaches (whether cross-sectoral or within aquaculture) generally appear to be less widely applied in marine than in freshwater environments, the need to mitigate the problem of excess nutrient/organic matter generation in intensive aquaculture has helped to drive interest in the concept of integrated multitrophic aquaculture (IMTA). As the name implies, the distinguishing feature of this approach is the explicit incorporation of species from different trophic positions or nutritional levels in the same system (Chopin and Robinson, 2004). Barrington *et al.* (2009) describe IMTA as an approach that combines the cultivation of fed aquaculture species (e.g. finfish/shrimp) with that of organic extractive aquaculture species (e.g. shellfish/herbivorous fish) and inorganic extractive aquaculture species (e.g. seaweed) to create balanced systems that promotes environmental sustainability (via biomitigation), economic stability (via product diversification and risk reduction) and social acceptability (via better management practices).

The IMTA approach is based on the premise that combining aquatic production at different trophic levels can allow aquaculture to have a minimal impact on the environment, while improving the profitability of raising multiple species. Although it has been demonstrated that in many cases IMTA provides economic benefits, it may not always provide a significant benefit to fish farmers in terms of directly increasing their profits (Troell, 2009). This may not matter if it provides the farmers with other benefits such as improving their ability to meet environmental standards. This latter benefit may prove decisive from the commercial point of view, as it may increase market access. In this respect, however, IMTA system operators may face challenges in differentiating their systems from other emerging alternatives such as inland and/or closed marine monoculture systems.

Other possible challenges to the expansion of IMTA systems relate to governance, whether in terms of the social acceptance of the technology in some parts of the world or in terms of shifting the management of integration from the level of the operator to that of the production area.

Finally, the ecological functioning of IMTA needs to be better understood. Much progress has been made in recent years in terms of improving understanding of nutrient recycling, mitigation of benthic impact and various other benefits provide by IMTA (e.g. sea-lice or disease control). However, there is a need for further research to support the development of efficient site-specific guidelines for sustainable IMTA.

Status and trends in the application of diversification practices across aquatic production systems

There appears to be no systematic global monitoring of the status and trends in the application of diversification practices in aquaculture However, it is clear that the relative contributions of the various types of systems described in this section are changing, in response to economic transformations, technical developments, constraints on space, system intensification, climate change, disease and other drivers:

- Extensive integrated aquaculture is declining, mainly due to pressures on land and water resources. There is a tendency towards monoculture systems with higher intensity production.
- Some polyculture systems may be losing ground, as the high value of certain species and the specialization of operations tend to favour the raising of single rather than multiple species.
- Water quality, environment and health issues are driving efforts to explore innovative approaches to integration that help to limit water exchange and reduce effluent impacts in some freshwater and brackishwater systems.
- Health and disease issues are forcing some intensive systems to mix species.
- Increasing interest in the use of marine space and the environmental constraints to this are providing incentives for integrated mariculture.
- Urbanization and interest in smallholder vegetable and fish culture are helping to drive the emergence of aquaponics.

Countries' responses on the presence and adoption of polyculture and aquaponics in different production systems are summarized in Table 19.

Table 19. Reported presence, and trends in the adoption, of polyculture and aquaponics by production system

Production system	Number of countries reporting the production system	Number of countries reporting the practice	Trends in the use of polyculture and aquaponics			
			Decreasing	Stable	Increasing	Not indicated
Culture-based fisheries	37	8	1	0	2	5
Fed aquaculture	60	19	1	3	5	10
Non-fed aquaculture	40	9	0	2	1	6
Mixed systems	59	13	1	1	4	7
Production system not specified	NA	3	0	0	0	3
All countries (n = 71)	NA	32	NA	NA	NA	NA
OECD (n = 20)	NA	11	NA	NA	NA	NA
Non-OECD (n= 51	NA	21	NA	NA	NA	NA

Note: NA = not applicable.
Source: country reports.

Nearly two-thirds of the 32 countries that reported the adoption of polyculture and/or aquaponics indicated that these practices are used in fed aquaculture systems, while approximately one-third report use of these practices in non-fed aquaculture. Forty percent of the reporting countries indicate the use of these practices in mixed production systems. Given the limited number of countries that reported on whether the use of polyculture and aquaponics is increasing or decreasing, it is difficult to draw generalized conclusions about trends.

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[4.3.5 Other management practices]

[EDITOR'S NOTE: Sections on other management practices on which countries were invited to report (see the country reporting guidelines) will be added.]

4.4 The use of food-processing micro-organisms[67]

[EDITOR'S NOTE: Information from the country reports will be added to this section.]

Overview of the roles of micro-organisms in food processing

Microbial fermentation has long played an important role in food processing. It contributes not only to food preservation and safety, but also to the nutritional value and sensory qualities of foods and to the diversity of people's diets. There may be more than 5 000 different types of fermented foods and drinks being consumed in the world (Campbell-Platt, 1987; Tamang, 2010). Classic examples include cheese, quorn, beer, wine, vinegar, soy sauce, yogurt and breads. The main groups of micro-organisms involved are bacteria, yeasts and filamentous fungi, also known as moulds (Tamang *et al.*, 2016).

In some countries, fermented foods are major components of local diets, often fortifying and adding variety to otherwise starchy, bland diets. For example, *gundruk*, a fermented and dried vegetable product is very important to food security in many Nepali communities, especially in remote areas and particularly during the off-season when the diet consists primarily of starchy tubers and maize, which tend to be low in minerals. In Africa, fermented cassava products, such as *gari* and *fufu*, are major foods for large parts of the population.

The emergence of alternatives such as refrigeration has reduced the significance of fermentation as a preservation technique in parts of the world. Where this is the case, the main role of fermentation often lies in the production of a wide variety of products with specific flavours, aromas and textures. It remains a relatively efficient, low energy and cheap means of preservation and its lack of reliance on the use of chemical additives appeals to some consumers (Battcock and Azam-Ali, 1998; Guizani and Mothershaw, 2007).

In addition to their roles in fermentation, micro-organisms are used to produce many compounds used in food processing, including enzymes, flavourings, fragrances and bacteriocins (substances produced by bacteria that kill or inhibit the growth of other bacteria).

Microbial food cultures whose metabolic activity helps to inhibit or control the growth of undesirable micro-organisms (e.g. pathogenic or toxogenic bacteria) are referred to as "protective cultures". These cultures play a role in fermentation, but can also be used to improve the safety of non-fermented foods, including meats, fruits and vegetables and seafood.

Recent decades have seen increasing interest in foods containing so-called probiotics, which have been defined as "live microorganisms which when administered in adequate amounts confer a health benefit on the host" (FAO/WHO 2002). Probiotic micro-organisms are mainly used in dairy products such as cheese, yogurt, ice cream and other dairy desserts. They have to be able to survive passage through the upper parts of the digestive tract (i.e. to resist gastric juices and exposure to bile) and to proliferate in and colonize the intestine. The most commonly used strains are lactic acid bacteria (*Lactobacillus* spp., *Enterococcus* spp. and *Bifidobacterium* spp.) (Ouwehand *et al.*, 2002; Saad *et al.*, 2013). However, other bacteria, and even yeasts, have been developed as potential probiotics (Ouwehand *et al.*, 2002). Micro-organisms and their metabolites have also been used in the production of nutraceuticals, or functional foods, i.e. foods, or parts of foods, that provide medical or health benefits, including the prevention and treatment of disease.

Food-processing micro-organisms are used under a wide variety of different circumstances, ranging from small-scale production using long-established traditional techniques to large-scale industrial applications. Large-scale enterprises in industrialised countries are able to access established culture collections (either internally within the company or from public collections) in which precisely characterized and defined microbial strains are maintained. They generally have sufficient resources at their disposal to support research and development and to acquire the technologies they need. In contrast, food processing in the "informal" sector is driven by the availability of raw materials and

[67] This section draws on the Background Study Paper prepared by Alexandraki *et al*. (2013),.

cultural traditions, with gradual development of technologies over time. Modern, large-scale production depends almost entirely on the use of defined starter strains, which have replaced the undefined strain mixtures traditionally used in food processing. This has dramatically improved culture performance and product quality and consistency. It also means that a relatively small number of strains are intensively used and relied upon by the food and beverage industries.

The majority of small-scale fermentations in developing countries are still spontaneous processes: a range of micro-organisms present at the start of the process compete – and those that are best adapted to the food substrate and the conditions in which they are maintained eventually come to dominate. In many cases, material from a previous successful batch is used to facilitate the initiation of a new process. This practice, known as “backslopping”, shortens the initial phase of the fermentation process and reduces the risk of fermentation failure. However, as demand for traditional fermented products grows and manufacturing has to be scaled-up, it tends to be necessary to introduce the use of starter cultures (isolated cultures that can be produced on a large scale). This often reduces the uniqueness of the original product and leads to the loss of the characteristics that originally made it popular.

Future priorities in the management of food-processing micro-organisms

Drivers and challenges

There are a number of challenges to the sustainable management of food-processing micro-organisms. Traditional food-processing practices and indigenous knowledge are in decline worldwide. Agricultural practices are changing and urbanization is changing dietary preferences. Product availability is being affected by the influence of climate change on production and post-harvest storage. There are food safety concerns about some traditional foods. The development of single-strain inoculations has tended to result in a lack of attention to the potential of mixed cultures and their contributions to the attributes of traditional products.

Several institutional, policy and legal issues also require attention. For example, local producers of fermented products are often ignored or marginalized by government agencies and financial institutions. Legal frameworks related to intellectual property rights, food safety and claims about health-promoting properties of particular products need to be strengthened and there is a need to further improve coordination and networking among those that rely on microbial fermentation.

Research and development

There is a need to facilitate and encourage more in-depth study of traditional food fermentations in order to improve the characterization of microbial populations, identify strains and species that play key roles in conferring quality attributes to products and select appropriate strains for use in the development of starter cultures. So-called “omics” approaches can provide important insights and their use should be promoted. Another priority should be to utilize knowledge of preservation mechanisms in food fermentations to further the development and applications of “natural” processing methods that can serve as alternatives to chemical and thermal preservation. Studies are also needed on the functional properties of traditional fermented foods to identify possible health-promoting (probiotic) effects. “Functional genomics” can be a valuable tool in such studies. Further research on the efficacy of nutriceuticals based on microbes is required. Preservation of these commodities also needs further study. In view of climate change, there is a need to develop mathematical models that that can predict the behaviour of microbial communities under changing conditions.

Starter cultures for small-scale producers

Introducing starter cultures for small-scale food fermentations is another priority area. Potential benefits in terms of improving product quality and safety have long been recognized. Use of starter cultures accelerates metabolic activities and means that fermentation can be better controlled. Progress has, however, been limited to date. Infrastructure and technical facilities need to be improved. In many regions, basic laboratory equipment and biobank facilities for preserving and storing microbial cultures are often lacking. Industrial bioreactor design needs to be improved, as does diagnostic equipment for monitoring starter culture performance.

Promoting small-scale starter-culture processing in rural areas is likely to require the use of "low-tech" procedures and the provision of support for local networking between the providers of starter cultures and small-scale processors. Key tasks include the development and implementation of simple but effective methods for preserving and maintaining traditional starter cultures without refrigeration and the further development and standardization of traditional methods to withstand climatic fluctuations.

Coordination and information exchange

Although, as described above, a degree of progress has been made in establishing mechanisms for coordination and information exchange among stakeholders, further strengthening is needed at both national and international levels. For example, efforts to improve the quality and safety of food produced by traditional "low-tech" processes would benefit from the creation of multistakeholder fora at local and national levels. Such bodies would need to address a wide range of tasks including the following:

- promoting the exchange of general, scientific and technical information;
- facilitating access to specialized technical information on food-processing biotechnology, including by promoting knowledge transfer between the public and private sectors;
- organizing training and educational activities;
- giving guidance and attending to concerns of small-scale processors;
- facilitating unbureaucratic, low-cost access to microbial strains suitable for use in small-scale operations from culture collections ;
- enabling communication and exchange between local and central governments and small-scale producers;
- providing guidance and support to governments on the application of food processing biotechnologies and on their role and importance in food safety and security;
- providing technical advice and facilitating access to science parks and other infrastructure; and
- supporting the dissemination of scientific and technical information generated by collaborative research projects.

Many of these tasks have international dimensions and hence the work of country-level stakeholder bodies needs to be coordinated at regional and global levels. There is a need, for example, to develop a comprehensive global database in which information on the nutritional and health-related properties of fermented foods can be collected and organized.

Training and education

Training and education for small-scale producers, both on practical techniques and on product marketing, is another priority. Trainers need to be trained to address the specific needs and concerns of this group. In addition to training *per se*, such trainers can potentially serve as a vital link between the formal and informal sectors, contribute to the work of national and international stakeholder bodies and support efforts to promote traditional fermented foods.

International cooperation

Cooperation of the kind organized by MIRRI in Europe (see above) needs to be replicated in other regions. A basis for this already exists in Asia, where the Asian BRC Network[68] has been established, and work is also underway in South America. Regional efforts, in turn, need to be brought together at global level. Collections need to work together to make the best use of new technologies. Common policies are needed to address regulatory issues such as the control of access to dangerous organisms and access and benefit sharing under the Nagoya Protocol.

[68] www.abrcn.net/

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4.5 The use of micro-organisms in agro-industrial processes[69]

[EDITOR'S NOTE: Informaton from the country reports will be added to this section.]

Introduction

Unicellular micro-organisms, including bacteria, fungi, yeasts and micro-algae, are components of all ecosystems and all food and agricultural production systems. They are vital to the provision of a wide variety of ecosystem services from soil formation and nutrient cycling, to water purification, pest control and climate regulation and even as a direct source of nutrition (see Section 1.2). Although microbial biodiversity is less "visible" than many other ecosystem components and its significance is often overlooked, humans deliberately utilize micro-organisms in a range of different agro-industrial processes. The most prominent of these are in soil fertility management and pest control (use of biofertilizers and biopesticides), composting of agro-industrial by-products, conversion of lignocellulosic[70] biomass into industrial products (including biofuels), environmental bioremediation and animal nutrition.

Overview of current use

Biofertilizers

A biofertilizer is a substance that contains living unicellular micro-organisms that when applied to seeds, plant surfaces or soil, colonize the rhizosphere[71] or the interior of the plant and promote growth by increasing the supply or availability of primary nutrients to the host. Biofertilizers supply nutrients through the natural processes of nitrogen fixation and solubilization of phosphorus. They may stimulate plant growth through the synthesis of growth-promoting substances. Some inoculants can improve plant uptake of nutrients and thereby increase the efficiency of use of chemical fertilizers and manures. Biofertilizers are essential components of organic agriculture and play a vital role in maintaining soil fertility.

Advantages of biofertilizers over their synthetic counterparts include their capacity to provide a wide range of nutrients, particularly micronutrients, their contribution to increasing soil organic matter content, their relatively low cost and the fact that they do not contain (or only in negligible amounts) harmful materials such as heavy metals. Disadvantages include a) much lower nutrient density, b) the need for different machinery from that used to apply than chemical fertilizers, c) difficulties with supply in certain areas, d) the need for special care in long-term storage (as they need to be kept alive), e) finite expiry dates, f) ineffectiveness if the soil is too hot or dry, g) potential loss of effectiveness if the carrier medium is contaminated by other micro-organisms or if the wrong strain is used, h) the need for the soil to contain sufficient nutrients for the biofertilizer organisms to thrive and work, i) limited effectiveness in excessively acidic or alkaline soils or if the soil contains an excess of their natural microbiological competitors, and j) constraints to availability caused by shortages of particular strains of micro-organisms or shortages of growth medium.

The effectiveness of a biofertilizer depends on the choice of microbial strain, which has to be suitable for the soil and climatic conditions in which it is used. A successful microbial strain will, inter alia, be able to successfully compete in colonizing the rhizosphere, have the potential to enhance plant growth, be easy to multiply on a mass scale, have a broad spectrum of action, be environmentally safe, be compatible with other rhizobacteria and be able to tolerate desiccation, heat, oxidizing agents and ultraviolet radiation (Nakkeeran *et al.*, 2005).

Micro-organisms used in biofertilizers come from a range of different taxa (species, genera, classes and phyla), ranging from bacteria to yeasts and filamentous fungi. They perform a variety of different

[69] This section draws on the Background Study Paper prepated by Chatzipavlidis *et al.* (2013).
[70] Structural material found in the cell walls of plants.
[71] The region of the soil surrounding plant roots that is influenced by secretions from the roots and inhabited by distinctive communities of micro-organisms.

functions, including nitrogen fixation, production of phytohormones and plant growth regulators, solubilization and phosphorus and other elements, production of siderophores (substances that facilitate the uptake of iron from the soil) and the formation of mycorrhizae (symbiotic associations between fungi and plants that, inter alia, facilitate the uptake of nutrients by the plants). Production of a biofertilizer involves the identification of micro-organisms that can perform the desired functions in the targeted agro-ecological conditions. These then have to be multiplied and packed in carrier materials that allow them to be stored and distributed effectively.

Biopesticides

Substances based on micro-organisms are used to control a variety of pests and diseases in food and agricultural systems. Their use can help reduce some of the problems caused by conventional pesticides, such as the loss of beneficial organisms (pollinators, etc.), damage to wildlife habitats and adverse effects on human health. However, there are some drawbacks, prominent among which are their susceptibility to environmental stress, the fact that they need to be kept alive and their slow kill rates.

Biopesticides based on bacteria are used to control plant diseases, nematodes, insects and weeds. The bacterium most widely used as a biopesticide is the insect pathogenic species Bacillus thurigiensis (Bt). During spore formation Bt produces Bt δ-endotoxin, a highly specific endotoxin that binds to and destroys the cellular lining of the insect digestive tract, causing the insect to stop feeding and die. The δ-endotoxin crystals are mass produced in fermentation tanks and supplied in the form of a sprayable product. Bt sprays kill caterpillar pests, fly and mosquito larvae and beetles. They are used on fruit and vegetable crops and on broad-acre crops such as maize, soybean and cotton. Some other biopesticides are based on the capacity of certain strains of bacteria to prevent plant diseases by outcompeting plant pathogens in the rhizosphere, producing anti-fungal compounds and promoting plant and root growth. Preparations based on bacteria of these kinds are used against a range of plant pathogens, including damping-off and soft rots.

Fungal biopesticides can be used to control plant diseases caused by fungi, bacteria or nematodes, as well as against some insect pests and weeds. They operate via competitive exclusion, mycoparasitism and the production of metabolites that adversely affect the target organisms. The most common commercial fungal biopesticides used in the nursery, ornamental, vegetable, field crop and forestry industries are *Trichoderma* spp., *Beauveria bassiana* and *Metarhizium anisopliae*. *Trichoderma* is able to colonize plant roots and out-compete pathogenic fungi for food and space; under certain environmental conditions it can attack and parasitize plant pathogens. It can stimulate plant host's defences and affect root growth. *B. bassiana* has proved effective in controlling crop pests such aphids, thrips and pesticide-resistant strains of whitefly. *Metarhizium anisopliae* is an entomopathogenic fungus used in an oil formulation sprays against desert locust (*Schistocerca gregaria*) plagues.

Baculoviruses are a family of naturally occurring viruses that infect only insects and some related arthropods. A virus of this kind is widely used in Europe and the United States of America to control the codling moth (*Cydia pomonella*), a pest of apple and other fruit trees. Most applications occur in conventional orchards, where its use can help minimize the risk of resistance to chemical insecticides. In Brazil, the nucleopolyhedrovirus is used to control the soybean caterpillar *Anticarsia gemmatalis*.

Non-pathogenic yeasts have also been developed into biopesticides. For example, a pesticide based on *Candida oleophila* strain O is used to control post-harvest fruit rots. The yeast acts as an antagonist to fungal pathogens such as gray mould (*Botrytis cinerea*) and blue mould (*Penicillium expansum*) that cause post-harvest decay.

Composting of agro-industrial by-products

Large quantities of agro-industrial by-products are generated worldwide, including straw, stalks, leaves, husks, shells, peel, lint, seeds/stones, fruit pulp, sugar-cane bagasse, sweet sorghum milling, spent coffee grounds and brewers' spent grains. Much of this material is made up of cellulose, hemicellulose and lignin. Most is either used as animal feed or burned. However, several groups of fungi are able to decompose these substances and convert them into compost that can be used as a soil amendment. Various agro-industrial by-products can also be used as substrates for medicinal or edible mushroom production.

[Livestock slurry management]

Production of microbial metabolites

As well as producing compost, micro-organisms cultured on agro-industrial by-products can supply a number of other useful products including organic acids, chemical additives, pigments, enzymes, food additives, antibiotics, biofuels, solvents and bioplastics.

Organic acids. Micro-organisms are widely used to produce organic acids used in the food and beverage industries and in the production of cosmetics, pharmaceuticals, leather and textiles, biodegradable plastics and coatings, cleaning products, herbicides and pesticides. Citric acid, for example, the most important bio-industrial organic acid, is produced commercially mainly via submerged fermentation using the fungus *Aspergillus niger*. Solid state fermentation and surface fermentation using this fungus cultivated on a range of agro-industrial by-products including corncob, sugar-cane bagasse, coffee husks, kiwi fruit peels, wheat bran, rice bran, pineapple waste, mixed fruit waste, maosmi[72] waste, sugar-beet molasses, sawdust with rice hulls, cassava waste, apple pomace and potato starch residue has been intensively studied. Microbial strain selection is very important in the production of organic acids. The micro-organisms used must have stable characteristics, be able to grow rapidly and vigorously, be non-pathogenic and produce high yields of the desired product.

Aroma and flavour compounds. Microbial biosynthesis or bioconversion systems are emerging as promising substitutes for synthetic methods of producing aroma compounds for use in the production of food, drinks, perfumes and essential oils. Both fungi and bacteria can be used to produce aroma compounds via fermentation (Dastager, 2009).

Enzymes. Fungi and bacteria grown on agro-industrial by-products in large-scale fermenters are an important source of enzymes used in a variety of industries including food biotechnology, animal feed, pharmaceutical, textile, paper and other technical and chemical industries. Rising demand for economical production methods, new functionalities, improved safety and reduced environmental impact is driving a trend towards the replacement of traditional chemical processes with enzyme-based processes. Microbial diversity is important in enabling the production of a range of enzymes suited for various different uses.

Fructooligosaccharides. Various strains of species belonging to the fungal genera *Aspergillus*, *Aureobasidium* and *Penicillium* grown on agro-industrial by-products such as corncobs, coffee silverskin, and cork oak can be used to produce fructooligosaccharides, substances used as sweeteners and as “prebiotic” substrates for beneficial microbiota in the gut (e.g. *Bifidobacterium* spp.).

Bioactive compounds. Micro-organisms grown on a variety of agricultural by-products, including wheat straw, rice hulls, spent cereal grains, various brans (e.g. wheat and rice) and corncobs, can be used in the commercial production of bioactive compounds, non-nutrient substances used as ingredients in the food and cosmetic industries.

Surfactants. These substances are used to decrease surface and interfacial tension in a variety of industrial processes. At present, surfactants used in industry are almost all derived chemically from petroleum. However, they can also be produced by micro-organisms. Microbially derived surfactants have several advantages, including low toxicity and good biodegradability. However, although interest in their use is increasing, they are not economically competitive with synthetically produced alternatives. Agro-industrial by-products with a high carbohydrate or lipid content can be used as substrates for biosurfactant production. Potential options include peat hydrolysate, olive oil mill effluent, lactic whey, soybean curd residue, potato process effluent and molasses.

Microbial pigments. There is growing interest in microbially derived substitutes for synthetic food colouring agents, some of which have been banned on account of their potential carcinogenicity and

[72] A kind of citrus fruit.

teratogenicity.[73] Currently, the cost of natural pigments is higher than that of synthetic colours, but this hurdle could be overcome by mass production. The fast growth rates of micro-organisms should help to give microbial pigments a competitive advantage over pigments extracted from plant or animal sources. Riboflavin (vitamin B2) (a yellow pigment permitted in most countries and produced by *Eremothecium ashbyii* and *Ashbya gossypi*) and pigments from *Monascus purpureus* and *M. ruber* are already in commercial use. Carotenoids (yellow pigments) are produced by several types of micro-organisms, but only microalgae have so far been used for commercial production. *Spirulina* spp. produce phycobiliproteins, such as phycocyanin (blue pigment), used in food and cosmetics.

Protein-enriched feed. A wide range of micro-organisms can be used to produce protein-enriched livestock feed from agro-industrial by-products (Ugwuanyi *et al.*, 2009). Potential substrates include cassava waste, coffee pulp, wheat bran and straw, corn stover, millet, sugar-beet pulp, citrus waste, mustard straw, agave bagasse, perennial grass, apple pomace and pulp, grape waste, pineapple waste, cactus pear waste, rice polishings, rice bran and straw, viticulture waste, corn straw, sugar-cane bagasse, sawdust, mango waste, palm kernel cake and cabbage and Chinese cabbage wastes.

Single-cell protein. Since ancient times, people in Africa and Mexico have been harvesting the cyanobacterium Spirulina from water bodies, drying it and using it as food. Several other species of cyanobacteria can also be used in this way. Single-cell protein can also be produced by a range of different fungal species grown on various agro-industrial by-products.

Biologically active polysaccharides. Many strains of bacteria, yeasts and filamentous fungi are used commercially to produce extracellular polysaccharides. For example, pullulan, a homopolysaccharide used in the manufacture of foods and other products, is produced from agro-industrial by-products by the yeast-like fungus Aureobasidium pullulans (Israilides *et al.*, 1999). Medicinal mushrooms, such as Ganoderma, are grown by solid state fermentation using agricultural by-products for polysaccharides and have a high economic value.

Bioplastics. Micro-organisms can be used in the production of several types of bioplastic. For example, acetic acid produced through the microbial fermentation of sugar feedstocks, such as beets, and by converting starch in corn and potatoes, can be polymerized to produce polylactic acid, a polymer that is used to produce plastic. Bioplastics can also be made from compounds called polyhydroxyalkanoates, which are accumulated by bacteria in the presence of excess carbon sources.

Biofuels. Micro-organisms are used to produce both liquid and gaseous biofuels. Bioethanol, for example, can be produced by simple fermentation processes using feedstocks such as sugar-cane stalks, sugar beet tubers and sweet sorghum, with yeasts as biocatalysts.

[Editor's note: A short subsection on vitamins will be added.]

Bioremediation

Bioremediation is the use of micro-organism metabolism to remove pollutants, for example from soils or water. The main advantage of bioremediation is its low cost compared to thermal and physico-chemical remediation. It also often offers a permanent solution, i.e. provides complete transformation (i.e. mineralization) of the pollutant rather transferring it from one phase to another.

Bioremediation can be conducted in several ways: *in situ* via methods such as bio-augmentation (the addition of externally sourced micro-organisms capable of degrading the targeted contaminant), biosparging and bioventing (methods involving the injection of air and, if necessary, nutrients to increase the biological activity of indigenous micro-organisms that can degrade the targeted contaminant); *ex situ* via methods such as a) landfarming (a process in which contaminated soil or other material is transported to a designated site, incorporated into uncontaminated soil and periodically tilled to aerate the mixture and promote the degradation of contaminants, composting), b) biopiles (structures in which contaminated soils are mixed with soil amendments and enclosed) or c) bioreactors (containers in which contaminated material and bioremediating micro-organisms can be maintained under controlled conditions).

[73] The ability to disturb the development of the embryo or foetus.

Ensiling

The use of lactic acid bacteria to improve the quality of silage is common in the Europe and North America. The practice can, inter alia, provide for faster fermentation and reduce the presence of yeasts and undesirable filamentous fungi, and thus increase the time that the silage remains stable upon exposure to air (Muck *et al.*, 2007; Tabacco *et al.*, 2011).

Future priorities

The subsections below present overviews of priorities for research and development in the main categories of micro-organism-based agro-industrial processes. General priorities for policy and institutional development in this field include improving frameworks for quality control of microbial products and for evaluating potential risks to human health or to the environment, improving registration policies for microbial products, improving education and awareness-raising, including extension programmes and demonstrations in farmers' fields, and improving partnerships between the public and private sectors.

Biofertilizers

Expanding the use of biofertilizers requires more research into the interactions between plants and rhizosphere micro-organisms. The rhizosphere is a highly dynamic system in which a vast number of micro-organisms interact simultaneously. Better understanding of the ecological factors that control the performance of nitrogen fixation systems in crop fields is essential. Priorities for research and development include strain selection – strains need to be able to establish themselves effectively in the targeted soils, perform well and be persistent in the field, tolerate environmental stressors (ultraviolet radiation, heat, desiccation, etc.), survive well in storage and have little harmful impact on the environment. Field trials need to be organized to test multiple strain inoculations. Potential objectives for genetic improvement activities include higher yield, faster growth, improved fermentation properties, better tolerance of process conditions, less formation of by-products, better resistance to bacteriophages (viruses that infect bacteria), new or modified activities and regulation of enzyme synthesis. New and improved carrier materials for bacterial inocula are also required. The potential use of bacterial biofilms as carriers is a significant emerging area of research. Promoting the use of biofertilizers will require evaluation of the economics of using them in specific circumstances, taking into account costs in terms of labour, equipment and other inputs and impacts on production. Ensuring quality control in biofertilizer production is another priority. Critical benchmarks need to be identified at all stages of the production process.

Institutional frameworks also need to be improved. Collaboration between research institutes and the biotechnology industry needs to be strengthened, inter alia in order to allow for industrial-scale testing of inocula. National and international guidelines for inoculum production and trade need to be established to protect end users and ensure product safety. Effective use of biofertilizers requires a high level of knowledge on the part of farmers. Education and training are therefore also priorities. Advice offered to farmers needs to be appropriate to local circumstances and kept up to date with ongoing technological developments. Links between researchers and farmers need to be improved. Local and traditional knowledge can potentially play a role in enabling the effective use of biofertilizers in local conditions.

Biopesticides

Increasing recognition of the need for safer and more environmentally friendly pest-control methods should create opportunities to expand the use of biopesticides. However, research and development are costly and biopesticides are often not able to compete in the market with synthetic alternatives. Continued investment in research needs to be ensured. Priorities include the establishment and strengthening of partnerships among and between public- and private-sector organizations, the establishment of appropriate legal frameworks in fields such as intellectual property rights and safety regulations for the release of new products, and efforts to educate and raise awareness among potential users and suppliers of biopesticides. Achieving better uptake of biopesticides may be easier in segments of the markets where conventional pesticides have relatively poor efficacy (e.g. in the control of slugs). The challenges involved in introducing the use of biopesticides vary from production system to production system. The environmental challenges in horticulture systems are typically fewer than in arable crops systems and the likelihood of success is therefore greater. Biocontrol-based integrated pest management has been adopted widely in the labour-intensive and technically complex greenhouse crop industry and by growers that have a high level of knowledge and are used to technological innovation.

Priorities for research include the need to ensure that effectiveness achieved in the laboratory can be reproduced in field conditions. Ultraviolet light, for example, is a major cause of rapid loss of activity in biopesticides after application to leaf surfaces in the field. Inability to withstand rainfall or dry conditions can also be a problem. Another challenge is posed by the fact that the activity spectra of biopesticides tend to be very narrow in comparison to those of agrochemicals. Host range can be addressed by using conjugal mating to produce strains that combines the host ranges of their parent strains. In addition to improving effectiveness in the field, there is also a need to improve the shelf-life of biopesticide products so that they can easily be distributed via the conventional distribution chains used for other products.

Improving knowledge of the genomes of pests and their microbial natural enemies will provide new insights into their ecological interactions and open new possibilities for strain improvement. Other potential targets for research include inoculation of plants with endophytic strains[74] of entomopathogenic fungi[75] to prevent infestation by insect herbivores, exploiting the volatile alarm signals emitted by plants as a means of recruiting microbial natural enemies as "bodyguards" against pest attack and using novel chemicals to impair the immune system of crop pests to make them more susceptible to microbial biopesticides. Many biological control agents produce secondary metabolites that have properties relevant to the control plant diseases. These metabolites should be studied in order to assess their potential for use in product development and to identify any potential harmful effects on the environment or on human health. Another potential option is the development of a "total system" approach to pest management, in which the farm environment becomes resistant to the build up of pests, and therapeutic treatments are used as a second line of defence (Nakkeeran *et al.*, 2005; Kaewchai *et al.*, 2009; Malusa *et al.*, 2012).

The use of fungi as biocontrol agents is relatively underdeveloped. There is still a wide gap between laboratory research and use in the field. Future research efforts need to focus on developing fungal products that have significant effects in the field and are stable in storage. Specific areas requiring research include choice of fungal strains, cheap and reliable methods for large-scale production, potential detrimental effects on the environment and human health, and the potential for combining the use of different types of beneficial fungi. Better communication between researchers and industry is needed in the early stages of product development (Nakkeeran *et al.*, 2005; Kaewchai *et al.*, 2009; Malusa *et al.*, 2012).

Biofuels

Rising demand for biofuels will mean that there is a need to take greater advantage of low-cost biomass (lignocellulosic material) from agriculture and forestry as feed stock. This will require significant improvements in technology. With regard to bioethanol production from lignocellulosics, specific challenges include the need to develop cost-effective pre-treatment strategies for the various lignocellulosic materials (e.g. increasing the digestibility of these by-products), reduce the costs of producing cellulase enzymes, ensure the availability of robust recombinant microbes (filamentous fungi, yeasts, bacteria) that provide high ethanol yields from the sugars produced from lignocellulosic substances and develop products and markets for non-reactive lignin by-product (e.g. potential use in paints and adhesives). In the case of biodiesel, which is generally produced from vegetable oils, residual oil present in oil cake (a by-product of oil extraction units) has great potential. Where biogas is concerned, one barrier to more widespread production is the fact that people in rural areas are often unable to afford the initial investment needed to set up a biogas plant. The development of biogas technology depends on political will. Governments and administrative authorities can promote

[74] Strains that live inside plants.
[75] Fungi that cause disease in insects.

expansion by providing access to technology and financial resources and by establishing a supportive legal framework. Governments can also play a supportive role in biogas research and in the dissemination of information.

Composting

The main priority in this field is promotion and dissemination of information to farmers on the benefits of vermicomposting (i.e. composting using worms).

Microbial metabolites

Research into micro-organisms, their genomics and their communities has great potential to allow the development of novel products and processes for use in agro-industry. Genetic sequencing and "meta" approaches (i.e. analysis of genomes, transcriptomes,[76] proteins, etc. from whole communities of micro-organisms) are opening yet more opportunities. Increased investment in "bioprospecting", in which ecosystems are surveyed for micro-organisms that can be tested for metabolite production of interest to agro-industry, should be considered (Paterson and Lima, forthcoming).

[EDITOR'S NOTE: This subsection will be expanded to note growing interest in unicellular organism proteins and lipids other extracts.]

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[76] The set of messenger RNA molecules in a cell or a population of cells.

4.6 The state of breeding

4.6.1 Genetic resources for food and agriculture

Plant genetic resources for food and agriculture

There is some form of public and/or private plant breeding programmes in most countries. The country reports submitted as contributions to *The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture* (FAO, 2010)[77] indicated that the number of programmes, particularly private sector programmes, had increased in the ten years since the first report on *The State of the World's Plant Genetic Resources for Food and Agriculture* had been published. Biotechnological techniques had evolved considerably and there was an increase in their use in plant breeding worldwide, although many breeding programmes, especially in developing countries, lacked the capacity to apply them.

In general, data from the country reports and from the FAO Statistical Database (FAOSTAT) indicated that investment mirrored crops' economic importance. Thus, major crops were receiving the bulk of breeding investments, although several country reports highlighted the importance of giving attention to underutilized crops. There appeared to have been an increase in the use of wild species in crop improvement, owing in part to the increased availability of methods for transferring useful traits from these species into domesticated crops. The country reports indicated that the principal traits targeted by plant breeders continued to be those related to yield of the primary product per unit area. Increasing attention was being paid to tolerance or resistance to pests, diseases and abiotic stresses. The country reports indicated an increase in farmer participation in plant breeding activities in all regions of the world.

Breeding programmes in most regions remain constrained by shortages in funding, trained personnel and technical facilities. Several country reports also expressed concern about the lack of fully effective linkages between basic researchers, breeders, curators, seed producers and farmers.

Animal genetic resources for food and agriculture

Breeding programmes for animal genetic resources for food and agriculture (AnGR) are implemented in a range of different circumstances. The stakeholders involved, the organizational set-up and the sophistication of the techniques applied vary greatly.

Breeding programmes for high-input systems generally involve well-developed systems for performance and pedigree recording and advanced methods of genetic evaluation to estimate the breeding value of individual animals or families. Breeding programmes in the dairy sector have been revolutionized in recent years by developments in genomics. With some variation from region to region and from species to species, the main operators of programmes in high-input systems tend to be breeders' associations, cooperatives or private breeding companies. The most advanced breeding programmes, particularly in the poultry, pig and to a lesser degree dairy sectors, tend to target only a limited number of breeds, generally originating from the temperate regions of the world. Selection criteria often encompass an increasingly wide range of traits, including those related to product quantity and quality, reproduction and health. Cross-breeding strategies of various kinds are widely used.

Breeding programmes for the low-input systems of the developing world tend either to be centralized public-sector programmes or community-level initiatives of some kind, often supported by outside agencies. Establishing and sustaining breeding programmes for such systems has generally proved to be challenging. For many breeds in developing countries, breeding programmes are either non-existent or in a rudimentary state. Country reports submitted as contributions to *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture* (FAO, 2015)[78]

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[77] The material presented in this subsection is largely based on The Second Report on the State of the Worlds Plant Genetic Resources for Food and Agriculture (FAO, 2010).

[78] The material presented in this subsection is largely based on The Second Report on the State of the Worlds Animal Genetic Resources for Food and Agriculture (FAO, 2015).

nonetheless indicated upward trends in the number of breeds in developing countries covered by some of the elements or “building blocks” of breeding programmes such as animal identification and performance recording.

Use of exotic breeds to replace or cross with locally adapted breeds is a popular strategy. Cross-breeding programmes need to be well-planned so as to ensure that cross-bred animals are suited to the production environments in which they are to be raised and that locally adapted AnGR are not eroded. There is growing recognition of the value of the locally adapted breeds of developing countries, for example in addressing challenges associated with climate change. However, there are many constraints to the development of effective breeding programmes for these breeds. In addition to the limited availability of financial resources and shortfalls in human and technical capacity, organizational frameworks that would enable effective participation of livestock keepers in the planning and operation of breeding programmes are often lacking. Systems and infrastructure for distribution of superior genetic material are also generally lacking, leaving little incentive for entrepreneurs to enter the business of developing and marketing breeding stock.

Forest genetic resources

Trees have subject to informal selection and germplasm transfer for centuries if not millennia (FAO, 2014a).[79] More systematic research and development efforts have been conducted for a little over a century and first tree breeding programmes were initiated in the 1930s. Most tree breeding programmes aim at gradual improvement of breeding populations rather than development of new varieties (exceptions include breeding of eucalyptus and poplars).

Until recently, tree breeding focused on species used for wood production and on improving a relatively small number of traits that would maximize economic gains (including growth rate, volume, stem form, processing and product quality). However, in recent decades government agencies and the private sector have subjected a wider range of tree species to domestication and formal breeding programmes to produce variety of goods including timber, pulp, fuelwood, fruit, nuts, oils, traditional medicines, dyes, resins and thatch, and to provide service functions. In addition, tree breeding efforts have increasingly focused on adaptability-related traits such as those conveying resistance to drought, fire, pests and diseases. These breeding programmes are primarily initiated by public agencies. The main drivers of change have included the increasing scale and unpredictability of environmental change and new demands for trees for food and nutritional security, environmental restoration and carbon sequestration.

Increasingly sophisticated approaches and technologies are being applied to tree breeding to generate faster rates of gain. Hybrid breeding, involving interspecific hybrids and wide provenance crosses, is used in many countries to produce trees with superior productive capabilities (and also to introduce genes for disease resistance). Furthermore, new molecular tools offer opportunities for marker-assisted selection to shorten the long cycles of breeding, testing and selection, and even for estimating quantitative genetic parameters directly from natural tree populations (e.g. El-Kassaby *et al.*, 2011). In many developing countries, however, the lack of skilled tree breeders constrains the use of advanced breeding methods.

Overall, much remains to be done to realize the full potential benefits of tree breeding programmes and the genetic diversity of natural tree populations, particularly in the tropics. In most countries, priority requirements include the establishment of national information systems and better coordination among stakeholders – among and within government agencies and departments (especially departments of forestry, agriculture and environment), research institutes and universities and the private sector. Developing a national FGR strategy is a key means of improving coordination between different actors.

Aquatic genetic resources for food and agriculture

[79] The material presented in this subsection is largely based on *The State of the Worlds Forest Genetic Resources* (FAO, 2014a).

The majority of farmed aquatic species are very similar to the wild type, i.e. to their wild relatives. As noted elsewhere in the report, the breeding and domestication of aquatic species is a relatively recent activity, except for a few species that were domesticated a few thousand years ago (e.g. common carp – see Balon, 1995). Some wild types can, however, be bred in captivity through manipulation of photoperiod or temperature, hormone treatment and through natural processes. Increasingly more and more aquatic species are being bred under farmed conditions and this has helped the aquaculture sector become the fastest growing food-producing sector (FAO, 2014b).

The breeding of ornamental fish has been an important aspect of Asian culture for millennia. The various koi carps and fancy goldfish have been bred into numerous shape and colour patterns and are extremely valuable. As with aquatic species raised as food, more and more ornamental species are being bred in captivity.

Once controlled breeding is established, a number of different genetic improvement methods can be applied to aquatic species. Among these, selective breeding has the longest history of use in aquaculture and it was the most common form of genetic technology reported in the country reports submitted for the forthcoming report on *The State of the World's Aquatic Genetic Resources for Food and Agriculture*. Other approaches include mono-sex production, hybrid production and triploid/polyploid production through chromosome set manipulation. Gene transfer and other genetic engineering technologies have been successful under research conditions, but have not been used commercially due to consumer resistance and environmental concerns. Genomic selection and gene editing show promise and may become increasingly important in the genetic improvement of farmed aquatic species (Dunham, 2011).

The country reports show that the use of genetic technologies and genetic resource management of some kind is occurring in about 50 percent farmed species. Approximately half of the country reports indicated that genetically improved aquatic organisms contributed at least somewhat to national aquaculture production. All country reports indicated at least some use of selective breeding in aquaculture: 35 percent to a great extent; 53 percent to some extent; and 13 percent to a minor extent. Genetic improvement of aquatic genetic resources is often the result of advanced breeding programmes conducted by large private companies in areas outside of the natural distribution of the species.

The objective of most genetic improvement programmes is to increase growth rate. However, colour, body shape, spawning time and fecundity can also be improved. Disease resistance is an important trait, especially in marine shrimp aquaculture, and programmes are improving this character in farmed aquatic species (Lightner, 2011).

Selective breeding and genetic resource management create tremendous opportunities to increase food production from aquaculture (Gjedrem et al, 2012). However, there are challenges. Genetic data are technically demanding and costly to collect. The availability of funding for breeding programmes is often inadequate. Expanding the role of public–private partnerships is a potential means of addressing some funding constraints.

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[4.6.2 Associated biodiversity]

4.7 The contribution of biodiversity for food and agriculture to food security and nutrition

[EDITOR'S NOTE: Information from the country reports will be added, including on the importance of wild foods to food security and nutrition.]

Biodiversity for food and agriculture and food security

The widely used definition adopted by the 1996 World Food Summit states that food security "exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life" (FAO, 1996). Over the decades, food security has increasingly come to be recognized a multifaceted concept (FAO, 2006). The 2009 World Summit on Food Security (FAO, 2009a) lists availability, access, utilization and stability as the four pillars of food security and also notes that "the nutritional dimension is integral to the concept of food security." Biodiversity for food and agriculture (BFA) is essential to all four of these pillars.

Availability

Although food supplies can be stored and transported to address temporary or local shortages, availability is ultimately dependent on production. To feed a global population expected to exceed 9 billion in 2050, it has been estimated that food production will need to rise to 50 percent above 2012 levels (FAO, 2016a). As discussed in Subsection 1.2, obtaining food from a wide range of different environments – terrestrial and aquatic, tropical, temperate and boreal, mountain, lowland, forest, steppe, desert and so on – requires a diverse range of plants, animals, bacteria and fungi, both as direct suppliers of food and as suppliers of ecosystem services that make food production possible. Increasing output will require (along with advances in many other fields) the implementation of well-planned breeding programmes in crop, trees, livestock and aquaculture species. It may require the domestication of additional food-producing species, and increasing the use of underutilized and neglected species. It will certainly require efforts to ensure that the natural resources upon which food production depends, including the diversity of crop, livestock, aquatic and forest genetic resources and of associated diversity in and around production systems, are managed sustainably and that the ecosystem services they provide are nurtured.

As discussed in (Sections 1.2 and 4.3), there are many ways in which biodiversity within one "sector" of food and agriculture can contribute to food production in another: crop plants provide feed for livestock; livestock providing manure and draught power for use in crop production; trees provide shelter for crops and livestock; fish and other animals help to control crop pests; and so on. Combining several different species, varieties or breeds within a given field, area of pastureland, forest or aquaculture unit may allow more efficient use of available resources and hence higher levels of food production. For example, in China four carp species are widely farmed together in the same pond: silver carp (a phytoplankton filter feeder), grass carp (a herbivorous macrophyte feeder), common carp (an omnivorous detritus bottom feeder) and bighead carp (a zooplankton filter feeder) (Naylor *et al.*, 2000). This system allows for efficient use of water resources (i.e. water at different depths) and feed resources within the pond.

Box 7. The nutrient productivity concept

The nutrient productivity concept was developed by FAO a means of promoting awareness among decision makers of the nutritional impact of different kinds of food production (FAO, unpublished, Charrondiere *et al.*, submitted).
The concept combines yield with nutrient composition (energy, protein, dietary fibre, iron, zinc, calcium, vitamin A, vitamin C and folate) and relates these measures to the nutritional needs (DRI – dietary reference Intakes) of humans. Nutrient productivity expresses the percentage of the DRI (either for one or for all nine selected nutrients) of ten adults for a year that is met by agricultural

product grown on one hectare in a year. Preliminary results show that this is a useful means of applying a nutrition sensitive lens to the process of deciding which varieties and species to grow. Even if only energy is considered, potatoes and bananas have a higher score than cereals. If all nine nutrients are considered, potatoes and bananas retain a high score and cereals score at a similar level to legumes. Animal products generally have lower scores than plant products. Milk and eggs score better than meat.

Nutrient productivity can be used to determine which particular crop variety produces more nutrients, with the option of focusing on the nutrients with the greatest relevance to public health.

In order to implement the concept across a range of countries and settings, more specific data will be needed on yield, life-time feeding and the composition of the nine selected nutrients at the level of the species, variety, breed or cultivar.

Access

The significance of the "access" pillar of food security lies in the need not only to ensure that sufficient food is available at world or national levels, but that individuals are able to acquire the food and nutrients they need. This means that they have to be able either to produce foods in sufficient quantity, quality (nutrient content) and diversity or be able to acquire them through purchases or some other kind of social arrangement. This pillar of food security is therefore dependent not only on biophysical aspects of food production, storage, processing and distribution, but also on the broader security of livelihoods at household and individual levels and on economic, social, political and legal factors at community, national and international levels.

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 when the household is unable to access inputs (pesticides, veterinary medicines, supplementary feed, etc.) that might ameliorate production conditions. Similarly, poor and potentially food insecure households may be particularly vulnerable to the effects of losing of ecosystem services underpinned by biodiversity, for example protection against pests or against disastrous events such as floods.

As discussed in more detail in Section 4.10, the livelihood significance of locally adapted domesticated genetic resources and associated biodiversity and the ecosystem services they supply is not limited to food production. For example, a range of different products (e.g. natural fibres from plants and animals) and services (e.g. transport services provided by animals) can be sold for cash that is then used to buy food. The capacity to supply outputs of this kind will often depend on the particular characteristics of the variety or breed in question (e.g. the strength and docility of an animal breed used for transport). Particular species, breeds or varieties may play particular roles in social and cultural life that help to build ties that can be crucial to obtaining food in times of need.

Access to food can also be affected by the practicalities of transport, storage and processing. Problems are particularly likely to arise in remote areas, in emergency situations or in other circumstances where the relevant technologies are difficult to access or use. Biodiversity for food and agriculture can contribute in various ways to addressing problems of this kind. For example, certain micro-organisms, referred to as "protective cultures", can be used to increase the shelf-life of food and protect it from spoilage by other micro-organisms and reduce the risk of contamination with mycotoxins (Beed *et al.*, 2011; Alexandraki *et al.*, 2013). In many countries, pack and draught animals continue to play an important role in transport, particularly in remote and inaccessible locations (FAO, 2015a).

Utilization

"Utilization" refers to the way in which food is used in order to create a state of nutritional well-being (FAO, 2006b). This involves, inter alia, selecting a nutritionally balanced diet and storing and preparing foods safely. A balanced diet will require a range of different foods and hence a range of plants, animals, etc. Studies have shown that diet diversity is a good predictor of diet quality, particularly in the case of children's diets (Moursi et al, 2008; Kennedy *et al.*, 2007; Rah et al, 2010).

Appropriate utilization also requires knowledge of foods and how to process, store and prepare them. It requires access to non-food inputs such as clean water and fuel. In some circumstances, again particularly in remote areas and for poorer people, these inputs will depend on local provisioning (e.g.

fuel supply) and regulating (e.g. water purification) ecosystem services that depend on biodiversity in and around production systems.

Stability

"Stability" refers to the fact that food security depends on adequate food being available to all individuals at all times, for examples with no seasonal shortages or shortages in years when harvests are poor (FAO, 2006). The presence of a range of different food-producing species, varieties and breeds that have different life cycles and different adaptive characteristics helps to maintain food supplies through the seasons of the year and through inter-year variations in rainfall, temperature, disease challenge, etc. The presence of food-producing organisms from more than one sector of food and agriculture, for instance crops and livestock or crops and aquaculture can contribute to the stability of food supplies, as an event that devastates one sector may have a less severe effect on another. Access to wild food products potentially serves as means of maintaining food intakes in the event of shocks that affect the production of domesticated species or otherwise affect access to food (e.g. because of reduced cash income) (Pattanayak and Sills, 2001; Thondhlana and Muchapondwa, 2013). More broadly, all the contributions that domesticated and associated biodiversity make to the resilience of agricultural and food production systems (see Section 4.9) contribute to the stability dimension of food security.

Biodiversity for food and agriculture and nutrition

Recent years have seen growing interest in the link between biodiversity and nutrition (FAO 2013a). In 2006, the CBD, FAO and Bioversity International jointly established the Cross-cutting Initiative on Biodiversity for Food and Nutrition. Initiatives since then have included the development of nutrition indicators for biodiversity (FAO 2008; 2011) and a publication from WHO and CBD (WHO/CBD, 2015) reviewing the state of knowledge on the contribution of biodiversity to health, including nutrition. This growing interest has meant growing recognition of the nutritional significance of diverse diets and particularly of wild foods and so-called underutilized or neglected crops. It has also meant growing interests in within-species differences in the nutritional value of food products. FAO in collaboration with the International Network of Food Data Systems (INFOODS) has developed the FAO/INFOODS Food Composition Database for Biodiversity (FAO 2013b). In 2015, the Commission on Genetic Resources for Food and Agriculture adopted Voluntary Guidelines for Mainstreaming Biodiversity into Policies, Programmes and National and Regional Plans of Action on Nutrition (FAO, 2016b) "to support countries in the integration of biodiversity into all relevant policies, programmes and national and regional plans of action addressing malnutrition in all its forms, and specifically to promote knowledge, conservation, development and use of varieties, cultivars and breeds of plants and animals used as food, as well as wild, neglected and underutilized species contributing to health and nutrition."

The proportion of the world population that is malnourished has declined over recent decades. However, even where food-energy deficits have been successfully addressed, dietary quality often remains a concern, particularly inadequacies in the intake of micronutrients (FAO, 2015b). Problems of this kind are sometimes exacerbated by a decline in dietary diversity and the replacement of micronutrient-rich local or traditional foods with more mainstream globally traded alternatives (Johns and Eyzaguirre, 2006). There has been a tendency to overlook the roles of non-mainstream crops – and wild foods – in the diets of (in particular) poor rural people (Heywood, 2013).

The transition towards a so-called "western" diet dominated by refined sugars and carbohydrates, refined fats, oils and meat that is taking place in several regions of the world as income rise (Popkin *et al.*, 2012) is giving rise to a number of health problems. It has been implicated in the rise of obesity – one-third of the world's adult population is overweight (Ng *et al.*, 2014) – cardiovascular disease, diabetes, autoimmune diseases and some cancers (Murray *et al.*, 2013).

Detailed studies of the nutritional significance of wild and underutilized species remain quite rare (Powell *et al.*, 2015). One notable exception is the Biodiversity for Food and Nutrition (BFN)[80] Project, in which Brazil, Kenya, Sri Lanka and Turkey – four countries rich in cultivated and wild edible biodiversity − are working to determine the nutritional value of over 150 native species, many of them wild and underutilized and to document traditional knowledge associated with their use (see Box 8). A number of other studies have provided evidence that in various production systems in various parts of the world wild and underutilized species make an important contribution to the diets of local people (see Section 4.7). Asian rice fields, for example, harbour a wide range of amphibians, crustaceans, fish, molluscs, reptiles and plants, many of which are important sources of foods and nutrients for local people, often providing essential micronutrients that are not found (or not adequately found) in rice, as well as an additional source of protein (Halwart, 2006; Halwart *et al.*, 2014). Traditional rice diets are often deficient in the amino acid lysine, but this can be compensated for by including fish and other aquatic animals foraged from rice fields in the diet. A study of the diets of mothers and children in a small-scale farming system in the East Usambara Mountains of the United Republic of Tanzania found that wild foods, mostly obtained from agricultural land, provided 31 percent of the vitamin A, 19 percent of the iron and 16 percent of the calcium content of the diet, with the contribution being greatest during the wet (more food-scarce) season (Powell *et al.*, 2013).

Box 8. The Biodiversity for Food and Nutrition Project

Brazil (see Box 9), Kenya, Sri Lanka and Turkey are home to a vast array of wild and cultivated biodiversity, whose nutritional potential remains largely unexplored and untapped. Much of it is rapidly disappearing as a result of environmental pressures or lack of use. The Biodiversity for Food and Nutrition Project is seeking to improve global knowledge of these resources and thereby enhance the well-being, livelihoods and food security of target beneficiaries in the four countries through the conservation and sustainable use of this biodiversity and the identification of best practices for up-scaling.
The initiative is exploring the nutritional properties of a number of traditional and/or neglected native edible species, both wild and cultivated (including varieties and landraces), to demonstrate their nutritional value. This knowledge will be used to incorporate local agricultural biodiversity into national and global policy instruments that address food and nutrition security through the promotion of healthy, diversified and sustainable diets. As of December 2016, the food composition of 93 species across the four countries had been documented and information on species in Brazil, Kenya and Turkey was being validated for inclusion in tailor-made national databases and the FAO/INFOODS database. The information obtained is also being used to raise awareness of the importance of local edible biodiversity and increase market demand for some of these species, many of which fetch higher market prices than their exotic counterparts. This can provide an incentive for farmers and communities to use and conserve these species, varieties and cultivars.

For further information, see the Biodiversity for Food and Nutrition website (http://www.b4fn.org/).

Significant intraspecific differences in nutritional content have been documented in most plant-source foods (FAO, 2013a; Burlingame *et al.*, 2009). These differences are sufficiently large to mean that eating one variety rather than another can make a significant difference in terms of the nutritional adequacy of the diet. Within-species differences in the nutritional quality of animal products have been relatively little studied and there are difficulties involved in distinguishing differences caused by

[80] The Mainstreaming Biodiversity Conservation and Sustainable Use for Improved Human Nutrition and Well-being Project or Biodiversity for Food and Nutrition (BFN) project is a multicountry initiative funded by the Global Environment Facility and led by Brazil, Kenya, Sri Lanka and Turkey. The project is coordinated by Bioversity International and implemented by FAO and United Nations Environment Programme. Additional resources were received from the Australian Centre for International Agricultural Research, the Vanguard Charitable Trust and the MacArthur Foundation for the school feeding programme in Kenya, and from FAO Kenya for the analysis of the nutritional content of local varieties and species and the development of an updated food composition table for Kenya that will include local biodiversity. The BFN Project contributes to the implementation of the Convention on Biological Diversity's Cross-Cutting Initiative on Biodiversity for Food and Nutrition.

genetics from those caused by management factors such as feeding. However, evidence suggests that there are some nutritionally significant differences between products from different breeds (FAO, 2015a).

Box 9. Brazil's experience in mainstreaming biodiversity in the Food and Nutrition Security Policy

Brazil achieved both the MDG target of halving the proportion of its people who suffer from hunger and the more stringent WFS target of reducing by half the absolute number of hungry people before the deadline of 2015.

The successful reduction of hunger and extreme poverty in both rural and urban areas in the last twelve years resulted from a well-coordinated array of cross-sectoral policies led by the government with strong engagement from civil society, rather than from any isolated action. Joint interministerial strategies became increasingly common, including mainstreaming biodiversity in FSN policies.

The Zero Hunger Program, launched in 2003, was the first step in translating the decision to end hunger into action, and introduced a new approach for the country that placed food security and nutrition and social inclusion at the centre of the government's agenda, while linking macroeconomic, social and sustainable agricultural and development policies.

The fight against hunger and poverty has remained at the center of the political agenda ever since and was reinforced after 2011 with the launch of the Brazil without Extreme Poverty Strategy. These new set of intersectoral policies built on the success of Zero Hunger and adopted the bold goal of eliminating extreme poverty in Brazil.

The underlining assumption of the Brazilian strategy to eradicate hunger was that poverty reduction, food security and support for family farmers were intimately connected. Besides social protection programmes, other key pillars of the Brazilian Food and Nutrition Security Strategy are:

- The Food Acquisition Program (PAA);
- The National School Meals Program (PNAE);
- The National Food and Nutrition Policy (PNAN);
- National Plan for Agroecology and Organic Production (PLANAPO I/II)

Brazil was one of the first countries to develop an institutional food procurement programme, in 2003, connecting the institutional demand for agricultural products and its food security strategy to family farmers. The PAA has three main objectives: (i) to support family farmers and family rural entrepreneurs' production and access to markets; (ii) to distribute food for people suffering from food and nutritional insecurity; and (iii) to build up strategic stocks. It uses direct and smallholder-friendly procurement modalities to buy food from smallholder farmers' organizations at market prices and distributes it to hospitals, schools, other public institutions and families in need.

Building on the PAA, the Brazilian Government boosted the PNAE in 2009, linking the well-established national school feeding programme with smallholder agriculture policies. States, municipalities and federal schools are required to purchase at least 30 percent of food for school meals directly from smallholder producers.

These programmes are complemented by the PNAN and incentives to organic agriculture and agroecological production from family farmers, aiming at making nutritious, diverse and sustainably produced foods accessible throughout Brazil's population. The first PLANAPO (2013-2015) benefited thousands of smallholder farmers through the provision of credit and crop insurance for agroecological food production; specific support to rural women; capacity development, rural extension and technical assistance. The plan was structured in four priority areas, among which the production and consumption of agroecological and organic products, and the conservation of natural resources. In the second edition of PLANAPO (2016-2019), access of family farmers to markets continues to be prioritized in line with the provisions of PAA and PNAE. The plan aims to have one million family farmers producing food using agroecological techniques by 2019.

The aforementioned federal policies provide entry points to the conservation and sustainable use of biodiversity, including of its genetic resources. The PLANAPO, for instance, recognizes the importance of "sociobiodiversity" products and the valorization of local experiences of use and conservation of plant and animal genetic resources, especially those involving the management of local breeds and traditional and creole varieties.

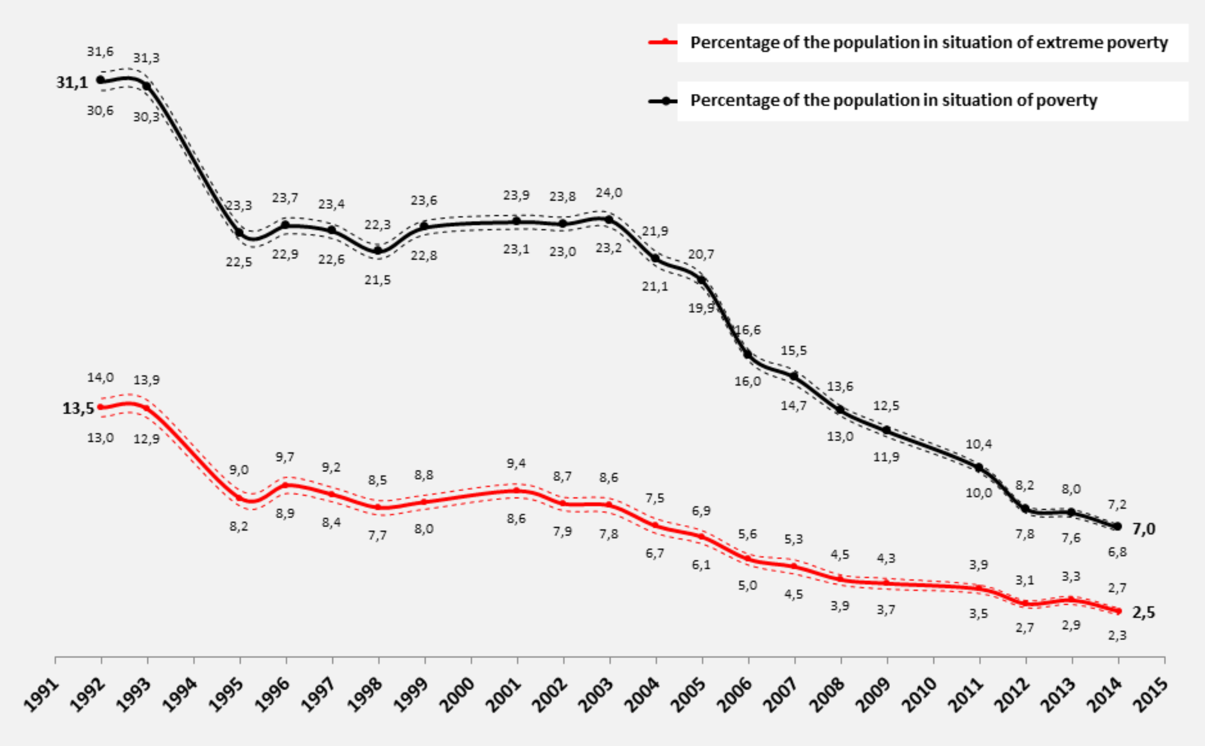
During the three years of the implementation of the PLANAPO I, a myriad of actions were taken to expand processes for the production, management, conservation, acquisition and distribution of genetic resources of interest to agroecology and organic production. These actions involved different ministries and national institutions, including EMBRAPA. Among them are the identification of organizations and networks involved in the conservation of genetic resources of agrobiodiversity adapted to agroecological and organic production, the support for the development of agroecology networks to intensify the sustainable use of agrobiodiversity, the establishment of community seed banks and other measures to increase access to creole and organic seeds by family farmers. Research and development, rural extension and technical assistance were also promoted.

Another federal initiative that was integrated to PLANAPO I and relates to biodiversity mainstreaming is the Plants for the Future Project that aims to survey, document and promote the conservation and sustainable utilization of neglected/underutilized plant species with nutritional value or economic potential (see Box 8). This initiative is related to the GEF-funded Biodiversity for Food and Nutrition Project (BFN)[81], which in Brazil is working together with the ministries responsible for the implementation of the FSN policies to promote the inclusion of foods from the Brazilian biodiversity in PAA, PNAE and nutrition education strategies. Among the activities led by BFN, nutritional composition analysis of 65 native fruit species is being carried out in partnership with public universities and research institutes across the country and will provide evidence to promote greater biodiversity mainstreaming in all aforementioned federal initiatives.

The PLANAPO II builds on the experience of the first plan, as well as on the Minimum Price Guarantee Policy for Biodiversity Products, which promotes biodiversity conservation, food security and income generation to local extractive communities by establishing minimum prices for some selected biodiversity products. “Sociobiodiversity” considerations were included as one of the axes of the second edition of PLANAPO, responding directly for at least 7 targets and 27 of its initiatives. In this context, a list of native biodiversity products that could be considered in institutional procurement programs was jointly released by the ministries of Social Development and the Environment (Ordinance MMA/MDS 163/2016). It recognizes the opportunity to expand the purchase of such products in the PAA and PNAE, while improving the diversification of diets, supporting family farming and increasing biodiversity conservation.

Figure 19. Evolution of poverty and extreme poverty rate in Brazil (1992–2014)

[81] The Mainstreaming Biodiversity Conservation and Sustainable Use for Improved Nutrition and Well-Being Project, or Biodiversity for Food and Nutrition Project for short, is led by Brazil, Kenya, Sri Lanka and Turkey. The initiative is coordinated by Bioversity International with implementation support from the UNEP and FAO, and contributes to the implementation of the Convention on Biological Diversity’s Cross-Cutting Initiative on Biodiversity for Food and Nutrition.



Source: IBGE/PNAD – Elaborated by SAGI/MDS

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[4.8 The contribution of biodiversity for food and agriculture to sustainable intensification]

4.9 The contribution of biodiversity for food and agriculture to resilience

[EDITOR'S NOTE: Additional material from country reports will be added to this section, particularly with regard to resilience outside the context of disaster management]

Introduction

Growing recognition that the capacity of food and agricultural systems to meet the requirements of a growing population is vulnerable to various kinds of shocks, some of which are likely to become increasingly frequent in the future (e.g. climate change-driven increases in the frequency of extreme climatic events), and that production systems need to adapt to the effects of (often accelerating) environmental, economic and social trends and drivers of change, has led to increasing interest in the concept of resilience.[82]

Although widely used, the term is not easy to define. The concept emerged in the ecological literature in the 1960s and 1970s to describe the response of ecosystems to disturbances. Resilience is sometimes conceived as the capacity of a system to remain in or return to a given stable state when subject to shocks. However, it is increasingly viewed in a more dynamic way – as the capacity to maintain particular properties (e.g. in the case of an ecosystem to continue supplying particular ecosystem services) in the face of change. Resilience in this sense might allow, for example, for an ecosystem to shift between different (more or less) steady states, in each of which a different set of processes allows function to be maintained (Elmqvist *et al*., 2003; Folke *et al*., 2004).

In the case of food and agricultural systems, where ecological functions interact with human management and with broader social, cultural and political structures and processes, it is even clearer that resilience has to accommodate change. The need to take this into account and address the multifaceted nature of resilience in human societies has led to the emergence of the concept of social–ecological resilience, which has been applied to a range of production systems in recent years (e.g. Darnhofer *et al*., 2010a,b; Berkes, 2012; Kremen and Miles., 2012; Cabell and Oelofse, 2012; Haider *et al*., 2012). Resilience in social–ecological systems has been described as the capacity to continually change, adapt and transform, through innovation, in response to external drivers and internal processes (Folke *et al*., 2010). Darnhofer (2014) proposes that resilience in farming systems can be understood in terms of three capabilities: buffer capability – the ability of the system to cope with shocks and continue functioning more or less as before; adaptive capability – the ability of the system to adjust in the face of external and internal drivers of change; and transformative capability – the ability to undergo radical changes, for example to transition successfully to a completely different farm enterprise or livelihood strategy. It has also been argued that in context of social development and disaster management there is a need to recognize a subjective element in the concept of resilience: to ask, for instance, resilience of what and for whom? (IFRC, 2016).

One of FAO's Strategic Objectives is to "increase the resilience of livelihoods to threats and crisis" (FAO, 2013a). Threats and crises are taken to include natural disasters, emergencies in the food chain (pest and disease outbreaks, food safety crises, pollution events, etc.), socio-economic shocks, violent conflicts and protracted crises (complex, prolonged emergencies combining two or more of the above) (FAO, 2016a). In this context, resilience has been defined as follows: "the ability to prevent and mitigate disasters and crises as well as to anticipate, absorb, accommodate or recover and adapt from them in a timely, efficient and sustainable manner. This includes protecting, restoring and improving livelihoods systems in the face of threats that impact agriculture, nutrition, food security and food safety" (FAO, 2016b).

This section addresses the contributions of biodiversity for food and agriculture (BFA) to resilience. It

[82] This section draws on the thematic study The contribution of biodiversity for food and agriculture to resilience of production systems to environmental change and uncertainty (Duval et al., 2016) commissioned to support the preparation of The State of the World's Biodiversity for Food and Agriculture. Further discussion and further examples of the contributions of BFA to resilience can be found in this paper.

first presents an overview of the ways in which BFA helps to build production systems and livelihoods that are resilient (i.e. are relatively well able to withstand, recover from and/or adapt to threats ranging from gradual environmental, social and economic changes, to climate change-driven increases in the frequency of extreme climatic events, and chronic emergencies and acute disasters associated with natural hazards, armed conflicts, etc.). It then looks more specifically at the roles of BFA in disaster risk management.

Overview of the roles of biodiversity for food and agriculture in resilience-building

As discussed elsewhere in this report (see in particular Section 1.2), the components of biodiversity present in and around production systems, individually and collectively, perform many protective and regulating functions that help to reduce disruption to food and agricultural production and to livelihoods. These functions can often be promoted by appropriate management practices (see Section 4.3) and in some cases their effects are felt far beyond the local production system (e.g. climate regulating and flood control services).

Biodiversity contributes to resilience in a number of different ways. Some components of biodiversity protect the surrounding environment in a direct physical sense. Plants, for example, often provide shelter to other organisms or in bind the soil and help prevent erosion. At a large scale, functions of this kind depend on the existence of a wide range of species (or populations within species such as varieties or breeds) capable of performing them in different environments. At a given location, they may be enhanced by the presence of a diverse range of species that complement each other's actions. The adaptive characteristics of an individual organism or species that enable it to survive in local conditions and deal with various shocks it may encounter (extreme weather, disease outbreaks, etc.) add to the resilience of the ecosystem processes and services to which the species contributes.

However, the role of biodiversity in resilience is not merely a matter of the ability of individual organisms or species to withstand shocks or harsh conditions or the physical protection they may provide. Any given ecosystem function, including those that help to protect the local environment from the effects of shocks, depends on a range of processes that generally involve a web of interactions between different components of biodiversity and the physical surroundings. These processes operate in environments that are not only spatially diverse, but also change over time. These changes, whether short-term events (shocks such as those mentioned above) or longer term trends (e.g. soil erosion or changes in the climate), may threaten to disrupt or overwhelm some of the ecosystem processes that underpin protective functions. The presence of a diverse range of species can help to reduce the risk that this will happen.

For example, if there are several species that are capable of fulfilling a given role in the ecosystem, the loss of one may be compensated for by the presence of the others. Alternatively (or in addition), different species may be particularly well suited to performing the role under different conditions and hence complement each other over time as conditions vary. If the environment is substantially altered, the presence of a range of species that adapt in different ways to change, tends to increase the likelihood that some species contributing to a given ecosystem function will be able to continue fulfilling their roles (Elmqvist *et al.*, 2003). Diversity may underpin the capacity of the system to re-organize itself in a way that allows functions to continue following a major disturbance (*ibid.*).

Resilience is conferred not only by diversity at species level. Within-species genetic diversity increases the likelihood that a population will be able to withstand or recover from shocks and adapt to change and hence to continue their contributions to the supply of ecosystem services (Folke *et al.*, 2004; Hughes and Stachowicz, 2004; Reusch and Hughes, 2006; Sgrò *et al.*, 2011). This applies both to wild and to domesticated components of BFA.

There is ample evidence that some varieties, breeds, or strains of crop plants, forest trees, livestock and aquatic organisms have distinctive traits that help them to cope with harsh conditions, including disturbances such as droughts or disease outbreaks (Moloney *et al.*, 2004; FAO, 2010; FAO, 2014a; FAO, 2015). From the perspective of a household or the food supply within a given area, diversity creates a kind of insurance effect. The presence of at least some crops, livestock, fish, etc. that can cope with shocks of various kinds reduces the risk of disastrous drops in production levels that may have severe impacts on well-being and undermine the capacity of the system to recover.

Diversity-based risk reduction strategies may involve raising a variety of different crop or livestock species that vary in their susceptibility to shocks such as disease outbreaks or droughts that may strike the production system (Hesse *et al.*, 2013). A similar effect can operate within species: different varieties and breeds of crops and animals have capacities to respond to particular stresses. Farmers in the Sahel, for example, tend to hedge against the threat of drought by planting both long and short cycle millet varieties (*ibid*.). Analysis of data from a survey in the Tigray region of Ethiopia showed that maintaining a large number of barley varieties reduced the risk of crop failure, with the effect being particularly marked in areas of degraded land (Di Falco and Chavas 2009). In addition to biophysical risks such as adverse weather or disease outbreaks, biodiversity-based diversification of livelihood strategies can also reduce risk associated with economic shocks such as the loss of markets for particular products. It is also important to note that livelihood resilience in smallholder agriculture in many developing countries depends on the ability to find food outside the farm. Off-farm sources of foods such as fish or forest products are often seasonally important and form an integral part of coping strategies during lean seasons (see Subsection 4.9 below)..

In addition to this type of insurance effect, utilizing a diverse range of crop, livestock, fish or tree resources can also directly enhance ecosystem characteristics that reduce susceptibility to stresses and shocks. For example, raising a range of species, varieties, breeds, etc. – including “cross-sectoral” mixes such as agroforestry, crop–livestock or crop–aquaculture production – within a given field, farm, area of pastureland, forestry plantation, aquaculture holding, etc. can make the production environment less stressful and shock prone. Many different mechanisms can contribute. For example, integrating intercrops, hedgerows and cover crops, particularly legumes, into a system can, inter alia, reduce drought stress by helping to conserve water in the soil profile (Buckles *et al.*, 1998) and help to replenish depleted soil fertility (Kang *et al.*, 1981; Sanchez 2000; Bunch, 2000; Kaumbutho and Kienzle, 2007). Crop diversification, including rotation and intercropping and the use of diverse forage plants in pastureland, can reduce pest damage and weed invasions (Altieri, 1999; Sanderson *et al.*, 2007; Chabi-Olaye *et al.*, 2007).

Integrating trees into a crop production system can help to maintain a favourable microclimate for crop growth in the face of unfavourable conditions in the wider environment, for example maintaining temperatures, humidity and levels of solar radiation within acceptable levels or preventing excessive fluctuation in soil moisture levels (e.g. Lin, 2007). Likewise, trees and shrubs can help protect animals from climatic extremes and provide fodder that can be utilized when other sources are in short supply (Johnson and Nair, 1985; Gregory, 1995; Wagner *et al.*, 2013). In turn, appropriately managed livestock can contribute to the resilience of crop production. For example, inclusion of a grazed pasture rotation in a cropping system can –, through the effects of grazing and dunging – promote the accumulation of soil organic matter, soil microbial activity and the diversity and density of soil invertebrate macrofauna and hence all the resilience-promoting benefits of healthy and biodiverse soils (Salton *et al.*, 2014). Grazing during a pasture rotation can also help to suppress weeds (Salton *et al.*, 2014; Concenço *et al.*, 2015). As discussed in Section 1.2, grazing animals can also be used in the management of fire risk and in the control of invasive plant species, thereby reducing the disruption caused by these kinds of events. Similarly, fish and ducks can contribute to pest control in paddy fields.

Over the longer term, genetic diversity allows crop, livestock, forest and aquatic populations to adapt to changing ecological conditions via natural selection or human-controlled breeding programmes. For example, newly developed drought-, heat- or disease-resistant varieties and breeds of crops, livestock and fish can help to maintain production system resilience in the face of climatic changes or emerging diseases. Genetic diversity also allows breeding programmes to adapt plant and animal populations to changing economic, social and cultural circumstances.

Another aspect of resilience that has begun to receive increasing attention is the role of human nutrition. Good nutrition can be regarded both as an essential “input” for resilience and as an outcome of resilience (FAO, 2014b). Well-nourished people are healthier, can work harder and have greater physical reserves; households that are nutrition secure are therefore better able to withstand and recover from external shocks. Resilient production systems and livelihoods are able to cope with shocks without requiring people to reduce the nutritional quality of their diets, allow for adaptation that enables good nutrition to be maintained in the face of potentially harmful trends (e.g. associated with climate change), and can if necessary be transformed to create new strategies for maintain or improving nutritional status (*ibid*.). BFA plays a key role in delivering well-balanced diets, in buffering diets against shocks and in providing resources for adapting and transforming food production in the face of change.

Use of biodiversity for food and agriculture in promoting resilience to disasters

Disasters and their impacts

Reporting countries were invited to list any disasters that had had a significant effect on their BFA over the preceding 10 years and to describe their effects on biodiversity and the delivery of ecosystem services. Fifty out of 71 reporting countries provided information. Table 20 gives an overview of the major types of disasters reported. A majority of natural disasters reported by countries are weather or climate-related.

Table 20. Natural or human-made disasters reported to have had a significant effect on biodiversity for food and agriculture and/or on ecosystem services in the past 10 years

Natural or human-made disasters	Reporting countries
Floods	Argentina, Bangladesh, Burkina Faso, Cameroon, Croatia, Ecuador, Ethiopia, Germany, Guyana, Hungary, India, Ireland, Mali, Nepal, Slovakia, Slovenia, Sri Lanka, Sudan, United Kingdom, Viet Nam, Yemen, Zambia
Droughts and heat waves	Afghanistan, Argentina, Belgium, Burkina Faso, Croatia, El Salvador, Ethiopia, Gambia, Germany, Guyana, Hungary, India, Ireland, Jordan, Kenya, Mali, Slovenia, Sri Lanka, Viet Nam, Yemen, Zambia
Cyclones/typhoons/hurricanes	Bangladesh, Cook Islands, El Salvador, Fiji, France, Grenada, India, Samoa, Solomon Islands, Viet Nam, Yemen
Storms	Argentina, Croatia, France, Germany, Hungary, Ireland, Slovakia, Slovenia, United Kingdom
Volcanic eruptions	Argentina, Cameroon, Ecuador, El Salvador, Ireland, Solomon Islands
Landslides	Argentina, Bangladesh, Cameroon, Nepal, Sri Lanka, Viet Nam
Epidemics (in animals and plants) and pest and disease outbreaks	Belgium, Burkina Faso, Estonia, Germany, Poland, Slovenia, Sudan, Sweden, United States of America, Zambia
Fires and wildfires	Argentina, Cameroon, Ethiopia, France, Jordan, Kenya, Mexico, Slovenia, Sri Lanka, Sudan, United States of America, Viet Nam
Cold, frost and heavy snow episodes	Belgium, Croatia, Ireland, Jordan, Slovenia, United Kingdom
Tsunamis	Bangladesh, India, Solomon Islands, Yemen
Earthquakes	Nepal, India, Solomon Islands
Heavy rainfall and hail storms	Ethiopia, Hungary, Slovenia, Zambia
Avalanches	Nepal
Armed conflicts	Lebanon, Yemen
Oil spills, mining pollution, chemical industrial accidents	Belgium, Finland, Hungary, Jordan, Lebanon, Mexico, Nepal, Sudan, Viet Nam, Finland, Jordan, Sri Lanka

Source: country reports.

Food and agricultural production systems and the communities that depend on them directly for their livelihoods are often severely affected by the effects of disaster (Doswald and Estrella, 2015; FAO, 2015b). One of the striking elements in many of the material presented in the country reports is the domino and/or multiplication effects of most of the disasters reported. These can be summarized as follows:

- earthquake→landslide→river obstruction or soil erosion;
- cyclone→flooding→pest and disease outbreaks and/or salinization and/or recrudescence of

invasive alien species;
- droughts or floods→ pest and disease outbreaks and/or recrudescence of invasive alien species;
- avalanche→river flood;
- volcanic eruption→high livestock mortality and crop destruction→rural migration;
- tsunami→destruction of agricultural infrastructures and boats.

These chains of events cause losses at production level in all sectors of food and agriculture and also in food processing and distribution. These losses, in turn, threaten food insecurity and livelihoods.

The disaster management cycle

The disaster management can be viewed as a cycle of actions: disaster risk reduction aims to strengthen the capacities of households and communities to protect their lives and livelihoods; emergency response involves the delivery of aid and relief aimed at saving lives and property; post-disaster actions (recovery and rehabilitation) promote the restoration of livelihoods, capabilities and services and allow disaster risk reduction actions to recommence (Bass *et al.*, 2008). BFA can be used to strengthen disaster management actions at each point in this cycle.

Roles of biodiversity for food and agriculture in disaster risk reduction

As described above, BFA help to make production systems and the supply of the ecosystem services they depend on more resilient to shocks of various kinds. BFA can be used both to reduce the risk that disastrous (or potentially disastrous) events occur (e.g. use in flood prevention) and to limit their effects on production systems (e.g. use of trees as shelter against extreme weather or resistant/tolerant crops, livestock or fish to reduce the effects of disease outbreaks). These roles can make a major contribution to disaster risk reduction. Well adapted genetic resources and management practices based on the sustainable use of BFA, including associated biodiversity and wild foods, can also play an important role in recovery and rehabilitation.

Certain production systems are recognized for their key roles in reducing disaster risk (see also Section 3.6). Forests, for example, are often vital to flood protection (UNEP, 2010). More generally, there is growing awareness of the significance of "natural infrastructures" in disaster risk reduction for hazards such as floods, storms and landslides, including because of their capacity to provide multiple benefits (e.g. aesthetic and recreational benefits and improvement of air quality) in addition to their protective functions (e.g. Sudmeier-Rieux, 2013). Nonetheless, ecosystem management is still often an overlooked element of disaster risk reduction. According to Renaud *et al.* (2013): "the role of ecosystems in the context of disasters is perhaps the most overlooked component in disaster risk reduction … and development planning."

Another link between ecosystem management and disaster management lies in the fact that ecosystem degradation often shrinks economic and livelihood options and can therefore drive people into marginal lands and fragile environments where they are more vulnerable to disasters (FAO, 2013b). This threat can be combated by building the resilience of the natural resource base in and around production systems, including by promoting the maintenance BFA that contribute to ecosystem functions and help to regulate the environment and by employing biodiversity-based management practices support the sustainability of farming, livestock keeping, aquaculture, fishery and forest production systems (see Section 4.3).

Many country reports highlight the importance of diverse crops and livestock in improving capacity to cope with disasters. The report from India mentions that in the floods-prone area of eastern Uttar Pradesh, local communities use a diverse range of crop varieties, trees, grasses and animals and the traditional knowledge and skills associated with them. Landless people are able to make a living by keeping small animals. When silt and sand spreads over paddy fields, people learn to grow watermelons, gourds and other vegetables and fruits. Ecuador reports that diversity between and within crop species means that there are always crops in the fields. Although some species and/or varieties are affected, others tolerate or resist the effects of disasters and are able to provide a harvest. The report from Tonga notes the benefits of growing diverse plots of mango varieties as some varieties have proved to be better able to cope with drought episodes.

Many management strategies based on the use of associated biodiversity and/or on mixed production (i.e. integrating different sectors of production – crops, livestock, fish, forest, etc.) can contribute to resilience against disasters. For example, aquasilviculture integrates aquaculture and mangrove forestry, providing both greater resilience to shocks such as extreme weather events and increased production... Further examples of how strategies of this kind promote regulatory ecosystem services that help to minimize the risk and impact of extreme events are noted in the overview presented above. Individual management methods that utilize biodiversity are discussed in greater detail in Section 4.3. It is also important to ensure that development activities do not disrupt the roles of ecosystems in disaster risk reduction. For example, flood risks can be increased by the loss of floodplain connectivity as a result of the construction of roads or dykes, the loss of water meadows due to river training or the removal of mangroves.

Roles of biodiversity for food and agriculture in disaster response and rehabilitation

In the immediate aftermath of a disaster actions focused on the use of BFA will often not be the first priority. Emergency responses will focus on saving lives and insuring basic requirements such as water, food and shelter are provided to the affected communities. However, BFA are often crucial to the rehabilitation phase and in preparedness and risk reduction measures against future disasters. Restoration of degraded systems is important, as in many cases s the degradation of protective functions increases the risk of severe impacts in future disasters.

Rehabilitation in food and agricultural systems often involves the distribution of seeds or animals to allow farming, livestock keeping, aquaculture or forestry activities to recommence and recover. Care is needed to ensure that the material distributed is adapted to local conditions and meets the requirements of local people in what may be difficult post-disaster conditions. The significance of ensuring that appropriate genetic resources are available for distribution during disaster rehabilitation is noted in a number of country reports. For example, Papua New Guinea highlights the importance of storing germplasm from crops identified as being tolerant to salinity, floods and droughts and notes that distribution of adapted seeds has been important in maintaining food security during the (drought affecting the country in 2015–2016. The report from the Cook Islands mentions that government response to disasters normally involves providing seeds and seedlings of short-term or annual vegetable crops, sourced from non-affected areas, to provide an immediate supply of food while damaged longer cycle crops such as bananas, passion fruit and papaya start to recover. Bangladesh reports that after cyclones such as Aila and Sidr soil in affected areas became more saline and that researchers screened for salinity tolerant varieties of rice and other crops that were multiplied and supplied to farmers. The United States of America mentions the Seeds of Success (SOS)[83] program, which helps to re-establish stable native plant communities on land being rehabilitated after disasters such as wildfires.

Gathering, hunting and fishing often increase after a crisis or disaster as a result of the destruction of production systems or displacement of populations. These activities can allow people to improve their nutritional intakes in times of scarcity. In manytropical floodplain systems where flooding is a frequent event, the resulting surge in fish catch is an important coping strategy as well as a source of food in the absence of alternatives and the loss of livestock and crops. Fishing nets and hunting gear are sometimes included in post-disaster emergency kits to help with short-term coping strategies However in the long term and if not practised sustainably their use can seriously damage local ecosystems and make them and their capacity to provide food less resilient in the face of future disasters. For example, mass-provision of fishing nets provided in emergency kits may result in significant over-fishing.

BFA's other roles in post-disaster management can include contributions to the biological control of mass pest outbreaks or to bioremediation following disastrous pollution events (see Section 3.4). Pack animals can be used to deliver food aid to inaccessible areas and there is also interest in the potential roles of micro-organisms in food preservation in disaster situations (Beed *et al.*, 2011).

[83] https://www.blm.gov/wo/st/en/prog/more/fish__wildlife_and/plants/seeds_of_success.htm

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[4.10 The contribution of biodiversity for food and agriculture to livehoods]

[4.11 Needs and priorities]

CHAPTER 5 – THE STATE OF CONSERVATION OF BIODIVERSITY FOR FOOD AND AGRICULTURE

[5.1 Introduction]

5.2 The state of characterization

Introduction

Lack of knowledge of the characteristics of the various components of biodiversity for food and agriculture (BFA) and of the trends affecting them is often a serious constraint to their sustainable use and conservation.

Knowledge is generated by a range of different stakeholders, including direct users of BFA, such as farmers, livestock keepers and breeders, fishers, foresters and aquaculture practitioners, as well as researchers and specialists of various kinds from the public, private and non-governmental sectors. National governments typically implement at least some policy measures to support and coordinate activities. The Convention on Biological Diversity requires its Parties to identify and monitor components of biological diversity and processes and categories of activities that "have or are likely to have significant adverse impacts on the conservation and sustainable use of biological diversity" and to maintain and organize data derived from identification and monitoring activities.

Effective management of the components of BFA requires information on a range of different attributes and how they change over time, including their geographical distribution, the size and structure of their populations, their functions within the ecosystem and roles in the supply of ecosystem services and distinctive characteristics that enable them to fulfil these roles or that might be valuable in the future. Potential threats to their survival or opportunities to promote their sustainable use and conservation need to be identified. Molecular characterization methods can be used, inter alia, to assess genetic variability within and between populations and for genetic characterization of traits (e.g. physical appearance, productivity, disease resistance and other adaptation traits) specific to given populations.

Plant genetic resources for food and agriculture

In the plant genetic resources for food and agriculture (PGRFA) subsector, the term "characterization" is used to describe the process by which gene bank accessions are described with regard to a particular set of universally agreed morphological traits, known as descriptors (FAO, 2010).[84] These traits are usually highly heritable, easily measured or assessed and expressed the same way in all environments. "Evaluation", on the other hand, provides data about traits that are generally considered to have actual or potential agronomic utility. Often, the expression of these traits varies with the environment, so valid conclusions require evaluation in different environments.

The state of characterization and evaluation is typically assessed on the basis of the proportion of accessions that have been characterized and evaluated. Despite ongoing work on the part of gene banks and associated programmes, often involving regional and international collaboration, a significant portion of germplasm accessions remain uncharacterized or not properly documented. Lack of standardization in data collection, storage and dissemination, along with suboptimal access to data, are also constraints. Many countries regard a lack of readily available characterization and evaluation data as a major constraint to the greater use of PGRFA in breeding programmes. Problems are particularly acute for underutilized crops and crop wild relatives, some of which are likely to assume greater importance in the future as a consequence of the effects of climate change. Molecular characterization of germplasm has become more widespread across regions and crops, although much remains to be done both to generate more data and make them more readily available. Systematic surveying and inventory of PGRFA *in situ* remains underdeveloped. This area of work tends to be constrained by a lack of funding, human resources, knowledge and coordination.

[84] The material presented in this subsection largely based on The Second Report on the State of the Worlds Plant Genetic Resources for Food and Agriculture (FAO, 2010).

Animal genetic resources for food and agriculture

Characterization of animal genetic resources for food and agriculture (AnGR) encompasses a range of data-gathering activities (FAO, 2015).[85] The unit of management in the AnGR subsector is generally the breed. A primary task of characterization activities is therefore to identify (if this has not already been done) the distinct breed populations present in the targeted area. Countries interested in promoting sustainable management of their AnGR will generally seek to establish complete national inventories of their breeds. Both phenotypic and molecular genetic studies can contribute to this process and to the accumulation of knowledge on recognized breeds and the relationships between them. Some phenotypic data can be obtained both through one-off surveys, others require extended longitudinal studies. One shortcoming of many AnGR characterization studies is that they have beene undertaken as academic activities, with the results destined to appear in the scientific press, rather than undertaken to provide information that can be utilized directly by stakeholders in the field. Data on breeds' production environments is needed if production data are to be interpreted properly, and they may also allow inferences to be drawn regarding the breeds' adaptive characteristics and help in the development of plans for their sustainable management. Assessing risk status requires data on the size and structure of breed populations. Data on breeds' geographical distributions can be useful in determining their risk status and in identifying the characteristics of the production environments in which they are raised. Keeping track of trends in breed risk status requires regular monitoring of population data and other factors that may threaten breeds' survival.

While recent years have seen some improvement in the state of inventory, characterization and monitoring activities for AnGR, major gaps remain, particularly in the developing regions of the world. Many countries consider that their breed inventories are not yet complete. Many breed populations are not subject to monitoring activities that are sufficiently comprehensive and regular to allow risk status to be tracked at optimum levels. The phenotypic data needed in order to adequately compare the performance of different breeds in specific production environments or to take advantage of developments in molecular genetics are often unavailable.

Forest genetic resources

Efforts to promote conservation and sustainable management of forest genetic resources (FGR) require information on, inter alia, levels of diversity, in particular tree populations and the extent of the risks facing them, the location of populations or individuals with rare alleles, relationships between genetic variability and environmental parameters, and trends in genetic variability, for example in response to silvicultural and harvesting regimes and environmental changes (FAO, 2014).[86]

Breeding programmes require information on the identity of species and populations with the greatest potential for commercial development, on desirable productive, service or adaptive traits in priority species, on genetic markers linked to adaptive or other desirable characteristics, and on sources of propagation materials. Data can be gathered through studies of morphological characteristics, use of various biochemical and DNA markers, field-based studies, provenance and progeny trials, and laboratory-based investigations.

At interspecific level, a lot of characterization data are captured through biological and forestry inventories undertaken in the course of resource management activities. However, such surveys often fail to capture and document the extensive genetic resources present in circa situm environments.

Characterization of intraspecific diversity is recognized as a central component of the conservation and management of individual tree species. However, the sheer number of species present in many countries makes characterizing any more than a small fraction of species at this level extremely challenging. Considerable information is available on the variability of the most commercially important species in four of the most widely planted genera globally: *Acacia*, *Eucalyptus*, *Populus* and

[85] The material presented in this subsection is largely based on The Second Report on the State of the Worlds Animal Genetic Resources for Food and Agriculture (FAO, 2015).

[86] The material presented in this subsection is largely based on *The State of the Worlds Forest Genetic Resources* (FAO, 2014).

Pinus. Efforts to characterize species that are less widely planted but important locally or in naturally regenerated forests are lagging and in urgent need of study.

Provenance testing – growing trees selected from different locations (provenances) in the same field environment so that observed variation among populations or individuals can be attributed to genetic differences – has a long history and continues to be used widely in tree breeding and improvement programmes. Provenance testing is time consuming, expensive and vulnerable to risks associated with natural disasters and other disruptions. However, as it does not require high levels of technical infrastructure or facilities, it is used widely in tropical countries, where trees often have fast growth rates and shorter rotation periods.

Great reductions in the costs of gene sequencing and increases in computer processing speed and power have led to a proliferation of DNA studies in tree species, including whole genome sequencing and rapid progress in identifying the location and function of specific genes.

As measuring changes in genetic variation in all or most trees species is impractical, monitoring in the FGR subsector is done either by monitoring only highest priority or model species or by monitoring surrogate measures such as the area of forest or tree cover. The level of FGR monitoring varies greatly between countries. Developed countries with well established national forest inventories and monitoring systems are better placed to document and describe changes in FGR than most developing countries. However, genetic monitoring of forests is at a very early stage of development, with only a small number of pilot studies having been implemented so far.

Even when FGR-related data are collected, they often remain scattered and difficult for potential users to obtain. FGR information systems urgently needed to be established or strengthened. The use of common protocols for FGR inventories, characterization and monitoring would help to ensure that data collected from different countries are comparable.

Aquatic genetic resources for food and agriculture

Characterization and monitoring of aquatic genetic resources for food and agriculture (AqGR) is carried out mainly at the species level. The international standard for reporting production is the Aquatic Sciences and Fisheries Information System (ASFIS) list and the classification system of the International Standard Statistical Classification of Aquatic Animals and Plants (ISCAAP). These lists are the international standard for listed species that are cultured or captured. Member countries provide an annual report to FAO on their fisheries and aquaculture production and this information can be publically accessed through FAO FishStatJ.[87] The information is also summarized in FAO's biennial publication series The State of World Fisheries and Aquaculture, which also provides information (at species level) on the status of marine capture fisheries (see Chapter 3).

There is at present no global information system on aquatic genetic diversity below species level (FAO, 2016) that could assist with characterization and monitoring AqGR. The international standard classification for use in fishery statistics, (the ASFIS list – see above), does not include any subspecies, stocks, strains or varieties of farmed species or their wild relatives. Powerful genetic sequencing and genetic mapping technologies are now making it easier and less expensive to characterize aquatic organisms at finer scales of resolution, such as the stock, strain and even individual pedigree levels (Liu, 2016). This will enable more refined reporting for culture species that have multiple strains, as well as for some of the highly migratory capture fishery stocks.

Although information on genetic diversity at within-species level can be extremely useful in AqGR management, little is collected or made available to potential users, except for some high-value species in developed countries. For example, within species data are available on salmonids and are used in managing populations in the wild.[88] About 75 percent of the country reports submitted for the forthcoming report on *The State of the World's Aquatic Genetic Resources for Food and Agriculture*

[87] http://www.fao.org/fishery/statistics/software/fishstatj/en
[88] http://www.nmfs.noaa.gov/pr/pdfs/species/sacramentoriver_winterrunchinook_5yearreview.pdf

(SoWAqGR) indicated that genetic information was used to only a minor extent or not at all in managing farmed aquatic resources.

In the aquaculture sector, monitoring at breed or strain level, as done in the terrestrial livestock sector, is constrained by a lack of standardized strain nomenclature and characterization, and the relatively recent history of strain development in aquatic species (FAO, 2016). In capture fisheries, genetic diversity is sometimes used in the management of high-value species, but this requires the establishment of baseline data followed by regular sampling, monitoring and analyses. The financial and technical capacity to do this is often lacking in many areas. Stock identification in capture fisheries has traditionally been based on geographic location, and production has been reported and monitored accordingly (e.g. North Atlantic cod stocks, Lake Victoria Nile perch, in-shore herring stocks and Columbia River chinook salmon).

For given countries or habitats, aquatic species can be categorized as native or non-native (sometimes called exotic or alien species). Introductions of aquatic species across national boundaries are recorded in FAO's Database on Introductions of Aquatic Species (DIAS).[89] DIAS, contains over 5 000 records from inland and marine ecosystems, including fishes, molluscs, crustaceans, echinoderms and plants. This database is not updated annually, and currently serves more as a historical record of introductions than as a monitoring system.

In addition to establishing or strengthening surveying and monitoring systems and national databases for farmed AqGR and for their wild relatives, priorities in this field of AqGR management include improving information on fish genetic diversity and adopting standard nomenclature for its description. Neither the SoWAqGR nor the FAO fisheries and aquaculture databases have required countries to list aquaculture farming systems or the state of aquatic ecosystems. Therefore monitoring and characterization of these elements are generally missing from global fishery reports. The draft SoWAqGR does note that the reason for the decline of many wild relatives of farmed aquatic species was due to habitat loss or degradation. Therefore particular attention needs to be paid to natural ecosystems and wild relatives that are threatened by environmental disturbances such as draining wetlands and the construction of dams or hydro-power plants.

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Liu, Z.J. 2016. Draft thematic background paper for the State of the World's Aquatic Genetic Resources, *Genome-based Biotechnologies in Aquaculture*, FAO, Rome.

[89] http://www.fao.org/fishery/dias/en

5.3 The state of characterization of micro-organisms[90]

[EDITOR'S NOTE: Material from country reports will be added to this section.]

Characterization of the micro-organisms involved in traditional food processing is an ongoing task. Only a fraction of the estimated 5 000 types of artisanal, including indigenous, fermented foods and beverages worldwide of have been studied scientifically. Where studies have been carried out they have often merely identified the primary microbiota in the finished product and perhaps undertaken some preliminary characterization of them. However, in-depth information on microbial communities, their structure, interactions, succession during the fermentation process, influence on product quality and safety is now rapidly accumulating. Studies are revealing the incredible complexity of practically all artisanal fermentations.

In the case of fermentations for which there is already a considerable body of knowledge on the role and activity of the relevant microbiota, the challenges enfacing the scientists and technologists are somewhat different. Here, the goals are to further improve reliability and product quality by optimizing starter culture performance and to eliminate those factors that impede the fermentation process. Many micro-organisms used in food production have already been sequenced genetically and this creates many new opportunities to improve culture performance and ultimately the safety, quality and composition of the food supply.

The use of up-to-date analytical methods is providing detailed information on roles of single strains and species in fermentation processes. This is enabling the selection of starter cultures and the management of the fermentation process to be fine-tuned to increase product quality (sensory, physical structure, texture, nutritional value, health/functional attributes, etc.) and products safety. Future trends in demand will inevitably create the need to expand and diversify the manufacture of traditional food products under conditions in which quality and safety can be guaranteed. This in turn will create the challenge for how to organize production on a large scale without losing the unique flavour and other traits associated with the original products. This will require a more thorough understanding of the types of micro-organisms involved and their specific activities. Improving "natural" processing methods as alternatives to chemical or thermal preservation will be another potential application.

Mathematical analysis of the biokinetics of food-processing micro-organisms is a quite novel but very promising and rich domain of research. Strains that show excellent functional behaviour under optimal laboratory conditions frequently fail in practical food processing. Because of the complexity of the processes involved it is often difficult to identify what is causing the problem. Predictive modelling may yield precious information about the relationship between the food environment and bacterial functionality and thereby contribute to optimal strain selection and process design.

High-throughput omics technologies and bioinformatics are providing new avenues for the development of rational approaches to improving the functionality and safety of microbial food processing (Alkema *et al.*, 2016).

Microbes used in food processing have relatively small genomes. Examples include the bacterium Lactobacillus casei (3.0 megabases, Mb), the yeast *Saccharomyces cerevisiae* (12.1 Mb) and the mould *Penicillium roqueforti* (27.9 Mb). Sequencing technologies have evolved at a fast pace in the last few years, and it is now possible to completely sequence a bacterial genome in a few hours and at a relatively low cost. Moreover, recent developments in single-cell sequencing (Nawy, 2014) allow the genomes of uncultured micro-organisms to be sequenced (at present, the vast majority of micro-organisms cannot be cultured in vitro). Complete, annotated genome sequences are available for thousands of bacteria and dozens of fungal species (NCBI, 2016). Comparative genomics takes advantage of these data to identify biological similarities and differences and evolutionary relationships between organisms. Partial genome sequencing (random or targeted) enables faster identification of genetic markers linked with (positive and negative) traits of interest. Single nucleotide polymorphism (SNP) microarrays can also be used for this purpose. DNA sequencing and microarray

[90] This section draws on the Background Study Paper prepared by Alexandraki *et al*. (2013).

technologies can also be used to detect pathogenic and toxigenic micro-organisms (Bergholz *et al.*, 2014).

Technologies that focus on gene expression (RNA-seq, gene expression microarrays), protein levels (mass spectrometry, protein chips) and metabolites (chromatography, mass spectrometry, nuclear magnetic resonance) are being used to identify and quantify gene products and other molecules at a high resolution. These data can be used to study the effects of the environment (temperature, humidity, nutrients, etc.) on microbial physiological properties and metabolic processes, and the impact of various industrial production parameters on gene expression and metabolite accumulation. Taken together, these data may be of use in controlling organoleptic characteristics and optimizing microbial food processing. Food-safety applications include risk analysis and detection and quantification of transcripts or proteins that predict the presence of undesirable molecules (Giraffa and Carmintati, 2008; Postollec *et al.*, 2011).

Metagenomics is the study of genetic material recovered directly from complex samples to characterize the diversity of microbial communities (Handelsman 2004; Nikolaki and Tsiamis 2013; Bokulich *et al.*, 2016). The ability to clone large fragments of metagenomic DNA allows entire functional operons (units of genomic DNA containing a cluster of genes under the control of a single promoter) to be targeted and creates the possibility of tracing entire metabolic pathways. Comparative metagenomics, in which libraries (collections of DNA sequences) prepared from different sites or at different times are compared (Randazzo *et al.*, 2009; Riesenfeld *et al.*, 2004), will allow understanding of microbial communities to be further advanced. Metagenomics and metatranscriptomics can be very powerful means of gaining insights into the microbiology of fermented foods. For example, they can provide information on critical fermentation parameters affecting quality and on interactions (and possibly trophic chains) between bacteria in fermentation ecosystems. These approaches will be propelled forward by the tremendous advances that are occurring in sequencing technologies. More widespread application of bioinformatics will help to maximize the insights derived from such studies (van Hijum *et al.*, 2012).

Much still needs to be done to improve cooperation with the research community. For example, strains cited in the scientific literature should, whenever possible, be secured for future use. Project consortia such as the European Consortium of Microbial Resource Centres (EMbaRC)[91] and organizations such as Microbial Resource Research Infrastructure (MIRRI)[92] and the Global Biological Resource Centre Network (GBRCN)[93] are trying to address these issues and several journals already are revisiting their policies to try and ensure the biological material on which published information is based is available for the future. Policies are also in place to ensure voucher specimens underpinning microbial taxonomy are preserved and made available for the long term. However, accessibility to key strains still needs to be improved (Stackebrandt *et al.*, 2014).

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5.4 Conservation of genetic resources for food and agriculture

Introduction

Conservation of biodiversity for food and agriculture comprises a range of actions taken with the aim of preventing the loss of diversity in the species, populations and ecosystems that constitute this category of biodiversity. Conservation actions can span all levels from practical management activities at the level of the production system or the gene bank to initiatives at policy level. Actions can be specifically targeted (e.g. aiming to protect a particular species) or more diffuse (e.g. aiming to protect the biodiversity in and around a given production system, or at national or global level). They can be more or less standalone activities or be part of coordinated programmes or strategies. They may or may not involve use (farming, gathering, etc.) of the targeted components of biodiversity.

The boundaries of conservation as a field of action are not always easy to define. For example, biodiversity may benefit inadvertently as a result of actions taken primarily in pursuit of non-conservation related objectives or survive because of the absence (for whatever reason) of damaging actions. Moreover, conservation involves, or depends on, a range of different components of biodiversity management, including various sustainable-use practices, characterization and monitoring, research, education and training, awareness-raising and the development of appropriate organizational, policy, legal and funding frameworks. However, not all biodiversity-related work in these fields focuses on conservation (see elsewhere in this section for more detailed discussion of the state of provisions in these fields). Management of domesticated species normally involves some attention to the need to maintain genetic resources for future rounds of production. However, this does not preclude the loss of genetic diversity, particularly that which may be valuable in the long rather than the short term. Within the country-reporting processes for *The State of the World's Biodiversity for Food and Agriculture* and the various global sectoral assessments of genetic resources there were inevitably some differences in how strictly the concept of conservation was interpreted.

Conservation activities are typically categorized as *in situ* or *ex situ* (see Concepts and Definitions section). There are, however, some differences in how these terms are used in the different sectors of food and agriculture. For example, where plant genetic resources are concerned, *in situ* conservation is often taken to include both on-farm conservation of domesticated crop species and conservation of crop wild relatives in natural or semi-natural ecosystems. However the term is sometimes used in a narrower sense to refer only to the latter (i.e. a distinction is sometimes drawn between *in situ* and on-farm conservation).

In the case of animal genetic resources, while *in situ* conservation broadly defined would include actions targeting feral populations or the wild relatives of domesticated animals, the term generally used to refer to the conservation of domesticated animals on farms and in other livestock production systems (e.g. by pastoralists). It has been defined as follows: "support for continued use by livestock keepers in the production system in which the livestock evolved or are now normally found and bred" (FAO, 2015). Where *ex situ* conservation of animal genetic resources is concerned, a distinction is drawn between *ex situ* in vivo and *ex situ* in vitro conservation (the latter is also referred to as cryoconservation) (*ibid*). *Ex situ* in vivo conservation is achieved "through the maintenance of live animal populations not kept under normal management conditions (e.g. in a zoological park or a governmental farm) and/or outside the area where they evolved or are now normally found and bred." *Ex situ* in vitro conservation is achieved "through the maintenance, under cryogenic conditions, of cells or tissues that have the potential to be used to reconstitute live animals and populations at a later date."

In the forest genetic resources sector, where conservation largely focuses on wild species, a third category – circa situm conservation – is distinguished from *in situ* and *ex situ* conservation. The term is used to describe a type of conservation that emphasizes the role of regenerating saplings in linking vegetation remnants in heavily modified or fragmented landscapes such as those of traditional agroforestry and farming systems (FAO, 2014). Conservation of forest genetic resources on farms often falls into this category. In other cases, it constitutes a type of *ex situ* conservation.

In the aquatic genetic resources sector, *in situ* conservation can refer to conservation in wild habitats or conservation of domesticated genetic resources in aquaculture systems.

In the case of associated biodiversity, *in situ* conservation refers to conservation actions that involve maintaining the targeted components of biodiversity in and around the production systems where they are normally found.

Where the conservation of live organisms is concerned, distinctions between *in situ* (or circa situm) and *ex situ* conservation are not always clear cut. In the animal genetic resources sector, for example, in vivo conservation can be regarded as a spectrum ranging from the maintenance of animals in very "artificial" environments such as zoos, through experimental farms and farm parks, to actions taken to support the maintenance of at-risk breeds by livestock keepers in normal production systems. Likewise in the case of species used in aquaculture, on-farm conservation is not always clearly distinguishable from *ex situ* conservation in a live gene bank.

Plant genetic resources for food and agriculture

Ex situ conservation of plant genetic resources is achieved through the storage of seed in specially designed cold stores or, in the case of vegetatively propagated crops and crops with recalcitrant seeds, the raising of living plants in field gene banks. In some cases, tissue samples are stored in vitro or cryogenically. A few species are also maintained as pollen or embryos. There is increasing interest in the conservation implications of storing DNA samples or electronic DNA sequence information.

Ex situ conservation represents the most significant and widespread means of conserving plant genetic resources. Most conserved accessions are kept in specialized facilities known as gene banks, maintained by public or private institutions acting either alone or networked with other institutions.

As of 2010, there were more than 1 750 individual gene banks worldwide, about 130 of which held more than 10 000 accessions each. There were also substantial *ex situ* collections in botanical gardens of which there were over 2 500 around the world. Gene banks were located on all continents, but there were relatively fewer in Africa than in the rest of the world. Among the largest collections are those that have been built up over more than 40 years by the CGIAR and held in trust for the world community. In 2010, there were an estimated 7.4 million accessions (1.4 million more than in 1996 when the first report on *The State of the World's Plant Genetic Resources for Food and Agriculture* was published). The Svalbard Global Seed Vault, opened in 2008, provides a secure global backup of crop diversity held in gene banks around the world providing insurance against both incremental and catastrophic losses. Concerted efforts have been made to deposit duplicate accessions from the CGIAR global collections and many national and regional collections.

For several staple crops, such as wheat and rice, a large part of the genetic diversity is currently represented in collections. However, for many other crops, considerable gaps remain. Interest in collecting crop wild relatives, landraces and neglected and underutilized species is growing. Many countries still lack adequate human capacity, facilities, funds or management systems to meet their *ex situ* conservation needs and obligations. This puts a number of collections at risk. The documentation and characterization of many collections is still inadequate and in cases where information does exist, it is often difficult to access. The overall poor documentation of *ex situ* collections also constrains efforts to reduce duplication of conservation measures and hence affects efficiency at global and regional levels. Greater efforts are needed to build a truly rational global system of *ex situ* collections. This requires, in particular, strengthened regional and international trust and cooperation.

In situ conservation of crop wild relatives generally occurs as a side-effect of efforts to protect habitats or charismatic species, rather than as a result of deliberate targeting. The main mechanism involved is the designation of protected areas of various types. As of 2014, 20.6 million km^2 (15.4 percent) of terrestrial and inland-water areas were designated as protected areas, an increase of about 1 million km2 since 2010 (Juffe-Bignoli *et al.*, 2014). However, the lack of specific measures targeting crop wild relatives increases the risk that important resources will fall through gaps in conservation coverage. Areas rich in crop wild relative diversity (e.g. areas of origin) are less well covered by protected areas than the overall global figures would suggest (FAO, 2010).[94] Wild relatives are often inadequately surveyed relative to other components of biodiversity, although surveys targeting these resources are becoming more common.

A substantial amount of crop wild relative diversity is located outside protected areas. Protecting this diversity may require, for example, specific management agreements between conservation agencies and those who own or have rights over the respective sites. Such agreements are becoming more common, especially in North America and Europe.

On-farm conservation efforts, particularly efforts to maintain traditional crop varieties, have gained considerable ground in recent years. Many programmes have been established and new tools have been developed that provide for better assessment and understanding of this diversity and the mechanisms through which it is maintained. Increasing attention has been paid, for example, to the significance of particular types of management system (e.g. home gardens), "informal" seed systems, the interface between wild and agricultural plants and ecosystems, traditional knowledge and the roles of particular groups of farmers as custodians of diversity. A number of different measures can be taken, depending on the circumstances, to support the maintenance of PGRFA *in situ*. These include adding value to local genetic resources via improved characterization, improving local materials through breeding and seed processing, increasing consumer demand through market incentives and raising public awareness, improving access to PGRFA and information about them, and the establishment of supportive policies, legislation and incentives. Recent years have, to varying degrees, seen positive developments in all these fields.

Despite the broadly upwards trend in the level of *in situ* and on-farm conservation activity for PGRFA, much remains to be done. There is a need for more effective policies, legislation and regulations governing the *in situ* and on-farm management of PGRFA, both inside and outside protected areas. Closer collaboration and coordination are needed between the agriculture and environment sectors. Many aspects of *in situ* management require further research.

Animal genetic resources for food and agriculture

In situ conservation measures for AnGR can involve a wide range of activities, including those that aim to increase demand for products and services from at-risk breeds (e.g. development of marketing opportunities for products, including niche products, and promotion of breeds' roles in tourism or in habitat or landscape management), those that focus on supporting or incentivizing livestock keepers (e.g. incentive or subsidy payments, recognition or award programmes, extension programmes or awareness raising), activities focused on breeding programmes and activities focused on participation and empowerment at community level. In the case of *ex situ* in vitro conservation the most commonly stored material is semen, followed by embryos. Oocytes, somatic cells and isolated DNA are also sometimes stored.

In situ and *ex situ* approaches to conservation are generally regarded as complementary to each other. For example, when AnGR are maintained *in situ* they can continue to evolve in response to changes in the production environment and knowledge and skills related to their management can also be preserved. *Ex situ* in vitro conservation provides a source of genetic material that be drawn upon as a backup if some disaster (such as an epidemic) strikes the live population or used in other ways to support the genetic management of the live population.

Most countries that participated in the reporting process for *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture* (FAO, 2015) indicated that they had at least some AnGR conservation activities in place. In vitro gene banks had been established by 64 (out of 128) reporting countries and a further 41 were planning to do so. Many of these gene banks were in the early stages of development and the collections often had many gaps in their coverage of relevant breeds and populations. The coverage of *in situ* conservation activities was also incomplete (i.e. many

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[94] Unless otherwise stated, the material in this section is based on analysis presented in *The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture* (FAO, 2010).

countries considered that their conservation measures were insufficient to adequately protect their breeds from the risk of extinction). However, a diverse range of different activities were reported. For example, countries were increasingly developing niche markets for speciality products as a means of increasing the profitability of potentially threatened breeds.

In some countries, inadequate funding, infrastructure and technical skills often remain significant obstacles to the establishment or further development of gene banks for AnGR. More generally, in order to strengthen both *in situ* and *ex situ* conservation efforts, there is a need to strengthen the basic human capacities and institutional structures needed for effective AnGR management, for example in the fields of research education and training, stakeholder (particularly livestock keeper) participation, policies and legal frameworks.

Forest genetic resources

In situ conservation is the preferred means of conserving forest genetic resources (FGR), as it is a dynamic approach that allows temporal and spatial changes in genetic diversity. *Ex situ* conservation, in contrast, is mostly static (maintains a one-off sample of genetic diversity). The main goal of the dynamic approach is to maintain evolutionary processes (natural selection, genetic drift, gene flow and mutation) within tree populations, rather than to preserve their present-day genetic diversity (e.g. Lande and Barrowclough 1987; Eriksson *et al*., 1993; FAO, FLD and IPGRI, 2004a). In most cases, it is also easier and cheaper to conserve tree populations in their natural habitats than under *ex situ* conditions. However, e*x situ* conservation of forest genetic resources (e.g. in seed banks, seed orchards, field collections, provenance trials, planted conservation stands or botanical gardens) is a necessary complement to *in situ* conservation, especially when population size is critically low in the wild.

In situ conservation of FGR is typically carried out in protected areas or managed natural forests by designating conservation stands for this purpose (FAO, DFSC and IPGRI, 2001). Both protected areas and managed natural forests may have some limitations from the genetic conservation point of view. It is commonly assumed that seemingly natural forests are always pristine forests or that these forests consist of autochthonous, genetically diverse tree populations. However, human influence has modified forests and their biodiversity for millennia in all parts of the world, including the seemingly intact and pristine natural tropical forests (e.g. McNeely, 1994). Most protected areas are established to conserve endangered animal and plant species or ecosystems, and rarely to conserve the genetic diversity of forest trees. Consequently, conservation of FGR is often given a low priority or not recognized at all in the management of protected areas. Furthermore, silvicultural treatments that may be necessary to maintain or enhance genetic processes within tree populations are often not permitted in protected areas. In the case of managed forests, past or current utilization and management practices may have altered the genetic composition of tree populations and some forest stands may have been established with tree germplasm brought in from other locations. Thus, the conservation value and suitability of a given tree population located in a protected area or a managed forest should be carefully evaluated based on historical records, if available, or other relevant information, before stands are designated for FGR conservation. Ideally, a network of such conservation stands should cover the whole distribution range of a tree species.

Many tree species produce recalcitrant or intermediate seeds that lack dormancy and are sensitive to desiccation and low temperature. Such seeds are short-lived and lose their viability within a short period of time (typically about two weeks). This is a major problem, especially in humid tropics, where more than 70 percent of tree species have recalcitrant or intermediate seed behaviour (Sacandé *et al.*, 2004). *Ex situ* conservation of these tree species is therefore based on field collections, *ex situ* conservation stands and breeding populations, as well as on more sophisticated approaches such as cryopreservation, seedling conservation, in vitro conservation, pollen storage and DNA storage (FAO, FLD, IPGRI, 2004b). In forest trees that have orthodox seeds, *ex situ* conservation can be implemented by drying and storing seeds at low temperatures. The seeds can be maintained in this way for years without losing their viability.

Countries that contributed to *The State of the World's Forest Genetic Resources* (SoW-FGR) reported a wide variety of *in situ* conservation efforts, covering in total nearly 2 000 species of trees, scrubs, palms and bamboo (including subspecies) (FAO, 2014a). However, interpretation of the concept of *in situ* conservation varies from country to country (e.g. whether or not the mere presence of a given tree species in a protected area can be regarded sufficient grounds for stating that it is subject to FGR conservation). Countries were not asked to report on the completeness of *in situ* conservation (i.e. whether conservation efforts cover the whole distribution range of a given species). These factors, along with the incompleteness of reporting, make the global situation difficult to assess. However, of nearly 8 000 species reportedly used by countries for various purposes, only about 12 percent were reported to be subject to any form of *in situ* conservation (FAO, 2014a). Although many countries reported that protected areas represent their main *in situ* conservation activity for FGR, most of these areas had not been designated with the aim of conserving FGR and did not have management plans specifically addressing this objective. Most *in situ* conservation of FGR takes place outside protected areas on a range of public, private and traditionally owned lands, especially in multiple-use forests and forests primarily designated for wood production. Unfortunately, *in situ* conservation of FGR within the world's many protected areas and managed forests remains poorly documented and countries have developed their national strategies for FGR conservation based on a variety of different approaches to and interpretations of *in situ* conservation. Work in Europe offers a rare example of the development of a regional strategy for FGR conservation based on a systematic assessment of existing conservation efforts (de Vries *et al.*, 2015; Lefévre *et al.*, 2013) and a harmonized concept of conservation units (Koskela *et al.*, 2013).

According to the SoW-FGR (FAO, 2014a), a total of 1 800 species are conserved *ex situ*, many of which are conserved only in botanical gardens. Of the 2 260 priority species listed in country reports, 626 were reported to be subject to some form of *ex situ* conservation. Only 135 were being conserved in more than one country. Globally, the total number of FGR accessions reported was 159 579, including an unknown number of multiple accessions. Most accessions are in field collections, including clone banks and provenance trials; far fewer are in seed or in vitro collections.

In conclusion, there is a need to enhance all types of FGR conservation. Priorities for action are set out in the Global Plan of Action for the Conservation Sustainable Use and Development of Forest Genetic Resources, adopted in 2013 (FAO, 2014b).

Aquatic genetic resources for food and agriculture

In situ conservation measures in the aquatic sector comprise actions taken to protect aquatic genetic resources (AqGR) both in the wild and in aquaculture. The main *in situ* measures for wild aquatic biodiversity are the establishment of protected areas and the use of fishery management methods that promote sustainable fishing and conservation.

The Aichi Targets call for countries to establish protected areas in 17 percent of their terrestrial and inland waters and 10 percent of their marine areas by 2020. However, the scientific basis for these targets and their actual meaning have been questioned and it is unclear if countries will be able to or willing to meet them (Charles *et al.*, 2016). Since 1996, criteria for identifying wetlands for inclusion in the Ramsar Convention's list of international importance under the Ramsar Convention have included criteria based on fish. The list's 2 200 sites represent the world's largest network of protected areas and make a major contribution to *in situ* conservation of aquatic genetic resources. However, it does not include marine areas.

Formally designated protected areas have been shown to be effective at conserving biological diversity (Ballantine, 2014). This is generally borne out in the country reports submitted for the forthcoming report on *The State of the World's Aquatic Genetic Resources for Food and Agriculture* (SoW-AqGR). However, although it is often believeds that increased biodiversity within the protected area will lead to increased production outside the protected area, this has not been well established and depends on numerous site specific conditions (Charles *et al.*, 2016; Fletcher *et al.*, 2015). It is recognized that there are several levels of protection in protected areas ranging from strict "no-take" areas to multiple use areas that are managed for a variety of purposes, including conservation and harvest. Some have interpreted the Aichi protected area target as referring to strict "no take" reserves (Charles *et al.*, 2016), but this may not be the case.

The country reports listed several objectives for conservation of AqGR, including, preservation of aquatic genetic diversity, maintenance of good strains for aquaculture production, meeting consumer and market demands, helping adaptation to the impacts of climate change and providing material for future breed improvement in aquaculture. Preservation of genetic diversity was reported to be the most important objective in both developed and developing countries. Meeting market demands was the least important objective, even in developing and least developed countries.

The ecosystem approach to fisheries and aquaculture, an approach that aims to "plan, develop and manage fisheries in a manner that addresses the multiple needs and desires of societies, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by marine ecosystem" (FAO, 2003), is being adopted by fisheries managers around the world (COFI, 2016). However, only a minority of reporting countries were able to report the existence of policies that clearly address the objective of conserving AqGR in fisheries and aquaculture. The country reports provide also little evidence of organized efforts specifically to promote the conservation of AqGR in modified ecosystems such as rice fields. To ensure the conservation of AqGR there is a need for better harmonization of fishery and environmental and for the development and implementation of appropriate regulatory measures for the management of wild relatives.

Most farmed aquatic species were domesticated relatively recently and *in situ* (on farm) conservation measures for such species are less common than for terrestrial domesticated animals and plants. On-farm conservation is not always clearly distinguishable from *ex situ* conservation in a live gene bank. A few examples exist of managed live-gene banks that maintain genetically improved farmed types under farming conditions that allow continued evolution; such facilities exist, for example, for carp in Hungary (Bakos and Gorda, 2001).

Ex situ measures for AqGR include the maintenance and captive breeding of live organisms in zoos, aquaria and live gene banks, the storage of cell lines and tissue cultures in vitro and the cryopreservation of male gametes, tissue cultures and cells. Thirty-three (70 percent) of the 47 countries that submitted reports for the SoW-AqGR indicated that *ex situ* conservation activities were being implemented at national level for aquatic organisms of national relevance falling within the scope of the report. A total of 344 species were being maintained in 112 *ex situ* collection in these countries. Among these species, 100 were considered to be threatened or endangered at national and/or international levels. Twelve countries had such species among their collections. Finfish account for 90 percent of the species conserved and aquatic micro-organisms such as rotifers and micro-algae for 10 percent. The finfishes are maintained both for direct human consumption and as live feed for aquaculture. The micro-organisms are in most cases used as live feed for aquaculture. About 20 percent of reporting countries indicated that they had in vitro AqGR collections (farmed species and wild relatives). A total of 95 aquatic species are maintained in these collections.

Priorities for improving the conservation of AqGR include, on the *in situ* side, maintaining and improving aquatic habitats, improving fishery management, designating freshwater and marine protected areas (taking into account genetic, ecological and demographic parameters to promote the conservation of distinct target populations), improving water management, reducing pollution, reducing the negative impacts of capture fisheries and using an ecosystem approach in the management of riparian and open water habitats.

Ex situ conservation efforts could be stepped up through the establishment of new conservation facilities and captive breeding programmes, as well as through research into conservation strategies and techniques, including live gene banks, cryopreservation of gametes and embryos and tissue banking. Although frozen seed banks function well in the plant sector, embryos and eggs of aquatic species are extremely difficult to freeze and keep viable. Therefore, it is only the male gamete that can be effectively cryopreserved. Research is addressing this problem, but no practical solutions have been found as yet (Lee *et al.*, 2013).

Hatcheries have been developed to raise aquatic species *ex situ* for eventual release back into the wild or into modified habitats such as rice fields and reservoirs. These are often called "conservation hatcheries" and they are intended to reduce the artificial selection pressures of the hatchery environment while increasing the naturalness of the environment in the hatchery (e.g. providing natural substrates and feed). This is common in restoration efforts in North America and Europe (Schramm, and Piper 1995). Although hatcheries can also contribute to capture fisheries, conservation hatcheries are usually devoted to rare, threatened or endangered species or stocks.

Associated biodiversity

In situ conservation programmes

[EDITOR'S NOTE: This section is only partially edited and review has not been completed.]

The majority of information in this chapter is extracted from regional reports which are a synthesis of the country reports submitted for *The State of the World Report on Biodiversity for Food and Agriculture* (SOWBFA) for that region.

From the regional syntheses reports it would seem that generally *in situ* conservation of associated biodiversity occurs as a result of efforts to conserve biodiversity in terrestrial, freshwater and marine ecosystems rather than as a specific programme targeting single or multiple species of importance to ecosystem function. Protected areas are reported by many countries in all the regions as contributing to the *in situ* conservation of associated biodiversity. The term 'protected area' includes Marine Protected Areas (MPA) the boundaries of which will include some area of ocean.

Monitoring protected areas and tracking species is often constrained because of resource limitations and as highlighted in Section 3, many countries indicated that resource (human and financial) limitations affected the development and implementation of *in situ* conservation of associated biodiversity. These constraints point to the need for a very targeted and focused approach, identifying the species of importance to food and agriculture and determining how to ensure that any risks to that species are mitigated. Partnerships and collaboration within and across countries and regions are also vital to minimize the constraints imposed by resource limitations.

An early study on threats facing 92 protected areas in 22 tropical countries concluded that most protected areas are successful in protecting ecosystems (Bruner *et al.* 2001). A recent global review by the World Bank shows that tropical protected areas, especially those conserved by indigenous peoples lose less forest than other management systems (Nelson and Chomitz 2011). A review of 112 studies in 80 MPAs found strikingly higher fish populations and larger fish inside the reserves compared with surrounding areas, or the same area before the reserve was established; fish from within the MPA help to replenish adjacent fished areas (Halpern, 2003). Fisheries monitoring in the Bamboung MPA in Senegal, for example, has demonstrated an increase in fish size, species biodiversity and biomass less than five years after its establishment. How effective protected areas are in delivering ecosystem services and conserving associated biodiversity depends on how well they are managed, how they are integrated with surrounding landscapes and land use strategies and whether they have the support of local communities (Lopoukhine *et al.* 2012).

Ecosystem services approaches provide opportunities for biodiversity conservation including the development of broader landscapes for conservation and therefore an increase in the possibilities for influencing decision-making; opportunities to add or create new value to protected areas; and the opportunities to manage ecosystems sustainably outside of protected areas. However they do have their limitations which include the conservation of species without utilitarian or economic value; ecological processes that do not directly benefit people; and critical ecological functions that may be undermined in attempts to optimize a target service (Ingram *et al.* 2012). Payment for ecosystem services (PES) can encourage farmers living in or near protected areas, buffer zones and biological corridors to adopt improved land management techniques, thereby reducing negative impacts on biodiversity.

In many countries, especially in Europe, agri-environment schemes are being utilized for conserving and promoting biodiversity. Flower strips are one example of these schemes, with the aim of supporting biodiversity, leading to an increase in "useful" species groups such as pollinators for crop pollination and natural enemies for pest control. A number of reviews have looked at the effectiveness of these schemes in achieving biodiversity enhancement. Klein and Sutherland (2003) found that the lack of robust evaluation studies prevented an assessment of the effectiveness of European agri-environment schemes and suggested that in the future, ecological evaluations must become an integral part of any scheme, including the collection of baseline data, the random placement of scheme and control sites in areas with similar initial conditions, and sufficient replication. They further recommended that the results of these studies should be collected and disseminated more widely, in order to identify the approaches and prescriptions that best deliver biodiversity enhancement and value for money from community support. Uyttenbroeck *et al.* (2016) considered the effect of flower strips on the economical balance and social recognition of the farmer with a view to increasing uptake and concluded that more research in these areas was required to provide better information for farmers to improve uptake of the approach.

In situ conservation of associated biodiversity in the different regions

Africa

Of the countries that submitted a country report from the Africa Region, Cameroon, Ethiopia, the Gambia and Kenya have reported *in situ* conservation initiatives that are in place for associated biodiversity. Examples of activities and initiatives are summarized in Table 21.

Table 21. *In situ* conservation or management activities or programmes for associated biodiversity for food and agriculture in Africa region

Examples of species	Examples of sites	Conservation objectives	Actions taken
Spirulina (Arthrospira fusiformis)	Lake Chitu, Killole, and Arenguade, and Oromiya region	To conserve micro algal diversity in alkaline water ecosystem for future utilization	Construction of physical and biological conservation structures around the lakes harbouring the microorganisms and reduction of human interference through community participatory action.
Various species of bacteria nitrogen fixing, mycorrhizal association	Various sites covering about 9.124.666 ha	Protection of biodiversity	Protected Area regulations forbid human activities
Insect larvae, tadpoles, *Achatina* sp (land snails)	Inland waterways, Forest floor farms and plantations	Foods, research, preservation of the species	Avoid agriculture and mining activities that can pollute waterways
Various amphibians, reptiles, birds, and mammals	Various parks and reserves	For income generation, foods, research and preservation of the species	Protected area regulations forbid human activities; special hunting seasons in parks and Reserves peripheral zones and in hunting zones
At least 232 trees species reported to be in association with tree mycorrhiza	Various parks and reserves, botanic gardens	Ecosystems services	Protected Area regulations forbid human activities
Spirulina (*Arthrospira fusiformis*), and *Rhizobium* sp, and many other unknown species.	All protected areas	(a) Biodiversity conservation; (b) To conserve micro algal diversity in alkaline water ecosystem for future utilization	(a) Construction of physical and biological conservation structures around the lakes harbouring the microorganisms and reduction of human interference through community participatory action; (b) Species management actions
Wildlife species such as Dacus vertebrates (fruit flies), *Bactrocera* sp. - tephritid fruit flies) and habitats	All protected areas	Fauna conservation	Species management actions
Various plants, for example, *Adansonia digitata* (baobab)	Parks, reserves and botanic gardens	Ecosystem services	Protected area regulations
Many mushrooms species	Bijilo & Pirang Forest Parks	Ecotourism and conservation	Protection against illegal activities
All forests species, whole	Githitho, several	Biodiversity conservation,	Monitoring and protections for

forests ecosystems	kayas forests	research, Education and livelihood enhancement	forests types including their associated biodiversity and ecosystems services

Source: country reports.

As an example, Kenya has nine marine protected areas (MPAs), including marine reserves, marine parks, man and biosphere reserves and national reserves. Kenya's MPAs were established to protect and conserve the marine and coastal biodiversity and related ecotones in order to enhance regeneration and ecological balance of coral reefs, seagrass beds, sand dunes and beaches, and mangroves. Studies have shown that the MPAs have improved fish availability through the emigration or spillover of fish to adjacent artisanal fisheries (Tuda and Omar, 2012).

Some of the reports analysed indicated that there are currently no national policies that include explicitly the management of biodiversity for food and agriculture, in particular, that of associated biodiversity. In the regional synthesis only Cameroon was identified as having a policy, namely the national policy on management of protected areas including marine reserves, which referred to sustainable use and conservation of associated biodiversity.

Asia

The countries of the Asia region acknowledge the importance of *in situ* conservation for the sustainable use of biodiversity for food and agriculture however conservation efforts tend to focus on animal and plant genetic resources. Countries highlighted the importance of natural protected areas for *in situ* conservation of associated biodiversity. Bhutan reported that more than 50 per cent of the country's territory is covered by natural protected areas. Some of these areas focus on the protection of very emblematic species, such as the snow leopard, but through this focus, habitats are conserved which would be important for associated biodiversity. Afghanistan provided an overview of the country's national parks and protected areas, including a list of species that are targeted for protection.

In Bangladesh, forests, mangrove forests and freshwater wetlands are conserved in protected areas. Thirty-seven protected areas particularly aim to conserve the diversity of forest ecosystems. Some of Viet Nam's protected areas also have a special focus on forests; the country established a series of special-use forests to protect the survival of rare endangered forest tree species. Viet Nam also mentioned having established a national conservation system, involving six ministries, for micro-organisms, as well as for animal, plant, forest and aquatic genetic resources, under which *in situ* and *ex situ* conservation are combined. Viet Nam lists 47 species of invertebrates that are conserved *in situ* in protected areas, including marine protected areas.

For all the initiatives described in the regional synthesis, the conservation focus was generally on multiple species. Some exceptions were noted, such as the *Tor putitora*, or golden mahseer, an endangered species of cyprinid fish being conserved in Nepal and *Glyptostrobus pensilis*, also known as Chinese swamp cypress, being conserved in Viet Nam. Generally the focus was biodiversity conservation but supporting self-recruitment was also provided as a conservation objective for invertebrates and vertebrates.

Table 22. Examples of protected areas with *in situ* conservation initiatives for associated biodiversity in Asia

Country	National Park/protected area	Species targeted
Afghanistan	Big Pamir	Alpine vegetation, such as *Ericaceae (*heath/heather), grasses, *Premula marcophyla*
	Ab-i- estada	Steppe vegetation, such as A*mygdalis spp, Cousinia spp, Tamarix spp* (tamarisk, salt cedar) and *Artemisia* spp
	Ajar valley (proposed)	*Salix spp* (deciduous trees and shrubs), *Tamarix spp*, Herbaceous plants such as, *Ephedra spp* (gymnosperm shrubs) *Zygophylum spp, Acantholimon steppe,* and *Carex stenophylla* (sedge) meadows communities and grazing areas.
	Bande Amir	Vegetation: Salix spp, Mentha longifolia (mint), Acantholimon (prickly thrift), Tulipa spp, Alliums spp, Gagea spp,and Ranunculus sp.
	Hamun-i- Puzak	*Phragmites australis* (perennial grasses) and algae, *Artemisia, Tamarix,*

		and migratory bird species.
	Nurestan	*Juglans* (walnut), *Betula* (birch), *Quercus* (oak), *Cedrus* (cedar), *Pinus* (pine), *Juniperus* (juniper) and Alpine shrub land.
	Dashte Nawar	Highland steppe vegetation, such as *Bromus* (grasses), *Puccinellia* (alkali or salt grass), *Aeluropus* (grasses), *Acanthelimon* (prickly thrift) community (G*laux maritima* (sea milkwort) *Crypsis aculeata (*annual grass), *Polygonum sibericum.* *Algae*
Vietnam	Ba Be National Park	Calocedrus macrolepis (Chinese incense-cedar) Manglietia conifera
	Ben En National Park	Calocedrus macrolepis
	Hoang Lien National Park	Medicinal plants and *Fokienia hodginsii* (conifer)
	National Park Pu Mat	Cunninghamia konishii (evergreen conifer) Fokienia hodginsii
	Earal and Trap KSo Protected Areas	*Glyptostrobus pensilis* (Chinese swamp cypress)
	York Don National Park	Dipterocarpaceae family
	Hon Mun Marine Protected Area in Nha Trang Bay	Marine genetic resources
	Cham Island MPA	Marine genetic resources
	Phu Quoc MPA	Marine genetic resources
Nepal	Lake Rara National Park	Endemic fish species
	Lake Phewa	Mahseer (Tor putitora)
Sri Lanka	Protected areas, including marine and natural forest	Varies
India	Dudhwa Sanctuary, Utar Pradesh;	*Labeo calbasu* (orange-fin labeo)
	Vembanad Lake, Kerala	Macrobrachium rosenbergii (giant river prawn)

Source: country reports.

In 2002, some 350 species of reef-building scleractinian corals (64 genera, 15 families, including distribution range extensions for some 40 species and 1 genus into Vietnam), 220 species of demersal fishes (102 genera, 38 families), 106 species of molluscs, 18 species of echinoderms and 62 species of algae and sea-grass were recorded in the Hon Mun Marine Protected Area (MPA) in Nha Trang Bay (Si Tuan *et al.* 2002). A recent study highlighted the threats posed to the biodiversity in this MPA, in particular, the coral diversity (Isaac *et al.* 2016).

With respect to the conservation and (to a far lesser extent) use of associated biodiversity and wild food species, countries referred, inter alia, to the following national policies and programmes:

- National Biodiversity Strategy and Action Plans (NBSAPs);
- National environmental policies, programmes and conservation strategies that contribute, inter alia, to the conservation of habitats and biodiversity;
- Agro-environmental schemes and rural development programmes;
- Wetland policies aiming to maintain wetland functions and values and promoting the integration of wetland functions in natural resource management and economic development;
- Policies and management plans to facilitate the implementation of ecosystem approaches (e.g. coastal zone policies promoting the conservation of coastal ecosystems, including mangrove and coral ecosystems, and their biodiversity in Bangladesh; and Viet Nam's management regulation of the Can Gio Mangrove Biosphere Reserve);
- Pest management policies promoting integrated pest management practices, including biological control;
- Environment Conservation Acts. In Bangladesh, seven areas defined as Ecologically Critical were defined under a similar Act; Soil and Water Conservation Acts;
- Wildlife Acts providing a legal framework to preserve and manage wildlife; and
- Climate change policies, strategies and action plans, including National Adaptation Programmes of Action (NAPAs). Viet Nam has defined clear objectives to protect the country from the effects of, and to adapt to, climate change. This is reflected, inter alia, in a series of laws and decrees (see http://snrd-asia.org/2016/03/15/strategic-mainstreaming-of-ecosystem-based-adaptation-in-vietnam-eba/).

Europe and Central Asia

Compared to other regions, Europe and Central Asia has a particularly high level of knowledge on the state and trends of associated biodiversity. Some targeted *in situ* conservation programmes exist, but most species are conserved through general biodiversity conservation efforts. However, programmes are on-going that target habitats and species in and around production systems, seemingly because of their beneficial roles in food and agricultural production. For example, conservation and development of wild bees and butterflies in Wallonia, Belgium through the use of flower-rich pasture strips in cropland. In the Netherlands, the maintenance and creation of field boundaries to support insect fauna and its role in providing pollination and crop protection services is considered a form of *in situ* conservation and management.[95]

Belgium, Bulgaria, Croatia, Estonia, Finland, France, Germany, Hungary, Ireland, the Netherlands, Norway, Poland, Slovakia, Sweden, Switzerland, Turkey and the United Kingdom indicated having *in situ* conservation initiatives in place targeting either a single or multiple associated biodiversity and/or wild food species as part of general efforts to conserve biodiversity in terrestrial, freshwater and marine ecosystems. Most of the examples given referred to conservation programmes seeking to maintain, protect and restore habitats and their rich array of species in and around production systems, for example dead-wood management to maintain biodiversity associated with forests and woodlands[96], the reintroduction of extensive mowing and grazing to allow the recovery meadows and grasslands rich in flowers, insects and birds, buffer zone management along field borders to support beneficial insects and the designation of protected areas on land and at sea.

In Europe the importance of forest deadwood for maintaining, conserving and enhancing biological diversity in forest ecosystems was recognized by the Ministerial Conference on the Protection of Forests in Europe (MCPFE) (2002) during the definitions of a set of Pan-European indicators for sustainable forest management. Deadwood can be usefully considered in order to measure the level of biodiversity (Indicator 4.5: volume of standing deadwood and of lying dead-wood on forest and other wooded land classified by forest type) (Paletto *et al.* 2012).

Most EU Member States mentioned the importance of direct support schemes under the Common Agricultural Policy, such as payments for agricultural practices that are climate friendly and beneficial to the environment and payments in support of sustainable forest management practices. Non-EU members in the region do not benefit from this support and may therefore have very different needs and priorities in terms of policy and programme development for the conservation and use of biodiversity for food and agriculture.

Some species, among many others, that are conserved through general biodiversity conservation efforts are presented in Table 23.

Table 23. Some of the species conserved in the region through general biodiversity conservation efforts

Type of associated biodiversity	Species
Invertebrates	Pollinating insects such as bees (*Apis mellifera* and *Bombus subterraneus*) and butterflies Native snail species (e.g. *Vertigo geyeri* and *Vertigo angistior*) Freshwater pearl mussels (Margaritifera margaritifera and Margaritifera durrovensis) Crayfish (Austropotamobius pallipes and Pacifastacus leniusculus)
Vertebrates	Various types of bat; A large number of fish species, including grayling (*Thymallus thymallus*), brown trout (*Salmo trutta*), Atlantic salmon (*Salmo salar*), common nase (*Chondrostoma nasus*); Amphibians and reptiles
Micro-organisms	Fungi, lichen and algae varieties

[95] The establishment of flower-rich habitats within or around intensively farmed landscapes has been shown to increase the ecological fitness of pollinator populations through enhanced larval and adult nutrition. Such strategies also provide secondary benefits to the farm and surrounding landscape, such as pest population reduction and soil quality improvement, generally enhancing the associated biodiversity within the landscape (Wratten et al. 2012).

[96] Species which depend on deadwood as a habitat or food source for all or part of their life cycle include lichens, fungi, bryophytes and a wide variety of different kinds of invertebrates, hole-nesting birds and mammals (Humphrey and Bailey, 2012).

Source: country reports.

Switzerland reported having a data centre that provides detailed descriptions of the country's amphibians and reptiles, their distribution as well as practical tips for conservation activities and Spain mentioned having developed recovery plans for two lizard species that are at risk of extinction.

The Fauna-Flora-Habitat and the European Bird Protection Directives, as well as Natura 2000, the EU-wide network of protected areas, were described as particularly important to the conservation and development of habitats and species in need of special protection.

With respect to the conservation of associated biodiversity, the importance of National Biodiversity Strategy and Action Plans was frequently mentioned. Individual country initiatives in this field include Germany's National Programme for the Conservation and Sustainable Use of Genetic Resources of Micro-organisms and Invertebrates and France's Agricultural Observatory of Biodiversity. The latter involves farmers in monitoring the state of different components of associated biodiversity in agricultural environments and identifying how these components relate to farming practices. In Estonia, *in situ* conservation is supported by various national strategic documents and initiatives, such as, Estonian bio-economy strategy (until 2030) and the Estonian organic farming development plan 2014-2020.

No examples were given of sub-regional/regional collaboration in the *in situ* conservation of associated biodiversity.

Latin America and the Caribbean

The Plurinational State of Bolivia, Ecuador, El Salvador, Grenada, Jamaica, Mexico, Nicaragua, Panama and Peru reported having *in situ* conservation programmes for associated biodiversity; these programmes generally referred to ecosystems, landscapes, seascapes and watersheds. Groups of species being conserved include mostly plants and animals with some examples of invertebrates and micro-organisms.

Jamaica reported the *in situ* conservation of multiple finfish species, conch, corals and sea urchins for management and recovery. Conservation actions include fish sanctuaries, replanting of corals and strategies to deter and combat alien species, such as lionfish.

Box 10. The Caribbean Fish Sanctuary Partnership Initiative (C-FISH)

(a) The Sandy Island/ Oyster Bed Marine Protected Area (SIOBMPA), Grenada
The SIOBMPA comprises an area of 787 hectares on the southwest coast of Carriacou. It is considered to be one of the most important marine ecosystems in the region. Safeguarding this area ensures the health of vital marine and coastal ecosystem including extensive coral reef system, mangrove forest, small islands, and sea grass beds.
(b) Bluefields Bay, Jamaica
Bluefields Bay is Jamaica's largest sanctuary which includes mangroves, seagrass beds, coral reef and artificial reef units, providing ideal habitats for fish to use as nurseries before migrating out of the sanctuary.

Source: http://www.c-fish.org/where-we-work/carriacou/

In Peru, especially in the Andean zone, *in situ* conservation of biodiversity for food and agriculture and associated biodiversity has been practiced for centuries. One such initiative, '*Proyecto Conservación In situ de Cultivos Nativos y de sus Parientes Silvestres*' targeted 11 native crop species, 19 crop associations and involved 154 communities in 53 districts.

Mexico presented an extensive report on initiatives for the *in situ* conservation of associated biodiversity, including vertebrates, invertebrates and microorganisms. Several marine fishing refuge zones throughout Mexico's coastline protect at total of 163 species of fish, crustaceans, conchs, and sea turtles.

The effectiveness of protected areas (PAs) in Mexico for biodiversity conservation (though not specifically that of associated biodiversity) was evaluated by the UNDP National Commission for the Knowledge and Use of Biodiversity (CONABIO-UNDP, 2009). The wide variability in the effectiveness of PAs in the protection of ecosystems and biodiversity is related to a variety of biogeographic and socio-institutional factors. Identified biogeographic factors include soil type, elevation, vegetation, topography, climate, and others such as routes of communication (roads and paths). Socio-institutional factors include the characteristics of the populations living in the PA and using its resources, as well as the characteristics of the institutions responsible for its management. Environmental conditions leading to productive activities, such as farming, livestock production or logging, and proximity of the PA to urban or tourist centres in the presence of growing population, together create adverse conditions for the effectiveness of PAs. By contrast, PAs with poor access, low productivity potential, low density of roads, and reduced populations engaging in low-impact production activities and who recognize and accept the reserve, tend to have low transformation rates. Generally it was found that the PAs which have been most effective are those which foster links with the communities located within or around them, and which have links with research centres, universities and NGOs. The study highlighted the importance of traditional agroecosystems, artisanal fisheries, and strategies for multiple uses of resources. Agricultural landscapes oriented towards multiple uses maintain abundant vegetation cover in the form of agricultural plots in various stages of succession, hedges, forest fragments and scattered trees, providing habitats for associated biodiversity.

Regional initiatives reported for the *in situ* conservation of biodiversity and wild food species include the C-Fish Project devised by the environmental not-for-profit CARIBSAVE Partnership. The project aims at strengthening community based fish sanctuaries and marine protected areas (MPAs) in five countries across the Caribbean – Dominica, Grenada, Jamaica, ,Saint Lucia, and Saint Vincent and the Grenadines − with the objective of generating significant environmental, social and economic benefits from sustainable fisheries to tourism to natural coastal defences.

In terms of the conservation of associated biodiversity country reports do not indicate any specific policies and programmes. The regional report selected the regulation on responsible fishing in Peru as a policy directly supporting sustainable conservation of associated biodiversity.

Near East and North Africa

Most countries, namely Egypt, Iraq, Jordan, Lebanon, Oman, Sudan and the United Arab Emirates reported on *in situ* conservation initiatives, such as natural reserves, marine reserves, forest reserves and botanical gardens. Objectives vary depending on the country. Oman reports that the objective of reserved areas is to conserve ecosystems. Jordan reports that the objectives are biodiversity conservation, awareness raising, utilization, research or as a source of genes. Jordan is monitoring *Vespa orientalis* (oriental hornet) in order to control its effect on local honey bees with the objective of conserving the local honey bees. Lebanon provided a long list of invertebrates that are conserved on organic farms for biocontrol, for example, *Opius concolor*, a parasite used for the control of olive fly. A number of countries did not specifically report the objective of their *in situ* conservation activities and also some of the examples reported by countries did not always directly relate to associated biodiversity.

Egypt has sought to protect its natural resources and marine biodiversity by establishing a network of six MPAs that are generally located in the Gulf of Aqaba and the Red Sea; most of them include interconnected marine and terrestrial sectors based on conserving coral reefs and accompanying systems. Egyptian waters have significant levels of biodiversity. There are more than 5,000 species, including 800 species of seaweeds and seagrasses, 209 species of coral reefs, more than 800 species of molluscs, 600 species of crustacean and 350 species of Echinodermata (Samy *et al.,* 2011).

Countries in the region report on several policies and programmes that support conservation and sustainable use of biodiversity for food and agriculture but do not explicitly address associated biodiversity. Laws, projects and programmes for the protection of the environment and wildlife may cover the issues of maintenance of ecosystem services and the conservation of associated biodiversity but do not address them explicitly. For example, in Sharjah, United Arab Emirates, the strategic goals of the Nature Reserves Authority include establishment and monitoring of natural reserves in the

Emirate to preserve and manage all their resources, as well as control of sources of pollution of the environment. Policies supporting the application of an ecosystem/landscape/seascape approach in the Near East region are mentioned by, Jordan, Iraq, Oman and Sudan.

Pacific region

In the Southwest Pacific region there are significant number of protected areas and marine sanctuaries, which support *in situ* conservation. For example, in Palau, the Palau National Marine Sanctuary is one of the largest protected areas of ocean covering 500,000 km^2 in the world. Palau has also established the first Shark Sanctuary covering roughly 600,000km^2. The sanctuary protects over 135 Western Pacific shark species as well as rays – species that are vital to the balance of the ocean's ecosystems.

Within the Southwest Pacific region only Kiribati reports *in situ* conservation of invertebrates through its work on sea cucumber ensuring population levels are sufficient to support economic activities. The Cook Islands, Kiribati, Palau and Papua New Guinea all report on *in situ* conservation of vertebrates with the objective being to increase and maintain populations. In some cases, cultural importance and awareness is also an objective. Marine invertebrates are also important for food security in this region, where land availability can be a constraint.

Locally Managed Marine Areas (LMMA) are found in 143 of Fiji's 410 *i-qoliqoli*[97] areas; 415 tabu (no-take) areas cover an area of over 960 km^2. The first LMMA site, established in 1997, covered 24ha and was set aside for clams.

Table 24. Some of the associated biodiversity species conserved through *in situ* conservation

Country	Species
Cook Islands	Rarotongan flycatcher *Pomarea dimidiata*; Rarotongan starling *Aplonis cinerasreus*; Cook Islands fruit dove *Ptilinopus rarotongensis*; Mangaia kingfisher *Todiramphus ruficollaris*; Cook Islands reed warbler *Acrocephalus kerearak*o and the Atiu swiftlet *Collocalia sawtelli*.
Fiji	Fish and invertebrates, corals
Kiribati	Wild bird, sharks, crab, tuna, corals, sea cucumber and other marine and terrestrial species are protected and conserved.
Palau	More than 1,300 species of fish and 700 species of coral are found in the protected area and over 135 Western Pacific shark species in the shark sanctuary.
Papua New Guinea	Species of Eastern Long-beaked Echidna and, Matsie's tree kangaroos, New Guinea Pademelon, Leatherback sea turtle and Wahnes's bird of paradise are being monitored.

Source: country reports.

Box 11. The Arnavons Community Marine Conservation Area (ACMCA), Solomon Islands

Since the ACMCA's foundation, the Arnavons have experienced a remarkable recovery. The number of hawksbill turtle nests that are laid annually at the Arnavons has doubled and biological surveys show that other species, such as giant clams and trochus, are also thriving. And in 2008, the ACMCA won the Equator Prize at the World Conservation Congress in Barcelona, earning recognition for its efforts to alleviate poverty through conservation. The conservation efforts have stimulated interest in sustainable agriculture with benefits for biodiversity and ecosystem health.

For most of the protected areas the conservation objectives include protection from commercial resource extraction; provision of a protected nursery ground for marine species; restocking of declining fish populations to ensure food and nutritional security and economic development. Generally multiple species are protected – for example, in Palau, more than 1,300 species of fish and 700 species of coral are found in the protected area.

[97] The *iqoliqoli* is the customary fishing ground which extends from the high-tide water mark along the shoreline to the most outer reef crest (that is it can be either a fringing or a barrier reef). Hence, a iqoliqoli may consist of the following biophysical features: shoreline with mudflats and/or beaches; mangrove ecosystem, fringing reef system, lagoon and barrier reef system. (http://www.sprep.org/pyor/reefdocs/CRISP/C2A5_Fiji_qoliqoli_tourism.pdf)

The Pacific has a number of sub-regional and regional initiatives which, although not specifically targeting associated biodiversity will through their implementation and management sustain associated biodiversity – these include:

- The Framework for Nature Conservation and Protected Areas in the Pacific Islands region, 2014-2020, providing guidance for the region on key priorities for biodiversity conservation and ecosystem management with clear linkages to NBSAPs and the Aichi Biodiversity targets.
- The GEF-Pacific Alliance for Sustainability (GEF-PAS) Integrated Island Biodiversity project conserves ecosystems, species and genetic diversity in the Pacific region. Countries involved include the Cook Islands, Nauru, Tonga and Tuvalu.
- Marine and coastal biodiversity management in the Pacific island countries (MACBIO) is being implemented in Fiji, Kiribati, Solomon Islands, Tonga and Vanuatu (2013-2018).
- The Micronesia Challenge[98] is a commitment by the Federated States of Micronesia, the Republic of the Marshall Islands, the Republic of Palau, Guam, and the Commonwealth of the Northern Marianas Islands to preserve the natural resources that are crucial to the survival of Pacific traditions, cultures and livelihoods. The overall goal of the Challenge is to effectively conserve at least 30 per cent of the near-shore marine resources and 20 per cent of the terrestrial resources across Micronesia by 2020.
- The Coral Triangle Initiative: The Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security (CTI-CFF) is a multilateral partnership of six countries (Indonesia, Malaysia, Papua New Guinea, Philippines, Solomon Islands, Timor-Leste) formed in 2007 to address the urgent threats facing the coastal and marine resources of one of the most biologically diverse and ecologically rich regions on earth. It is defined by its extremely high marine biodiversity.
- The Dugong and Seagrass Conservation Project[99] aims to enhance the conservation of dugongs (Dugong dugon) and their associated seagrass ecosystems in eight countries in the Indo-Pacific region (Indonesia, Madagascar, Malaysia, Mozambique, Solomon Islands, Sri Lanka, Timor-Leste and Vanuatu).
- GEF-funded Forestry and Protected Area Management (FPAM) in Fiji, Niue, Samoa and Vanuatu project is designed to strengthen the capacity of Fiji, Niue, Samoa and Vanuatu to arrest the continuing loss and degradation of their native forests and at the same time, improve in sustainable ways the livelihoods of rural populations whose dependence on biodiversity is a contributing factor. The targeted countries are located in two of the World's 34 'Biodiversity Hotspots' where the richest and most threatened reservoirs of plant and animal life are found.

No one national policy or programme specifically refers to associated biodiversity. Protected Areas Acts and Regulations address the management of protected areas or areas where special measures need to be taken to conserve biological diversity and the regulation of biological prospecting research. Papua New Guinea has the more recent Policy on Protected Areas (2014). Papua New Guinea has a number of policies acknowledging the wealth of diversity in the country and establishing conservation and sustainable use approaches. Conservation and sustainable use of biodiversity is well captured in the fifth Pillar, 'Environment Sustainability and Climate Change' of the PNG Vision 2050.

North America

For the North America region, a report was submitted by the United States. In the United States of America, key trend data on biodiversity tracks four primary indicators with regards to the impact of agriculture on these indicators:

- Freshwater species
- Birds
- Pollinators
- Soil biodiversity

In the United States of America focused conservation efforts involving the farming community, federal and state agencies and nonprofit organizations can yield results in species conservation.

[98] http://www.nature.org/ourinitiatives/regions/asiaandthepacific/micronesia/howwework/
[99] http://www.dugongconservation.org/

Nationwide declines in some grassland-nesting bird species have increased efforts in preserving, managing and restoring grassland habitat. The designation of the greater sage-grouse as an Endangered Species led to sagebrush conservation initiatives which focused on the shared vision of wildlife conservation through sustainable ranching, providing win-win solutions for producers, sage-grouse and 350 other obligate species. Similarly active wetland restoration has seen positive trends in populations of wetland-dependent birds.

Most of the initiatives reported by the United States of America refer to the impact of agriculture on biodiversity, rather than biodiversity for food and agriculture. However, addressing concerns about species decline also has positive impacts for farmers and agriculture systems. Studies have shown that foraging waterfowl significantly reduce standing stalks from the rice fields which are a major challenge for farmers in rice cultivation (Brogi *et al.* 2015).

The United States of America have also put significant efforts into conserving pollinator habitats because of concern over declining bee populations. The National Pollinator Health Strategy, released in 2015, has ‘increasing and maintaining cumulative pollinator habitat acreage in critical regions of the country’ as one of its three outcome metrics.

Policy mechanisms in the United States of America that support *in situ* conservation of associated biodiversity would include regulatory approaches where policies ban or restrict activities that pose a threat to biodiversity either directly or indirectly and land preservation and restoration programmes where activities protect or restore landscapes.

The Conservation Stewardship Program (CSP) presents a significant shift in how the Natural Resources Conservation Service (NRCS) provides conservation program payments. CSP participants receive an annual land use payment for operation-level environmental benefits they produce. Under CSP, participants are paid for conservation performance: the higher the operational performance, the higher their payment. The CSP programme has nearly 3,000 CSP contract holders that have selected enhancements that establish pollinator habitat in non-cropped areas on their lands. Through these enhancements, participants seeded over 11,000 acres of nectar and pollen producing plants in field borders, vegetative barriers, buffer strips, and waterways, providing increased diversity for pollinator habitat. Additional CSP enhancements beyond the ones targeted to habitat also continue to support producers in reducing pesticide application and providing a critical food supply for pollinators and beneficial insects.

Needs and priorities

The background study paper of the Commission on ‘Climate change and invertebrate genetic resources for food and agriculture: state of knowledge, risks and opportunities’ found there were many gaps with regards to knowledge of invertebrate resources as affected by climate change. In the area of conservation, use and access, in particular, the report identified a need for technologies and approaches to ensure the conservation and promotion of generalist natural enemies in agricultural landscapes through improved knowledge of landscape-level movement, and the effects of resources such as spatial and temporal refugia and alternative food sources (Cock *et al.* 2011)

In Asia lack of funding and human resources to manage protected areas appears to be an issue that is shared by all countries. In Afghanistan, political instability and social unrest have been a major constraint to advancing work in the area of *in situ* conservation. Even so, some new sites were recently designated as national park/protected areas to ensure the conservation of, inter alia, alpine vegetation, wild plant, fruit and nut varieties, and bird species. Viet Nam is strongly committed to the maintenance and continued development of a widespread network of national parks, nature reserves, cultural and historical sites and “special-use” forests that are home to many rare and endangered species, including species of relevance to food and agriculture.

In the North Africa and Near East region funding support was also highlighted as a constraint to the implementation of *in situ* initiatives. Other countries, such as Algeria and Sudan, emphasized the importance of a national framework or strategy to support conservation, sustainable use and valuation of biodiversity for food and agriculture, including associated biodiversity. Both Iraq and the United Arab Emirates reported on the need for increased establishment of protected areas, with the United

Arab Emirates specifying that 12 per cent of terrestrial waters and 14 per cent of coastal and marine areas required protection.

In Europe and Central Asia countries tend to agree that the conservation of biodiversity for food and agriculture requires an integrated approach that balances *in situ* and *ex situ* conservation strategies. Examples of sectoral genetic resources being conserved through a combination of the two strategies were given but there were hardly any reported examples of this strategy being used for associated biodiversity.

In Latin America and the Caribbean addressing current financial and qualified human resource limitations was identified as a priority by all countries. The countries also identified a significant number of needs and priorities with regards conservation of BFA which mainly addressed the lack of knowledge and information on associated biodiversity, from better characterization to the effect of, for example, microorganisms in agricultural systems productivity.

The Africa region identified the lack of assessment on state and trends of associated biodiversity and ecosystem services which is a constraint to developing an enabling policy environment and to generally improving awareness on the importance of associated biodiversity for food and agriculture. As with other regions, limitations in human resources with relevant skills and finance hamper research and development in this area.

Countries in the Pacific region agreed that increasing information to strengthen awareness regarding the importance of associated biodiversity in food security and agriculture was a priority. Australia, in its 5th National Report to the Convention on Biological Diversity, reported that focusing on landscape-scale and ecosystem approaches to conservation and habitat protection, including by building connectivity of fragmented ecosystems, has proved to be a useful model to improve conservation outcomes. Similarly Palau highlighted the need to promote increased use of ridge-to-reef, landscape and ecosystem approaches. Capacity building was identified as a key priority, in particular, taxonomic expertise. Because of capacity limitations a rational approach should be taken as to ‘who does what and where’. The presence of several regional agencies already involved in conservation means that the region is well-placed to develop a regional approach to identified priorities. As with other regions increasing funding support was also recognized as a priority.

At the regional and international level Germany stressed that there was a need to step up and prioritize international and regional collaboration in the field of associated biodiversity, in particular, the work on micro-organisms, invertebrates and ecosystem approaches should be strengthened within the framework of the FAO Commission on Genetic Resources for Food and Agriculture.

Ex situ conservation of associated biodiversity

[EDITOR’S NOTE: Section will be completed and information from the country reports will be added]

The state of micro-organism conservation[100]

Microbial culture collections have been established in many countries and play a key role in the storage and supply of micro-organisms for research and development. Collections vary in size, form and function. Stored materials include culturable organisms (e.g. most algae, bacteria, filamentous fungi, yeasts, protozoa and viruses), their replicable parts (e.g. genomes, plasmids, complementary DNA), viable but not yet culturable organisms, and cells and tissues. Databases of molecular, physiological and structural information relevant to the collections are also held. Collections range from small undertakings with limited coverage, collected and maintained by single researchers, through larger operations based in laboratories within large multifunctional organizations, to institutional entities developed solely as public service collections and covering a broad range of organisms from many sources. Collections may focus on a particular kingdom (e.g. fungi or bacteria) or on specific genera. They may focus on a specific use, for example on industrial enzymes or antimicrobials or on particular host crops. They may be linked to a particular sector, such as the environment, health care, education, or agriculture.

[100] This section draws on the Background Study Paper prepared by Alexandraki *et al*. (2013),

The number of food-processing micro-organisms in culture collections remains much less than the total number used. Although many microbial strains involved in traditional and small-scale food processing operations have been isolated and studied, relatively few of these have been deposited in national or other well-maintained institutional culture collections.

The concept of the microbial culture collection as a repository of micro-organisms has in recent times given way to the more advanced concept of the microbiological resource centre. According to OECD (2001), biological resource centres "are an essential part of the infrastructure underpinning life sciences and biotechnology. They consist of service providers and repositories of the living cells, genomes of organism, and information relating to heredity and the functions of biological systems. [They] … contain collections of culturable organisms (e.g. micro-organisms, plant, animal and human cells), replicable parts of these (e.g. genomes, plasmids, viruses, cDNAs), viable but not yet culturable organisms, cells and tissues, as well as databases containing molecular, physiological and structural information relevant to these collections and related bioinformatics."

Conservation methods

A range of different methods can be used to preserve micro-organisms in laboratory conditions. The primary objective is to maintain the organisms in a viable state, without morphological, physiological, or genetic change, until they are required for use. Ideally, complete viability and stability should be maintained, especially in the case of important research and industrial isolates; the traits required to produce particular foods need to be maintained. However, additional factors such as ease of use, availability and cost may have to be considered. The following paragraphs provide short overviews of the main preservation methods available. For further information, see Smith *et al.* (2001), Tsonka and Todor (2005) and Simões *et al.* (2013).

Preservation through subcultivation. This method involves repeated cultivation of the organism on an agar nutrient medium. It is widely used and is perhaps the oldest, simplest and most cost-effective method for maintaining micro-organisms under laboratory and industrial conditions, especially if cultures are required frequently and quickly. Conserved material is often refrigerated, as this extends the intervals between each round of cultivation. Intervals vary depending on the type of micro-organism involved, ranging from 30 days to several years at 3 to 5 °C. The average longevity for yeasts is one to three months. Some bacteria can be maintained for five to twelve months and filamentous fungi for over five years. Representatives of the bacterial genus Streptomyces remain viable 26 years. Some fungal strains having been maintained since 1895 using this method.

Preservation under mineral oil. This method, generally only used for yeasts and filamentous fungi but which can also be used successfully for bacteria, involves covering a well-grown microbial culture on a liquid or agar nutrient medium with sterile non-toxic mineral oil. This limits the access of oxygen, which reduces metabolism and growth. It also reduces cell drying. The length of time for which micro-organisms can be maintained using this method varies from several months to several years. Many cultures have been found to deteriorate under mineral oil and have to be transferred regularly to reduce this effect. However, organisms that are sensitive to other techniques can be stored using this method. Disadvantages include the possibility of samples being contaminated by airborne spores, retarded growth on retrieval and the potential that continuous growth under adverse conditions can have a selective influence. Preservation under mineral oil is nonetheless recommended as a storage method for laboratories with limited resources and facilities.

Water storage. Immersion in sterile water can be used to extend the life of a culture grown on agar. It is generally used for preserving fungi, including yeasts. The shelf-life of fungi in water is variable, but there are examples of phytopathogenic fungi having been stored successfully for ten years using this method. The advantages of storage in water are low cost and easy application. However, the length of storage is often limited and some fungi will not survive submerged even for short periods. As with all methods that allow growth or metabolism during storage, it is considered only to be useful for short-term preservation and should be backed up by longer-term storage methods.

Silica gel storage. This method involves inoculating a suspension of fungal propagules onto cold silica gel. The culture is then dehydrated to enable storage without growth or metabolism. Silica gel storage has a number of advantages: it is cheap, simple and does not require complex apparatus.

However, it can only be used for sporulating fungi. Organisms of this kind have been stored for seven to eighteen years in silica gel and appear to remain morphologically stable after resuscitation.

Soil storage. This technique can be applied to a range of micro-organisms that can withstand a degree of desiccation, for example to the spores and resting stages of filamentous fungi and bacteria such as Bacillus spp. The method involves inoculation of double autoclaved soil with 1 ml of spore suspension in sterile distilled water and then incubation at 20 to 25 °C for five to ten days, depending on the growth rate of the fungus. This initial growth period allows the fungus to utilize the available moisture before the induction of dormancy. The bottles are then stored in a refrigerator (4 to 7 °C). This can be one of the most practical and cost- efficient ways to preserve filamentous sporulating micro-organisms. Other advantages include good viability of cultures for up to ten years, a reduced chance of mite infection and the option of repeatedly obtaining inocula from the same source.

Drying. This method takes advantage of the natural ability of micro-organisms to fall into anabiosis, a state of suspended animation. A range of materials can be used as carriers for the cultures and drying can be done at room temperature or by heating to 36 to 40 °C. Drying is widely used to preserve brewery and bakery yeasts.

Freeze-drying. This is a very effective means of preserving bacteria, yeasts and the spores of filamentous fungi. The freeze-drying process involves water being removed from the sample by sublimation under a vacuum. If carried out correctly, freeze-drying prevents shrinkage, structural change and helps retain viability. The many advantages of freeze-drying include the fact that the specimen is totally sealed and protected from infection and infestation. Cultures generally have good viability/stability and can be stored for many years. Ampoules take up little space and can be easily stored. Samples do not have to be revived before postal distribution. However, freeze-drying does have some disadvantages: some isolates fail to survive the process; others have reduced viability and genetic change may occur. The freeze-drying process is relatively complex and can be time-consuming and expensive. Ampoules of freeze-dried organisms must be stored out of direct sunlight. Chilled storage will reduce the rate of deterioration and extend shelf-life.

Liquid-drying. This method is a useful alternative for the preservation of bacteria that are particularly sensitive to the initial freezing stage of the normal freeze-drying process. The distinctive feature of liquid-drying is that cultures are not allowed to freeze. Drying occurs direct from the liquid phase. The method can be used for the drying and long-term preservation of nearly all yeast genera (Malik and Hoffmann, 1993).

Cryoconservation. This method involves the storage of samples at very low temperatures. Although little metabolic activity takes place below -70 °C, recrystallization of ice can occur at temperatures above -139°C and this can cause structural damage during storage. The favoured method is therefore storage at ultra-low temperatures, normally -150 to -196 °C, in vapour or liquid phase nitrogen, respectively. Provided adequate care is taken during freezing and thawing, the culture will not change, either phenotypically or genotypically. To reduce the risks of cryo-injury, traditional cryopreservation methods have involved controlled cooling at a rate of -1 °C per minute, typically in the presence of a cryoprotectant such as glycerol, trehalose or dimethyl sulphoxide (DMSO) (Smith and Ryan, 2012). The choice of cryoprotectant is a matter of experience and varies according to the micro-organism. A lot of research has gone into establishing the optimum cooling rate.

As with other methods of preservation liquid nitrogen cryopreservation has advantages and disadvantages. Advantages include the length of storage (considered to be effectively limitless if storage temperature is kept below -150 °C), the wide range of organisms that can be conserved and the fact that organisms remain free of contamination when stored in sealed ampoules. Disadvantages include the high cost of apparatus and the need for a continuous supply of liquid nitrogen. If the supply of nitrogen fails (or the double-jacketed, vacuum-sealed storage vessels corrode and rupture) then a whole collection can be lost. The technique therefore should not be used in places where a regular supply of liquid nitrogen cannot be guaranteed.

Cooperation in conservation

A number of organizations help to promote coordination, collaboration and discussion among the holders of culture collections. The World Federation for Culture Collections (WFCC), Microbial Strain Data Network (MSDN), and Microbial Resource Centres (MIRCENs) operate globally. WFCC oversees the World Data Center for Microorganisms, which holds information on 708 culture collections in 72 countries and regions, together containing over 2.5 million cultures[101] (the figures do not cover all the collections in the world, as there are many private industrial collections and some in independent researchers' laboratories). The European Culture Collection Organization (ECCO) fosters initiatives that help collections obtain support and organize the delivery of products and services. For example, European Community Framework Programme projects include the electronic catalogue project Common Access to Biological Resources and Information (CABRI),[102] which sets operational standards for European biological resource centres. Cooperation is also fostered through national and international affiliations such as the Belgian Coordinated Collection of Micro-organisms (BCCM)[103] and the United Kingdom National Culture Collection (UKNCC).[104] Information on other important networks, federations and societies (e.g. the Asian Consortium for the Conservation and Sustainable Use of Microbial Resources[105] and the United States Culture Collection Network[106]) can be found via the WFCC web site.[107]

MIRRI brings together European microbial resource collections and stakeholders (collection users, policy-makers, research programmes and potential funders) to improve access to high-quality microbial resources in an appropriate legal framework. It aims to provide coherence in the application of quality standards, homogeneity in data storage and management and workload sharing. It will link European collections to partners elsewhere in the world.

Several initiatives have sought to design quality-management systems for microbial culture collections. The first community-designed system was the WFCC guidelines for the establishment and operation of collections of micro-organisms.[108] Quality management systems have also been established by national culture collection organizations such as the UKNCC and by various project consortia, including CABRI.

Needs and priorities

Inadequate funding and shortages of trained personnel are often significant constraints to the operation of culture collections. There may be opportunities for collections to find novel ways of obtaining funding, for example by developing novel commercial products or services or by obtaining donor grants for research activities (Smith *et al.*, 2014; Antunes *et al.*, 2016). However, care needs to be taken in the choice of such activities so as not to divert collections too far away from their main responsibilities (Smith, 2012; Simões *et al.*, 2016).

Developments in technology are opening new opportunities for culture collections. However, taking full advantage of these developments can be challenging. Harnessing new technologies will often require the establishment of partnerships with manufacturers or with other collections or institutions. Bioinformatics is becoming increasingly important to the operation of collections. New ways of collecting, storing, analysing and presenting data are needed. Preservation techniques also need to be further improved, including the development of techniques that allow the cryoconservation of micro-organisms that are currently difficult to preserve. Molecular tools are increasingly being used to differentiate between strains and to aid in their identification. Non-optimized preservation techniques can lead to genetic changes in conserved samples and collections should be using molecular techniques to determine whether they are preserving strains without change (Smith, 2012). Characterisitcs important to the food industry need to be assessed and it needs to be demonstrated that

[101] http://www.wfcc.info/ccinfo/statistics/
[102] http://www.cabri.org/
[103] http://bccm.belspo.be/
[104] http://www.ukncc.co.uk/
[105] www.acm-mrc.asia
[106] www.usccn.org
[107] http://www.wfcc.info/collections/networks
[108] www.wfcc.info/guidelines

these are preserved in micro-organisms held in culture collections. Procedures need to be in place to preserve food micro-organism threatened by climate change.

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CHAPTER 6 – THE STATE OF PROGRAMMES, POLICIES, INSTITUTIONS AND CAPACITIES

6.1 Introduction

This chapter discusses the institutional framework affecting the management of biodiversity for food and agriculture, looking first at the roles of different categories of stakeholders and their organizations, then at the state of ancillary components such as education, training and research, and finally at the state of policies and legislation affecting biodiversity for food and agriculture.

6.2 Stakeholders in the management of biodiversity for food and agriculture

Producers and their organizations

Producers in the crop, livestock, forest and aquatic sectors range from small-scale farmers, livestock keepers, foresters, fishers and aquaculture practitioners to very large commercial companies. All rely on biodiversity for food and agriculture and their actions can have major consequences for the state of biodiversity.

Much of the world’s biodiversity for food and agriculture is raised in, or associated with, small-scale production systems. Where domesticated biodiversity is concerned, small-scale producers tend to rely on the adaptive characteristics of the species, breeds and varieties that they raise, i.e. on traits that allow plants and animals to survive and produce in harsh and changing local conditions without the need for large quantities of external inputs. They often make use of multiple products and services supplied by multipurpose breeds and varieties. Diverse production environments and diverse uses usually mean that a relatively diverse range of genetic resources are maintained. Small-scale producers are often also key players in the management of associated biodiversity. Lack of access to external inputs means that they are often heavily dependent on the ecosystem services provided by the associated biodiversity in and around their production systems.

The maintenance, revival or adaptation of traditional management practices sometimes contributes significantly to the sustainable use and conservation of biodiversity in and around production systems, as do ongoing processes of innovation on the part of small-scale producers. A number of such cases are noted in the country reports. Jordan, for example, mentions the establishment of programmes based on the traditional rangeland management system known as *Hima* to address the effects of overgrazing and erosion of pastures used by livestock. Further examples are discussed in Chapter 4.

Women farmers, livestock keepers, fishers and forest dwellers often play important, although sometimes overlooked, roles in the use and conservation of biodiversity for food and agriculture. Several country reports, note the significance of women’s roles in production and processing of food and agricultural products and in the collection of wild foods. Some reports mention particular species that are largely cultivated or gathered by women or note women’s roles in the maintenance of traditional varieties. In the case of livestock, it has been argued that locally adapted breeds can be particularly important for women and hence that women can be particularly significant custodians of these breeds (FAO, 2012). Locally adapted animals tend to be relatively easy to care for (and hence raising them can be combined more easily with child-rearing and household tasks) and are often able to make good use of common property resources such as communal pastures and feed scavenged from waste ground (and hence important for women as a section of the population that is disadvantaged in terms of land ownership).

Some country reports note the significance of local knowledge held by women to the management of BFA. Cameroon, for example, mentions that in some rural communities women monitor the presence, growth and the ripening of important wild food and medicinal plants in their forest and farm lands and that when preparing land for cropping they make sure that important plants are maintained. Women are reported to be the main conservers of such plant species and to have good knowledge of their phenology, how to harvest them sustainably and how to process them for household use or for sale.

Despite being major stakeholders in the sustainable management of biodiversity, small-scale and indigenous producers in all sectors are often marginalized and excluded from decision-making processes that affect their production systems. Their livelihoods are often under threat. In many countries, civil society organizations (CSOs) of small-scale producers play a significant role both in terms of campaigning and advocacy and in terms of promoting practical activities relevant to sustainable use and conservation of biodiversity for food and agriculture.

On the campaigning side, some small-scale producers' CSOs have sought to challenge the so-called industrial model of production and consumption, counterposing an approach based on agroecology that, in the words of the Declaration of the International Forum for Agroecology (2015), " *displaces … the control of global markets and generates self-governance by communities … minimizes the use of purchased inputs … requires the re-shaping of markets so that they are based on the principles of solidarity economy and the ethics of responsible production and consumption … promotes direct and fair short distribution chains … implies a transparent relationship between producers and consumers, and is based on the solidarity of shared risks and benefits … challenge[s] and transform[s] structures of power in society [and] put[s] the control of seeds, biodiversity, land and territories, waters, knowledge, culture and the commons in the hands of the peoples who feed the world.*" Calls have been made for research to be reframed based on participatory methods that will support a more "ecological" model of food provision (CSO Parallel Forum, 2009). At relatively local level CSO's campaigning activities target a range of BFA-related issues, including the maintenance or re-establishment of collective local control over resources such as forests, grazing lands and fisheries (IPC, 2016).

Producers' and community-based organizations of various kinds contribute in many practical ways to the sustainable management of local production systems, whether by providing practical support and advice on management techniques, facilitating the collective management of local resources or providing support for the marketing of local products (see Box 12, Box 13 and Box 13 for examples).

Some producers' organizations are more focused than others on the management of biodiversity for food and agriculture. In some cases, the use, development and/or conservation of a particular component of biodiversity is the main objective of the organization. For example, in many countries, particularly in the developed regions of the world, breeders' associations are the main players in livestock breeding programmes, particularly for ruminant species (see Section 4.6). Beekeepers' organizations play an important role in bee management and maintaining the supply of pollination services. The country report from Jordan, for example, mentions a project initiated by the Jordan Beekeepers Union that succeeded in involving beekeepers in conserving and planting trees to provide forage for honeybees; over 20 000 trees were planted by union members in 2013–2014. The report from the Gambia mentions the important role of women oyster farmers' associations in various management activities. For example, the Niumi Women Oyster Famers' Association is reported to be collaborating with the country's Department of Parks and Wildlife Management in monitoring shellfish exploitation in the Niumi National Park. Examples from Senegal and Ecuador of the roles played by community-based organizations in promoting sustainable fishing are described in Box 12 and Box 14.

Box 12. Community control of a coastal ecosystem – an example from Senegal

In 2008, worried about the decline in fish stocks, local communities in Mangagoulack, in Casamance, Senegal, decided to create the Association of Fishermen of the Rural Community Mangagoulack (APCRM). The association established a community conserved area named Kawawana. The name derives from the Djola expression "Kapooye Wafolal Wata Nanang", which means "our patrimony, for us all to preserve". The conservation area was demarcated and rules put in place to control access to the coastal waters and combat the use of destructive methods and the resulting high pressure on local fishery resources.

In 2010, APCRM obtained statutory rights of management for Kawawana, including a preferential right to fish on the local coastal strip. Mangagoulack is the first local community in Senegal to have been devolved management rights for coastal fisheries.

The waters of the conserved area are divided into three zones, denoted by the colours red, orange and yellow. No fishing or collecting shells or wood is permitted in the red zone. The orange zone is reserved for fishing to supply local consumption and markets. The yellow area is open to fishing, but there are limitations on the fishing methods and gear that can be used.
The red zone is marked with fetishes and revives the local tradition of "sacred bolongs". It acts as a refuge for aquatic life. Mangroves and inlets provide habitat for humpback dolphins, manatees, fish and shellfish. The new management arrangements rapidly increased fish stocks and improved the local diet. Three years after the creation of the conservation area, local fishermen's catches had doubled.

Source: Adapted from IPC, 2016, with additional information from ICCA Registry, 2012.

Box 13. Agroforestry under local control – an example from Costa Rica

Coproalde Network (Coordinadora de Organismosno Gubernamentales con Proyectos Alternativos de Desarrollo) was formed in 1988 in Costa Rica, bringing together NGOs and peasants' and indigenous peoples' organizations working on alternative development projects. In around 2009, Coproalde members started to implement successional agroforestry systems. The initiative was motivated by exchanges with peasants from the Plurinational State of Bolivia via the "campesino a campesino" (farmer-to-farmer) methodology. The systems mimic forest ecological conditions and provide great food diversity from small plots of land. In 2 000 m2, it is possible to plant 85 species for food and medicinal purposes. The plots enable families can ensure their food and nutritional security and obtain extra income by selling surplus in local markets.

Source: Adapted from IPC, 2016 (based on testimony from Juan Arguedas Chaverri, Red COPROALDE, Costa Rica, 2014).

Box 14. The role of a women's group in promoting sustainable fishing – an example from Ecuador

The Pescado Azul (Blue Fish) Women's Association of Isabela in the Galapagos promotes responsible fishing by empowering the community's women. The association emphasizes traditional knowledge and the conservation and sustainable use of marine resources. Illegal and unsustainable fishing in local coastal waters have led to the overexploitation of sea cucumbers, spiny lobsters and a variety of fish species. To reduce pressures on these resources, Pescado Azul promotes alternative livelihood opportunities. The main focus has been on developing value-added smoked products from sustainably sourced yellowfin tuna. Wood from guava shrubs, an invasive species, is used to smoke the fish. Products are marketed under the Pescado Azul brand and the association has developed links with ecotourism operators to help identify markets. Other activities have included reforestation of local mangroves and efforts to promote ecological awareness.

Sources: Country report of Ecuador and UNEP, 2013.

Although a large share of the world's output of food and agricultural products is still supplied by small-scale producers, large-scale commercial production is expanding and increasingly dominant in many subsectors. Large-scale producers can often draw on technologies and inputs that enable them to profitably raise crops and livestock from a narrowing range of high-producing varieties and breeds or to extract vast amounts of fish or timber from aquatic and forest ecosystems. Although ultimately dependent on the range of ecosystem services provided by biodiversity for food and agriculture, they can often operate relatively independently of the local ecological processes that have traditionally underpinned and constrained food and agricultural production. Large-scale specialist companies are playing an ever greater role in breeding (genetic improvement) programmes for domesticated plants and animals, often focusing their efforts on a relatively narrow range of species, breeds and varieties. In some subsectors such as poultry, the breeding industry has become very concentrated in the hands of a small number of companies.

Many country reports note the need to strengthen the involvement of producers in the sustainable management of biodiversity. Education and awareness-raising among producers, both about management methods and about initiatives being taken by local or national authorities to promote effective management of biodiversity, are mentioned as priorities in many reports. Some note the importance of capitalizing on local knowledge, ensuring equitable access and benefit-sharing arrangements or putting in place more effective mechanisms for producer participation in decision-making processes. Lack of incentives for sustainable management is noted in some reports as a constraint to producer participation. The report from Ethiopia, for example, notes the potential of niche markets or other forms of value addition as a basis for incentivizing greater producer involvement. Some reports note that given the significant role of women in the use and conservation of BFA there is a need to support their livelihood activities (e.g. by promoting more equitable access to resources) and facilitate their participation in decision-making. The country report from Cameroon, for example, mentions that women are being trained as forest agricultural engineers, forest engineers, eco-guards, wildlife technicians and being sensitized in forest resource management. Participatory workshops on ecological appraisal methodologies and conservation are reported to be enabling women in local communities to participate in decision-making on how to invest in and sustain their local resources.

Several reports note the significance of community-based organizations and other collective bodies in promoting participation in sustainable management activities, along with the need to improve collaborative links among such group and between them and other stakeholders. The report from Viet Nam, for example, mentions the significance of a range of different entities, including People's Committees, especially at commune and district levels, the Women's Union, Farmers Association and Youth Union. The report from Zambia notes the significance of the traditional leadership in local communities as potential catalysts for the participation of local people. The report from the Netherlands notes a shift in mechanisms for implementing agri-environmental schemes away from a focus on individual enterprises and towards the establishment of collective bodies intended to improve information sharing and allow schemes to be implemented over larger areas and hence have a greater impact.

Private-sector industry and trade

Many private companies, large and small, are involved in processing and transporting food and agricultural (including forest and aquatic) products and retailing them to consumers or use such products as inputs for a range of different industrial processes. The requirements of users at all points in the value chain influence demand for raw materials and hence the characteristics of crop, livestock, forest and aquatic production systems. Similarly, a range of industries serve as suppliers of inputs to food and agricultural production and can influence the types of production practised. As well as acting as markets or suppliers, industries outside the immediate food and agriculture sector can affect BFA via their impacts on land use or the effects of pollutants they release (see Chapter 2). They may also benefit from the various regulating ecosystem services provided by BFA (and biodiversity more generally) – maintenance of water supplies or disaster-risk reduction, for example. The cultural and habitat services provided by biodiversity can be valuable to the tourism and recreational industries.

The public sector

Public policies and the activities of public-sector organizations can have a major influence on the state of BFA. Protecting biodiversity is typically a stated objective of national environmental policy. Parties to the Convention on Biological Diversity are obliged to have national strategies, plans of programmes in place to address conservation and sustainable use of biodiversity and to integrate these themes into relevant cross-cutting policies. In many countries, the public sector plays a significant role in promoting the conservation and sustainable use of domesticated genetic resources.

The public sector can both directly operate projects and programmes in the field of biodiversity management or take measures that influence the actions of other stakeholders, for example via legal measures, provision of incentives or provision of information. Public-sector programmes in fields such as education, research, conservation, characterization, breeding, research and education are discussed in Subsections 6.4. Policy and legal frameworks relevant to biodiversity for food and agriculture are discussed in more detail below (Subsection 6.9).

Public entities devoted specifically to the management of associated biodiversity are not widely mentioned in the country reports. The report from the United States of America refers to the National Microbial Germplasm Program, which aims to ensure that the genetic diversity of agriculturally important micro-organisms is maintained. Reported activities include the authentication, and characterization of potentially useful microbial germplasm, conservation of microbial genetic diversity, and facilitating the distribution and utilization of microbial germplasm for use in research and industry. Also mentioned in the same report is the National Invertebrate Genetic Resource Program, which aims to inventory and characterize the various insect species, races, stocks, strains, biotypes and other genetic entities associated with agricultural systems and to document their interactions with agriculture and the environment. Activities implemented under this program include the preservation of reference specimens, maintenance of genetically important germplasm, documentation of specific insect stocks, management of databases and distribution of material to researchers and breeders.

The non-governmental sector

In addition to the producers' organizations discussed above, non-governmental and civil society organizations contribute in various ways to the management of BFA, some focusing particularly on environmental and conservation issues and others more on livelihood and rural development. The country report from Bangladesh, for example, mentions Policy Research for Development Alternative (UBINIG), a community-led and community-based policy and research organization that has connections to farmers, weavers, fishers, artisans and craftspeople, community health providers and rural entrepreneurs and works to conserve forests and the livelihoods of indigenous communities. It aims to foster climate change adaptation by promoting knowledge and practices that help to minimize river erosion, selection of appropriate seed for specific agro-ecological zones and the conservation of mangroves in coastal areas. The report from Nepal notes the role of NGOs such as Local Initiatives for Biodiversity, Research and Development in the establishment of community seed banks that enhance access to, and exchange, use and management of, genetic resources.

The general public

The general public benefit in many ways from the products and services provided by food and agricultural production systems. Their choices as consumers and their political choices as citizens have the potential to influence the management of BFA. As described in Chapter 3, in some countries citizen scientists make an important contribution to monitoring the status of particular categories of biodiversity. A considerable amount of work on conservation projects is undertaken by volunteers from among the general public.

[International organizations]

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6.3 State of cooperation

As well as involving a diverse range of stakeholders, the management of BFA spans the conventional boundaries between the subsectors of food and agriculture and those between food and agriculture and nature conservation. Strengthening the sustainable use and conservation of BFA often requires actions on a large geographical scale (e.g. across watersheds or along migration routes) and involving a wide range of different stakeholders. Countries are interdependent in their use of genetic resources in the crop, livestock, fishery, aquaculture and forest sectors (Bartley *et al.*, 2009; FAO, 2009; Koskela *et al.*, 2009; FAO 2010; FAO, 2014a; FAO, 2015). The distributional ranges of associated biodiversity species often cross national boundaries and some categories such as invertebrate biological control agents (Cock *et al.*, 2009) are exchanged internationally. Global challenges such as climate change and emerging disease threats require global responses. Multistakeholder and international cooperation in BFA management is therefore vital.

Cooperation at the national level

BFA is rarely singled out as a distinct and well-defined target for collaborative activities. However, the country reports describe a range of multistakeholder initiatives focusing on various aspects of BFA management or that include BFA management under broader umbrellas. Examples include committees and councils addressing ecosystem services, climate change, genetically modified organisms, invasive alien species, organic agriculture, access and benefit-sharing and the financing of biodiversity-related programmes. Several countries report that national policies, plans and strategies in fields such as these have been developed through multistakeholder consultative processes. In some cases, efforts are being made to mainstream biodiversity into broader efforts to develop rural areas or the national economy more broadly. The report from Ethiopia, for example, notes that the country's Climate Resilient Green Economy Strategy provides an important mechanism for mainstreaming biodiversity into the agriculture, forest, power and transport sectors. Some countries note multistakeholder initiatives to improve the integration of BFA-related issues into their national biodiversity strategies and action plans or, in more general terms, to strengthen coordination in the implementation of these instruments. Even where no permanent collaborative bodies or frameworks have been set up, multistakeholder collaboration often occurs at project level or between individual institutions such as universities and research centres.

Some countries are making efforts to promote a more cross-sectoral approach to research. For example, the country report from Finland notes that three major sectoral institutions in applied research, the Game and Fisheries Research Institute, the Finnish Forest Research Institute and Agrifood Research Finland, are being merged into one body, with the aim of strengthening collaboration in the fields of biodiversity for food and agriculture, associated biodiversity and wild foods (among others) and improving the cost-efficiency of research.

National multistakeholder bodies addressing the management of genetic resources are increasingly being established in the crop, livestock and forest sectors. However, they are still absent in many countries. For example, out of 130 countries that submitted country reports for *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture* (FAO, 2015), 78 indicated that in 2014 that they had a national advisory committee for animal genetic resources in place. Cross-sectoral cooperation in the management of genetic resources (i.e. between the crop, livestock, forest and aquatic sectors) is often limited. Some country reports,[109] however, mention national strategies, plans or policies that address genetic resources management in multiple sectors, national bodies (e.g. committees, research centres or networks) that coordinate work across sectors (see Box 15 for example) or (less frequently) specific cross-sectoral initiatives such as joint marketing campaigns for products from locally adapted livestock and crops. Within each sector there are numerous examples of projects and programmes that involve a range of stakeholders (FAO, 2010; FAO, 2014a; FAO, 2015). Many countries, however, consider that mechanisms for involving

[109] Reports submitted for *The State of the World's Biodiversity for Food and Agriculture* and those submitted for previous global assessments of genetic resources.

stakeholders, in particular small-scale producers, in the planning and implementation of management activities remain inadequate (*ibid*.).

Box 15. The Norwegian Genetic Resource Centre and its genetic resource committees

The Norwegian Genetic Resource Centre was established by the Ministry of Agriculture and Food to monitor, increase the conservation and use of plant, forest and animal genetic resources for food and agriculture, facilitate access to them and increase knowledge and awareness on their conservation and sustainable use. Having a single centre working on a large share of the country's genetic resources for food and agriculture, Norway is in a strong position both to identify and to take advantage of the synergies between the different sectors and to weigh the trade-offs, of which there are few. The centre organizes both regular and ad hoc meetings during which its sectoral committees on animal, plant and forest genetic resources, both jointly and separately, discuss and provide advice on, inter alia, the centre's strategic and action plans and national policies of relevance to genetic resources for food and agriculture (e.g. environment-related policies). Joint meetings of the three genetic resource committees have led to interesting exchanges of knowledge and expertise across sectors on issues such as the characterization of genetic resources, *in situ* and *ex situ* conservation and the development of indicators.

Source: Country report of Norway.

Where associated biodiversity is concerned, any programmes that promote conservation and sustainable use of biodiversity in food and agricultural production systems are likely to involve a degree of collaboration between producers and other stakeholders such as public-sector bodies or NGOs that are providing coordination or support. The report from Ireland, for example, notes in this context that various management measures favourable to associated biodiversity are being promoted via the participation of farmers in agri-environmental schemes, i.e. incentive schemes operated by the public sector within the framework of European Union legislation (see Subsection 6.8). The report from Finland notes that many projects in which environmental authorities, NGOs, advisers, and land-users cooperated from the beginning have produced impressive results. Generally, however, the country reports provide few indications that producers or other local stakeholders are heavily involved in planning or prioritizing conservation and management activities for associated biodiversity or that there is much collaboration in this field among producers' or community-based organizations.

Some country reports describe participatory approaches that involve producers or the general public in the monitoring of certain types of associated diversity. For example, the report from France mentions the Agricultural Observatory of Biodiversity, an initiative of the Ministry of Agriculture that involves stakeholders, particularly farmers, in monitoring agricultural biodiversity and the links between the biodiversity and agricultural practices. Responsibility for scientific coordination is assigned to the Natural History Museum and organizational support is provided by the Permanent Assembly of Chambers of Agriculture. Monitoring protocols have been established for earthworms, terrestrial invertebrates, butterflies and pollinators. Results are published annually (Box 16). The report from Grenada notes that the Ministry of Agriculture, Lands, Forestry, Fisheries and the Environment has established voluntary linkages with research institutions, NGOs and stakeholder groups, which work in collaboration to share primary data that inform the conservation and sustainable use of biodiversity in marine and coastal environments that support important fisheries.

Box 16. France's Agricultural Biodiversity Observatory

The Agricultural Biodiversity Observatory (ABO,) was established in 2009. It is participative sciences tool meant for farmers from all types of production systems.

The ABO has two main objectives. First, it aims to feed a scientific database with information to be used to, among others, develop biodiversity indicators in agricultural environments and establish the links between biodiversity and farming practices. The second goal is to raise awareness of biodiversity and farming practices amongst the stakeholders involved, farmers in particular, and accompany them

in the evaluation of their practices. The ABO was established as part of the Ministry of Agriculture's commitments in the framework of France's National Biodiversity Strategy. It builds upon the participative sciences programme 'Vigie-Nature' of the National Museum of Natural History.
At the national level, this tool is coordinated by the Ministry of Agriculture, Agrifood and Forestry, the National Museum of Natural History and by the Permanent Assembly of Chambers of Agriculture, in collaboration with the University of Rennes.[110] At the local level, several actors, including members of associations or chambers of agriculture, provide support to the farmers who participate on a voluntary basis in the implementation of the following four protocols:
a) Counting and characterization of butterflies
b) Observation of nesting sites of pollinators
c) The use of identification tools for the observation of terrestrial invertebrates
d) Observation of earthworms
All these protocols are environmental friendly.
In addition to these protocols, farmers are encouraged to monitor their farming practices and reflect on the linkages between these practices and associated biodiversity.
The Observatory publishes its results on a yearly basis.[1] To this date, results are insufficient to draw any significant conclusions about the status and trends of agricultural biodiversity. Nevertheless, efforts undertaken by national actors, local partners and the farmers involved in the observatory have enabled the development of a tool suitable enough for the development of interesting indicators based on the data gathered so far.
These indicators should shortly be integrated into the National Observatory for Biodiversity (www.indicateurs-biodiversite.naturefrance.fr) for broader distribution.
Beyond the farmers directly involved, ABO has a far larger indirect impact, playing a key role in raising awareness among the agricultural community with regard to associated biodiversity related issues. For example, in 2016, several professional agricultural organizations on a national level have submitted their long-term commitment to the National Strategy for Biodiversity and expressed their wish to see the further development of the ABO and encouraged farmers to get involved in this initiative.
Several lessons have been drawn by the Ministry of Agriculture: on the one hand, sufficient time is needed to ensure the regular and coherent participation of any group of stakeholders. On the other hand, the tool has actually raised awareness among the agricultural community, as shown by the active commitment of actors in this sector.

Provided by Patricia Larbouret, Christophe Pinard and Pierre Velge.

Collaborative awareness-raising, education or training initiatives related to associated biodiversity are not widely mentioned in the country reports. One exception is an initiative led by the Jordan Beekeepers' Union in collaboration with the country's National Centre for Agricultural Research and Extension and Royal Botanic Gardens and the Honeybee Online Studies (HOBOS) Project (Germany) that taught school and university students about the value of honeybees as bio-indicators and providers of pollination services and about the health-supporting properties of honey bee products.

Improving cooperation among stakeholders is widely recognized in the country reports as a priority. Where constraints are noted, they often relate to a lack of mechanisms for exchanging information or organizing participatory decision-making processes. The need for training and awareness-raising among stakeholders is mentioned in some reports, as is the need to overcome financial constraints. The report from Finland notes that there is a need to establish incentives that encourage, recognize and reward the engagement of university researchers in decision-making processes.

Cooperation at the international level

[EDITOR'S NOTE: Information from international organizations reports will be included in this section in the final draft]

[110] See http://observatoire-agricole-biodiversite.fr/resultats.

As discussed in Subsections 6.9, BFA management is addressed in a number of global policy and legal instruments and by a number of international organizations. As well as guiding and regulating activities at national level, this international institutional framework serves to promote wider and more effective global, regional and bilateral cooperation.

Many country reports provide information on international collaborative activities in BFA management. As at national level, many of these activities target broader areas of natural resources, biodiversity or environmental management rather than BFA as a distinct category. Examples include the joint management of transboundary habitats and wildlife corridors, *ex situ* conservation networks for particular species, cooperation in combating wildlife crime, certification schemes for sustainable practices and joint research projects, programmes and networks.

In the crop, livestock, forest and aquatic sectors a number of regional and international networks contribute to the sustainable use, development and conservation of genetic resources (FAO, 2010; FAO, 2014a; FAO, 2015). Some are dedicated to genetic resources management in a broad sense across the whole of the respective sector, while others address specific species or specific aspects of management. Numerous international governmental and non-governmental organizations and fora contribute to collaborative activities in genetic resources management at global and regional levels. There are also many bilateral initiatives and collaborative activities involving small groups of countries.

Relatively few country reports provide details of international or regional collaborative activities involving partners that specifically target components of associated biodiversity or their roles in the provision of ecosystem services to food and agriculture. The report from Burkina Faso notes the country's involvement with the African Reference Laboratory for Bee Health[111] and the African Bee Health Project.[112] The reference laboratory, an initiative of the International Centre of Insect Physiology and Ecology and the African Union Interafrican Bureau for Animal Resources, supported by the European Union, is in Nairobi, Kenya, and has satellite stations in Cameroon, Ethiopia and Liberia, as well as in Burkina Faso. The report from Jamaica mentions C-Fish (the Caribbean Fish Sanctuary Partnership Initiative), a project established by the not-for-profit CARIBSAVE Partnership that aims to strengthen community-based fish sanctuaries and marine protected areas in five countries across the Caribbean.

Box 17. Appointment of national focal points and participation in global assessments of genetic resources and biodiversity for food and agriculture

Over recent years, countries have been invited by FAO to establish National Focal Points (NFP) to be responsible for coordinating reporting activities for the various global assessments of genetic resources and biodiversity prepared under the auspices of the Commission on Genetic Resources for Food and Agriculture, i.e. in addition to *The State of the World's Biodiversity for Food and Agriculture* (SoW-BFA), the "State of the World" reports on the plant, animal (livestock) and forest subsectors of genetic resources and the forthcoming report on the aquatic subsector. To varying degrees, these NFPs have taken on a broader role in their respective sectors in terms of coordinating genetic resources management activities at national level, promoting regional and international collaboration in genetic resources management and serving as a permanent point of contact with FAO.

Establishment of an NFP can be seen, in the first instance, as an indication of a degree of awareness at government level of the significance of biodiversity and genetic resources in the respective sectors (or across food and agriculture) and of a willingness to participate in global reporting activities. In many cases, NFPs play a wider role in role in promoting a range of different management activities, including in the fields of monitoring and reporting on the status of and trends of biodiversity and genetic resources, promoting the sustainable use and conservation of these resources, including as and where appropriate responses at policy level, and ensuring effective mechanisms for stakeholder participation.

[111] http://bees.icipe.org/index.php

[112] http://bees.icipe.org/index.php/project/programme-objectives

In the case of the SoW-BFA, 123 countries have nominated a NFP and 71 have officially submitted a country report. Figure 20shows the distribution of these countries in the form of a world map. A full list of reporting countries can be found in the "About this publication" section among the front matter of the report. Figure 21 and Figure 22 summarize the sectoral and institutional affiliations of the NFPs nominated for the SoW-BFA process.

Figure 20. National Focal Points and country reporting for *The State of the World's Biodiversity for Food and Agriculture*

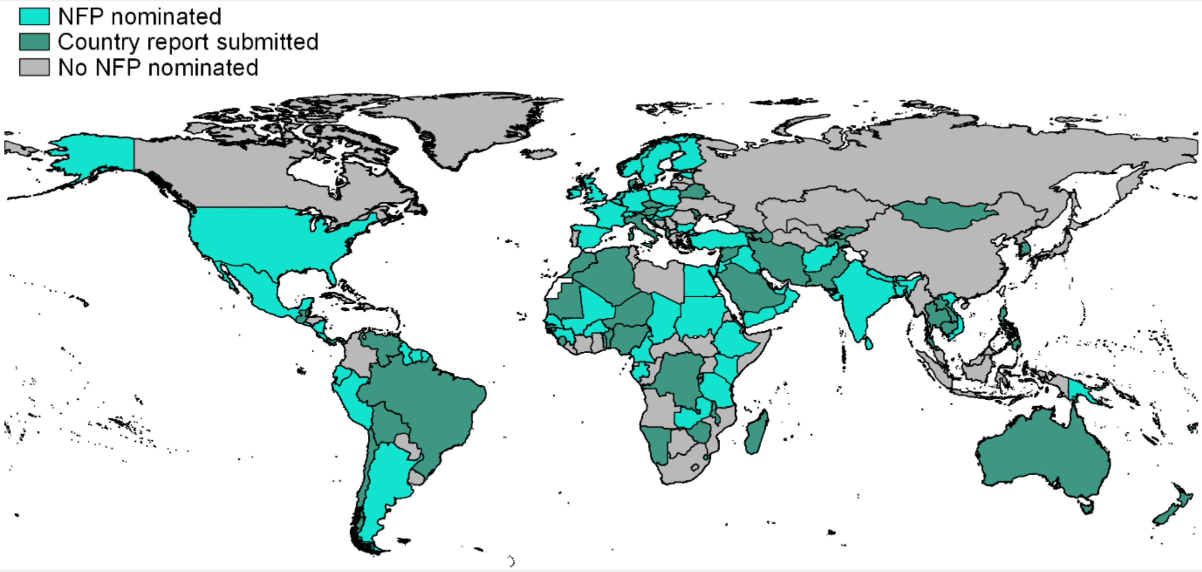


Figure 21. Sectoral affiliations of National Focal Points

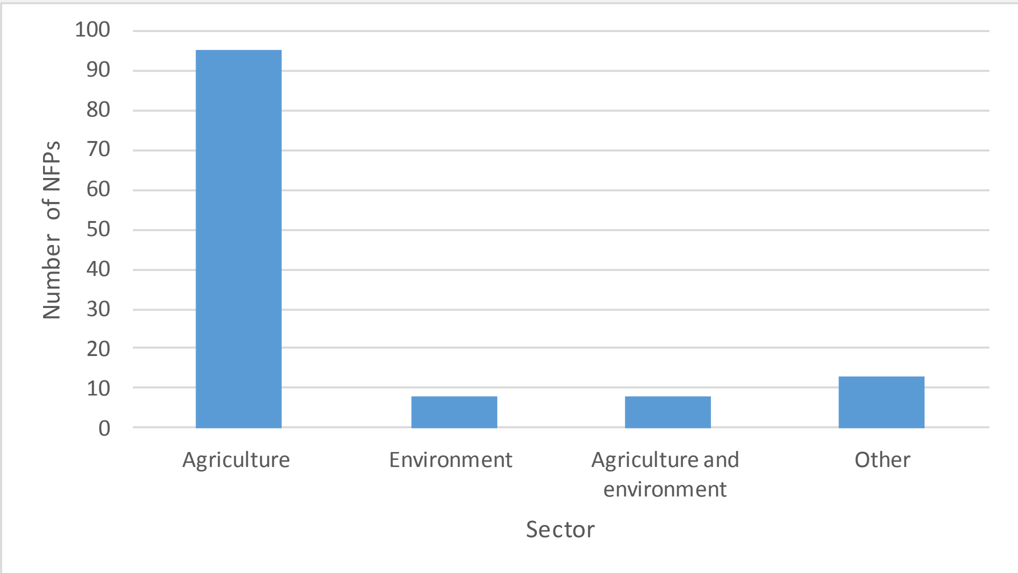


Figure 22. Institutional affiliations of National Focal Points

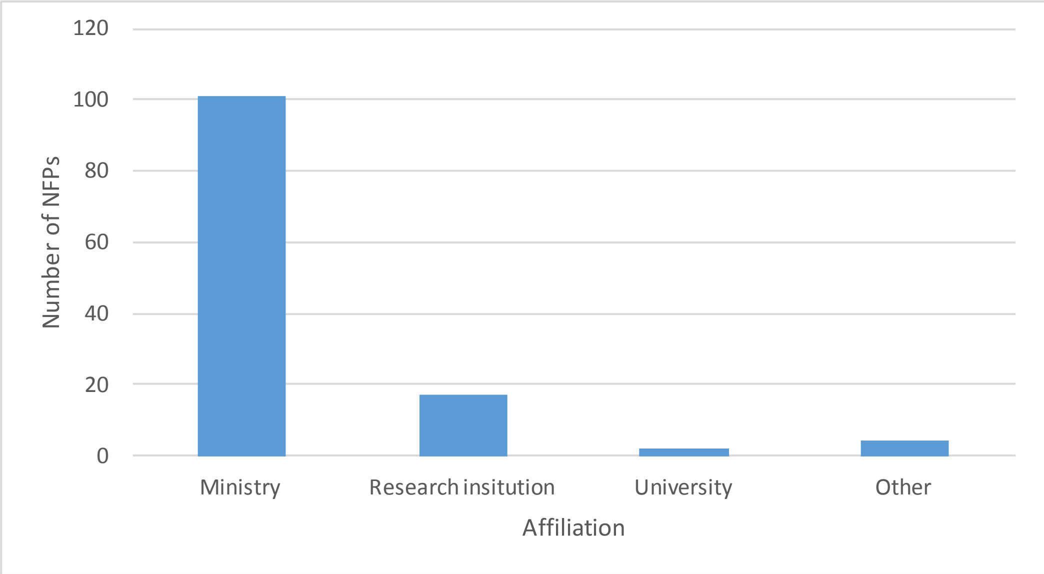


Figure 23, Figure 24 and Figure 25 show the distribution of country-report submissions for *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture* (SoW-AnGR2) (FAO, 2015), *The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture* (SoW-PGRFA2) (FAO, 2010) and *The State of the World's Forest Genetic Resources* (SoW-FGR) (FAO, 2014). In the case of animal genetic resources, 129 countries submitted reports; 113 submitted reports on plant genetic resources; and 86 submitted reports on forest genetic resources and (full lists of reporting countries can be found in the respective reports). Although the number of reports submitted on forest genetic resources may seem low in comparison with other processes, reporting countries accounted for 85 percent of the global forest area. In the case of the forthcoming report on The State of the World's Aquatic Genetic Resources for Food and Agriculture, 47 countries had submitted reports in time for the inclusion in the draft report presented to the Commission's Sixteenth Regular Session in January 2017.

Figure 23. Country reporting for The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture

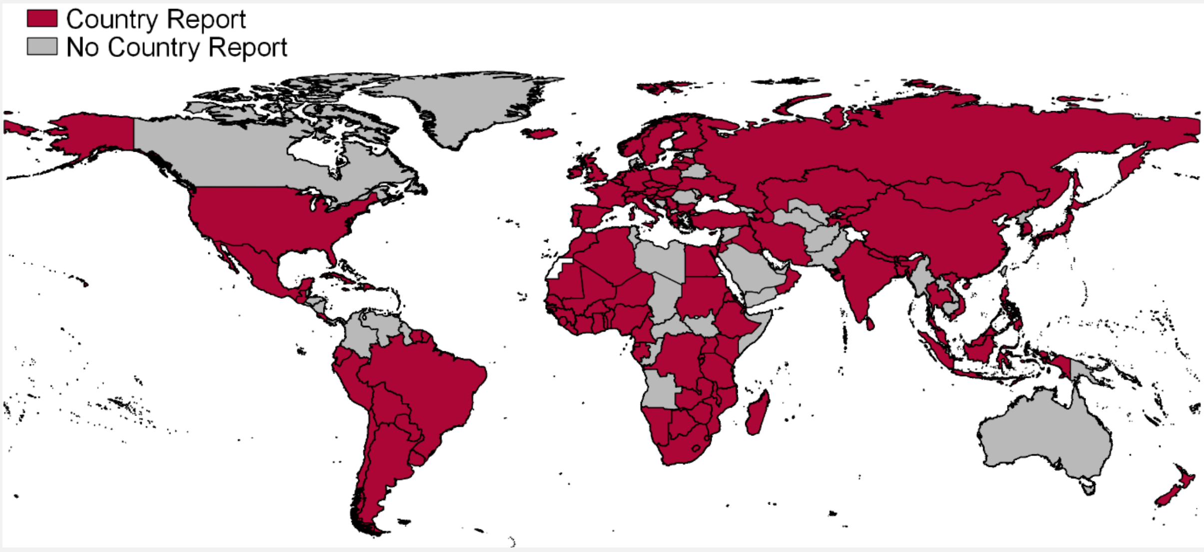


Figure 24. Country reporting for The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture

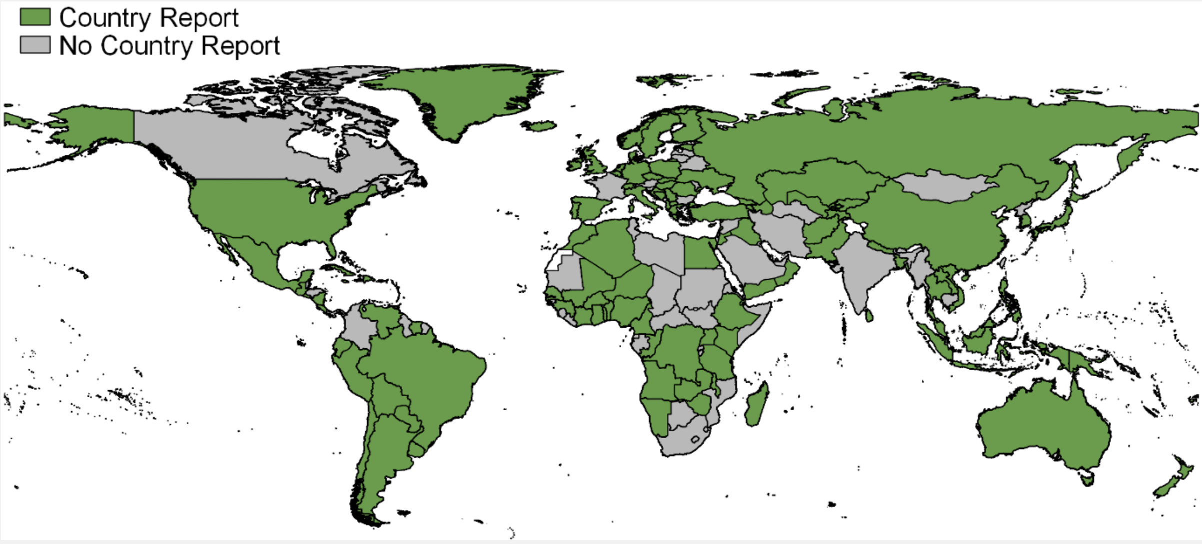
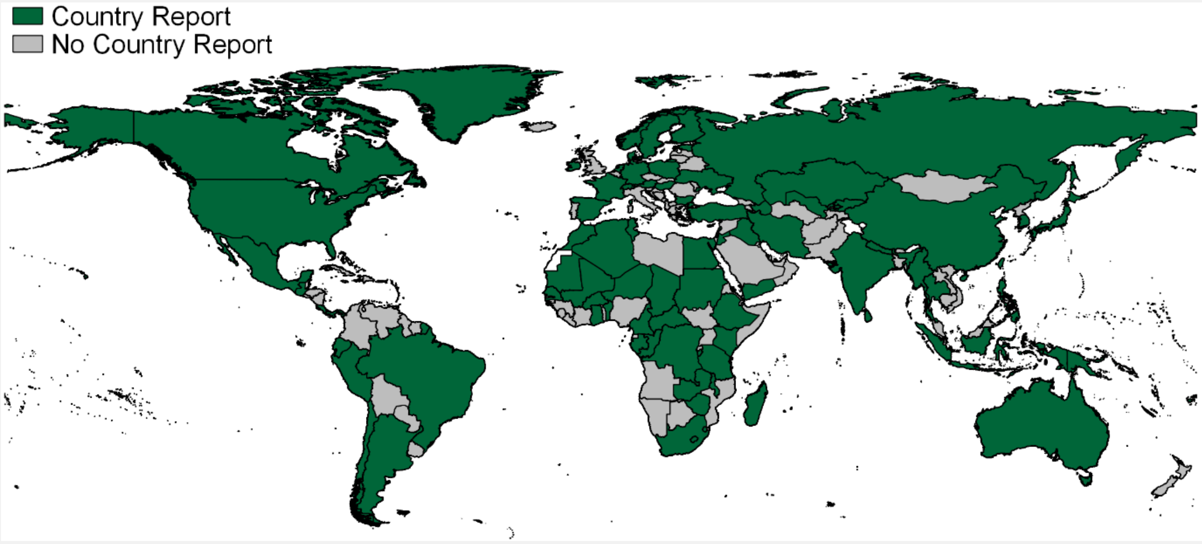


Figure 25. Country reporting for *The State of the World's Forest Genetic Resources*



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FAO. 2014a. *The State of the World's Forest Genetic Resources.* Rome (available at http://www.fao.org/publications/card/en/c/1a3bfc88-7fd8-4d6d-8690-87251e24dde0/).

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6.4 The state of education and training

Lack of knowledge and shortages of well-trained personnel can seriously constraint the sustainable management of genetic resources for food and agriculture. Effective education and training programmes are therefore vital elements of institutional frameworks for the management of these resources. Improving the skills and knowledge of scientists and technicians, development workers, NGOs, producers and policy-makers is vital to the sustainable management of BFA.

Plant genetic resources for food and agriculture

The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture (FAO, 2010) reported that the preceding years had seen a number of improvements in the state of education and training on PGRFA-related topics, including expanding opportunities for collaboration at regional and international levels. Donor-funded research projects with human resources components had played a significant role. More short-term informal courses and MSc and PhD programmes were being offered by universities, and training materials and laboratory facilities for training had been improved in a number of countries, incorporating recent advances in biotechnology and information and communication technologies. However, there was still a need to strengthen capacity in education and training to meet expanding demand for new, well-trained professionals and to upgrade the skills and expertise of current personnel, including on the *in situ* and *ex situ* management of crop wild relatives and wild food plants and their use in base broadening and genetic enhancement. Most national programmes concerned with on-farm management of PGRFA were aiming to build both their own professional capacity and that of the farmers they were working with.

Despite the positive developments, in some parts of the world, particularly in Africa, training and education capacity remained limited overall. Many NGOs and development agencies lacked sufficient qualified personnel to impart the necessary training to farming communities.

Animal genetic resources for food and agriculture

Weaknesses in education in the field of animal breeding and management of animal genetic resources for food and agriculture (AnGR) remain widespread, particularly in the developing regions of the world. Country reports submitted as contributions to *The Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture* (FAO, 2015) indicated that educational programmes devoted to AnGR management as a distinct topic were not common and were restricted largely to Europe. Major gaps were also reported in training and technical support programmes for the breeding activities of livestock-keeping communities, although many countries reported that progress had been made in this field. Training and awareness-raising activities were relatively widely reported elements of conservation programmes, although there appeared still to be a lot of scope for strengthening activities of this kind.

Forest genetic resources

As in the other subsectors of food and agriculture, a review of the state of education and training on forest genetic resources (FGR) presents a mixed picture. Although forestry is widely taught in universities around the world, FGR management is rarely recognized as a distinct discipline (FAO, 2014). In many cases, issues such as FGR conservation, tree breeding and management of non-wood forest products are inadequately covered. Worldwide, there has been a decline in enrolment in forestry programmes and many universities have had to revise and repackage their courses in order to attract students. Most countries do not have specific programmes dedicated to the task of raising public awareness of FGR and the significance of their conservation and sustainable use. However, awareness raising activities are undertaken by a range of different stakeholder groups, including governments, botanical gardens, small woodlot partnership programmes, environmental NGOs and forest or tree-specific conservation groups. In some countries, the provincial or central forestry authorities organize

FGR training workshops. Training on relevant laws, regulations and policies has increased understanding of the importance of FGR and helped to promote their protection and sustainable use.

Aquatic genetic resources for food and agriculture

The forthcoming report on *The State of Aquatic Genetic Resources for Food and Agriculture for Food and Aquaculture* states that all reporting countries indicated the presence of at least one institution involved in education and training in the field of aquatic genetic resources for food and agriculture (AqGR). General AqGR management was the most frequently reported topic for training courses, followed by characterization and monitoring, conservation, genetic improvement and economic valuation. Countries, on average, ranked increasing the technical capacities of institutions as their top priority for improving education and training in this subsector, noting that this required (inter alia) infrastructural improvements such as the installation of modern equipment and facilities for genetic research. Other priorities included raising awareness of the importance of AqGR and increasing information sharing between institutions.

Associated biodiversity

Associated biodiversity and its management fall within the scope of a wide range of academic disciplines. Many country reports mention the relevance of higher-education courses in “pure” sciences such as biology, ecology, zoology, entomology, botany, evolutionary biology, microbiology, genetics, biochemistry, soil science and oceanography and those on more applied, food- and agriculture-related topics such as agriculture, agronomy, horticulture, plant breeding, forestry, agroforestry, animal science, veterinary medicine, rangeland management, seed science, food science, fisheries and aquaculture. Some countries mention courses focusing on land use and the management of natural resources such as water and watersheds, on biodiversity and wildlife management, on rural development and on topics such as climate change and disaster management. Some countries, mostly in Europe, mention course titles that emphasize sustainability or that combine agricultural with environmental elements. A few reports mention courses on agro-ecology.

Few countries mention courses that specifically focus on the use and conservation of biodiversity or genetic resources in the context of food and agriculture or that explicitly address particular components of associated biodiversity. The report from Costa Rica mentions courses on agrobiodiversity and food security and on the conservation and use of agrobiodiversity, as well as a course on tropical apiculture.

Many country reports provide information on extension and training activities for farmers and other producers working in food and agriculture. Some mention the roles of farmer field schools, farmer group extension programmes or community-based organizations. Some refer to training on the importance of associated biodiversity. The report from Bangladesh, for example, mentions farmer field schools that provide training on integrated pest management and on the need to maintain soil biodiversity. Experiences with farmer field schools on integrated pest management in Nepal are described in Box 18. A number of country reports mention training activities that while not explicitly focused on associated biodiversity address closely related topics such as the sustainable management of soils. Several reports mention training on wildlife-friendly or environmentally friendly farming. Training on organic farming is mentioned in several country reports.

Box 18. Farmer field schools on integrated pest management – experiences from Nepal

Nepal introduced farmer field schools on integrated pest management (FFS-IPM) in 1998 in response to an outbreak of the rice pest Nilaparvata lugens (brown planthopper) that had occurred previous year in the Chitwan district. The approach has been modified and applied in other production systems (vegetable, cotton, potato, maize, tea and coffee) and to address other aspects of management. Farmer field schools now operate in all the 75 districts of Nepal.

Studies have found that most IPM-FFS trained farmers change their cultivation practices, for example using improved seeds, using a mixture of organic and inorganic fertilizers, reducing the use of

chemical pesticides, using crop rotation, improving the timing of irrigation and fertilizer application and introducing the use of biopesticides. Farmers become more knowledgeable about of the negative effects of pesticides on beneficial organisms of agro-ecosystem.
Many farmers who have participated in IPM-FFS have improved their incomes. Many also state that they feel more empowered and that they have developed leadership capacity. The IPM-FFS involve farmers in regular discussions, discovery-based learning and making presentations. These activities help to develop self-confidence and improve decision-making abilities. Women farmers report that their self-confidence has greatly increased. Many participants have joined in local farmer groups and cooperatives. Women have become active in the planning, implementation and management of local development programmes. Such changes have transformed the role of rural women within the household and helped to reduce a number of social problems.

Source: adapted from the country report of Nepal. For further information, see Jha,(2008), Bhandari (2012) and Esser et al. (2012).

The country reports also list training activities for a range of other stakeholders working in agriculture, fisheries, forestry and other fields related to food and agriculture, as well as for those working on wildlife conservation. Explicit references to training on the use and conservation of associated biodiversity are not frequent. The report from the Netherlands mentions that under the European Union’s Local Skills for Biodiversity Project, training materials on the use of an ecosystems approach in local planning have been developed for the staff of local and regional administrations, in particular planners, and that within the framework of this project, training workshops have been conducted in the Netherlands and in several other countries. It further notes that “Biodiversity in Action” training events are organized for local organizations and government officials and that the Louis Bolk Institute offers training for farmers, policy-makers and commercial businesses, on topics such as sustainable soil management. Where surveying and monitoring is concerned, the report from Ireland notes that the National Biodiversity Data Centre runs an extensive annual programme of training and identification workshops, many of which are run in conjunction with national organizations, to help build capacity in biological recording. Over 20 workshops covering a range of taxonomic groups are held each year. Specific workshops on monitoring and the identification of bumblebees and butterflies are provided as part of the centre’s national monitoring schemes for these insects.

Many country reports note that there is a need to strengthen education and training related to associated biodiversity. Specific requirements vary from country to country, but the reports indicate a widespread need for a greater focus on associated biodiversity (and BFA in general) in education at all levels. A number of reports note that biodiversity-related issues are not well integrated into higher-education courses on food and agriculture or other aspects of land use. In some cases, there is reportedly a separation between courses related to conservation and those related to the use of biodiversity. This, in turn, can lead to a lack of interdisciplinary skills among professionals. Some reports note the need to improve the supply of graduates trained in specific skills relevant to the management of biodiversity, such as taxonomy, surveying, documentation, economic valuation and the use of technologies such as cryoconservation.

Ongoing capacity-development among professionals and technicians is also widely noted as a priority. Some countries mention the need for better training and extension among farmers and other users of biodiversity. There is also widespread recognition of the need for awareness-raising among the general public – and in some cases among policy-makers – on the importance of BFA, including associated biodiversity. Many country reports recognize that as well as organizing training activities there is a need to improve access to information (e.g. via publications and information systems) and create opportunities for stakeholders to interact and exchange knowledge and ideas.

Reported constraints to improving the state of education and training include shortfalls in funding and a lack of cooperation and exchange of information among educational institutions and other stakeholders.

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[6.5 The state of research]

[6.6 The state of implementation of the ecosystem approach]

[6.7 The state of valuation methods]

6.8 Incentives for the conservation and sustainable use of biodiversity for food and agriculture

Introduction

As described elsewhere in this section, and in Sections 4 and 5, a range of different management practices, programmes, policies and legal instrument can contribute to the conservation and sustainable use of biodiversity for food and agriculture (BFA) at genetic, species, ecosystem, production system and landscape/seascape levels. The adoption of BFA-friendly measures, however, can be constrained by a number of different barriers, including economic limitations, social pressures, technological and knowledge gaps and motivational constraints (see Chapter 2 for a description of drivers of change affecting BFA and their management).

Establishment of protected areas, fishing bans or restrictions on livestock grazing often come at a high cost to local communities of farmers, forest dwellers, livestock keepers or fisher folk (Beyerl *et al.*, 2016; Pechacek *et al.*, 2013). Increasing connectivity within and across production systems, for example by establishing pollinator strips at field margins or within plots, conserving riparian forest buffers to protect vulnerable habitats and function as corridors for wildlife, maintaining livestock corridors to ensure herd mobility in semi-arid areas, creating fish ways on or around artificial and natural barriers to facilitate the migration of diadromous fishes, necessitate coordinated efforts among stakeholders (Goldmann *et al.*, 2007; Kitchell *et al.* 2014). The adoption of practices that improve conservation and sustainable use of BFA, for example mulch sowing in combination with no or reduced tillage to conserve biodiversity in the soil, is often constrained by risk aversion and by barriers stemming from the need for the investment of money, time or effort (e.g. on training).

Measures that promote the conservation and sustainable use of BFA may also involve structural changes that increase diversity within production systems. In addition to the examples mentioned above related to increasing connectivity of systems, such changes may include those that promote systems (e.g. mixed and organic system) and management practices (e.g. crop rotation) that increase diversity and promote ecosystem services. Barriers to the implementation of measures of this kind may include the need for large upfront economic investments, the need to deal with variance in output (productivity and/or earnings) or the need for skill development and training. Where choice of species, breeds and varieties is concerned, economic viability is a major factor. Farmers, forest dwellers, livestock keepers and aquaculture farmers may avoid using local varieties and breeds because of their low productivity and/or low consumer demand. The loss of traditional knowledge related to breeding may also limit the use of some species, varieties and breeds.

Incentive measures can be a means of overcoming barriers to the implementation of practices that favour the sustainable use and conservation of BFA. This section describes various types of incentives used for this purpose and presents a number of examples drawn largely from the country reports. Further information on incentives related to the management of genetic resources in the crop, livestock and forest sectors is provided in the respective “state of the world” reports (FAO, 2010, 2014, 2015a).

Types of incentives for the conservation and sustainable use of biodiversity for food and agriculture

Incentives supporting the conservation and sustainable use of BFA can take various forms and originate from public programmes or from private-sector investment (Figure 26): This spectrum of incentives can be divided into the following categories:

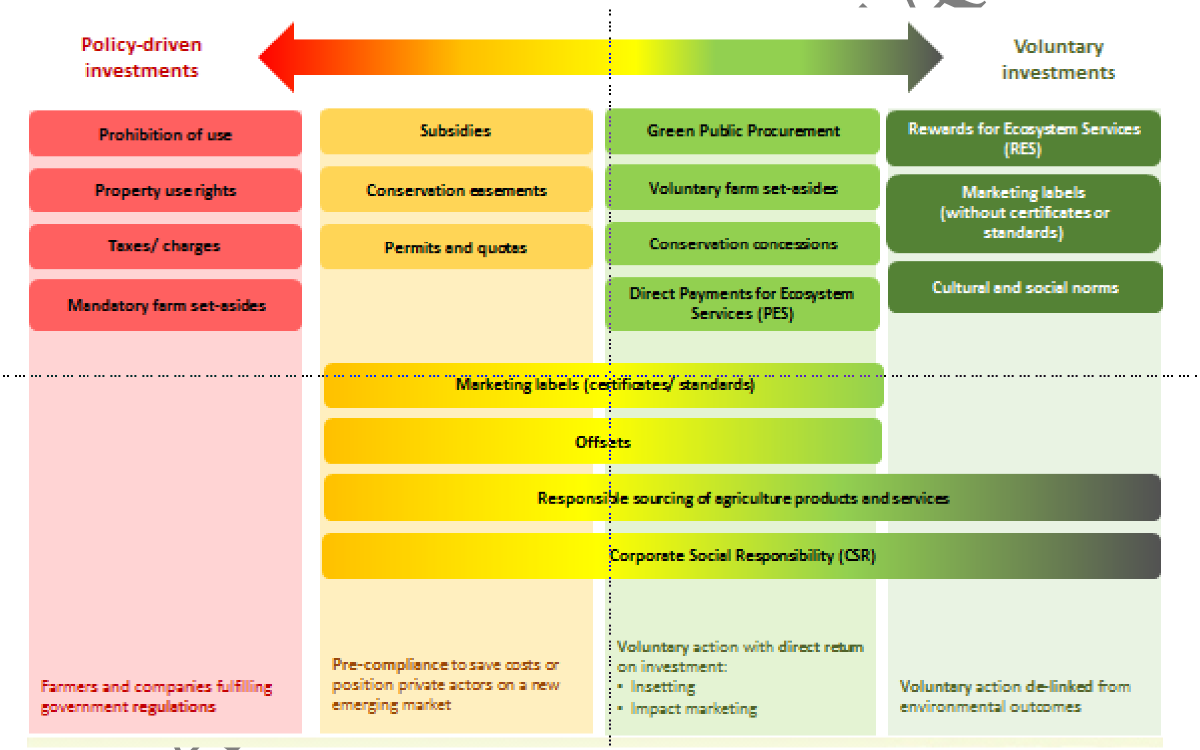
- Policy driven/mandatory regulations: act as disincentives to biodiversity-damaging activities. They include prohibition of practices with detrimental consequences for biodiversity, environmental or “green” taxes, conservation levies, trade bans for certain species and regulation of property and use rights. The removal of subsidies that serve to discourage biodiversity conservation can also be considered in this category as in economic terms it is equivalent to the imposition of an environmental tax. Regulations can also positively promote biodiversity conservation and restoration through tax exemption practices beneficial to biodiversity.
- Flexible regulations: consist of a vast array of policies, programmes and market-based initiatives

that influence a given activity. Examples include subsidies, biodiversity permits premium pricing systems and quotas for regulated activity, offsets and certificates and standards for ecolabelling.

- Voluntary investments: programmes and initiative that promote stakeholders' engagement in biodiversity conservation on a voluntary basis. Examples include direct payment for ecosystem services, conservation concessions and corporate social responsibility.

In many countries, existing public programmes and private sector investment to support BFA-friendly practices already provide such incentives. Single incentive measures are, however, unlikely to be sufficient to overcome barriers to the conservation and sustainable use of BFA. Mechanisms that combine multiple incentives are encouraged by the Convention on Biological Diversity[113] (CBD) (CBD, 2008). An enabling policy framework can improve the coordination of policy instruments to create a "package of actions" supporting the adoption of sustainable production practices that will benefit biodiversity (Garrett and Neves 2016b, FAO 2016b, FAO 2015c). For example, public policies that aim to improve farm productivity can be combined with those that reward conservation practices that support biodiversity.

Figure 26. Spectrum of incentives that can be combined as an integrated package to support biodiversity conservation, improved food security and sustainable production



Source: Garrett and Neves, 2016a.

Reported examples of incentive measures

Table 25 presents examples, of practices promoting the conservation and sustainable use of BFA for which countries report the provision of incentives.

Table 25. Examples of practices promoted through the provision of incentives

Sectors	Sustainable practices for which incentives are provided	Countries reporting
Crop production	Organic farming or conversion to organic farming	Belgium, Costa Rica, Croatia, Estonia, Finland, Poland, Norway, Spain, United Kingdom, United States of America

[113] COP 9 Decision IX/6 Incentive Measures (Article 11) https://www.cbd.int/decision/cop/default.shtml?id=11649

	Reduced fertilization and pesticide use	Bangladesh, Belgium
	Reduced tillage and prevention of nutrient runoff from crop fields	Belgium, Norway
	Retention of landscape features such as trees (inline, in groups or isolated), field margins, ditches, terraces	Belgium, Estonia
	Conservation or enhancement of field margins for pollinators	Belgium, Poland, United Kingdom, United States of America
	Improved connectivity through habitat corridors	United Kingdom, Costa Rica
	Protection of plant genetic resources	Croatia, Ecuador, Estonia, Ethiopia, Finland, Hungary, India, Ireland, Panama, Peru, Poland, United Kingdom
Forestry	Increased agroforestry and reforestation	Belgium, Costa Rica
	Conversion of non-native forest to native woodlands	Ireland
	Conservation and restoration of mangrove forests	Ecuador
	Establishment of forest gene banks	Slovenia
Livestock	Maintenance of grasslands	Norway, Slovenia, Spain, United States of America
	Grassland nutrient management	Ireland
	Protection of indigenous breeds of domestic animals	Croatia, Finland, India, Ireland, Kenya, Nepal, Norway, Spain
Fisheries and aquaculture	Temporary suspension of fishing activities for over-exploited stock	Slovenia
	Re-orientation towards more sustainable fishing practices	Gambia, Mexico
	Restoration of fish habitats and migration routes	Hungary, Nepal
	Conversion to organic, low-impact aquaculture	Mexico, Slovenia
	Wetland conservation	Bangladesh, United States of America
Intersectoral	Protection of endangered species inside or outside protected areas	Estonia, Ireland, Poland, Slovenia, United States of America
	Control and management of invasive species	Cameroon
	Support towards certification scheme	Belgium, Cameroon, Spain, United States of America

Source: country reports.

Country reports from European Union Member States refer to a range of incentive measures promoting the sustainable use and conservation of BFA that are linked to EU-level policies and programmes such as the EU Biodiversity Strategy. The EU Biodiversity Strategy, adopted in 2011 to halt the loss of biodiversity and ecosystem services in the EU, works in accordance with legal instruments such as the Birds Directive (Directive 2009/147/EC),[114] the Habitats Directive (Directive 92/43/EEC)[115] the EU Water Framework Directive[116] and the Regulation on Invasive Alien Species (EU Regulation 1143/2014)[117] (see also Section 6.9 on policies and legal frameworks).

Most reports from EU countries mention the importance of direct support schemes under the EU's Common Agricultural Policy, including payments for agricultural practices that are climate friendly and beneficial to the environment. To be eligible for this form of payment, farmers need to comply with a set of standards that contribute to preventing soil erosion, maintaining soil organic matter and soil structure, ensuring a minimum level of maintenance of crop diversification and permanent grassland, avoiding the deterioration of habitats, protecting and managing water on their land, and

[114] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0147&rid=1
[115] http://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A31992L0043
[116] http://eur-lex.europa.eu/resource.html?uri=cellar:5c835afb-2ec6-4577-bdf8-756d3d694eeb.0004.02/DOC_1&format=PDF
[117] http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1417443504720&uri=CELEX:32014R1143

retaining landscape features (e.g. hedges, ponds, ditches, trees, field margins, terraces) that enhance biodiversity conservation. Country reports also mention payments in support of sustainable forest management practices (some 90 percent of EU funding for forests comes from the European Agricultural Fund for Rural Development).

The country reports make few specific references to the contribution of EU agri-environmental schemes to the conservation and sustainable use of components of associated biodiversity with well-defined roles in the provision of ecosystem services to food and agriculture (pollinators, soil-dwelling organisms, pest natural enemies, etc.). The report from the United Kingdom notes that the practices targeted by agri-environmental schemes include “establishing pollen and nectar mixes on the edges of arable fields to increase the availability of essential food sources for insects, including those that contribute to the pollination of agricultural crops” and “creation of flower rich margins that provide habitat for beneficial predators.” It further notes that in the wider countryside agri-environmental schemes incentivize practices that benefit pollinators, although these schemes are not intended specifically as a means of promoting pollination services in crop production. The report from Slovenia mentions that the benefits of agri-environmental schemes in crop production systems include the provision of food sources for bees and increasing microbiological activity in the soil.

Countries mention various other EU-level initiatives that support local food production and short food supply chains. One example is the School Fruit Scheme,[118] financed by the EU, which contributes to increasing the use of local food in educational institutions. The scheme, which has been in place since 2009, distributes fruits and vegetables for free to school children. Slovenia’s country report documents that local farmers and agricultural cooperatives represent one-third of suppliers for the scheme. The measure is complemented by the introduction of school gardens. Also relevant are projects financed or cofinanced by the EU’s LIFE[119] programme that target the conservation of biodiversity in areas that fall within the Natural 2000 network.[120]

European countries outside the EU also report a number of schemes that incentivize sustainable use and conservation. In Switzerland, for example, 32 organic farming associations, as well as the Research Institute of Organic Agriculture, are members of Bio Suisse, a private-sector umbrella organization that has developed common and uniform standards for organic agriculture and processing, as well as a common label. Organic produce carrying the label has a market share in Switzerland of about 60 percent. In Norway, 4.3 percent of productive forest area is classified as protected forest area. Part of this protected forest zone falls under the voluntary protection scheme (*frivillig vern*). Under this scheme, forest owners voluntarily propose forest areas where they will not undertake logging activities, thereby helping to ensure the conservation of key biotopes. Owners receive financial compensation based on opportunity cost value.[121]

The country report from the United States of America describes a number of different incentive schemes supporting the maintenance of habitats, including a project aimed at reducing the conversion of wetlands and grasslands into cropland. It describes several programmes under which farmers and ranchers can receive support for increasing and improving pollinator habitats. For example, under the Conservation Stewardship Program (CSP), which provides long-term stewardship payment for advanced conservation systems, nearly 3 000 CSP contract holders have taken action to establish pollinator habitat in non-cropped areas on their lands. Participants have seeded over 11 000 acres (approximately 4 450 hectares) of nectar and pollen producing plants in field borders, vegetative barriers, buffer strips, and waterways.

In other regions, incentive schemes supporting the sustainable use and conservation of BFA are comparatively uncommon. However, countries report some relevant schemes. Many of these share a number of common characteristics:

- they tend to be implemented at local/subnational scale rather than national scale;
- they include support for the creation of cooperatives, associations and community-based initiatives

[118] http://ec.europa.eu/agriculture/sfs_en
[119] http://ec.europa.eu/environment/life/
[120] http://ec.europa.eu/environment/nature/natura2000/index_en.htm
[121] http://frivilligvern.no/

rather than targeting individual producers;

- they often involve the establishment of alternative income-generating activities;
- they often target the maintenance of genetic resources and local varieties to promote food security;
- they tend to target improvements to the environmental performance of local food production for local use rather than ecolabelling and increased market-opportunities;
- individual incentives are often not integrated into a "package" with other incentives.

A few countries report long-running national-level incentive schemes. For example, Costa Rica's Forest Law No. 7575 of 1996[122] provides the regulatory basis for smallholders and owners of natural forests and forest plantations to receive direct payments for the environmental services and biodiversity conservation that their forests support.[123] Between 1995 and 2015, payments for the protection and recovery of forest habitats under this regulation amounted to about US$320 million. Approximately 14 500 contracts have been signed with landowners, covering more than 1 million hectares, with about 6 million trees planted in agroforestry systems.[124] The report from Costa Rica also notes that the country's Biodiversity Law No. 7788[125] establishes incentives in the form of public recognition schemes such as "Ecological Flag" and national and local prizes for those who stand out for their actions in favour of conservation and sustainable use of biodiversity. The law also foresees tax exemptions on equipment and materials that are regarded as indispensable for the development, research and transfer of appropriate technology for the conservation and sustainable use of biodiversity.

The report from Ecuador mentions "*Socio Bosque*", a major national programme that has been in place since 2008. The programme targets areas where there is rapid land-use change, areas critical for the maintenance of ecosystem processes and areas with high levels of poverty. Conservation agreements are signed with landowners to protect native forests. Once an agreement is signed, payments (varying according to size of forest area covered) are made annually for a period of 20 years. Since 2013, Socio Bosque has been complemented by the *Socio Manglar* programme, which supports the conservation and restoration of mangroves. *Socio Manglar* has a component related to livelihoods and sustainable use of natural resources. Beneficiaries who sign a conservation agreement acquire "use rights" to sustainably extract resources such as shells, crabs, crabs and fish (respecting time and area restrictions specifically designed to promote the conservation of each species).

Viet Nam reports a national programme of payments for environmental services from forests. [126] Initially (beginning in 2008), two provinces were targeted. In 2010, Decree No. 99/2010/ND-CP[127] mandated the establishment of a national scheme. The main services targeted are protection of watersheds, protection of landscapes and biodiversity for touristic purposes, carbon sequestration and provision of spawning grounds, feeds, natural seeds and water for aquaculture. The report further notes that the country's National Biodiversity Strategy (MNRE, 2015) includes the objectives of improving policies and institutional capacity related to the implementation of payments for the forest ecosystem services at national scale and piloting a payment for ecosystem services policy applicable to marine and wetland ecosystems.

Countries from various regions also reported other examples of incentive schemes that support the certification for production practices. These include the International Foundation for Organic Agriculture,[128] International Organic Accreditation Service,[129] International Programme for the

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[122] Ley Forestal No. 7575: http://faolex.fao.org/cgi-bin/faolex.exe?rec_id=004894&database=faolex&search_type=link&table=result&lang=eng&format_name=@ERALL
[123] Further information on payments for environmental services schemes in Costa Rica can be found in Pagiola (1996).
[124] The country report cites Roldán (2015).
[125] Ley de Biodiversidad N° 7788 de 23 Abril 1998 http://www.wipo.int/wipolex/en/text.jsp?file_id=20869
[126] The report cites Pham *et al*. (2013), which can be consulted for further information on payments for environmental services schemes in Viet Nam.
[127] Decree No. 99/2010/ND-CP on the Policy on Payment for Forest Environment Services: http://www.ecolex.org/details/legislation/decree-no-992010nd-cp-on-the-policy-on-payment-for-forest-environment-services-lex-faoc100744/
[128] https://www.ifoam.bio/
[129] http://www.ioas.org

Endorsement of Forest Certification,[130] and the Forest Stewardship Council,[131] GLOBALG.A.P. livestock certification[132] and the Marine Stewardship Council[133.] Also reported are farm accreditation schemes, for example those promoted by LEAF (Linking Environment and Farming)[134] and Conservation Grade.[135]

While not necessarily documented in the country reports, integrated packages of incentives are already being implemented in some of the reporting countries. For example, in Mexico, the Biodiversity Commission, CONABIO, coordinates co-financing from public and private sources to provide farmers with incentives to ensure that traditional farming systems remain productive and avoid further slash and burn of the Mesoamerican Biological Corridor to protect biodiversity. Cash and seedlings financed through the national payments for environmental services scheme help enable farmers to rehabilitate and reforest their land to comply with forest laws and maintain the MesoAmerican Biological Corridor. Once their land is rehabilitated, farmers are assisted by CONABIO to access further incentives from public programmes and private-sector investment to improve productivity (e.g. through training, use of improved crop varieties, improvements to soil fertility) and develop post-harvest production to increase access to higher-value markets. The integration of investments from agricultural and environmental sectors has enabled a landscape-level approach that creates a package of incentives that supports improved production and thereby reduces the need for further agricultural expansion and associated threats to biodiversity.

Needs and priorities

Incentive schemes can help farmers, foresters, livestock keepers, fishers and aquaculture practitioners overcome immediate and long-term technical, institutional, cultural and financial barriers to the adoption of sustainable production practices that benefit BFA. A wide range of different types of incentives, from both public and private sources, can be used. Some country reports provide examples of incentive schemes that promote the conservation and sustainable use of BFA, including ecolabelling certification, in-kind rewards and compensatory payments. Others, however, note the absence of measures and their coordination, and highlight the need to create them.

Better mapping of existing public programmes and private sector incentives would help countries to identify synergies between incentives measures. It would also provide an opportunity to improve the coordination of multiple incentives into a package of actions that support the conservation and sustainable use of BFA. Challenges to the establishment of multiple incentive programmes include the need for a high level of coordination required between institutions and across scales (international, national, subnational), the need to engage with the private sector and promote responsible investment, and the need for cross-sectoral dialogue within food and agriculture (i.e. between the crop, forest, livestock, fisheries and aquaculture subsectors) and beyond. For further discussion of needs and priorities in this field, see FAO (2015a and 2016a).

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[130] www.pefc.org/
[131] https://ic.fsc.org/en
[132] http://www.globalgap.org
[133] https://www.msc.org/
[134] LEAF (Linking Environment and Farming) http://www.leafuk.org/leaf/home.eb
[135] www.conservationgrade.org/

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6.9 Policy and legal frameworks

Introduction

An appropriate legal and policy framework is often regarded as a key prerequisite for effective management of biodiversity for food and agriculture (BFA) at national level. However, assessing the state of policies and legislation and their influence on BFA and its management often remains challenging. Countries face a range of different challenges and have a range of different approaches to the deployment of legal and policy measures to address issues in BFA management. Laws and policies both within and beyond the field of BFA management may have indirect or unintended effects. Practical impacts may be constrained by weak implementation or because provisions have failed to keep up with emerging issues in BFA management.

Plant genetic resources for food and agriculture

Plant genetic resources for food and agriculture (PGRFA) are targeted by national laws and policies in a number of different fields. The main fields of legislation affecting PGRFA management include phytosanitary protection, seed systems, intellectual property rights, farmers' rights and biosafety. The importance of a coherent national approach to PGRFA management is widely recognized and many countries have established national programmes of one kind or another, backed up to varying degrees by national legislation and policy initiatives. In several fields, national-level frameworks are influenced by the existence of legal and policy instruments at regional or global levels. As of October 2016, 140 countries, plus the European Union, were Parties to the International Treaty on Plant Genetic Resources for Food and Agriculture (FAO, 2016).

Seed systems

In most countries, the seed system is highly regulated: from the release of new varieties and quality control of seeds to the legal status of organizations that implement seed control and certification and variety release procedures. *The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture* (SoW-PGRFA-2) (FAO, 2010) noted three main trends in this field: emergence of voluntary arrangements regarding seed certification and variety release; the growing use of accreditation principles within official national rules and standards; and the regional harmonization of seed laws. These conclusions remain valid today.

Intellectual property rights

In the field of intellectual property rights, the SoW-PGRFA-2 noted that the number of countries providing legal protection to plant varieties through plant breeders' rights had been increasing over the preceding decade, with increasing numbers of countries in Africa, Asia, Latin America and the Caribbean, the Near East and eastern parts of Europe having enacted legislation of this kind. Debates over the issue of patenting in the PGRFA sector had also become increasingly prominent, with various countries having amended legislation in this field. At the time (2010), 68 countries were members of the International Union for the Protection of New Varieties of Plants (UPOV). As of April 2016, the number had increased to 72 (UPOV, 2016).[136]

Farmers' Rights, biosafety and phytosanitary legislation

The issue of Farmers' Rights[137] had also become an increasingly hot topic. Many countries had developed, or were in the process of developing, legislative and other measures addressing this issue. Concerns over biosafety had also been increasing and were increasingly being addressed in national

[136] In addition, the African Intellectual Property Organization became a member in 2014.

[137] Article 9 of the International Treaty on Plant Genetic Resources for Food and Agriculture states that "In accordance with their needs and priorities, each Contracting Party should, as appropriate, and subject to its national legislation, take measures to protect and promote Farmers' Rights, including: a) protection of traditional knowledge relevant to plant genetic resources for food and agriculture; b) the right to equitably participate in sharing benefits arising from the utilization of plant genetic resources for food and agriculture; and c) the right to participate in making decisions, at the national level, on matters related to the conservation and sustainable use of plant genetic resources for food and agriculture."

legislation. Many countries had also introduced or updated phytosanitary legislation, in large part in response to the adoption of the revised International Plant Protection Convention in 1997.

Strengthening legal and policy frameworks for PGRFA

Potential means of strengthening legal and policy frameworks for PGRFA management include: the establishment of nationally endorsed strategies and plans for the conservation and use of PGRFA that set priorities, distribute roles and allocate resources for management actions in the sector; raising awareness and strengthening capacity among policy-makers with regard to the complexities of the legal and policy issues affecting the conservation, use and exchange of PGRFA. Efforts need to be made to ensure that legal and policy instruments are appropriate to the needs and capacities of the respective country and are non-conflicting and complementary.

Animal genetic resources for food and agriculture

Where policies are concerned, a growing number of countries have responded to the adoption of the Global Plan of Action for Animal Genetic Resources (FAO, 2007) by developing their own instruments, generally referred to as national strategies and action plans (NSAPs), as a means of putting global recommendations into practice at national level. Legal instruments that address AnGR management activities such as conservation and genetic improvement in a relatively “joined-up” way are also becoming more widespread (FAO, 2015).

Many countries have also developed legal and policy instruments addressing individual components of AnGR management, including surveying and monitoring, official recognition of breeds, breeding programmes, the use of reproductive biotechnologies, conservation programmes, importation of genetic material, research programmes, use of transgenic technologies, and access and benefit-sharing (see Subsection 6.9). Although the number of countries that have put instruments in place has been increasing in recent years, many still report gaps and weaknesses that need to be addressed. (It is important to note in this context that the absence of a law does not necessarily represent a weakness and that some countries report that they are well served by relatively unregulated approaches to most aspects of AnGR management.)

AnGR issues are, to a degree, gaining a foothold in broader policy and legal instruments in the livestock, agricultural and environmental sectors. For example, most National Biodiversity Strategies and Action Plans, the main instruments for country-level implementation of the Convention on Biological Diversity, include some AnGR-related provisions.

Although countries have been quite active in recent years in developing new legal and policy measures in the AnGR field, many report constraints to implementation. These include a lack of human and financial resources, logistical problems, lack of coordination between different government departments, excessive bureaucracy, lack of awareness on the part of stakeholders and lack of clarity in the formulation of legal and policy texts. Identifying the most appropriate way forward in terms of updating national legal and policy frameworks for AnGR can be challenging and needs to be based on thorough analysis of gaps, needs and capacity to implement different policy and regulatory options (FAO, 2015). Stakeholder involvement in the development of policy and legal frameworks often needs to be strengthened.

Forest genetic resources

Many countries have no specific laws or policies on forest genetic resources (FGR) or have instruments that are outdated (FAO, 2014). However, a number have laws and policies of relevance to FGR, most commonly instruments targeting the conservation and protection of national forests. In some cases, these include FGR-related provisions. Potential steps towards strengthening policy and legal frameworks for FGR include developing national policies, plans or programmes for FGR management and ensuring that FGR-related concerns are better accounted for in national forestry policies and laws. Any efforts to develop or update policy and legal frameworks for FGR will need to involve multiple stakeholders.

Aquatic genetic resources for food and agriculture

As discussed in Section 6.3, the main global non-binding policy document addressing AqGR is the FAO Code of Conduct for Responsible Fisheries (CCRF) (FAO, 1995). Many governments have incorporated elements of the CCRF into national legislation and policy. The country reports submitted for *The State of the World's Aquatic Genetic Resources for Food and Agriculture* (SoW-AqGR) indicate that AqGR are also addressed by a range of other national instruments, including in the fields of conservation, fisheries, aquaculture and trade. National legislation often restricts the importation of non-native aquatic species in order to protect local biodiversity or local business. For example catfish are not allowed to be imported into California for fear of introducing channel catfish virus. Many countries have fishery management plans that regulate the time and quantity of fishing activities and what species can be harvested. However, some national policies are in conflict with international obligations: for example those related to the local harvest and trade of threatened and endangered species. In many countries aquatic species are covered under laws protecting endangered species. Aquatic species are also addressed in many conservation-related policy documents such as National Biodiversity Strategy and Action Plans drafted for the CBD.

Particularly notable in the aquatic sector is the absence of provisions similar to those related to farmers' rights and breeders' rights in the terrestrial cop sector. This is a consequence of the relatively recent domestication of aquatic species; aquaculture farmers have not had millennia to develop or care for farmed aquatic species as has been the case for terrestrial species. Genetic improvement of farmed aquatic species has often been done by large companies or international institutions with modern breeding facilities, and at locations outside the centres of origin of the respective species (Bartley *et al.*, 2009). In such cases, no indigenous group was responsible for the genetic improvement of the species and there would be no basis for a claim for farmers' or breeders' rights. Policies relating to *ex situ* conservation (i.e. gene banks) are also not as well developed as in the crops and livestock sectors due to the difficulty of storing frozen eggs and embryos from aquatic species.

Key reported constraints to the implementation of AqGR-related policies include a lack of awareness, a lack of technical capacity and a lack of resources. In fact, many countries have adequate policies on AqGR, especially at the species level, but lack the resources to implement and enforce them. One of the more significant policy gaps concerns cross-sectoral development and management of freshwaters and inland aquatic ecosystems. There is strong competition among users of freshwater (e.g. industry, agriculture, hydro-electric generation, municipal drinking water and navigation, aquaculture and fisheries) to have water managed for their benefit. However, the fishery sector is often left out of policy discussions on the use of freshwater, and as a result water management policies often favour other sectors to the detriment of living aquatic resources such as fish (Bartley *et al.*, 2016).

Associated biodiversity

The country reports indicate that associated biodiversity is generally not targeted as a distinct category for policy purposes, falling instead within the scope of broader instruments targeting biodiversity, the environment, sustainable development or agricultural practices.

National policies addressing biodiversity or environmental protection generally include measures that directly or indirectly affect the maintenance of habitats in and around food and agricultural production systems. The same is true for those addressing more specific problems, such as climate change, invasive species or desertification, and those targeting specific types of ecosystem such as forests, mountains, lakes or coastal zones. Whether directly targeted or not, associated biodiversity will often benefit from policies that reduce pollution of land and water, prevent destructive land-use changes or restrict environmentally unfriendly practices in agriculture, livestock production, forestry, fisheries or aquaculture. Some country reports mention efforts to integrate biodiversity into national planning and policy development across a variety of different economic sectors. The report from Sri Lanka, for example, notes that this is done via the country's Biodiversity Conservation Action Plan. It further notes that biodiversity is reported to be adequately integrated into some sectoral policies (e.g. those addressing forests, wildlife, wetlands, coastal and marine habitats, fisheries and agriculture) but not in others (e.g. those addressing industrial and service sectors, including urban development, harbours, tourism, mining, energy, roads and telecommunications). Most countries have prepared a National Biodiversity Strategies and Action Plans (NBSAP) as a basis for the implementation of the CBD at national level. The extent to which these instruments specifically address biodiversity for food and agriculture, associated biodiversity and the ecosystem services they deliver varies from country to country (Box 19).

A number of country reports, particularly from Europe, note the significance of agri-environmental schemes under which farmers are incentivized to manage their land in environmentally friendly ways. Some of these schemes target species or habitats that have well-recognized beneficial roles in agriculture (see Section 6.8). In general, however, schemes often focus more on protecting wildlife from the effects of environmentally unfriendly management practices than on maintaining and enhancing the benefits that biodiversity provides to food and agriculture.

The country reports generally include little information on policies devoted to specific categories of associated biodiversity. Pollinators are the category most often targeted by national plans and strategies. For example, the country report from Belgium mentions a federal bee plan targeting the preservation of pollinators, particularly bees. The plan included about 30 actions and measures dealing with six main issues: risk assessment (including pesticide risk analysis); integration of pollinator management into other policies and measures (including economic measures); orientation of markets in favour of pollinators; monitoring of honey bees and wild bees; animal-health policy; and the traceability of hives (for honey bees only). The report from the United Kingdom mentions the National Pollinator Strategy (DEFRA, 2014), which aims to safeguard insect pollinators by taking action across five key areas: supporting pollinators on farms; supporting pollinators across towns, cities and the countryside; enhancing repose to pest and disease risks; raising awareness of what pollinators need to survive and thrive; and improving evidence on the status of pollinators and the services they provide. The United States of America's National Strategy to Promote the Health of Honey Bees and Other Pollinators (Pollinator Health Task Force, 2015), which aims to improve pollinator habitat and reduce stressors affecting pollinators, is another reported example.

In addition to instruments focused on biodiversity or environmental protection, many country reports list policies that aim to promote economic and social goals such as livelihood development, food security and poverty reduction. Some reports explicitly note the need for policies that address links between biodiversity and productivity in food and agricultural systems. For example, the report from the Bahamas notes the need to develop a national fisheries development plan that, inter alia, addresses the "conservation and restoration of coastal habitats and wetlands important to fisheries recruitment and to the health of fringing reefs."

A number of reports also note the significance of instruments that aim to limit the negative effects of development in sectors such as energy, transport and construction on associated biodiversity. The report from Germany for example mentions a policy that promotes the integration of habitat corridors for wildlife (not explicitly for associated biodiversity) into the transport network. Another example of the integration of biodiversity-related concerns into transport policy is provided in the report from Norway, which mentions that the country's National Transport Plan includes a provision addressing the protection of biodiversity along the edges of roads, railway lines, etc.

As with other categories of biodiversity, legal instruments can have a significant influence on sustainable use and conservation of associated biodiversity. They can, inter alia, serve to enforce restrictions on biodiversity-unfriendly practices in food and agricultural production and in other industries, to restrict overharvesting of wild products, to set criteria for support measures for beneficial practices and to assign responsibilities to institutions and stakeholder groups involved in conservation and sustainable use. Many country reports list laws dedicated to the protection of biodiversity, along with those in a range of other fields that include biodiversity related provisions. Little information specifically related to associated biodiversity as a category or to particular categories such as pollinators or soil-dwelling organisms is included.

The state of legal and policy provisions in a complex field such as the management of biodiversity is difficult to evaluate. Threats to biodiversity and constraints to sustainable management clearly vary from country to country and the extent to which such issues can be addressed via legislative means will depend on countries' capacities to assess gaps and needs, develop relevant instruments and implement legal measures once they are in place. The country reports generally do not present detailed assessments of gaps in policies and legislation and their effects on the management of associated biodiversity (or BFA more generally). This may, in part, relate to a lack of information on the effects of existing provisions. The country report from Sri Lanka, for example, notes that although policies and programmes are considered to have played a key role in promoting and safeguarding biodiversity, specific outcomes in terms of the state of biodiversity and the supply of ecosystems services have not been assessed. More fundamental may be a lack of awareness of the importance of associated BFA among policy-makers and administrators.

Some specific weaknesses are noted. For example, the report from Ecuador mentions the absence of an appropriate legal framework defining the roles and competences of institutions involved in managing biodiversity. Some countries note a general need to strengthen policies targeting associated biodiversity. The report from Nicaragua, for example, mentions that while the country has made significant progress over recent years with regard to policies targeting domesticated biodiversity, it still lacks an effective medium- to long-term strategy for the management associated biodiversity, as well as for wild foods and ecosystem services.

The country reports note a number of different constraints to the development of legislation addressing the conservation and sustainable use of associated biodiversity and wild foods. In some cases, the development of legislation is reportedly hampered by a lack of legal specialists in this field. Some reports note that a lack of awareness of the significance of associated biodiversity means that legislation in this field is not prioritized. Some mention perceived conflicts with the need to increase the output of food and agricultural systems or with other economic activities. Some mention opposition from producers and other stakeholders who fear that legal restrictions will affect their livelihoods.

Lack of knowledge of associated biodiversity, the production systems in and around which they are found and the benefits they supply is noted in some country reports as a constraint to the development of effective legal and policy instruments. The potential impacts of different measures may not be well understood, particularly given the time scales over which they may play out and the interactions that may occur between different ecosystems and different economic sectors. These interactions underline the importance of intersectoral and interministerial collaboration in the formulation of laws and policies. The country reports indicate that cooperation at this level often remains insufficient. Some reports note that improving information systems and exchange of information between different stakeholders would help to strengthen policy- and law-making.

A range of different factors can constrain the implementation of laws and policies. The country report from Cameroon, for example, referring to the implementation of legislation on the use of wild foods, notes that constraints include a lack of awareness on the part of rural dwellers: people may be unaware of the rules (a problem exacerbated by a lack of translations into local languages) or not understand why they have been introduced. It also notes that poor transport infrastructure constrains the activities of law enforcers. Some reports mention that implementation is affected by a lack of funding or by a lack of security in rural areas (because of armed conflicts, etc.). Others note that problems are caused by contradictory legislation, the existence of loopholes or by a lack of cooperation between different agencies or lack of clarity as to their mandates.

In summary, the relatively undeveloped state of policy and legal frameworks specifically addressing associated biodiversity for food and agriculture may relate in part to a lack of awareness as to the significance of these resources and a lack of clarity as to ministerial competences. It may also relate to objective difficulties in address cross-sectoral matters of this kind in a coherent way.

Box 19. Agrobiodiversity, associated biodiversity and ecosystem services in National Biodiversity Strategies and Action Plans

Most countries have prepared a National Biodiversity Strategies and Action Plans (NBSAP) as a basis for the implementation of the CBD at national level. The extent to which these instruments specifically address biodiversity for food and agriculture, associated biodiversity and the ecosystem services they deliver varies from country to country.

In 2015, FAO conducted a non-exhaustive assessment providing quantitative data and qualitative findings on the importance of ecosystem services and biodiversity in relation to agricultural processes (primarily for crops, forest trees and livestock production) in NBSAPs (FAO and CBD, 2016). In September 2016, FAO built on this assessment by analysing the NBSAPs submitted since 2014, focusing on agrobiodiversity in general, ecosystem services related to agricultural production and agroforestry as a diversified production system/management practice.[138] Table 26 presents the regional breakdown of NBSAPs included in the analysis.

Table 26. National Biodiversity Strategy and Action Plans submitted in each region and included in the analysis

Region	Number of NBSAPs
Africa	45
Asia	22
Europe and Central Asia	47
Latin America and the Caribbean	33
Near East and North Africa	18
North America	1
Pacific	14
World	180

A total of 180 NBSAPs published on the CBD website[139] since 1995 were analysed.[140] The frequency of keywords, chosen because of their relevance to ecosystem services that support agriculture and sustainable land management practices, was measured. The English keywords can be seen in Table 27. These were translated into French, Spanish, Portuguese and Latvian for use with NBSAPs published in these languages.

Table 27. Keywords used in the analysis of National Biodiversity Strategies and Action Plans

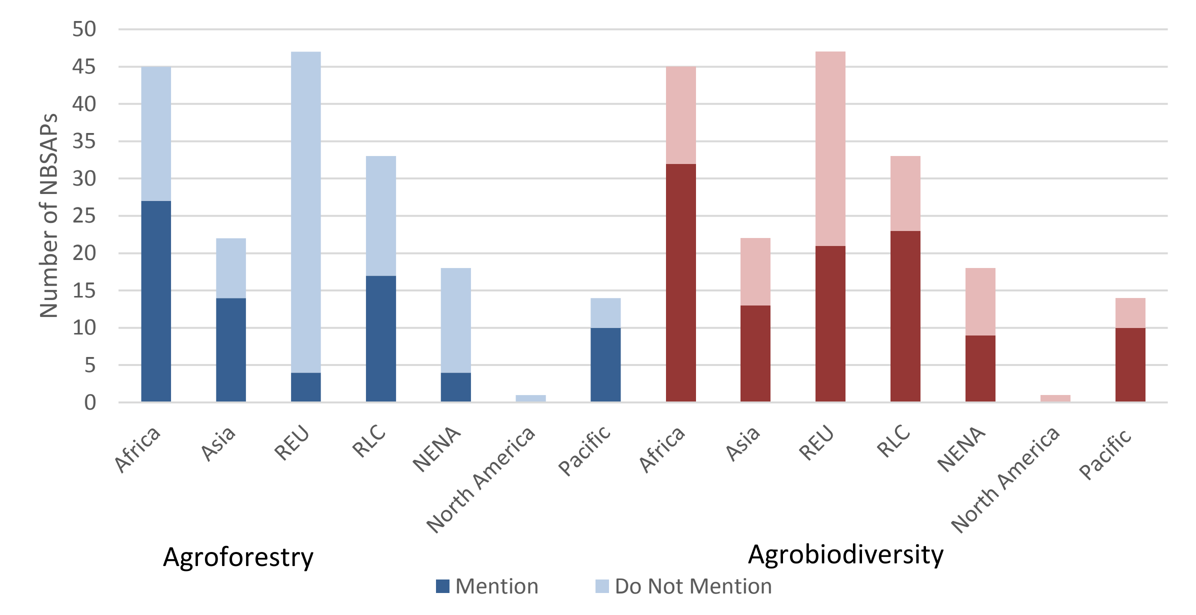
Broad keyword	Individual terms and expressions searched
Ecosystem services	Ecosystem service, ecosystem function, ecosystem process
Pest and disease regulation	IPM, integrated pest management, biological control, biological pest control
Soil biodiversity and fertility	Soil biodiversity, soil fertility
Pollination	Pollination, pollinator
Agrobiodiversity	Agrobiodiversity, agro-biodiversity, agricultural biodiversity, agricultural biological diversity
Agroforestry	Agroforestry, agro-forestry

Agrobiodiversity is mentioned in 60 percent of all NBSAPs (Figure 27), although it should be noted that in some cases the actions mentioned under this heading are largely or exclusively focused on crop and animal (livestock) genetic resources. (An analysis of the inclusion of animal genetic resources issues in NBSAPs is provided in the second SOW-AnGR − FAO, 2015.) Agroforestry is mentioned in 46 percent of NBSAPs. Several mention that it is a means of promoting the *in situ* conservation of agrobiodiversity. The NBSAP from Tonga notes, for example, that "Mixed planting of different species, often with strong symbiotic interrelationships, promotes ecological stability [while] at the

[138] For countries that submitted more than one version of their NBSAPs, only the most recent version was included in the analysis.
[139] https://www.cbd.int/nbsap/introduction.shtml
[140] The analysis followed the methodology used in the earlier assessment. Details are provided in FAO and CBD (2016).

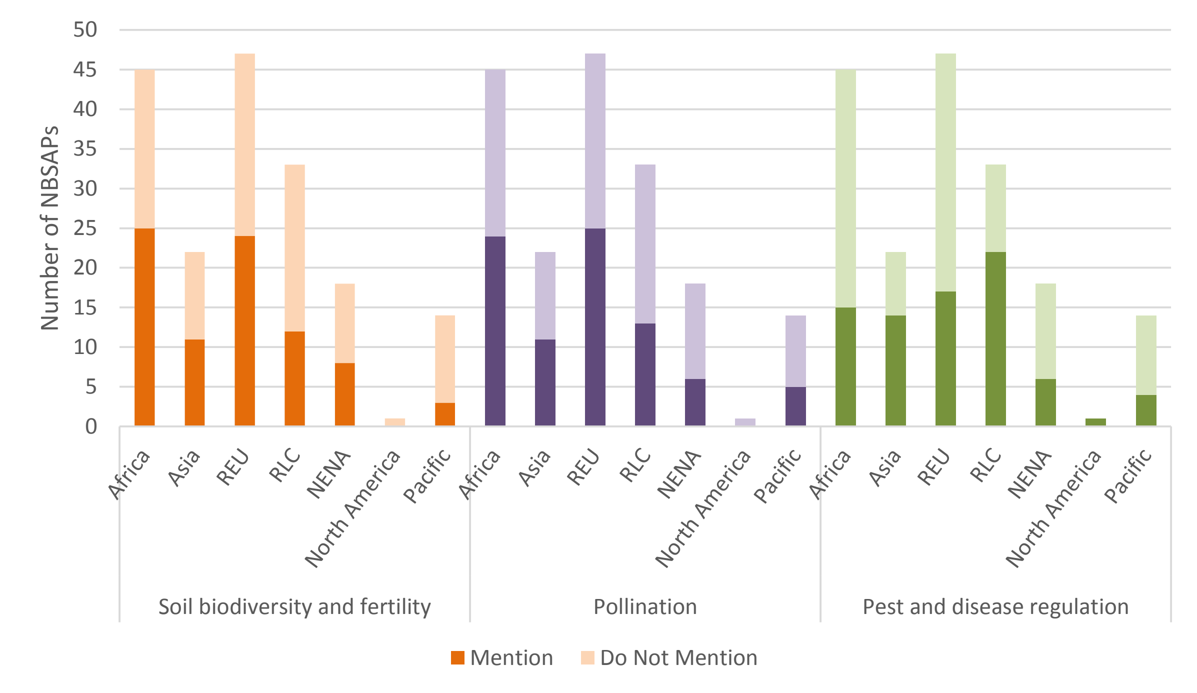
same time providing a range of produce" (TDE, 2006). It also mentions plans to provide farmers with training on agroforestry systems. Liberia's NBSAP states that "tree planting and establishment of woodlots should be an integral part of rural development programmes" (EPA, 2004).

Figure 27. Number of countries making reference in their NBSAP to agrobiodiversity and agroforestry, by region



Seventy-nine percent of the NBSAPs include a reference to "ecosystem services" in general. Pollination services are addressed in 47 percent (Figure 28). Several note the importance of pollination for food and agriculture and include an estimate of the value of pollination services. For example, Zambia's NBSAP mentions that the value of pollination services to national agriculture is estimated to be around US$74 million per year (Ministry of Lands, Natural Resources and Environmental Protection, 2015). Several NBSAPs highlight declines in pollinator populations and the potential increase in costs this may bring to agriculture. The pollinator focused activities set out in the NBSAPs vary from country to country. The NBSAPs of some European countries mention payments to farmers for maintaining flower strips around crop fields (FAO and CBD, 2016). Throughout Turkey's NBSAP, considerable attention is paid to a lack of information about the relationship between pollinators and other species. Turkey therefore plans to devise a programme for the "identification, monitoring, conservation, improvement and sustainable use of pollinator diversity in both agricultural and related ecosystems (MEF, 2007)." Uganda's NBSAP indicates that it may be necessary to discontinue the heavy use of certain agrochemicals, as local communities have noted a severe decline in pollinator populations in the vicinity of fields where these chemicals were applied (NEMA, 2015).

Figure 28. Number of countries making reference in their NBSAP to soil biodiversity and fertility, pollination and pest and disease regulation, by region



Issues relating to pest control are mentioned in 44 percent of the NBSAPs. Again, proposed actions vary greatly, as countries face a range of different pest-related challenges. Examples include an emphasis in Bahrain's NBSAP on biological control of the red weevil (Supreme Council for Environment , 2016). Myanmar's NBSAP includes proposals for more certification schemes (e.g. organic certification) for farmers and for more frequent training programmes in all aspects of IPM (MECF, 2015).

Matters relating to soil biodiversity and fertility are raised in 46 percent of NBSAPs. Concerns over soil degradation and declining soil fertility mean that overall soil health is widely addressed.. Some NBSAPs, Italy's for example (Ministero dell'Ambiente, 2010), note that soil biodiversity is an essential prerequisite for the delivery of a number of other important ecosystem services. Few NBSAPs specify detailed strategies to tackle the problem of the loss of soil fertility and soil biodiversity. Those that do address the problem often frame improvements as a positive side-effect of other measures such as the promotion of agroforestry. For example, the Gambia's NBSAP mentions plans to encourage agroforestry activities, which it states will positively affect soil fertility (MOECCWW, 2015). Other NBSAPs mention plans to address the issue, but without providing specific details of the actions to be undertaken. For example, Solomon Islands' NBSAP mentions planned community-based projects that will aim to develop sustainable resource management to minimize soil degradation (MECM, 2009).

Overall, the keyword searches indicate that despite quite frequent references to agrobiodiversity, relatively few NBSAPs explicitly address major agriculture-related ecosystem services such as pollination, biological pest control and the maintenance of soil fertility (proportions ranging from 44 percent to 47 percent). Moreover, many of the NBSAPs that do mention the keywords do so in the context of acknowledging problems as opposed to proposing solutions.

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[6.10 Access and benefit sharing]

[CHAPTER 7 – THE WAY FORWARD]